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Abstracts - Résumés

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Combined 3D interpretation of multiple geophysical and petrophysical data over the Newton epithermal Au-Ag deposit in British Columbia

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The Newton prospect is an epithermal Au-Ag deposit associated with Late Cretaceous felsic intrusions emplaced into broadly coeval volcanic and sedimentary rocks. Au-Ag mineralization is mainly hosted in the felsic sequence (felsic volcanic rocks, quartz feldspar porphyry, and monzonite). Gold mineralisation occurs in disseminations of pyrite and marcasite within quartz-sericite alteration (phyllic zone). ZTEM, aeromagnetic, and ground electrical resistivity-induced polarization methods were applied over the Newton property. The mineralization zone is characterized by relatively low electrical resistivity and high chargeability anomalies. In order to evaluate geophysical models in integration with geological information, extensive petrophysical measurements (magnetic susceptibility, electrical resistivity, and gamma ray spectra) were collected on drill-core samples. This study shows that combined 3D interpretation of multiple geophysical and petrophysical data can lead to a more geologically informative interpretation than what can be modeled by using these methods in isolation. **(*SS3, Wed. 3:00*)**

Role of Pan-African magmatism in uniting plates of Gondwana: The example of Mons Claudianus batholith, Egypt

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The Neoproterozoic Pan-African tectono-magmatic cycle is considered as one of Earth's most remarkable events. This cycle produced volumetrically significant magmatism including the Mons Claudianus Batholith (MCB) of eastern Egypt. It is made up of diorite-tonalite-trondhjemite lithologies, containing variable contents of quartz, plagioclase, K-feldspar, calcic-amphibole, biotite and magmatic epidote, with accessory titanite, zircon, apatite, magnetite and rare ilmenite. The MCB exhibits a wide range of SiO_2 (59-74 wt%), Al_2O_3 (14-21 wt%), CaO (2-6.5 wt%), Na_2O (3.3-6 wt%), Sr (75-968 ppm), Rb (11-71 ppm), and Zr (73-231 ppm). The suite is depleted in Ti, K, Rb, Nb, Y, Hf, and HREE. Chondrite-normalized REE patterns are moderately fractionated (Ce/Yb, 20-56) and commonly exhibit a small positive Eu-anomaly. The MCB is calc-alkaline in nature and shows strong arc geochemical signatures [Nb & Ti depletions, large Ba enrichment, high Sr/Y (58), and Zr/Sm ratios (45, on average, which are much greater than the chondritic value of 28)], all indicative of melting of a subducted oceanic crust. In addition, its relatively high Al_2O_3 and Na_2O contents, along with its low K_2O/Na_2O ratios (0.38, on average) are also consistent with typical slab melts. Mafic liquids produced in an Andean-type arc environment produced the MCB dioritic magma. The latter fractionated (plagioclase, amphibole, epidote and magnetite) to give the more felsic varieties. As a result of its breakup, vestiges of fragmented Rodinia were assembled into Gondwana. Magmatism that produced the MCB accompanied the closure of the Mozambique Ocean via NW-SE oblique convergence of E & W Gondwana (*ca.* 680-620 Ma) which took place in association with a transpressional tectonic regime. This inference is consistent with a U-Pb age of 663 Ma obtained on zircon. The emplacement of voluminous calc-alkaline magmatic pulses such as that of the MCB and many other batholiths formed several large Pan-African belts. The latter welded older continental fragments together and assembled them into the Gondwana supercontinent. **(*SY3, Wed. 2:40*)**

The geology of the Courageous Lake FAT deposit

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Seabridge Gold's FAT deposit, within the Courageous Lake Greenstone Belt represents the rare possibility of economic, well-preserved epithermal gold deposit in the Archean. The deposit is within the Yellowknife Supergroup of the Central Slave province, NWT; a fertile gold producing district known principally for the Giant and Con mines. The Courageous Lake Greenstone Belt lies unconformably above a sodic granite pluton within a rift basin; episodic volcanism is preserved because it is overlain by conformable sedimentary rocks, implying rapid burial. The package then underwent deformation, was tilted vertically and metamorphosed to greenschist to lower amphibolite facies. The latter is likely the same province-wide orogenic event which resulted in the formation of the Con and Giant mines. Gold mineralisation at FAT occurs as 8 stratabound domains within a rhyolite to dacite volcanic tuff sequence, overlain by shallow-water, fine-grained turbidites. Sub-aerial, principally lithic and ash tuffs are usually well preserved and generally interbedded with aqueously reworked tuffs. The bulk of the reserve tonnage is contained within 3 adjacent, central domains each with distinct and unique textural styles. Deformation is present, but the domains are sheared to different extents. Within these domains, refractory gold is present, mainly within acicular arsenopyrite and is broadly associated with sericite and silica alteration proximal to and within quartz veins. Mineralised textures range from sulphide-filled, undeformed, rounded and ellipsoid lithic fragments in primary volcanics to disseminated sulphides within foliated and sheared tuffs. Thin sections show that the sulphide habit and distribution varies in each domain. Geothermal processes associated with volcanic activity, and late-stage shearing congruent with regional metamorphism may have both contributed to the endowment and distribution of gold. **(*SY5, Poster*)**

Trace elements in sulfide assemblages from the Levack-Morrison Ni-Cu-PGE ore system, Sudbury, Ontario: Looking for chemical fingerprints of ore processes

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The Levack and Morrison deposits are in one of a few ore systems associated with the Sudbury Igneous Complex (SIC) where there is continuity between contact Ni-Cu ores and footwall Cu-Ni-PGE (platinum group elements) vein and low-sulfide ore types. The magmatic origin of high-Ni, low-PGE contact type deposits is reasonably well established. These deposits are widely recognized as segregations of immiscible sulfide melts that accumulated along the floor of the SIC during cooling of this impact melt sheet. In contrast, the origin of mineralization within the footwall is not well understood, in part because of the different styles of mineralization in the footwall environment. Some authors have emphasized the significance of magmatic processes and a link with contact ores, whereas others have favoured hydrothermal or metamorphic processes in remobilizing elements from the magmatic contact ores based on alteration assemblages (*e.g.* quartz, epidote, amphibole) related to mineralization. In the Morrison deposit the footwall ores are divided into three different subtypes: a transition zone between contact and footwall type ores (Upper Morrison, Ni ≈ Cu), Sharp-walled, chalcopyrite (ccp) veins (Middle Morrison, Cu-PGE-Ni), and disseminated low-sulfide, high-PGE mineralization (Morrison Deep, PGE-Cu). To determine if chemical fingerprints are distinct for each mineralization style, the trace element contents in the three major sulfides (po, ccp, pn) were measured by LA-ICP-MS. Our results from contact, transition footwall, sharp-walled veins, and disseminated low-S PGE identified unique and distinctive trace element characteristics for each. The most relevant is that the average Se content in ccp (in ppm $\pm 1\sigma$) increases with depth: 44 ± 2 in contact type deposit, 88 ± 7 in transition type deposits, 155 ± 13 in veins, and 257 ± 15 in the deeper (disseminated) deposits. Trace element diagrams (*e.g.* Cd *vs.* Se in ccp, Co *vs.* Se in po, As *vs.* Se and Co *vs.* Se in pn) showed that the deposit types could be distinguished from each other. **(*GS5, Fri. 9:20*)**

Tourmaline in the metasedimentary country rocks of the McArthur River uranium deposit, Saskatchewan

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Tourmaline is a common alteration mineral of many hydrothermal deposits and its composition and species reflect the nature of the mineralizing fluids. Therefore, characterization of tourmaline in hydrothermal deposits is important. In the Athabasca Basin, the occurrence of dravite (Mg-rich tourmaline) has been reported as a regional alteration mineral and also in and around uranium deposits. The results of a detailed study of alteration minerals in the McArthur River uranium deposit, the world largest high-grade uranium deposit, reveals three different species of tourmaline. The majority of tourmaline around the McArthur River deposit is magnesiofoitite (alkali-deficient tourmaline), as reported from the Rabbit Lake by Rosenberg and Foit (2006). Magnesiofoitite is paragenetically late as it forms overgrowths on earlier tourmaline of dravite. Dravite likely formed during the regional metamorphism of sedimentary rocks under upper amphibolite facies conditions and associated injection of pegmatite. They form dark brown to black grains in metapelites and pegmatite. In thin section they are light brown to yellow pleochroic euhedral-subhedral, coarse-grains (>0.5 mm), and form wide (1-2 cm) oriented veins and isolated grains surrounded by fine-grained magnesiofoitite, and/or illite. They show little compositional variation among different grains, $[(?_{0.4}Na_{0.6})(?_{0.2}Mg_{1.9}Fe_{0.5}Ca_{0.2}Ti_{0.2})(Al_{5.9}Fe_{0.1})(Si_{5.7}Al_{0.3}O_{18})(BO_3)_3(OH_{3.8}F_{0.2})$; ? = vacancy], although a few grains show Fe-rich cores (high schorl component) and dravitic rims. Dravite contains 1.24 (± 0.09, 1σ) wt% TiO_2, 89 – 280 ppm Zn, 51 - 630 ppm Cr, 190 - 1500 ppm V, and atomic F/Cl ratios range 98 – 11000. Dravite contain high LREE ($[LREE]_N/[HREE]_N$) > 7), and has a positive Eu anomaly.

Paragenetically late tourmaline, magnesiofoitite (alkali-deficient dravite; $[(?_{0.7}K_{0.1}Na_{0.2})(?_{0.4}Fe_{0.1}Mg_{2.0}Al_{0.5})Al_6(Al_{0.1}Si_{5.9}O_{18})(BO_3)_3(F_{0.02}OH_{3.98})]$; ? = vacancy), has a vacancy (0.7-0.86 apfu) in the x-site (alkali site). They are fine-grained (<0.2 mm), and form radial aggregates around earlier dravite, within veinlets (<2 mm) or as matrix. Magnesiofoitite is bluish white in hand specimens and clear in thin section. The distribution of magnesiofoitite and its close spatial association with the U mineralization and ore-bearing basement faults (P2 fault) suggest that it formed from uraniferous fluids. The presence of U (up to 3.7 ppm U) in magnesiofoitite supports this interpretation. **(*SS24, Fri. 8:40*)**

Rosenberg, P.E., & Foit, F.F., Jr., 2006. Magnesiofoitite from the uranium deposits of the Athabasca Basin, Saskatchewan; The Canadian Mineralogist **44**: 959-965.

Ore fluids recorded in the compositions of magnesiofoitite and alumino-phosphate-sulfate (APS) minerals in the basement along the P2 structure and the McArthur River deposit, Athabasca Basin

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The P2 reverse fault is a reactivated structure in the southeastern Athabasca Basin that hosts the McArthur River uranium deposit, the largest high-grade unconformity-type uranium deposit yet discovered. This study is to document alteration below the unconformity, specifically within and near the P2 deformation zone and the basement-hosted Zone 2 ore body, in order to evaluate the role of the P2 fault as the conduit for basinal and basement fluids and identify fertile alteration. The results of this study show that the P2 structure is the site of multiple stages of diagenetic-hydrothermal alteration, which produced illite, sudoite, Fe-Mg chlorite, clinochlore, kaolinite, aluminum phosphate-sulfate minerals (APS) and tourmaline. Below the unconformity, the assemblage of illite plus sudoite is common in pelite and pegmatite regardless of proximity to the P2 fault, and kaolinite is distributed along the unconformity; however, the assemblage of magnesiofoitite (alkali-deficient Mg-tourmaline) plus LREE-rich APS has only been found in close proximity to the P2 structure.

Along the P2 fault, magnesiofoitite forms fine-grained (<0.2 mm) matrix, aggregates, overgrowths on metamorphic/magmatic dravite (< 2 mm), and veinlets (< 2 mm) that cross-cut sudoite and illite. APS form zoned pseudo-cubes (1 – 20 µm), disseminated and clustered within fine-grained matrix in altered metapelite and pegmatite and vary compositionally from LREE-rich, to Ca- or Sr-rich. Magnesiofoitite contains low contents of LREE ($[LREE]_N/[HREE]_N$) ≈ 0.2), yet significant amounts of U (0.2 – 3.7 ppm), Cr (2.9 - 110 ppm), V (65 – 260 ppm) and W (0.03 – 0.347 ppm). The low LREE in magnesiofoitite is consistent with its close proximity to LREE-rich APS, implying that the two minerals are contemporaneous. Some crystals of magnesiofoitite are essentially free of alkalis. Overall, low alkalis (<0.3 in apfu) and high U plus W in magnesiofoitite suggests that the fluids were acidic and oxidized in order to transport soluble complexes of U^{6+} and W^{6+}. This fluid character is further supported by the co-precipitation of APS: significant Al solubility requires acidic fluids and the presence of SO_4^{2-} confirms the oxidized nature of the fluids.

The presence of these co-genetic minerals along the P2 structure suggests that the P2 fault was a conduit for uraniferous fluids; however, the fluids did not form uranium deposits all along the P2. The evidence further substantiates models in which the localization of large deposits required the focusing of an ascending reduced fluid to precipitate uraninite from the descending oxidized uraniferous fluid. **(*SS7, Wed. 9:40*)**

The formation of the Matoush uranium deposit in the Otish Basin, Quebec, Canada

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The Matoush uranium deposit is situated in the Paleoproterozoic Otish Basin, northern Quebec, Canada, and is hosted by the Indicator Formation sandstones. The dominant mafic Matoush dyke and a minor pegmatite intruded the Indicator Formation along the steeply dipping Matoush Fault around 2.17 Ga and are both altered to varying degrees. The related hydrothermal activity produced Cr-rich dravite and muscovite in both the dyke and in the most permeable horizons in the proximal sandstones, to a distance not more than a few tens of meters. The sheet-like uranium ore-bodies are closely associated with the Matoush dyke, with two types of uraninite-dominated mineralization: (1) massive to semi-massive mineralization at the contact between altered mafic dyke and the permeable Active Channel Facies of the Indicator Formation, and (2) less significant disseminated mineralization situated in the Cr-muscovite- and Cr-dravite-altered proximal sandstones.

Regional diagenesis, involving oxidizing evolved marine fluids, produced mostly illite and leached U from accessory phases in the Indicator Formation sandstones. Uraninite formed as basinal-fluid-borne U^{6+} was reduced in contact with the altered and reducing mafic dyke (massive and semi-massive ore) and by Fe^{2+} contained in Cr-dravite and Cr-muscovite in the altered sandstone (disseminated ore) at specific levels in the Indicator Formation. The partial destruction of Cr-rich minerals resulted in *in-situ* re-precipitation of Cr as eskolaite, which co-precipitated with uraninite; the ferric iron precipitated *in situ* as hematite. Laser ablation ICP-MS dating of uraninite gives an age of 1695 ± 110 Ma.

On the basis of its unique characteristics, the Matoush deposit can be classified as a variation of sandstone-hosted deposits, defined mainly by the nature of the reductant and reduction mechanism, with Fe from the mafic minerals in the Matoush dyke and pre-existing Cr-dravite and Cr-muscovite as the reductants. This unusual reduction mechanism underlines the great variability of reductants that can be involved in the formation of sandstone-hosted U deposits. **(*SS7, Wed. 4:00*)**

Stable isotopes (O, H, S, C) and fluid inclusions document fluid mixing in the ore-forming systems of the Daraloo and Sarmeshk copper deposits, central part of the Dehaj-Sardoeieh belt, south Iran

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The Daraloo and Sarmeshk copper deposits occur in a NW-SE trending fault zone in the southern section of the Cenozoic Urumieh-Dokhtar Magmatic Belt of Iran. In this zone, a belt of alteration defines a NW-SE trending zone 10 km long and 0.5-1 km wide with these two deposits located at the NW and SE ends. The area is characterized by a series of porphyritic tonalite-granodiorite plutons of inferred Miocene (?) age that cut Eocene andesitic volcanic and pyroclastic rocks. All these rocks are intruded by post-ore granodiorite plutons and dykes. Fluid inclusion microthermometry and stable isotopic analysis (O, H, S, C) on representative samples from mineralized and barren veins and various alteration assemblages are used to constrain the nature of the fluids and the PTX conditions of the mineralizing event. Five fluid inclusion assemblages (FIAs) are observed: (I) Liquid rich L-V type; (II) Vapor-rich L-V type; (III) L-V-Halite type; (IV) L-V-Sylvite(?)-Hematite type; and (V) L-V-Multi-solid type, including hematite. The FIAs record the evolution through the paragenesis, that is potassic to phyllic-argillic alteration, of an early high-T (Th = 230-400ºC) and saline (33-50 wt. % eq. NaCl) magmatic fluid that was trapped near 3 kbar, as indicated by the Th of L-V-Halite inclusions, to lower-T and lower-salinity (0-23 wt.% eq. NaCl) fluids that record the ingress of meteoric fluids. The highest-T and most saline fluids are mainly recorded in early barren magnetite + quartz veins in the core of the alteration system and are considered to be the most primitive magmatic fluid in the deposit. Cooling of this fluid coincides with potassic alteration and the main-stage copper mineralization. Dilution of the residual, cooler magmatic fluid after main-stage copper introduction is coincident with feldspar destructive (phyllic-argillic) alteration. Isotopic data for vein minerals indicate $\delta^{18}OH_2O$ values, calculated for 300º to 400ºC, range from -4.5 to 6.8‰ for quartz (n=16), 2 to 4‰ for barite (n=2), and 3.2 to 5.2‰ for calcite (n=2). These data suggest mixing of magmatic-derived fluids with meteoric fluids, which is also supported by δD (fluid inclusions in quartz) values of -62 to -100‰. In addition, $\delta^{34}S$ values of 2.2 to 8.7‰ (n=13) for pyrite and chalcopyrite and 13 to 14.6‰ for barite (n=2) suggest that sulfur is either crustal in origin or represents mixing of mantle and crustal reservoirs, as does $\delta^{13}C_{calcite}$ data of 0 to 0.7‰ (n=2). **(*SS3, Poster*)**

Geology, alteration-mineralization and whole-rock geochemistry of the Daraloo and Sarmeshk porphyry Cu +/- Mo deposits, central part of the Dehaj-Sardoeieh belt, south Iran

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The Daraloo and Sarmeshk copper deposits occur in a NW-SE - trending fault zone in the southern section of the Cenozoic Urumieh-Dokhtar Magmatic Belt of Iran. In this zone, a belt of alteration-mineralization defines a NW-SE trending zone 10 km long and 0.5-1 km wide with the two deposits located at the NW and SE ends, respectively. The area is characterized by a series of porphyritic tonalite-granodiorite plutons of inferred Miocene (?) age which cut Eocene andesitic volcanic and pyroclastic rocks. All these rocks are intruded by post-ore granodiorite plutons and dykes. Alteration assemblages comparable to those in other porphyry Cu ± Mo systems are well developed in both deposits. The earliest alteration, distinguished by fracture fillings and replacement textures, generated magnetite ± K-feldspar - rich, sulfide-poor zones in the centre of the intrusions and adjacent country rocks. The early magnetite alteration was followed and partially overprinted by a potassic stage which coincides with the main-stage copper mineralization. Propylitic alteration (epidote-chlorite-carbonates) defines an outer halo mainly developed in the volcanic rocks. Feldspar-destructive alteration (phyllic ± argillic), locally controlled by faults and late fractures and mostly in the outer part of the potassic zone and transition to the propylitic alteration, overprints the potassic and propylitic alteration. The mineralization, occurring as quartz-sulfide stockwork and dissemination in both the intrusions and volcanic rocks, is characterized by abundant pyrite and magnetite, minor chalcopyrite, and trace bornite and molybdenite. Magnetite, common in both deposits, occurs both in quartz-sulphide veinlets as well as discrete magnetite veinlets and disseminations. Supergene enrichment is poorly developed at Sarmeshk, but an enrichment zone 5 to 40 m thick occurs at Daraloo. This lack of an enrichment zone at Sarmeshk might be attributed to a less efficient leaching, due to the intense silicic alteration, and lower copper assays in the original mineralization. Geochemistry for representative samples of the porphyritic intrusions and the volcanic rocks indicates they are both subalkaline/calc-alkaline and conform to intermediate compositions (*i.e.*, granodiorite- tonalite and andesite-andesitic-basalt), whereas elemental trends (increase in K_2O, Na_2O and ∑REE, decrease in Al_2O_3, P_2O_5, Fe_2O_3, TiO_2, MgO, MnO, CaO and Sr) suggest crystal fractionation controlled magma evolution. Trace- element plots (*e.g.*, Nb-Y and Ta-Yb) suggest an intra-continental volcanic arc setting for the rocks with an origin due to partial melting of a subduction-modified metasomatised mantle, as reflected by LILE enrichment, HFSE depletion negative Nb and Ti anomalies in primitive-mantle normalized spider diagrams. **(*SS3, Poster*)**

Relationship between evolution of a 1.9 Ga shallow marine felsic caldera and the Garpenberg "super giant" volcanic-, limestone- and skarn-hosted Zn-Pb-Ag deposits, Bergslagen, Sweden

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The Bergslagen region comprises a 250 × 250 km relic of a major continental magmatic province. Shallow marine environments dominated throughout accumulation of most of the 2-10 km thick felsic volcanic successions. The rocks are commonly strongly deformed, are metamorphosed from upper greenschist to upper amphibolite facies and locally granulite facies, and are invaded by numerous synvolcanic to early orogenic granitoids.

Bergslagen is the cradle of the Swedish mining and manufacturing industry. Mining, smelting and processing have been going on for than 1000 years. More than 6000 mineral deposits and prospects are known in the region, including various types of iron oxide and polymetallic base metal sulphide deposits. During the 1960's – 80's most of the sulphide deposits were interpreted to be sea-floor exhalative deposits. However, recent studies suggest that most of them are replacements, in and adjacent to, shallow marine stromatolitic limestones, which represent pauses within, or local refuges from, the anomalously intense felsic volcanism.

Due to recent discoveries, the historic Garpenberg mining area has become the largest polymetallic sulphide deposit in Bergslagen (>110 million tonnes production and resources). On-going exploration and research of the Zn-Pb-Ag-Cu-Au deposits at Garpenberg suggest they are essentially synvolcanic hydrothermal deposits that formed by stratabound replacement of limestone and adjacent volcanic rocks directly beneath the caldera vent of a large marine rhyolite-dacite volcano. The ores and alteration styles are in part similar to VMS, intrusion-related skarn and high-temperature carbonate replacement deposits (CRD). The caldera is defined by a subaqueous rhyolitic pumice deposit that is more than 300 m thick and over 10 km in strike extent, stratigraphically above the main ore-host limestone. The entire succession is intruded by dacitic sills that are chemically similar to dacitic volcaniclastic rocks within the volcanic succession and to a granodiorite deeper in the footwall. These dacitic sills and the granodiorite may represent a resurgent post-caldera phase of magmatism. Alteration related to the Garpenberg ore deposits locally extends up into the hanging-wall pyroclastic unit indicating that ore formation probably occurred after the climactic caldera-forming eruption and could possibly be related to the resurgent magmatism. **(*SS6, Thurs. 8:40*)**

Lake sediment grab sampling versus coring for environmental risk assessment of metal mining

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Current practices for baseline studies of sites to be developed for mining include surface grab sampling of sediments in aquatic receiving environments. In contrast, vertical sediment coring is a universal tool in paleolimnological research. This study evaluates the effectiveness of sediment grab sampling versus sediment coring for environmental risk assessment of metal mining. The former Aldermac mine (Cu, Zn, Au and Ag), 15 km west of Rouyn-Noranda in Abitibi, Quebec, operated from 1932-1943 and discharged acid mine drainage into the watershed downstream. The study area is representative of both a common mineral deposit type and historical mining practices. Surveys of bulk sediment grab samples (2011-13) were done using a Ponar® sampler that penetrated to a depth of approximately 5-10 cm at 34 sampling sites. Co-located sediment cores, 30-45 cm long, were collected using a modified 10-cm diameter gravity corer at 33 sites and were subsampled at 0.5 to 5-cm depth intervals. Geochemical results from quick regional grab sampling provided estimates of baseline metal concentrations in surface sediments, contaminant sources, and the spatial extent of metal contamination. Sediment samples retrieved by longer cores produced estimates of both spatial and temporal factors: naturally-occurring metal concentrations (pre-industrial background), current metal concentrations, contaminant sources, and the duration and spatial extent of contamination. Although regional grab samples provide more sample material and are faster and simpler to collect than gravity coring, the results are imprecise because they are bulk data integrated over roughly 5-10 cm of depth; they also lack a time dimension. Coring, core extrusion, and subsampling at distinct depth intervals provide chemical stratigraphy of metal deposition. Coring also affords potential for more targeted data to fingerprint contaminant sources, assess diagenetic metal mobility, and determine stability of metal-bearing phases at discrete sediment horizons. These research-grade investigations can be optimized for practical use in environmental risk assessment. Bulk grab sampling offers a first approximation of regional metal distributions in shallow sediments. However, when more detailed investigation is warranted under environmental risk assessment regulations, sediment coring can not only provide estimates of the true ranges of naturally-occurring metal concentrations (natural background), but also measurements and timelines of metal increases from industrial activities. **(*SS16, Poster*)**

Quaternary volcanic centers and their relation to geothermal activity near Fallon, western Nevada, USA

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Upsal Hogback is a <25 ka volcano situated near Fallon, Nevada and its Naval Air Base. It was formed by phreatomagmatic eruptions creating tuff cones composed primarily of coarse, indurated lapilli tuffs with abundant volcanic bombs. Rare ash tuffs and cross bedding also occur. The volcano consists of two complexes: the north complex comprising of one vent, and the south complex made of one to three vents. Given its proximity to Fallon, it is important to constrain its age. Age constraints on the edifice indicates that it would have erupted during the late history of glacial Lake Lahontan, leading to both effects on the volcano during its eruption and on its post-volcanic morphology. There is substantial evidence for a subaerial or shallow subaqueous emplacement, but only the upper part of the edifice is palagonatized. This indicates a tuff cone was produced, which has been since modified by erosional effects of Lake Lahontan to resemble a tuff ring. Olivine and plagioclase phyric bombs from Upsal Hogback were analyzed, and show enrichment in LREE compared to HREE. Overall, the north complex is less enriched in REE compared to the south complex. Both complexes have flat HREE patterns, denoting a spinel peridotite or a low percent garnet peridotite mantle source. Two other volcanic centers neighbor Upsal Hogback, the younger Soda Lakes (maars) and the older Rattlesnake Hill (volcanic neck), with similar REE signatures. The samples from both complexes are geochemically distinguishable in major and trace elements but have similar $^{143}Nd/^{144}Nd$ values. They differ in $^{87}Sr/^{86}Sr$ values, which could be from Sr contamination from Lake Lahontan brines. All three volcanoes are situated in the Humboldt Lineament, a zone of lithospheric thinning. These volcanoes also are located on the boundary between the Basin and Range, a zone of extension, and the Sierra Nevada, as well as on the edge of the Walker Lane, a zone of dextral shear. Geothermal potential exists in the area, including a producing geothermal plant at Soda Lakes along with several other plants in Churchill County. The source of magma for the volcanism is an asthenospheric intraplate mantle source, produced after pronounced lithospheric thinning during the late Pliocene and Quaternary, which likely is critical to the geothermal activity. **(*SS6, Thurs. 10:40*)**

Major and trace element geochemistry of basal Wollaston Group graphitic pelitic gneisses in the eastern sub-Athabasca basement, Canada: paleoredox environment and source of metal enrichments

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The largest unconformity-type (U/C-type) uranium deposits in the world are hosted by the Proterozoic Athabasca Basin in northern Saskatchewan. The basin is underlain by strongly deformed high-grade basement rocks of Archean to Paleoproterozoic age, which include within its eastern part, basal Wollaston Group pelitic gneisses, *sensu lato*. Although studied for >35 years, uncertainties still remain about the U/C-type model, including the origin of the transition metals (*e.g.* Co, Cr, Ni) concentrated within the deposits. Here, we present new insights about some of the possible basement source rocks to these exceptional U deposits.

Our present study focuses on the major and trace element geochemistry (including redox-sensitive trace elements and iron valences) of tourmaline- and sulfide-bearing, graphitic pelitic gneisses of the Paleoproterozoic Wollaston Group. Fresh to strongly altered samples were collected both distal and proximal to known U/C-type uranium mineralization (*e.g.* Key Lake, McArthur River), since many of the known U/C-type deposits of the eastern basin are found close to graphitic pelitic gneisses within high-strain (*i.e.* ductile to brittle) structural zones. These gneisses are interpreted to be metamorphosed black shales that were deposited in a continental margin back-arc marine environment, like those deposited worldwide during the Shunga event at about 2.1 Ga, and are being studied to determine their petrochemical characteristics, facies and paleoredox variations, P-T-X conditions of Hudsonian metamorphism, and importantly their relationship(s) to U/C-type uranium formation.

The study of several hundred samples of graphitic pelitic gneisses and associated lithological units following this methodology was carried out in order to constrain the evolution of the stratified marine environment during *ca.* 2.1 Ga deposition on a rifted Archean continental margin. The graphitic pelitic gneisses are highly variable in composition, with C and S ranging from 0.5 to 7.5 and 0.2 to 10.0 wt%, respectively. The abundances of Co, Cr, La, Ni, Th, and V are comparable to, but higher than, those of post-Archean shale. After assessing the degree of element mobility, we conclude that the wide range of chemical variation in the fresh graphitic pelitic gneisses reflects original facies variations of metal content and constrains original paleoredox conditions. This study shows that pre-Athabasca metal enrichments within the basal Wollaston Group represent the most likely source of metals, such as As, Co, Cr, Cu, Mo, Ni, Pb, V, and Zn, for the unconformity-type deposits. Ongoing research is comparing the fresh gneisses with strongly altered varieties via isocon analysis to establish the metal source link. **(*SS7, Wed. 9:20*)**

Geoscience knowledge requirements for professional registration: A primer for students as to the use of the GKE document

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A goal for many geoscience (geology, geophysics, environmental geoscience) students in Canada is to eventually become a Professional Geoscientist in order to practice as a licensed professional. Requirements for professional registration are tabulated in the “Geoscience Knowledge and Experience Requirements for Professional Registration in Canada” (GKE). This document, developed by the Canadian Geoscience Standards Board, a committee of Geoscientists Canada, provides a comprehensive summary of the foundation and elective science and geoscience curricula and work experience considered to be appropriate background for licensure as a Professional Geoscientist. This presentation outlines how students and regulators across Canada should use this document.

The fundamental assumption in the GKE is that the necessary geoscience knowledge is gained through the equivalent of a 4-year B.Sc. degree in Canada, which includes 9 courses in “foundational” science (*e.g.* chemistry, physics, mathematics), and 18 courses in specific “foundational geoscience” subjects for the major disciplines of geoscience. Some professional programs at universities (*e.g.* engineering) are formally accredited by professional societies, whereas geoscience programs are not. Thus, local regulators develop a list of courses, in consultation with university faculty, that are available in their province or territory that cover the required areas. Although local requirement lists may vary slightly, this set of courses is used as a check list for each individual applicant, including those trained internationally. It is also important to note that students who might not have majored in geoscience originally, but who have since taken the necessary courses (as a graduate student or by another route) can satisfy the requirements for registration. In addition, part of the time in a graduate program may count towards the geoscience experience requirement for registration.

A new 2-year project is underway to outline the skills or competencies that a Professional Geoscientist should have by the time of registration. Some of these may require the completion of a particular course or set of courses during a B.Sc. program; others may be demonstrated via specific work experience. The development of these competency requirements provides another tool for geoscience regulators to properly and fairly evaluate applicants for professional licensure, and especially those applicants who are internationally-trained. **(*SS4, Thurs. 3:20*)**

Diffuse reflectance spectroscopy of volumetrically minor carbonate minerals

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Carbonates are the most abundant carbon-bearing minerals on Earth, with over 300 IMA approved species. By far the most abundant near Earth's surface are calcite and dolomite, found in sedimentary and metamorphic formations. Other phases such as siderite, magnesite, and aragonite are also relatively common. The vibrational spectra of these carbonates are well studied, and characteristic overtones/combinations are often used for exploration purposes on Earth, Mars, and elsewhere.

Formation conditions and stability fields are much more restricted for most other carbonate phases, which make their identification particularly useful for thermodynamic and geologic setting interpretation. Carbonate detections on Mars have been limited, potentially due to the assumption that the same carbonates that are common on Earth are also the most volumetrically significant on Mars. Given the probable lack of a near-surface biosphere, and environmental conditions conducive to metastable carbonate stability, carbonates that are comparatively rare on Earth could be present in significant volumes on Mars.

Considering the wide applicability of reflectance spectroscopy for terrestrial and planetary exploration, we have studied a suite of 35 naturally-occurring carbonate minerals using reflectance spectroscopy, atomic absorption/emission, ICP-MS, wet chemistry, and X-ray diffraction.

Preliminary results indicate that anhydrous carbonates generally conform to typical common carbonate vibrational spectra. Variations in carbonate chemistry and crystal structure produce systematic spectral changes through the entire spectrum (feature shifts, split vibrations) which should enable remote identification.

Hydrated carbonate minerals have markedly different spectral characteristics than anhydrous phases. The NIR features are strongly subdued, missing, or entirely different. A sharp difference in the 3 µm hydration feature between Mg- and Ca- and/or Na-bearing phases is also present, while all phases have very low albedo across the entire MIR spectrum. These spectral characteristics are also characteristic of oxalates ($MC_2O_4 \cdot (X)H_2O$; the second most volumetrically common type of carbon-bearing mineral). Carbonate fundamentals are similar in hydrous and anhydrous carbonates. The OH (and HOH) fundamentals, as well as combinations and overtones, are strongly affected by variations in intramolecular and intermolecular hydrogen bonding. Metal-hydroxyl interactions are also cause small variations in vibrational and charge transfer features, while contributing to the low albedo by additional absorption.

Given the significantly different NIR spectra and very low MIR albedo of hydrous carbonates, our results indicate that significant volumes of these species could be present on Mars, but may have been overlooked. Our results also provide a database for the detection and discrimination of important carbonate minerals in terrestrial settings. **(*SS21, Poster*)**

Osmium, Ir, Ru and Rh whole-rock concentrations controlled by crystallizing chromites from sulfide-poor picritic magma from the Emeishan large igneous province, Southwestern China

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Because Os, Ir, Ru and Rh behave as compatible elements during crystal fractionation of sulfide-undersaturated Mg-rich magmas, it appears that chromite controls an amount of these elements whole-rock concentrations. For this study, picrites and a few associated flood basalt samples were collected from the Late Permian Emeishan Large Igneous Province (ELIP) in southwestern China. The Emeishan picrites have relatively higher MgO content (?13 wt.%), higher Ir platinum-group element (IPGE) content (?IPGE = 2.64-8.59 ppb) and lower Pd/Ir ratios (1.7-12.6) than associated flood basalts (MgO <10 wt.%; ?IPGE = 0.03-1.19 ppb; Pd/Ir = 14.3-245). These values are consistent with the high Fo content (85-93 mol%) of olivine phenocrysts which have crystallized from these picritic magmas indicating that the picrites represent the parental magma of the associated flood basalt. Based on whole-rock analysis, the picrites can be divided into: high-Ti and low-Ti series. The high-Ti picrites exhibit high Ti/Y (?450) and contain chromites with Ti content >1.25 wt.%, whereas the low-Ti picrites exhibit lower Ti/Y (<450) and contain chromites with Ti content <1.25 wt.%. The chromites which have crystallized from both magmatic series can be subdivided into: i) olivine-hosted chromite inclusions; ii) chromite microphenocrysts in the groundmass. The latter chromite population is mainly characterized by Ti-rich magnetite overgrowth rims. This feature is consistent with the relatively low Mg# of these chromite microphenocrysts (30-51 for high-Ti picrites; 40-64 for low-Ti picrites) compared to the high Mg# of the chromite inclusions (38-59 for high-Ti picrites; 52-73 for low-Ti picrites) which have possibly crystallized in equilibrium with the host olivines. The microprobe data show that there is no significant difference in Cr# (Cr# = [Cr/Cr+Al]) between the olivine-hosted chromites and the chromite microphenocrysts in the groundmass which range from 62 to 76 for high-Ti picrites and 58 to 72 for low-Ti picrites. This study investigates the role of chromite in the control on the whole-rock concentration of Os, Ir, Ru and Rh by *in-situ* laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS) analysis of chromites from sulfide-undersaturated picrites from the ELIP. The distinction between IPGE (+Rh) in solid solution and IPGE (+Rh)-bearing phase inclusions is essential to determine the effect of crystallizing chromites from sulfide-poor picritic magma on the control of IPGE (+Rh) whole-rock budget. It will be very interesting to compare the IPGE (+Rh) content in solid solution between olivine-hosted chromites and chromite microphenocrysts for both magmatic series. The *in-situ* analysis results will presented. **(*GS5, Poster*)**

Brittle deformation of the Hackett River volcanic belt, Slave Province, Nunavut, Canada

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The eastern domain of the Slave craton, located in the northwestern Canadian Shield, hosts the ˜ 2.68 to 2.66 Ga Hackett River greenstone belt which is comprised of the Hackett River assemblage (HRA; including several volcanogenic massive sulphides deposits) and the ˜ 2.65 Ga overlying turbiditic metasedimentary rocks of the Beechey Lake Group (BLG) (Burwash Basin).

Both of these rock packages have been deformed by ductile F_1 and F_2 folding. Subsequently, these rocks have been brittley deformed as evidenced by vertical fractures and fault breccias. These fractures form NNW to NW major shears accompanied by N and NE conjugate fractures. Late mafic dykes intrude some of the major shears. An important N-S structural break was observed in the field and crosscuts the Main VMS deposit in the HRA, forming a copper rich zone to the West and a pyrite riche zone to the East. Displacements along these brittle structures vary from decimeter-scale to typically less than 10 meters but may be greater further to the east approaching the Hanimor Gneiss Complex. In the BLG, fractures are well developed in a regional dextral system.

Lineament interpretations using geophysical data and a digital elevation model reveal three main structural orientations. We interpret the pattern as a Riedel type shear where a dominate NW to NNW oriented set of structures corresponds to “D” dextral major shear fabric, with minor N-S “R” fabrics and conjugate NE “R' ” sinistral fabrics. These structures could be related with the Paleoproterozoic sinistral Bathurst fault system (˜ 1.73 Ga) located to the east of Hackett River. The Bathurst fault system affected the Paleoproterozoic Goulburn Supergroup during the intracratonic wedge shape indentation of the Archean into the Paleoproterozoic Thelon Tectonic Zone of the Rae Province. **(*SS14, Poster*)**

Using biotite composition of the Devonian Lake George granodiorite, New Brunswick, as a Proxy for Magma Fertility and Differentiation in W-Mo-Au-Sb Mineralized Magmatic Hydrothermal Systems

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The Early Devonian (412+5/-4 Ma, zircon U-Pb) granodioritic Lake George polymetallic deposit, New Brunswick, Canada, is a metaluminous to weakly peraluminous, calc-alkaline body that shows volcanic arc affinity. The stock is cut by stibnite-quartz veins and quartz-scheelite-molybdenite veinlets. Fresh biotite from this intrusion was analyzed at both the core and rim by electron microprobe, and along rim-to-rim transects by laser ablation-ICP-MS at the University of New Brunswick to test whether biotite preserves a record of magma evolution (in terms of halogens and trace-elements) that may help identify: a) W-Mo-Au-Sb fertility of the magma; b) processes responsible for enrichment of these elements.

Subhedral biotite phenocyrsts (0.5 to 1.5 mm) are reddish brown in colour (indicative of reduced I-type source) and locally altered to chlorite. Crystallization temperature for biotite phenocrysts were estimated on the basis of Ti-in-biotite thermometry and averaged 716°C. However, altered grains recorded lower temperature around 645°C.

Al-in-hornblende and biotite geobarometry revealed two populations of pressures around 4.3 and 2 Kb respectively, indicating of two crystallization depths for this porphyritic intrusion. Crystallization of amphibole at higher pressure clearly indicates a high water content of the source magma. Hydroxyl is also the most dominant component of the hydroxyl site (Average 1.89 wt%) in biotites. The limited range of IV(F/Cl) values of the Lake George biotite suggests that they equilibrated with one fluid.

Despite homogeneous intragranular major element chemistry, evidence of magma evolution is recorded by core-to-rim trace element variations. For example, Cu, Rb, Cr, K, Mo, Sn, Cs and W increase from cores to rims, whereas Ba, Ni, Mn, and Li act inversely. Sb distribution is homogeneous at an average value of 0.15 ppm. Trace element zoning may result from changes in pressure, temperature, or fluid conditions; this characteristic along with increasing F/Cl ratio from core to rim of biotites in the Lake George intrusion indicates fractional crystallization in the body. Furthermore, estimation of biotite/liquid partition coefficients may help in understanding magma fertility, as it can provide important modelling constraints on metal behaviour toward the late stage fluid. For example, K_{Sb} is 0.06 in fresh biotites, increasing to 0.77 in more altered biotites reflecting enrichment of these elements towards the late stage fluid.

Based on these observations, the concept of using mica composition to help identify fertile Acadian magma systems has been established; this method may be a useful tool to indicate a difference between barren and mineralized granophile-element rich systems. **(*SS24, Fri. 8:00*)**

Magmatic mica and its potential as an indicator of magma fertility in the granitoids of New Brunswick

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The mineralized intrusions of New Brunswick are related to crustal growth processes that occurred during Acadian Orogeny, post Acadian uplift, and Neo-Acadian Orogeny. They were emplaced pre-, syn-, late-, and post-tectonically between 423 and 360 Ma. These intrusions have affinities ranging from primitive to highly evolved A-, S-, and I-types granitoids, and are associated with Sn, Ta, Li, Sb, W, Mo, Cu, and Au, as well as base-metals and U mineralization.

Biotite crystallizes over a wide range of conditions and reacts very sensitively to physio-chemical conditions of the magma; this sensitivity makes mica a great mineral for identifying the petrogenetic, mineralization, and alteration processes of the host granitic rocks. The following features make biotite a valuable probe of magma composition: 1) It is the most important reservoir of any excess aluminium in granites that do not contain modal garnet, cordierite, or the Al_2SiO_5 polymorphs; therefore, it directly reflects the peraluminosity of the host magma in such rocks, 2) it is the most readily available indicator of oxidation state, and 3) it can provide information about the F and Cl content of the magma. Mineralized and barren rocks are characterized by different chemical variations in biotite. For instance, mineralized biotite is characterized by lower Mg and Ti contents relative to biotite from barren rocks; they also have higher amount of Al comparing to biotite from barren phases.

Several studies have shown that biotite, continuously equilibrates with the host liquids. Therefore, core-to-rim study of this mineral and its compositional zoning may provide a record of magma evolution so that the origin and evolution of granitoids can be discerned. Furthermore, the chemical composition and the colour of this mineral strongly reflects the tectonic origin of its host. For instance, the bright red colour of biotite indicates peraluminous collisional granitic pluton and reflects a high total Fe content with low $Fe^{3+}/(Fe^{2+} + Fe^{3+})$ and probably the presence of Ti^{4+}.

In part this study aims to calculate fluoride and chloride activity of aqueous fluids based on F and Cl contents in the minerals containing hydroxyl and halogens determined by combined electron microprobe and LA ICP-MS analysis. The final data will be compared to the whole rock geochemistry. These results are expected to help constrain crystallization conditions, volatile exsolution and fluorine-chlorine activity of fluids associated with these intrusions. They should also indicate the degree of subsolidus re-equilibration via various geothermobarometry techniques. **(*SS5, Poster*)**

Geochemistry of the Plutonic suites of the northeast of the Superior Province (NESP), Quebec, Canada: A preliminary metallogenic approach

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The Ministry of Natural Resources of Quebec (MRN) carried out a mapping program in the NESP (1997-2003) which led to the compilation of a large amount of analytical data. The Minto block exposes on its surface a large amount of archean plutonic rocks corresponding to the first step of the continental growth on the Earth (3.9-2.6 Ga). This cratonization is marked by the evolution of a typical archean magmatism corresponding to sodic tonalite magmatism, then followed by more potassium resulting from the presence of archean granodiorites and granites. The majority of these intrusive rocks belong to the TTG (Tonalite-Trondhjemite-Granodiorite) plutonic series. TTG series in the NESP appear relatively rich in silica content (SiO_2 > 60%), poor in ferromagnesian like MgO (MgO < 4 wt.%), TiO_2 (0.0-1.5 TiO_2 wt.%) and Fe_2O_3 (Fe_2O_3 < 5 wt.%). They are also poor in K_2O (1.0-4.5 K_2O wt.%) but relatively rich in Na_2O (3.0-6.0 wt.% Na_2O) who is typical for this type of igneous rock. Their La/Yb (0.0-200ppm) and Sr/Y (0.0-600 ppm) ratio is higher. This geochemical link with adakites highlights the 'arc signature' of TTG series. Tardi-archean granites in the NESP show a higher content in K_2O (4.0-6.0 wt% K_2O) than primitive TTG. This enrichment in potassium implies that their magmatic mechanism set up close to their modern equivalents. In many archean craton ore deposits are spatially associated with TTG series and tardi-archean alkaline granites.

It becomes possible to determine the mineral potential establishing a typology of suites, analyzing their distribution in comparison with regional data and targeting areas of metallogenic interest.

Many authors have shown empirically that mineralization types Cu-Au and Cu-Mo tend to be spatially associated with oxidized and less fractionated intrusive (magnetite series) whereas mineralization types Sn and Sn-W seem to be associated with reduced and more fractionated intrusive (ilmenite series). New FeO unpublished data highlight the oxidation state of granitic rocks in the NESP. Regionally, a favourable metallogenic potential for Cu-Au -Mo and Cu magmatic mineralization appears. Most of intrusives belong to the evolutionary magnetite series. However, heterogeneity in terms of oxidation and fractionation suggests a potential in Mo, Sn-W and -W mineralization. Using multivariate statistical analysis, it seems that fractionation state of plutonic rocks in the NESP controls the major part of data distribution. Regional analysis of oxidation and fractionation will highlight the metallic potential of granitic suites and therefore new areas of metallogenic interest across the NESP. **(*SS24, Thurs. 5:00*)**

Damaged Goods: Structural controls on the Hammond Reef disseminated gold deposit, Ontario

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The Archean Hammond Reef gold deposit in NW Ontario, Canada, is a large, disseminated, low-grade gold deposit. The mineralization at Hammond Reef is structurally controlled but not vein-hosted and not found within a terrane-bounding fault. It is characterized by low-grade disseminations of gold-pyrite in a pervasive altered- to partially altered brittle fracture zone that cuts across earlier low-angle shears in the tonalite gneisses. The mineralized zone dips steeply at the surface and shallows at depth. The alteration zones are characterized by a variable mineralogy of albite, sericite, pyrite, calcite, ankerite, quartz, chlorite and minor hematite. The highest-grade gold zones are always associated with pyrite, but barren pyrite is also common.

The controls on formation of the Hammond Reef gold deposit are not well understood. The deposit is concentrated in an altered fracture zone adjacent to, but not within, the nearby Marmion Shear Zone – a terrane-bounding structure of regional extent. This suggests mineralization may have a relationship with the tectonic history of multiple deformation events in the region. A kinematic study of the adjacent Finlayson Lake greenstone belt, where metamorphic conditions and structural fabrics are better preserved than in the felsic gneiss, reveals the regional deformation history. We have identified a prolonged structural and fluid flow history of the Marmion Shear Zone, which we link to both unknown, and previously identified tectonic events. Within the deposit we have identified at least two sets of juxtaposed fractures forming an anastomosing network. The older set is geometrically related to the Marmion Shear Zone. The younger set is parallel to a newly identified shallowly dipping thrust fault cutting the tonalite body. This fault controls the limit of the alteration and may play a major role in trapping fluids within the fractured damage zone and facilitating alteration. Ongoing field, microstructural and geochemical studies are focused on determining the specific structural setting of the deposit and establishing the relationship between mineralization and the regional Mesoarchean tectonics. **(*SY5, Thurs. 8:00*)**

U-Pb age and Hf isotope data of detrital zircons of exotic Devonian sandstones from the southeastern Rheinisches Schiefergebirge near Giessen, Germany

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In the Rhenohercynian zone of the Variscan orogen in Germany early and late Devonian sedimentary successions of suspect provenance occur in the allochthonous assemblage of the Lindener Mark and Giessen nappes. A combination of faunal and sedimentological data suggested that the allochthonous successions most likely derive originally from northern Gondwana.

In order to test for the northern Gondwanan origin we applied U-Pb detrital zircon age determination and Hf isotope analysis by LA-SF-ICP-MS. We studied 5 units between the cities of Giessen and Marburg. We analyzed around 150 detrital zircons of each sample and considered only ages which are less than 10% discordant. U-Pb ages range between 3300 Ma and 372 Ma. Age distributions in all samples are very similar with two major peaks. The older peak is around 2000 Ma with ~27% of ages, the younger one is around 600 Ma with ~71% of ages. Ages between 1650 and 1200 Ma are very scarce (~2%). These essentially bimodal zircon age spectra are similar to typical NW African zircon age spectra with the main abundances connected to the Eburnean and Cadomian orogenies at *c.* 2000 Ma and *c.* 600 Ma, respectively. Contrastingly, siliciclastic units derived from the Old Red Continent to the north include abundant zircon ages between 2000 and 1000 Ma.

The Hf isotope patterns of all samples are also very similar. The Hf isotopic compositions of selected dated zircons (n=208) at the time of their crystallization vary between –33 and +12. 42% of zircons have positive εHf(T) and can be considered to contain juvenile components. Truly juvenile compositions are represented by 15% of data. The majority of the juvenile grains have Hf depleted mantle model ages (Hf TDM) between 1.7 and 1.2 Ga, with a peak between 1.5 and 1.4 Ga. The total range of Hf TDM is between 3.2 and 0.64 Ga. The data form two vertical arrays in time *vs.* εHf(T) space at *c.* 2.0 and 0.6 Ga. εHf(T) values of the former range between +7 and -33, those of the latter are between +12 and -33. This suggests that both crust formation events involved mixing of juvenile magmas with variable amounts of old crustal components. Our data coincide with similar data from Saxothuringian units also of NW African provenance.

Our data confirm that the allochthonous units of the Lindener Mark and the Giessen nappe in the Rhenohercynian zone originally derive from a position in NW Africa. **(*SY1, Wed. 2:40*)**

Geochemomineralogy: Our investigations of igneous processes through laboratory experiments and computer simulations

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Understanding igneous petrogenesis requires quantitative knowledge of the equilibrium behaviour and kinetic controls of all possible processes involved, from the genesis of a primary melt deep within a planetary body to eruption at the surface. Together with students and colleagues, I have been quantifying some of these fundamental processes and constraining their rates and their impacts in igneous systems. Our measurements of melt saturation with various minerals and partitioning of elements between minerals, melts and fluids provides us with the knowledge to model the role of crystal fractionation in igneous processes, the formation of magmatic, massive sulfide ore deposits, and correlate the lethality of large igneous processes to the sulfur concentrations in the magmas. Using our measurements of elemental and isotopic diffusion in silicate melts we can constrain the effects of diffusive homogenization of elements and isotopes and calculate the non-equilibrium compositions of magmatic gases due to rapid bubble growth. The combination of bubble growth experiments with computer simulations provides important information on the failure of volcanic foams and the infrasonic signals they produce. And, our computer simulations and experiments on pegmatite formation point toward the fundamental role the formation of a fluid phase plays in the genesis of giant crystals. Athough these studies are far from the classic definition of mineralogy, each process is fundamentally controlled by the atomic scale structure and interactions between fluids, melts, and, of course, crystals, thus the term "geochemomineralogy". **(Plenary Address*, Thurs. 11:05*)**

Recognizing and preserving our geological and mining heritage in the Northwest Territories, Canada

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Geological heritage or geo-heritage is part of our shared past. It links us to events in Earth history that humans strive to understand. Future research will continue to unlock our geo-heritage for generations to come. Recognizing and understanding our geological heritage helps us celebrate the unique and rich history of our Earth.

Canada's Northwest Territories (NWT) has a spectacular landscape and extensive geological past starting with the very oldest known Precambrian gneiss dated at four billion years old along the Acasta River. Well-exposed, ancient sequences of pillowed basalt lava flows, laminated stromatolites, and granitoid plutons, all carved and polished by past glaciations, crop out near Great Slave Lake, NWT. There are NWT localities, collectively spanning much of the geologic time scale, with world-wide to local geological significance that can be recognized as part of our global geological heritage.

Geo-heritage is recognized differently around the world; within National Parks, UNESCO World Heritage Sites, GeoParks, Provincial Parks, Protected Areas, Conservation Areas, and on private lands. Not everyone has the background in Earth Science to readily understand what they see, so it is necessary to communicate this information to the public through a variety of media. It can be communicated via museums, public and private displays, film, websites and digital resources, field trips and onsite tours, books, and paper resources.

In Canada's North, the NWT Mining Heritage Society was formed in 1999 to preserve and display the geological and mining heritage of the Northwest Territories. The society promotes geology awareness and education in the North and its current focus is to build an NWT Mining and Geological Interpretive Centre near Yellowknife, adjacent to a former gold mine. Completed to date are long-term public displays of rocks, minerals, and mining objects maintained at the Yellowknife Airport, the federal government Greenstone Building, and the Northern Frontier Visitors Centre. Outdoor displays of mining equipment and geological samples near the future museum and interpretive centre have been established as a visitor site and field trip launching area. Future considerations include GeoPark or UNESCO World Heritage site designations for the area, which hosts spectacularly preserved Archean pillowed basalt flows and related volcaniclastic and intrusive rocks. Challenges include working next to a mine site undergoing long-term remediation and in an unsettled First Nations land claim area. **(*SS15, Fri. 9:20*)**

Tectonostratigraphy of the Rapitan Group, NWT and YT

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The Rapitan iron formation (Rapitan Group, NWT and YT, Canada was deposited in a rift basin during the Neoproterozoic "snowball Earth" glacial episode (*ca.* 711 Ma) and is stratigraphically associated with glacioclastic turbidites and diamictites. The Rapitan Group overlies the Coates

Lake Group, a rift succession that lies at the base of the Windermere Supergroup. Exposures of the Rapitan Group are geographically discontinuous, and define two sub-basins: the Snake River basin (northwest), which contains iron formation >100 m thick, and the Redstone basin (southeast), in which the iron formation thin (local maximum 35 m). Sedimentological differences in the two basins have led to conflicting interpretations of the group's formation-level stratigraphy, with significant implications for iron formation deposition. Pronounced lateral thickness and lithofacies changes in iron formation and the underlying Sayunei Formation correspond to crustal-scale basin growth faults that are also expressed in older stratigraphic units (Mackenzie Mountains Supergroup and Coates Lake Group); these faults also define the basin margins delineate major sea-floor depth zones. In the Snake River basin, the Coates Lake Group is absent, iron formation is thickest, and the Sayunei Formation underlying the iron formation contains unusually coarse-grained rocks, suggesting that this basin's initial subsidence lagged behind that of the Redstone basin (*i.e.*, post-Coates Lake Group), and had steeper margins than the Redstone basin, where the Sayunei Formation is predominantly siltstone and iron formation is thin and discontinuous. The differing slope angles of the recently faulted margins of the two sub-basins margins directly controlled the style and rate of sedimentation during Sayunei Formation deposition, resulting in the dramatically different grains sizes in each basin, and also controlled the thickness of the water column below the iron chemocline, thereby controlling the thickness of iron formation, where siliciclastic input was minimal, and of red diamictites where siliciclastic input was significant. The close relationship of faulting, basin inheritance, patterns in sediment composition, sediment colour, and iron formation thickness in the Rapitan Group suggests that continental rifting was a much more significant underlying mechanism in Neoproterozoic glacial deposits than is commonly perceived. **(*SS13, Poster*)**

Age and provenance of detrital muscovite from the Ediacaran-Cambrian boundary zone in Atlantic Canada: Implications for the paleogeographic position of Avalonia

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Avalonia in the northern Appalachian orogen locally includes clastic sedimentary sequences which span the Ediacaran – Cambrian boundary, including the Global Boundary Stratotype Section and Point (GSSP) at Fortune Head, Newfoundland. The GSSP at Fortune Head is set at the first appearance of the complex trace fossil Treptichnus pedum that is found worldwide. Another change that is evident in the GSSP section, as well as in equivalent sections in southern New Brunswick and Cape Breton Island, is the abrupt appearance of coarse detrital muscovite in the vicinity of, but a few metres below, the boundary. The muscovite persists throughout the Cambrian stratigraphy. A source for the muscovite is not known within Avalonia, which is dominated by low-grade volcanic and volcaniclastic rocks that are associated with magmatic arc-type hornblende-bearing granitoids which lack muscovite. The large volume of quartz-rich sedimentary rocks, combined with the abundance of detrital muscovite, imply a large continental source area and river systems throughout the Cambrian, and hence potentially provide important clues about the location and source area(s) of Avalonia and global paleogeography at the end of the Precambrian. Single grain $^{40}Ar/^{39}Ar$ ages published for detrital muscovite of southern New Brunswick and southeastern Cape Breton Island contain a prominent record of 650-630 Ma ages, with variable amounts of radiogenic ^{40}Ar loss and younger ages due to overprinting Paleozoic events. A new suite of additional samples was collected across the GSSP at Fortune Head and up section into the Random Formation and from corresponding units in southeastern Cape Breton Island, to extend the earlier work through parts of the GSSP that may have experienced less metamorphic overprint. Laser $^{40}Ar/^{39}Ar$

analyses in the ANIMAL facility of Auburn University for this additional suite yield probability distributions of ages dominated by a single mode of *ca.* 630 Ma. We find no ages greater than *ca.* 630 Ma (with ~110 analyses per sandstone sample), and age distributions are variably skewed to a smaller number of crystals that lost ^{40}Ar and yield apparent ages as young as Devonian. The original source rock was likely a medium- to high-grade metapelite metamorphosed and deformed at 630 Ma, or coarse-grained aluminous granites or granitic pegmatites. These aluminous muscovite-bearing rocks were likely a major component of the source area for Cambrian sediments deposited in Avalonia. Furthermore, it was exposed or became accessible very abruptly and very close to the end of the Ediacaran. **(*SY1, Wed. 9:40*)**

Valentine Lake: A trondhjemite-hosted orogenic gold deposit in the Dunnage Terrane (Exploits Subzone), Newfoundland

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Marathon Gold Corporation's Valentine Lake property is located in the Exploits Subzone of the Newfoundland Appalachians, approximately 20 km east of the main Iapetan suture - the Red Indian Line (RIL). The property contains numerous auriferous zones, largely hosted within trondhjemite of the Neoproterozoic (563±2 Ma) Valentine Lake Intrusive Suite (VLIS). The largest recognized zone (Leprechaun Gold Deposit) contains measured and indicated resources totalling 10.59 Mt at 2.28 g/t Au (775,000 oz. Au) as per August 1, 2013 press release. Gold mineralization occurs almost exclusively in quartz-tourmaline-pyrite (QTP) veins, stockworks and adjacent vein selvedges. Vein networks are proximal to a 30 km regionally extensive, brittle-ductile shear zone, which defines the eastern contact of the VLIS with the more competent Silurian Rogerson Lake Conglomerate (RLC). A suite of variably-deformed mafic dykes, oriented sub-parallel to shear, are also concentrated in this zone. Significant orogenic gold occurrences have been previously discovered within the more intensely deformed Cambrian volcanic sequences of the adjacent Victoria Lake Supergroup (VLSG), located immediately north-west and approximately 10 km east of the RIL. Here, gold mineralization is also localized along late brittle-ductile shear zones, a characteristic that essentially mimics the structural control observed in the VLIS mineralization. Detailed mineralogical and geochronological (rutile U-Pb) studies are designed to elucidate the timing and nature of gold mineralization and related alteration at Valentine Lake, and test the possibility of multiple mineralization episodes that correlate with Salinic (Silurian) and/or Acadian (Devonian) orogenic events. Petrographic, lithogeochemical and zircon U-Pb analysis of representative mafic dyke samples is directed at constraining their age and timing with respect to proximal gold mineralized zones. This study should provide better understanding of the timing and specific process(es) of gold mineralization at Valentine Lake, with potential application to a refined exploration strategy. **(*SY5, Poster*)**

Provenance of the sedimentary rocks in the eastern North Caribou greenstone belt, western Superior Province of Canada

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The North Caribou greenstone belt in the North Caribou Terrane is considered to be the nucleus of the Western Superior Province and also hosts the Musselwhite Au deposit. The central part of the belt is underlain by siliciclastic sedimentary rocks of the Eyapamikama Lake Assemblage. Recently, Duff *et al.* (2013) found young detrital zircon (~ 2680 Ma) in the northeastern part of the belt adjacent to the terrane boundary. In order to characterize and evaluate the distribution of these relatively young sedimentary rocks, 14 samples were collected from the eastern part of the belt. The rocks in the northern part are arkosic sandstone and wacke and show minor recrystallization of quartz/feldspar and minor deformation parallel to the margin of the belt.

These immature, unmetamorphosed rocks contain elevated MgO (>1%), Ni (27.5-104 ppm), Cr (42-180 ppm), low total REE (48-88 ppm) and relatively undifferentiated signature (Th/Sc: 0.67-0.83, $[Ce]_N/[Yb]_N$: 8.1-19, Cr/Zr: 1.3-2.1, $[Eu]_N/[Eu^*]_N$: 0.88-1.1). The data suggest a contribution of mafic igneous rocks, along with granitoid and felsic volcanic rocks. εNd (2700 Ma) show a narrow range between -1.0 and -0.5, which supports a significant contribution of mafic rocks and also contemporaneous igneous rocks. Rocks from the central portion are arkosic sandstones that were metamorphosed under low greenschist facies and altered to contain calcite. They show low Mg (<1%), Ni (17-24 ppm), Cr (9-50ppm), relatively high total REE (104-166 ppm) and slightly evolved geochemical signature (Th/Sc: 0.8-2.1, $[Ce]_N/[Yb]_N$: 14-21, Cr/Zr: 0.07-0.27, $[Eu]_N/[Eu^*]_N$: 0.63-1.1). The data suggests mostly granitic sources. The εNd values at various possible ages are low; from -6.5 to -5.5 at 2700 Ma and from -3.8 to -3.0 at 2800 Ma. The data suggest old granitic rocks as the dominant sources for the sediments. The data suggests at least two distinct sedimentary rock types in the eastern portion of the belt. The rocks in the northeastern part of the belt are similar to that of the Timiskaming-type rocks in other greenstone belts that are spatially associated with large gold deposits. **(*SY5, Thurs. 3:00*)**

The jarosite-rich "Golden Deposit", Northwest Territories, Canada, as an analogue for Mars

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The jarositic cold seep emplaced Golden Deposit, in Northwest Territories, Canada, (65º11'58" N, 124º38'15" W) is an excellent analogue to similar jarositic patches that have been identified on Mars. Surficial deposits of the OH-bearing iron sulfate mineral jarosite have been observed in several places on Mars, such as Meridiani Planum and Mawrth Vallis. Jarosite is thermodynamically stable under a majority of temperature and pressure conditions on present-day Mars and, as such, jarosite may contain chemical or textural indicators of Mars' history, perhaps including evidence of biological activity.

Martian jarosite deposition mechanisms are not known, but by comparing Martian sites to analogous sites on the Earth, conditions of formation, and thus paleoenvironments on Mars during the time of deposition may be postulated. The Golden Deposit is visible from the air as a brilliant golden-yellow patch of unvegetated jarosite-rich sediment, approximately 140 m × 50 m. It appears as a patchwork of raised polygons, with acidic, iron-bearing water flowing from seeps in troughs between polygonal islands. Although UV–Vis–NIR spectral analysis detects only jarosite, mineralogy, as determined by X-ray diffraction and inductively coupled plasma emission spectrometry, is predominantly natrojarosite and jarosite, with hydronium jarosite, goethite, quartz, clays, and small amounts of hematite. Water pH varies significantly over short distances depending on proximity to acid seeps, from 2.3 directly above seeps, to 5.7 several m downstream from seeps within the deposit, and up to 6.5 in ponds proximal to the deposit. This site is of particular interest because mineralogy (natrojarosite, jarosite, hematite, and goethite) and environmental conditions (permafrost and arid conditions) at the time of deposition are conceivably analogous to jarosite deposits on Mars. **(*SY4, Wed. 10:20*)**

Plagioclase textures and zoning patterns in the Miocene Dowdy Ranch Andesite, Central California Coast Ranges: Implications for open and closed system behavior in magmatic systems

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The Miocene Dowdy Range Andesite (DRA) of the Central California Coast Ranges is part of a northwestward-younging volcanic sequence that formed by northward movement of the Mendocino triple junction, formation of a slab window, and infilling of this window by asthenospheric mantle. The highly porphyritic andesite contains plagioclase phenocrysts with a wide array of disequilibrium textures such as normal, reverse, oscillatory and patchy zoning patterns and sieve and sponge textures within a single thin section, providing an opportunity to reconstruct andesite crystallization processes in a complex tectonic environment. The DRA contains metasedimentary, granulitic, and gabbroic xenoliths and displays arc-like trace element chemistry. It shows glomeroporphyritic, intersertal and hyalopilitic textures with plagioclase as the dominant phase both as phenocrysts and in the groundmass. Other groundmass minerals include orthopyroxene, clinopyroxene, and ilmenite. The presence of abundant quartz xenocrysts rimmed by augite coronas and the absence of mafic enclaves suggest that incorporation of crustal material played an important role in forming the andesite.

Back-scattered electron images, detailed petrography, electron microprobe analysis of zoned plagioclase shows that there are both concordant and discordant relationships between anorthite content (An) and FeO. Plagioclase cores vary in composition from An_{45-65}. Clear rims surrounding spongy zones are common and show abrupt and significant (~10-50% An and 5-20 wt% FeO) increases in both An and FeO, as is expected if the chamber replenished by more mafic magma. Clear rim compositions are consistent from sample to sample, suggesting that the phenocrysts experienced a common history during the late stages of crystallization. Patchy zoning shows a range in composition from An_{45} in dark patches to An_{55} in light patches and with ~5-10 wt% change in FeO content. Oscillatory zoning in plagioclase phenocrysts, which may reflect rhythmic changes in temperature and/or $P(H_2O)$ during crystal growth, shows both HALF (High Amplitude Low Frequency) and LAHF (Low Amplitude High Frequency) zoning patterns. Some phenocrysts have several zones of resorption marked by increases in both An and FeO, consistent with repeated episodes of magma replenishment. CSD (Crystal Size Distribution Studies) plots indicate the formation of andesite due to two main processes; 1) magma mixing/recharging and 2) recharge filtering. Complex plagioclase and pyroxene zoning patterns and core to rim changes in both An and FeO contents with CSD studies exhibit combination and repetition of both open and closed system magmatic processes during the formation of DRA. **(*GS3, Poster*)**

Diagenetic controls on hydrothermal fluid flow in the Osiris, Isis, and Isis East Carlin-type Au showings, Nadaleen Trend, Yukon

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The Rackla Au Belt is located 55 kilometers northeast of Keno City in Central Yukon and contains the Nadaleen Trend, a fault-bounded package of Cambrian to Neoproterozoic aged units. The Nadaleen Trend also contains the first Carlin-type Au showings to be found in Canada; the most significant are the Conrad and Osiris zones. In this project, the diagenetic and cementation history of the Osiris, Isis, and Isis East zones is being studied to gain an understanding of the factors controlling fluid flow. This will help in the prediction of the location of Au away from feeder faults and will add to the overall understanding of the geological history of the Nadaleen Trend.

Mineralization in the Osiris, Isis, and Isis East zones is hosted by silty carbonates from the Upper Neoproterozoic Windermere Supergroup, which have been affected by anticlinal folding and thrust faulting. Gold is often found in decarbonatized, silicified and realgar-mineralized zones commonly associated with faulting. Away from the faults, Au grades are often correlated with large intervals of dolomitization, suggesting matrix permeability is an important factor controlling mineralization. Previous work has suggested that Au is associated with thin rims of “fuzzy”-textured arsenian pyrite overgrowing earlier pyrite, similar to some of the deposits in the Carlin District.

A petrographic and cathodoluminescence study was carried out on 502 samples and a paragenetic sequence has been constructed. The host rocks are wackestones and lime mudstones. These units were dolomitized during early diagenesis and then crosscut by low Mn-calcite veins and disseminated pyrite was also precipitated at this stage. The next paragenetic stage involved the precipitation of quartz, barite, sphalerite, Cu-As sulfides, Pb-As-sulfides and texture-destructive hydrothermal dolomite. Stylolites and higher-Mn calcite veins post-date the base metal mineralization. The ore stage consists of high-Mn dolomite veins and the formation of small amounts of arsenian pyrite. High-Mn calcite veins, realgar, orpiment and a second phase of stylolite development were the last events to affect the rocks. Stable isotope and fluid inclusion analyses are being used to determine the source and composition of the fluids and a model of the evolution of the hydrothermal system through time will be presented. **(*SY5, Thurs. 4:00*)**

Geology of the turbidite-hosted Mustang gold showing, Lower Eastmain greenstone belt, Superior Province, Quebec

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The Mustang gold showing occurs on the Wabamisk property belonging to Virginia Mines Inc. The showing is located 60 km south of the Eleonore Mine (Goldcorp), in the Lower Eastmain greenstone belt that forms part of the La Grande Subprovince. The gold-bearing Mustang vein returned up to 23.28 g/t Au over 4.6 meters (channel) and 22.65 g/t Au over 2.25 meters (drill hole).

The mineralization is hosted by turbiditic sedimentary rocks (Auclair Formation) that occur in the upper part of the stratigraphic sequence. Outcrop and trench mapping in mineralized areas reveal that the sediments have undergone at least three phases of deformation including NNW-trending F_1 folds refolded by ENE-trending, steeply east-plunging regional F_2 folds. The main foliation (S_2) is ENE-trending and axial planar to F_2 folds. D_3 is defined by a NE-trending disjunctive crenulation cleavage. Eight lithologies were identified and four generations of quartz veins (± carbonate, feldspar) were distinguished using cross-cutting relationships. Early veins are deformed by F_2 folds and dismembered while later veins are only slightly deformed. Many gold-bearing veins are subparallel to the bedding, whereas some are axial planar to F_2 folds. The Mustang vein (N240/80°) was stripped and drilled over 420 meters laterally. Its thickness varies from a few centimeters to 2.5 meters. The Mustang vein was emplaced subparallel to bedding at an early stage of D_2. The vein contains milky and smoky quartz with laminar textures and clasts of altered and foliated wall rock. The wall rock hosting the Mustang vein is silicified and sericitized (± actinolite, clinozoisite) and contains 1 to 10% sulphide minerals including arsenopyrite porphyroblasts, pyrrhotite stringers aligned sub-parallel to the main foliation (S_2) and traces of pyrite and chalcopyrite. The mineralized zones and geological setting show some analogies in terms of structure and styles of mineralisation to turbidite-hosted gold deposits such as the Meguma mineralization in Nova Scotia and Bendigo-Ballarat in Australia.

The Mustang vein is another example of the many different styles and settings of gold mineralization in the James Bay area, and one that illustrates the potential of the sedimentary assemblages to host gold mineralization. **(*SY5, Poster*)**

Neoarchaean disaggregation and reassembly of the Superior Craton by continental drift on a subductionless, stagnant-lid Archaean Earth: Comparisons with Venus

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The S&W Superior craton is a Neoarchaean tectonic collage, with diachronous (~2.72 to ~2.68Ga) collisional orogenesis propagating N to S, with an average interval of ~10my between collisions. Most tectonic models for the Superior assume terrane accretion is the result of uniformitarian plate tectonics (arcs, ridges); because long histories of 'arc' magmatism are inferred, requiring correspondingly lengthy subduction intervals and consumption of 500-1000km wide oceanic tracts. This makes it difficult to rationalize a uniform collision polarity and short intervals between collisions for assembly of such tiny terranes. Modern subduction zones have lithofacies and geochemical signatures that differ from those found in Archaean terrains. Linear volcano-plutonic island and continental arcs develop above the locus of slab degassing/melting during subduction. Modern constructional arc strato-volcanos are surrounded by tuff-lahar aprons and commonly erupt abundant andesites. Yet andesites are among the least common Archaean lavas and Archaean lahar deposits are rarely described. Phanerozoic arc magmas show characteristic trends on the Th/Yb *vs.* Nb/Yb diagram that are parallel to the OIB/MORB array, attributed to pre-melting metasomatism of the mantle wedge by fluids/melts released from the subducting slab. In contrast, most Archaean lavas define oblique arrays indicating assimilation-fractional crystallization processes. When the rarity or absence of Archaean ophiolites, overprinting thrust and fold belts, high-pressure rocks and paired metamorphic belts is also considered, uniformitarian-type Archaean subduction seems implausible. Evidence from Venus implies that continental drift and Himalayan style indentation and escape tectonics occurs on telluric planets without arcs or ridges due to basal mantle traction on deep, stiff, cold, buoyant sub-continental mantle keels. Application of such a model to the S&W Superior would involve southward drift of the northernmost block (Hudson's Bay Terrane, with the deepest mantle keel in the Superior), with sequential accretion, imbrication, and anatexis of small, closely spaced 'terranes' to the leading edge of the drifting craton. Although most S&W Superior 'terranes' were interpreted to have been independent fragments prior to their assembly, many share similar geological histories, with older (pre-2.8Ga) basement and abundant coeval Neo-Archaean magmatism. We propose that most originally belonged to an older Superior (I) craton that was partly disaggregated by the arrival and radial outflow of large mantle plumes at ~2.75-2.7 Ga during a mantle overturn event. The lithospheric mantle beneath zones of maximum extension like the Abitibi and Wabigoon was destroyed by thermo-chemical corrosion or attenuated by necking, such that only juvenile magmas erupted in these newly oceanized areas. **(*SY3, Thurs. 3:40*)**

Paleoproterozoic (2.5-2.0 Ga) event stratigraphy: Its potential for interbasinal correlation

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Correlation of Precambrian sedimentary successions is hindered by poor age constraints. It is possible to overcome this limitation by means of event stratigraphy based on recognition of marker beds that represent stratigraphic expression of global events. This approach might be particularly applicable to Paleoproterozoic sedimentary successions since the 2.5-2.0 Ga exosphere was affected by a number of distinct tectonic, magmatic, climatic, and biogeochemical perturbations that are recognizable in the sedimentary record. These events, in ascending order, are: 1) a 2.48-2.45 Ga superplume event expressed in the rock record by large igneous provinces, rifting, and deposition of Banded Iron Formations, 2) an extended glacial epoch (*ca.* 2.45-2.22 Ga), with potentially 4 glacial evens, accompanied by carbon isotope excursions, 3) the Arrowsmith orogeny and associated *ca.* 2.32 Ga felsic volcanism, 4) a period of enhanced chemical weathering (*ca.* 2.32-2.1 Ga) in association with a major carbon isotope excursion, 5) a *ca.* 2.25-2.2 Ga superplume event that formed extensive plateau basalts and dikes, 6) the Great Oxidation Event that started at 2.4-2.3 Ga and ended at *ca.* 2.1 Ga, and 7) the final breakup of the Kenorland supercontinent at 2.1-2.0 Ga.

Sedimentary rift successions deposited before the glacial epoch contain detrital uraninite and pyrite. Atmospheric pO_2 may have changed during the glacial epoch in response to fluctuations in the exogenic carbon cycle. Worldwide, the third glacial event was followed by deposition of mature, Al-rich quartzites linked to oxidizing continental weathering producing acidic groundwaters favoring chemical weathering. The *ca.* 2.32 – 2.1 Ga carbon isotope excursion also overlaped and succeeded the glacial epoch. The carbon isotope excursion is thought to have lasted more than 100 Ma and was likely accompanied by an increase in atmospheric oxygen. Carbonate successions deposited during the carbon isotope excursion contain pseudomorphs of anhydrite and gypsum suggesting warm and arid climate. The end of the carbon isotope excursion between 2062 ± 2 Ma and 2113 ± 4 Ma was accompanied by voluminous mafic volcanism which has been related to the supercontinent breakup. Deposition of BIFs, phosphorites, Mn-rich sediments, organic-rich shales with high organic carbon contents and with some carbon isotope values of organic matter as low as -40 - -45‰ coincides in age with the end of the carbon isotope excursion. Recognition of these events combined with high precision geochronology and sequence stratigraphy has a great potential for interbasinal correlation and the understanding of the evolution of the Paleoproterozoic exosphere. **(*SY7, Fri. 8:00*)**

Example of bimetasomatism between feldspathic blocks and dolomitic marble at the Des Cèdres spinel occurrence, Grenville Province, Québec

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At the Des Cèdres dam (western Québec), Mg-Al spinel occurs in high grade (upper amphibolite or granulite) metasedimentary rocks of the Mont Laurier terrane of the Central Metasedimentary Belt, Grenville Province. At this occurrence, spinel and forsterite (Fo97) are transparent, but too heavily fractured for use as gemstones. Two rounded blocks of feldspathic rock (up to 1.5 m in size) included in medium-grained dolomite-bearing marble are exposed on the eastern shore of the Lièvre River. The feldspathic rock is composed of antiperthite, calcic clinopyroxene, biotite, and ilmenite. These blocks are separated from the host marble by multiple concentric zones of metasomatic mineralization, the largest of which is dominantly composed of phlogopite (>95%) except in deformed calcite-bearing regions. Metasomatic assemblages are divided into four distinct units: (1) Innermost zone composed of concentric phlogopite bands. Forsterite occurs sparingly, and microscopic grains of baddeleyite are rare; (2) Forsterite-rich rock with subordinate spinel, magnesite, and local aspidolite; (3) Forsterite-spinel-calcite rock with phlogopite. The spinel crystals display a purplish-blue colour, and occur as idiomorphic crystals to 6 cm in size. Thin retrograde rims of diopside and pargasite surround grains of forsterite and phlogopite, respectively. The proportion of calcite in this rock increases outward; (4) Recrystallized coarse-grained calcite. This locality is the first reported occurrence of aspidolite (“sodium-phlogopite”) in Canada. The observed banding differs from the expected metasomatic zoning between silica-rich to carbonate-rich rocks, where the mineral assemblage varies in mineral abundance along chemical potential gradients of major elements, especially Si and Al. The complex mineralogy suggests that the activities of other components, such as alkalis and water, likely contributed to the variation in mineral assemblages. **(*SS24, Thurs. 3:20*)**

Kiggavik (Nunavut, Canada): Lithostratigraphy and regional geological structure, new insights

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The Kiggavik Uranium deposits are hosted within Archean psammites to pelites of the Woodburn Lake Group (2.71Ga?) and Paleoproterozoic metaquartzite recently attributed to the Keyet River/Amer Group (2.5-1.9Ga). Although the contact between both units was often targeted by exploration because often mineralized, the metaquartzite unit remains today poorly defined from a lithostratigraphic or a structural point of view. Many topics are still debated: orthoquartzite *vs.* paraquartzite, metasedimentary *vs.* hydrothermal (silicification), lenticular bodies *vs.* thrust wedge, or even the nature of the contact with the underlying metasedimentary Woodburn Lake Group.

Drill hole core observations, petrographic analysis and geochemical data are used to define the lithostratigraphical and lithostructural units in the Kiggavik area in order to define the regional structure, localize and understand hydrothermal alteration corridors and related uranium deposits.

In the Kiggavik area, the metaquartzite is up to 300m-thick and is constituted by alternating layers of metavolcanics (metarhyolites), massive quartzite and psammitic to pelitic gneiss. The contacts between these lithologies are most often abnormal (mylonitic or faulted) but in some holes gradual contacts are visible. These gradual contacts indicate continuous deposition of the alternating metavolcanics, massive quartzite and psammopelitic gneiss, in a well-defined temporal unit. Total rock systematical geochemical analysis along cores shows distinctive geochemical signature between these lithologies. For instance, immobile elements like Al, Ti or Bi display distinctive values allowing the differentiation between the fresh psammopelites of the metaquartzite, in which values average ≈10pct Al_2O_3, ≈0.2pct TiO_2 and ≈6ppm Bi, and the Woodburn Lake Group, in which values average ≈15pct Al_2O_3, ≈0.5pct TiO_2 and ≈0.6ppm Bi. The U content is also a distinctive tracer showing higher values within the fresh metaquartzite unit, ≈25ppm, than within the Woodburn Lake Group, ≈5ppm.

The bottom of the metaquartzite unit is represented by a characteristic quartz-eyed rhyolite. In one of the studied holes, the contact with the underlying psammopelitic gneiss of the Woodburn Lake Group is a non-tectonized sharp contact, parallel to the main S_1 foliation, which is interpreted as an unconformity.

This lithostratigraphic pile is used to build a geological map and several geological cross-sections that illustrate the main geological structure of the Kiggavik area and allow to better establish the framework of the Kiggavik Uranium deposits. **(*SS7, Poster*)**

Late Neoproterozoic plutons in the southern Cobequid Highlands, Nova Scotia, Canada: Field relations, petrology, and petrogenesis

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Complex geological relationships further complicated by widespread high-strain zones have hindered geological understanding in the southern Cobequid Highlands of northern mainland Nova Scotia. Although generally considered part of Avalonia, the rock types and ages are not typical of other parts of Avalonia. New mapping has led to more detailed resolution of the geological units, although reliable radiometric ages are still needed in order to understand their age relations. This study focuses on known or inferred Late Neoproterozoic plutons (Frog Lake, Debert River, and McCallum Settlement) in the main Bass River block, between the Rockland Brook and Cobequid faults, as well as the lithologically similar Gunshot Brook Pluton in the eastern part of the highlands. The Debert River, Gunshot Brook, and McCallum Settlement plutons include a range of rock types from diorite to tonalite, granodiorite, granite, and alkali-feldspar granite. Previously reported U-Pb (zircon) ages from these plutons range from are *ca.* 612 to 575 Ma; however, not all of the published analyses are concordant or reliable. Frog Lake pluton refers to heterogeneous, variably mylonitic bodies of dioritic rocks which are scattered throughout the southwestern part of the study area. Hornblende from one of the dioritic bodies previously yielded a $^{40}Ar/^{39}Ar$ age of 622±3 Ma, suggesting that it is older than the other plutons. Plagioclase in dioritic samples from the Frog Lake and McCallum Settlement plutons has labradorite-andesine compositions, whereas more granitic samples contain less calcic plagioclase. Amphibole is mainly magnesio-hornblende in dioritic samples but ferrohornblende in granodioritic to granitic samples. Biotite compositions are consistent with those of biotite formed in calc-alkalic suites. New whole-rock chemical data from 54 samples, together with previously published data for a similar number of additional samples, suggest that quartz dioritic to granitic units of the Debert River, Gunshot Brook, and McCallum Settlement plutons are a cogenetic calc-alkaline suite formed in a subduction-related Andean-type continental margin. However, a compositional gap and different chemical trends suggest that the more mafic (dioritic) components of those plutons may be related to the dioritic bodies which form the Frog Lake pluton. The most mafic samples from the Frog Lake bodies have higher Ti, V, and FeOt/MgO ratios, and display tholeiitic trends, indicating that they may not be genetically linked to the calc-alkaline suite. **(*SY1, Poster*)**

Geochemistry and Nd-isotopes of Archean volcanic rocks from the Cameron-Beaulieu volcanic belts, Slave Craton: Petrological evolution and VMS potential

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The Cameron-Beaulieu volcanic belts are approximately 100 km east of Yellowknife in the south-central Archean Slave craton. These bimodal Neoarchean greenstone belts overlie and wrap around the >2.9 Ga Sleepy Dragon basement complex. Detailed bedrock mapping in the Sharrie Lake and Turnback Lake areas of the Cameron-Beaulieu belts help resolve stratigraphy, and associated geochemical studies help evaluate the petrological evolution and VMS potential of these volcanic belts.

In the Yellowknife greenstone belt, the *ca.* 2663 Ma Banting Group is the younger of two volcanic sequences. It is bimodal and the rhyolites have a distinct HREE depletion and lack a negative Eu anomaly. Rocks that share this age and pattern are well-defined in the Yellowknife domain, but are not prevalent in the rest of the Slave craton. Instead, bimodal volcanic sequences throughout the Slave craton tend to be older than the Yellowknife Banting (*ca.* 2.69-2.67 Ga). The geochemistry of the felsic volcanic rocks in these sequences show two patterns: (1) HREE depletion with no Eu anomaly, similar to Banting in Yellowknife, and (2) flat HREE pattern with a variable negative Eu anomaly. The majority of the felsic volcanic rocks that host VMS deposits in the Slave craton, including the rhyolites in the *ca.* 2680 Ma Sharrie and Turnback sequences, contain this latter signature. Sm-Nd isotope data will provide further insight to the evolution of these volcanic packages.

The volcanic rocks in the Sharrie and Turnback areas host several prospective Cu-Pb-Zn showings, commonly at mafic-felsic and volcanic-sedimentary interfaces. The felsic volcanic rocks associated with these showings plot as FII rhyolites, according to the Superior craton classification scheme. Sunrise, XL, BB, and several other VMS deposits in the Slave craton also share the same FII pattern. While FIII rhyolites are characteristic of most large VMS deposits in the Superior province, FII rhyolites are still viable targets, as seen at Val D'Or, Selbaie and, in part, Noranda. Significantly, outside the Superior province, many VMS deposits have the FII signature. The volcanic rocks in the Beaulieu-Cameron River volcanic belts are locally consistent with a VMS-bearing environment and further exploration is required to thoroughly evaluate VMS potential. **(*SS14, Fri. 2:00*)**

U-Pb geochronology of detrital zircon in Silurian sandstones of eastern Maine: A glimmer of hope

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A significant breadth and thickness of Silurian flysch occupies a key position along the axis of the Appalachians of Maine between Laurentia and Avalon. Because it is draped across the remains of "Ganderia" and various accreted peri-Gondwanan fragments and postulated suture zones, the flysch obscures relationships among the pre-Silurian terranes. Detailed lithostratigraphic and lithofacies mapping indicates at least three Silurian basins. The Miramichi terrane was a sediment source dividing the Fredericton trough to the southeast from the Aroostook-Matapedia basin to the northwest. To the southwest, these two basins merge into the Central Maine basin, with sediment derived from Laurentian-based terranes to the northwest, and a tectonically obfuscated southeast margin.

Age spectra have been obtained by SHRIMP U-Pb analysis of detrital zircon from eight samples of Silurian sandstone from the Houlton-Kellyland-Waterville area. For all samples, the youngest grains are between *ca.* 435 and 425 Ma, supporting the inferred Silurian depositional ages, but not allowing clear stratigraphic sequencing among the samples. Despite the rarity of volcanic rocks within the basin, all have significant ages in the *ca.* 450 to 430 range, in most cases resolved into two peaks. Neoproterozoic ages (700-550 Ma) are present in only three samples: (1) from the northwest margin of the Fredericton trough (Flume Ridge Fm), (2) from the eastern side of the Central Maine basin (Hutchins Corner Fm), and (3) from near the merging of the Aroostook-Matapedia basin with the Central Maine basin (Mayflower Hill Fm), west of the Miramichi. The other five samples are either believed to be stratigraphically higher or are of uncertain stratigraphic position. All samples contain a significant component of Grenvillian ages (1.35-0.95 Ga).

Our preliminary conclusions are: (1) The Laurentian dispersal pattern extends across all the major faults within our sampled area (Central Maine, Messalonskee Lake, Norumbega-Fredericton), so these faults do not bound Silurian basins. Note that work in progress by Dokken and Waldron in New Brunswick suggests, however, that Laurentian detritus did not spread entirely across the Fredericton trough. (2) Absence of Gondwanan detritus in five samples scattered across all three basins suggests that much of the sampled area did not have sediment sources from the southeast. (3) The geographic distribution of those samples which do have clear Gondwanan signatures is not simple, suggesting restricted sediment dispersal, either at earlier stages of basin filling or proximal to eroding source areas, in an environment of coalescing submarine fans. **(*SY1, Wed. 2:00*)**

Tectonic evolution of the western Rae craton of Laurentia/Nuna: Improving the 'bar code' for paleocontinental reconstruction

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The history of the tectonically complex Rae craton is by no means fully resolved but evidence is accumulating that its history was independent of the Hearne craton before later incorporation within Laurentia/Nuna. Growing acceptance of the idea of a separate Rae allows us to reframe perspectives on how the supercontinent concept applies to the Precambrian and the pivotal role Rae craton may have played. Testing the viability of paleocontinental reconstructions, however, and thereby better determining Rae's role in an antecedent supercraton (Nunavutia) and in the later assembly of Nuna depends on developing detailed and accurate 'bar codes'. Because it holds key evidence of Rae's earlier involvement in Nunavutia (Arrowsmith orogenesis) and its subsequent involvement in Nuna (Thelon-Taltson orogenesis), the western Rae is of fundamental importance. Much of our current understanding of the tectonic evolution of this region is predicated on Hoffman's original analysis in which he ascribed the Thelon orogen to collision of Slave craton and Rae cratons. This model was later refined with recognition that the colliding terranes were Buffalo Head in addition to Slave. Subsequent geochemical-isotopic investigation of granitic rocks of the Taltson magmatic zone (TMZ) concluded that these plutons were more likely generated inboard of a plate margin, raising the possibility that Slave craton may have accreted to Rae at an earlier stage. Evidence has since accumulated for the existence of a distinct late Neoarchean to early Paleoproterozoic orogenic belt inboard of the Thelon-Taltson orogen, the 'Arrowsmith orogen'. This belt's existence necessitates rethinking of current tectonic models/paradigms. Robust Arrowsmith orogenic effects have now been recognized well into the interior of the Rae. Whereas this, along with the longevity of orogenesis, supports the notion that the western Rae represents a long-lived accretionary margin, important questions remain. Among these are: when did the process of accretion begin, at 2.3 Ga, or earlier and what colliding blocks were involved? Slave craton, as proposed by some, or other, as yet unidentified, terranes? Furthermore, when did accretion end and what were the dynamics involved in the transition to Thelon-Taltson orogenesis? What role did supracrustal successions deposited within the transitional period play? The concept of a long-lived accretionary orogen also contravenes a recent theory for a global magmatic shutdown within this timeframe. This talk will explore our existing knowledge of the west-southwest Rae in the context of theories of Precambrian earth history and in an attempt to focus future research questions. **(*SY7, Fri. 9:20*)**

Amazonian craton tectonism recorded in the evolution of the Roraima Basin, Guyana, South America

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The *ca.* 1.87 Ga Roraima Supergroup is a succession of clastic sedimentary rocks that represent deposition in one of the largest known continental sedimentary basins on Earth, spanning Guyana, Brazil, Suriname, and Venezuela. We studied outcrop exposures and 23 drill cores in Guyana where the Roraima Supergroup comprises lithofacies representing lacustrine upper shoreface, playa, braided river, and alluvial fan environments. Detailed cm-scale logging of the drill cores allowed us to identify facies, evaluate accommodation changes, and determine sequence stratigraphic bounding surfaces.

The Roraima Supergroup is punctuated by three episodes of source-area uplift followed by subsidence, wherein major erosional surfaces are overlain by coarse lithic, arkosic to quartz-rich conglomerates and sandstones deposited in high-energy braided rivers, which are overlain by lacustrine upper shoreface, playa lake, and eolian facies. Tectonism played a major role in lithofacies distribution and the generation of sequence boundaries. Amalgamated braided fluvial channels reflect tectonic stasis and little creation of accommodation, whereas thick intervals of lacustrine to playa lake sandstones reflect basin subsidence and substantial creation of accommodation.

Diagenesis records four significant alteration events driven by tectonism on the Amazonian Craton. These events are early and shallow burial, intrusion of mafic sills, deep burial, and late alteration. The most notable of these is the intrusion of the Avanavero Suite diabase sills at *ca.* 1790 Ma that caused intense metasomatism, which together with preceding early burial cementation, resulted in significantly reduced fluid-conducting capabilities in the sandstones early in the history of the basin. The mineral chemistry of intrusion-related epidote, calcite, and titanite suggests that Mn, Sr, and REE were mobile in the Roraima Supergroup during the intrusive event, likely facilitated by elevated fluorine concentrations. Mixing of basinal fluids with intrusion-related fluids is suggested by C and O isotopic compositions and $^{87}Sr/^{86}Sr$ ratios in calcite. Renewed subsidence subsequent to the intrusions caused burial of the Roraima Supergroup, and allowed interaction of the sediments with basinal fluids at elevated temperatures (~250°C). This produced white mica alteration, which occurred predominantly at low water/rock ratios based on O and H isotopic compositions. $^{40}Ar/^{39}Ar$ dates between 1815±12 Ma and 1723±10 Ma of white mica, and U-Pb dates around 1820 Ma of fluorapatite, temporally constrain these three burial and intrusion-related fluid events. Late alteration likely accompanied uplift and erosion, resulting in a lower-temperature mineral assemblage that occurs preferentially in brittle fractures and near the modern erosion surface. **(*SS13, Thurs. 4:00*)**

Evaluating the economic metal potential of pegmatites of the Hall peninsula, Baffin Island, Nunavut

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A number of granitic pegmatites intrude the country rock on the Hall Peninsula, southern Baffin Island, Nunavut Territory. This project studies the distribution, composition, and petrogenesis of a selected number of these pegmatites that have not been previously examined in detail.

Pegmatites are known to occur across Baffin Island, with many identified on the Hall and Cumberland peninsulas. There are published reports of occurrences of tourmaline, beryl, and other unusual minerals in several of these pegmatites. Because their surface exposures are generally quite small in comparison with other types of mapped units, pegmatite bodies on the order of one to tens of metres wide are not usually represented on 1:250,000 scale geological maps, at which most of the geology of Nunavut is currently mapped. A more thorough examination of their distribution and volume is required to understand their significance in the region. We anticipate that this work will highlight the potential of Baffin Island pegmatites to companies that are interested in rare earths/rare metals exploration.

The goal of the project is to determine the following: are Hall pegmatites enriched in rare earth elements and/or Li, Cs, and Ta; what is their paragenesis; what is their parent melt (tonalite gneiss, metasediments, or another source); and what is their age of crystallization?

With an understanding of their origin and characteristics, the presence or absence of economic minerals in the Hall pegmatites and how they fit into the geologic evolution of southern Baffin Island can be better determined. Field evidence suggests that they are a late-stage event because they are undeformed and retain a number of primary textural characteristics of coarse-grained pegmatites. One hypothesis under consideration is that they represent the products of the last phase of partial melting of the country rock.

Research is being conducted in partnership with the Canada-Nunavut Geoscience Office. The pegmatite exposures are being located through analysis of remote sensing imagery and follow-up field work. Further analysis of Hall Peninsula pegmatites will be performed using LA-ICP-MS techniques on muscovites and feldspars. Cumberland Peninsula pegmatite samples may also be included as part of this study to provide a broader regional context. **(*SS11, Poster*)**

Characterization of invisible gold at the Beattie gold deposit, Abitibi, Canada

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Invisible gold has been recognized in several types of deposits around the world, most notably in mesothermal and sediment-hosted gold deposits (Carlin and black shale-types). A common feature of these deposits is the occurrence of arsenic in the system, as arsenopyrite and arsenian-pyrite. The Beattie gold deposit (89,7 Mt @ 1.56 g/t Au containing 5,55 Moz Au) is located in the Abitibi greenstone belt, near the Porcupine-Destor Fault Zone, and is associated with the Beattie syenite porphyry. A significant fraction of the ore is controlled by the lithology and is associated to iron-carbonate and potassic alteration. The ore consists of bulk-tonnage-low-grade disseminated arsenian-pyrite and arsenopyrite with invisible gold.

Electron microprobe analyses revealed gold concentrations reaching up to 270 ppm in arsenic rich zones of arsenian-pyrites. LA-ICP-MS analyses on gold bearing pyrites indicated good correlations of gold with As, Ag, and Cu, and moderate correlations of gold with Bi, Hg, Te, Se, Mo. High-resolution Transmission Electron Microscopy (TEM) investigations on an extracted focused ion beam (FIB) foil show the complexity of the gold-bearing pyrite crystals. High angle annual dark field (HAADF) images reveal areas with complex zonation patterns. Copper-rich zones of about 2 microns alternate with As-rich zones of similar width, which consist of multiple bands of about 10 nm with varying proportions of As, Au and Ag. Electron Dispersion X-ray (EDX) line scans revealed that one of these bands host a relatively very high content of Au and As. TEM bright-field images or HAADF images do not show any features of gold nanoparticles, which unequivocally suggests that gold is bound to the crystal lattice of this specific zone of pyrite, heavily enriched in arsenic (about 3 to 4 wt. % As).

These results bear on the notion of solubility of Au in pyrite. They reconcile the well-known association of Au and As at the deposits and the macroscopic sample scales on one hand, and on the microscopic and nanoscopic scales on the other hand. The alternating discrete As ± Au bands and Cu-enriched zones suggest that Au mineralization occurred as distinct pulses of hydrothermal to magmatic-hydrothermal fluids, some of them being Au and As-rich, and others being Cu-rich. **(*SY5, Thurs. 2:00*)**

Complex depositional environments of Paleozoic black shales: Insights from core and sulphur isotope analyses of the Upper Devonian Kettle Point Formation, southwestern Ontario

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Despite recent interest in black shales as hydrocarbon reservoirs, the depositional environments of these rocks remain enigmatic. This study aims to help elucidate the mechanisms and factors behind the deposition of black shales by conducting lithological and geochemical analyses on an Upper Devonian black shale in southwestern Ontario, the Kettle Point Formation. The Kettle Point Formation was deposited in an epeiric sea during the Acadian Orogeny and is paleogeographically situated in the Chatham Sag between the Appalachian and Michigan basins. Detailed core and thin section analyses reveal that the Formation can be subdivided into three distinct lithofacies: greyish green mudstones interbedded with interlaminated black shales and separated by thick intervals of non-interlaminated black shales. Contacts between interlaminated black shales (below) and greyish green mudstones (above) are typically bioturbated, whereas sections of non-interlaminated black shales appear to be devoid of any evidence of life but contain sulphide nodules. Preliminary sulfur isotope data from 50 samples spread throughout the formation show a largely consistent background value for the black shales around -20 $\delta^{34}S$, punctuated by a substantial positive excursion of ~ 32 ‰ (up to 12.87) correlated with a significant interval of greyish green mudstones.

A model for the deposition of the Kettle Point Formation is proposed based on the integration of the lithological and geochemical results. Variations in lithology are reflected in $\delta^{34}S$ values and are attributed to changes in the intensity and vertical extent of anoxia in the water column. Shifts in anoxia, in turn, were driven by sea level fluctuations with peak depth corresponding to the acme of anoxia and the deposition of thick packages of non-interlaminated black shales. Interbedded interlaminated black shales and greyish green mudstones record lower intensities of oxygen deficiency overall, but fluctuating at a finer level between anoxic and dysoxic conditions respectively. The transition to more oxygenated waters is interpreted as the result of a drop in relative sea level and a corresponding increase in water column mixing. Positive $\delta^{34}S$ values, correlating to the dysoxic mudstones, are interpreted as signaling a significant decrease in primary productivity that led to a drop in sulfate reduction by bacteria in oceans. **(*SS2, Wed. 2:20*)**

Integration of mineralogy and rock physics proprieties applied to the footprint of the Canadian Malartic gold deposit

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The Canadian Malartic gold mine contains over 14 Moz of gold (past production and current resources). Gold mineralization is mostly hosted in meta-sedimentary units of the Pontiac Subprovince, which are cut by a variety of felsic to mafic intrusions. Eleven representative samples of meta-sedimentary non-mineralized host rocks (siltstone, mudstone and greywacke: Au < 0.005 ppm) and of various styles of mineralization (Wolfe, Zone A and CM Keel zones) were studied in detail to determine the relationship between their rock physical properties and mineralogical composition. The results reveal that the non-mineralized sedimentary rocks have higher saturated bulk density (2.76-2.81 g/cm^3), apparent porosity (0.37-0.57 %), magnetic susceptibility (3.3-7.5 10^{-4} SI) and remanent magnetization (1.5 10^{-3} - 2.1 10^0 A/m) than the mineralized samples. Auriferous samples have higher average resistivity (4 - 34 10^3 Ohm.m). The range of Koenigsberger ratios (Kn: 0.03-0.93) and chargeability (2.5-27. ms) data are similar for non-mineralized and auriferous samples, except for one anomalous non-mineralized sample with the highest proportion of pyrrhotite. The non-mineralized samples with high magnetic susceptibilities have higher proportions of pyrrhotite and/or ilmenite (up to 0.5 %). In the auriferous samples, these minerals are replaced mainly by pyrite (up to 4%), which explain their lower magnetic susceptibilities (3.6-23 10^{-5} SI). The higher average resistivity values in most of the mineralized samples are interpreted to be due mainly to replacement of the phyllosilicates and plagioclase aligned along the main tectonic fabric by variable proportions of quartz, alkaline feldspar and/or carbonate; however the highest values are observed in a weakly mineralized sample (0.013 g/t Au) with porphyroblasts of amphibole. The relationship between porosity and saturated bulk density is intriguing and will be further investigated. These preliminary results will be further integrated with a larger data base to determine the critical parameters that would be applied to better understand the Canadian Malartic footprint and explore for similar gold deposits. *"CMIC-NSERC Exploration Footprints Network Contribution 014."* **(*GS1, Poster*)**

The quest for better precision and more accuracy: Revisiting upper intercept ages

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The geological literature on the Precambrian is littered with U-Pb (ID-TIMS) ages that rely on upper intercepts through variably discordant data. Sometimes such data involve linear regressions through data points involving more than one mineral, *e.g.* zircon and baddeleyite. Implicitly or explicitly such upper intercept ages rely on the assumptions that Pb loss patterns were similar for 1) different minerals, and 2) different degrees of discordance.

Neither of these assumptions is easily justified and, generally, they are probably wrong. Thus, many of the resulting upper intercept ages are open to re-interpretation. The degree of potential re-interpretation can be judged by some simple diagnostics: how discordant is the least-discordant datum; the degree to which the more (most) discordant data point(s) determines the slope of the regression; the likelihood of the apparent lower intercept (and slope); and any other ad hoc choice of regression line (*e.g.*, aiming to fit most of the points, even if this relies on more discordant points and/or different minerals).

Excluding inheritance, the ^{207}Pb/^{206}Pb age of the least discordant data point provides a minimum age. For many baddeleyite datasets, where the least discordant data point is ~0.5–1.5% discordant, this age commonly provides a better estimate of the crystallization age than an upper intercept from a shallow-sloping regression that also fits highly discordant data. More highly discordant data points (*e.g.* 5–15%) are a poor guide to the Pb loss trajectory of the best quality grains and their Pb loss likely involved different processes—minor surface-related Pb loss (*e.g.* due to recoil or interaction with ground water) for ~1.0% discordant data, versus more ancient open system behaviour for more altered highly discordant grains. In other words, the overall Pb loss pattern does not need to follow a straight line on a U-Pb concordia diagram, but often describes a curved path, with more discordant fractions involving grains that not only lost more Pb, but also started Pb loss earlier.

We will present several important case studies. One notable example is the curious 1918+9/-7 Ma age for "differentiated ultramafic sills intruded into lower Povungnituk Group" strata of the Cape Smith belt. This age interpretation relies on a shallow-sloping regression through discordant baddeleyite data, while also trying to fit a zircon point. An alternative interpretation of the same data suggests this sill is *c.* 1885±2 Ma, in agreement with other recent data. The sill actually intrudes deep-water sedimentary rocks near the stratigraphic top of the Povungnituk Group, not near the base, simplifying the overall Povungnituk–Chukotat stratigraphy and age pattern. **(*SS17, Wed. 8:40*)**

The Abitibi breaks: Syn-orogenic extensional faults inverted as thick-skinned thrusts, and explaining the link with economic gold mineralization

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In the Abitibi greenstone belt, empirical association of large gold deposits with major E–W-trending fault zones and structural panels of synorogenic clastic rocks has long been recognized. This association is duplicated in other cratons, often blow-by-blow, and also in younger terranes, arguing for a genetic system that involves the following critical elements:

1) major crustal-scale fault zones;

2) synorogenic clastic basins, unconformably overlying previously deformed greenstones (s.l.);

3) a flare-up in syn- to late-orogenic alkaline magmatism dominated by syenite-clan rocks;

4) lamprophyre dykes;

5) rapid deepening of the clastic basins, then filling by upward-coarsening detritus carrying the youngest detrital zircons (*e.g.*, 2667-69 Ma in the Abitibi);

6) deformation, tectonic burial, and preservation of wedges of the clastic basins in the structural footwall of the main faults;

7) further shortening, and steepening of the faults to near-vertical, and local overturning;

8) degeneration of the faults to zones of late strike-slip.

The key faults (the "breaks") post-date early high-level fold-thrust structures. This, together with several other observations, indicates the breaks originated as synorogenic, crustal-scale extensional faults during a phase of syn- to late-orogenic extension, as seen in many orogenic belts. This immediately explains the basin formation and sudden flare-up in alkaline magmatism. Crustal extension and alkaline magmatism increased heat flow into the lower crust and drove the onset of hydrothermal fluid generation. In the Abitibi, most of the faults were listric to the south. Shortly after 2667 Ma, they were inverted as thick-skinned thrusts, burying basin remnants and gold deposits in their structural footwall. Significant uplift of the hanging walls removed synorogenic clastic rocks and most gold deposits, explaining the fundamental asymmetry of these settings. Local overturning during later deformation, and further disruption during final strike-slip (with ~10–50 km net offsets) further complicates the overall picture (Bleeker, 2012, Ontario Geological Survey, OFR 6280, p. 47-1 to 11). Gold mineralization may have started during extension but peaked during thrust inversion and subsequent shortening. The delayed response (peak gold mineralization following extension) is likely a function of deeper magmatic processes and slow heat conduction in the lower crust.

The synorogenic ("Timiskaming") unconformity, specifically its preservation, is a key diagnostic for the overall tectonic environment, the original footwall-side of the fault, and preservation of the optimum crustal level. The overall structural model is highly predictive, providing a specific search tool for identification and evaluation of similar settings across northern Canada and other cratons. **(*SY3, Thurs. 9:00*)**

New U-Pb ages for some key events in the Sudbury area, including the Creighton Granite and Joe Lake metagabbro

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The Sudbury area, straddling the boundary between the Archean Superior Province and the Paleoproterozoic Southern Province, hosts a rich and in part unique Precambrian rock record, not in the least the deformed and down-folded remnants of one of Earth's largest and oldest preserved impact structures: deeply exhumed Archean basement, numerous Paleoproterozoic dyke swarms, the intracratonic rift and platformal succession of the Huronian Supergroup and related intrusions, the Sudbury Igneous Complex (SIC) and other elements of the 1850 Ma impact structure, the Whitewater Group, younger Proterozoic igneous events and, to the south, the products of successively younger orogenic fronts.

Obtaining precise ages on some of these units has proven challenging, particularly for those that predated the impact and experienced shock metamorphic effects and associated Pb loss. Additional Pb loss at younger times (*e.g.*, multiple Proterozoic events, and recent) further complicates discordance patterns, making upper intercept age interpretations uncertain and non-unique. Definitive answers on some of the key ages will only come from more concordant data. The ability to analyse ever smaller single grain fragments, and to pre-treat these with "chemical abrasion", may finally resolve some of the key ages. Additional answers will likely come from finely targeted SIMS dating. In this talk we will present new results on a number of key units from the Sudbury area.

Our data finally resolve the age of the Creighton Granite and Copper Cliff Rhyolite, confirming that these units form a single magmatic system emplaced at *c.* 2455–2460 Ma—a subvolcanic sill low in the Huronian rift (Creighton), overlain by an extrusive, cogenetic, rhyolite complex of flows and volcaniclastics (Copper Cliff). The Creighton Granite sill shows co-mingling with Matachewan gabbro sills and was folded prior to emplacement of the SIC. Our data for the Murray Granite are consistent with those of Krogh *et al.* (1996), but less discordant, with a preferred upper intercept of 2463±13 Ma.

On the North Range, the Joe Lake Gabbro is an Archean metagabbro body, in agreement with field relationships. It grew metamorphic zircons at 2657±9 Ma and was intruded by relatively undeformed granitic pegmatite dykes at 2648±9 Ma.

As expected, the concentric Hess Offset dyke is indeed part of the Sudbury event, at *c.* 1849 Ma, as is the more evolved, granophyric, radial Pele Offset dyke. Another speculative offset ("Pyroxenite") dyke proves to be part of the Matachewan event. Dating of several other units, including the South Range "Trap dykes" and younger felsite dykes, is in progress and ages will be reported as results become available. **(*SS17, Wed. 9:40*)**

Integrating X-ray absorption spectroscopy (XAS) and non-traditional isotope measurements to evaluate permeable reactive barrier materials

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Permeable reactive barriers provide an alternative approach for remediation of contaminated groundwater. The design of these systems requires comprehensive understanding of the reaction mechanisms and reaction capacity of the barrier materials. The integration of XAS and measurements of non-traditional isotope ratios has potential to provide a more comprehensive understanding of mechanisms occurring at the surfaces of the reactive materials. Laboratory batch experiments using organic carbon and zero valent iron show rapid removal of Cr(VI) from solution. Synchrotron-based X-ray absorption near-edge structure (XANES) analyses indicate the accumulation of Cr(III)-bearing phases, principally $Cr(OH)_3$, and absence of Cr(VI) in the reactive materials. Measurements of Cr-isotope ratios indicate enrichment of $^{53}Cr/^{52}Cr$ in the remaining dissolved Cr(VI) pool. The batch data were fit with a Rayleigh type fractionation curve, and differing fractionation factors were observed for these two materials. Column experiments also indicated Cr(VI) reduction, accumulation of Cr(III)-bearing phases and enrichment of ^{53}Cr in solution. However, column experiment data could not be fit with a simple Rayleigh model. Reactive transport modeling suggests that a two mechanism reaction system is required to describe the experiment results. Experiments focused on Se(VI) utilizing organic carbon, zero valent iron, and mixtures of these materials indicate rapid removal of dissolved Se in batch and column experiments. XAS examination of reactive materials from batch experiments indicates the progressive formation of a series of increasingly reduced Se species. These observations suggest that measurements of non-traditional isotope ratios combined with mineralogical characterization using XAS techniques have the potential to provide improved estimates of reactive barrier system performance and longevity. **(*SY6, Fri. 10:20*)**

Timing and geochemical signatures of metasomatism along the Grenvillian Heney Shear Zone, Mont Laurier terrane, Quebec

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The Heney Shear Zone (HSZ), bisecting the Mont Laurier terrane, is a *ca.* 980-940 Ma extensionally-reactivated thrust fault, associated with orogenic plateau collapse during the Ottawan deformation pulse of the Grenvillian orogeny. The marbles, quartzites, and alkaline igneous rock achieved upper-amphibolite to lower-granulite facies metamorphism during the Shawinigan pulse of the collision. The shear zone is delineated by a marked discontinuity in Ar-Ar cooling ages: the western block remained >500°C until *c.* 950 Ma, whereas the east cooled 200 m.y. earlier. The marbles are relative coarse grained and contain >3 µm calcite deformation twins that are overprinted by thinner deformation twins, indicating deformation persisted during cooling. Stable isotope (^{13}C and ^{18}O) analysis of calcite and dolomite crystals from the marbles, reveal couple depletion of isotopic signatures within the shear zone: mean $\delta^{13}C$ values are ~3‰ lower and $\delta^{18}O$ values are ~4‰ lower in the shear zone than the surrounding less deformed rock. Hornblende syenite and granite-syenite complexes lack any high-temperature metamorphic textures and instead display primary (re)crystallization features such as planar indentation, myrmekite and perthite. Whole rock geochemistry indicates the granite-syenite complexes exhibit low Ti, P, Nb and Ta values and high Rb, Ba and Th values. Potassic and sericitic alteration is pervasive within these complexes along the HSZ. We concur with Kretz (2009, Can. Min. 47) that these granite-syenite complexes are a product of metasomatic alteration. Irregularly zoned titanites from the granite-syenite complexes have been dated with LA-ICP-MS U-Pb geochronology. Single spot analyses yielded a quasibimodal age distribution with a main age population at 1040-1020 Ma and another at 1090-1060 Ma. The latter age is associated with Skootamatta-Kensington plutonic suite, but we interpret the 1040-1020 Ma age population as dating the timing of significant metasomatism and potassic alteration. We envisage the western Mont Laurier terrane witnessed a protracted residence under elevated temperatures, which triggered metasomatic alteration and production of the granite-syenite complexes. Our titanite ages reveal crystallization of the complexes 100 m.y. before regional cooling, which was likely a consequence of orogenic collapse accommodated by the HSZ. Moreover, our data suggest the HSZ was a long-lived conduit for fluids: maximum strain and depleted $\delta^{13}C$ and $\delta^{18}O$ values are recorded at the center of the 4-5 km wide shear zone. **(*SS20, Poster*)**

Are out-of-sequence thrusts really "out-of-sequence"?

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Out-of-sequence thrusts (OOSTs) form behind the trace of a basal thrust, not sequentially in the direction of system propagation. OOSTs influence many subduction zone settings, plate boundary fault systems, provide a mechanism to thicken accretionary wedges while providing a passage for fluid escape out of these systems, influence the development of forearc basins and may provide a bottom boundary fault for channel flow. In addition, OOSTs are earthquake generating and possibly tsunamigenic because they are steeper than décollements and will therefore focus vertical movement.

The Purcell Thrust is an OOST that juxtasposes the eastern margin of the Selkirk Fan Structure (Omineca Crystalline Belt) onto the western margin of the Porcupine Creek Anticlinorium (Rocky Mountain Foreland Belt), and is itself offset by the Trench Normal Faults (TNTs, Rocky Mountain Trench; northwest of Golden, BC to the Big Bend region along the Columbia River). Geochronology demonstrated that peak regional metamorphism was between 159 and 172Ma, corresponding to the Jurassic collision of the Intermontane Superteranne with the western margin of ancestral North America. Movement along the Purcell Thrust occurred between 107 and <85Ma, as the Insular Superterrane collided with North America. Early Eocene extension coupled with movement along the Trench Normal Faults occurred from 61 to 54Ma.

Geometrical reconstructions of movement along the Purcell Thrust and TNTs were used to support up to 10km of dextral strike-slip movement along the Purcell Thrust, in addition to 7-10km of dip slip movement. Thermobarometric calculations using THERMOCALC v3.1 combined with the garnet-biotite thermometer and GASP barometer failed to observe a statistically significant barometric break across the Purcell Thrust. Calculations of diffusional penetration distances demonstrated that kyanite + staurolite grade garnets smaller than 5mm in radius were probably chemically altered by retrograde cation diffusion: which when accompanied by movement along the Trench Normal Faults, may have disguised this barometric break.

As per other OOSTs, the Purcell Thrust formed behind the trace of the basal thrust, is steeper than the basal décollement, and is proposed to have formed in a channel flow horizon during the collision of the Insular Superterrane. However, are OOSTs really out-of-sequence? Literature review demonstrates that OOSTs occur in many of Earth's fold & thrust belts, and many sand-box or numerical modeling reproduce OOSTs. Here it is proposed that OOSTs are a normal event in the tectonic development of most fold & thrust belts. **(*SY3, Fri. 9:20*)**

Developing a competency profile for the profession of geoscience – report on progress

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In September 2012, Geoscientists Canada received funding from Employment and Social Development Canada's Foreign Credentials Recognition Program for a 30 month project to carry out four interrelated initiatives in the area of admissions support for the provincial/territorial bodies. The central and largest initiative involves the development of a competency profile for the geoscience profession in Canada.

In 2013 in Winnipeg, the authors presented on the design and objectives of this important national initiative, as work was getting underway. This presentation will report on work completed and will provide an overview of the resulting profile, which will enter a consultation phase late in 2014.

A competency is the ability to perform a practice task with a specified level of proficiency. Professional competence is enabled by the possession of competencies.

A key rationale for development of the competency profile is the move by other professions both in Canada and around the world, away from traditional credentials-based admissions assessments at entry-to-practice, and towards a system that is based on a combination of academic outcomes and practice abilities.

The resulting profile will address the full spectrum of abilities that result from the geoscience education and supervised experience required in order to undertake geoscientific work, independent of direct supervision.

Development of the profile has followed an iterative process involved key input from Subject Matter Experts who are geoscientists, representing a diverse sampling of the profession. The process included a full international review of published material related to geoscience competencies. A consultation phase then a validation procedure will follow.

Subsequent work will determine specific indicators of proficiency related to each competency that an individual is expected to demonstrate in order to become a Professional Geoscientist (P.Geo) and will suggest appropriate methodologies to assess competencies. **(*SS4, Thurs. 3:00*)**

Economic potential of the AusJam gold mine tailings deposit, Main Ridge, Clarendon parish, Jamaica

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The Central Inlier is one of 28 exposed Cretaceous volcanic and sedimentary rocks in Jamaica. It is the second largest of its kind, occupying an area approximately in the geographic centre of the island. During the mid to late 1980's, the Government of Jamaica, with the assistance of the Canadian International Development Agency (CIDA) undertook an island-wide metallic minerals survey which lead to the discovery of a gold mineralization. This mineralization is hosted by the Main Ridge Formation which is one of the principal stratigraphic units in the Inlier. The deposit itself occurs as low sulphidation veins with gold and silver grades reaching 11ppm and 4ppm respectively.

In March 2001, the first modern gold mine in Jamaica was established by AusJam Ltd at Main Ridge district. However, operations ended in December 2003. The ore is highly weathered and required semi-autogenous crushing only. It was processed using the cyanide leaching method with the ore having a residence time of eight hours. The waste product from the operation was stored in two membrane lined ponds. Since the closure of the mine, the price of gold has increased by over 400%. As a result, the once sub-economical tailings deposit has become more economical. The larger of the two ponds, which is estimated to be 18m deep, was considered for chemical analysis to determine the metal content.

Sampling of the tailings pond was done in June 2011 and April 2012, first using a hand held auger and then a hollow tube auger and piston corer for deeper sampling. The results of analysis showed that the average grade of gold and silver in the upper 10m of the pond was 0.35 ppm and 1.26 ppm respectively. Calculation of the reserve estimation suggests that the reprocessing of the tailings could prove viable if considerations such as the method of extraction are taken into account. **(*SY5, Thurs. 3:40*)**

Volcanology of the Waconichi Formation, Lemoine area, Abitibi Subprovince, Chibougamau, Quebec: Implications for VMS exploration

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The Archean Abitibi greenstone belt remains one of the best areas in the world for volcanogenic massive sulphide (VMS) exploration. In the Chibougamau district, the majority of VMS exploration focuses on the Waconichi Formation (Roy Group) that is composed of bimodal volcanic and subvolcanic units. The Waconichi Formation hosts the Cu-rich Scott deposit and the now mined-out Lemoine auriferous VMS deposit, ranked as the second highest grading VMS deposit in Canada with 0.76 Mt of ore at 4.2 g/t Au, 4.2 wt % Cu, 9.6 wt % Zn and 83 g/t Ag. Volcanic architecture reconstruction of the Waconichi Formation east of the Lemoine deposit is the main focus of this MSc study.

The study area is bordered to the North by the 2728 Ma synvolcanic Doré Lake Complex and to the South by transitional basalts from the upper Lemoine member of the Waconichi Formation (previously the Gilman Formation). Mapping, core logging, petrography and geochemistry indicate that the area contains multiple felsic units such as the Lemoine Rhyolite, the Hangingwall QFP, the Marelle Rhyolite, the Alpha Rhyolite (previously the Zr-rich Marelle Rhyolite) and the Coco Lake Rhyolite (previously the upper Lemoine Rhyolite). The Waconichi Formation also includes the Lemoine Andesite and the Lemoine Dacite. The Lemoine deposit lies stratigraphically on top of the Lemoine Rhyolite and is overlain by the Hangingwall QFP.

A better understanding of the distribution and emplacement of each unit was the main objective set for summer 2013. Outcrop mapping and the descriptive logging of more than 7000 m of core have made it possible to establish the distribution of felsic units, to better define volcanic textures and to identify major volcanic facies in the units. The work carried out confirms the effusive nature of the Lemoine Rhyolite. The Coco Lake Rhyolite and the Marelle Rhyolite are represented exclusively by coherent facies and their location at multiple stratigraphic levels suggests an intrusive nature. Lobes and fragmental facies in the Alpha Rhyolite are observed in drill core indicating an effusive nature. The Alpha Rhyolite is locally strongly altered with chlorite and sericite and is situated lower in the stratigraphy than the Lemoine Rhyolite that forms the footwall to the Lemoine deposit. This indicates a strong control of volcanic facies on the distribution of the hydrothermal alteration and suggests that hydrothermal activity occurred in zones lower in the volcanic sequence, perhaps prior to the formation of the Lemoine deposit, opening new horizons to VMS exploration. **(*SS6, Thurs. 10:20*)**

Petrology, mineralogy and geochemistry of the Beattie syenite, Abitibi Subprovince, Québec

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The Beattie syenite is composed of a series of lenticular bodies and dykes north of the Porcupine-Destor fault zone in the town of Duparquet, approximately 32 km north of Rouyn-Noranda. The largest body measures 3.3 km long and 425 m wide and is flanked by a series of smaller lenses and dykes principally to the south and northeast. The intrusion has yielded zircon ages of 2682 ± 1 Ma and 2682.9 ± 1.1 Ma and hosted the major part of the Au-mineralization of the now defunct Beattie mine, an important producer of gold in the area from 1933 to 1956 (9.66 Mt at 4.88 g/t Au). A total of 5 petrographic units are defined:

1 - The most abundant unit is the porphyritic Beattie syenite. This unit demonstrates a poor trachytic texture, as defined by the alignment of tabular sub- to anhedral alkali feldspar phenocrysts (2% - 10%; 2 mm – 10 mm) set in a red aphanitic matrix.

2 - Small ellipsoid lens (< 75 m) of the equigranular magnetite-bearing syenite unit intrudes into the porphyritic Beattie syenite unit. This unit has fewer, euhedral to anhedral alkali feldspar phenocrysts (2% - 10%; 2 mm – 10 mm) which are set in a fine-grained feldspathic matrix with unaltered titanite and actinolite replacing clinopyroxene.

3 - The southeast is dominated by the porphyritic Central Duparquet syenite unit. This unit contains numerous coarse equant euhedral alkali feldspar phenocrysts (2% - 25%; 5 mm – 16 mm) set in a red or grey aphanitic matrix. Locally, phenocrysts form a very poor glomeroporphyritic texture.

4 - The megaporphyritic syenite unit intrudes into the porphyritic Central Duparquet unit as irregular masses and dykes (< 180 m). The unit demonstrates a weakly defined trachytic texture, as manifested by the alignment of the coarse tabular alkali feldspar phenocrysts (5% – 20%; 1 cm – 6 cm), hosted in a red aphanitic matrix. Locally, phenocrysts form a glomeroporphyritic texture.

5 - The lath syenite unit occurs as numerous ~ m-width thin dykes, which cross-cut all other petrographic units. These dykes display a characteristic trachytic texture, as defined by the preferential alignment of alkali feldspar laths (20% – 50%; 1 cm – 3 cm) set in a grey or red aphanitic matrix.

Detailed field, petrological, geochemical and mineralogical studies indicate that the syenite intruded at shallow depths through a sequence of injections, yielding the five comagmatic units. Subsequently, the syenite was subjected to a series of cross-cutting hydrothermal alterations and brittle deformation events, combined with both cross-cutting and overprinting metamorphism to the greenschist facies. The Au-mineralization in the syenite and country rocks is attributed to the hydrothermal alteration associated with brittle deformation. **(*SS24, Thurs. 3:00*)**

Keynote (40 min): Global age distribution of detrital zircons, the supercontinent cycle, and subduction flux through time

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The global age distribution of detrital zircons has quasi-periodic highs and lows that are interpreted to correlate with the supercontinent cycle. Observed abundance of zircon ages in river sands fluctuates through more than an order of magnitude, with maxima at *ca.* 2.7, 1.9, 1.0, and 0.45 Ga and minima at *ca.* 2.3, 1.6, 0.9, 0.7, 0.40, and 0.21 Ga. The age distribution is shaped in various ways by factors including differences in zircon production at rifts, arcs, and collisional orogens; preservation, exhumation, destruction, and recycling of zircons; and methodological and regional sampling biases. The first-order maxima and minima have been explained by two largely incompatible models. Model 1 holds that global subduction flux (area subducted per unit time) is constant, that minima correspond to times when intraoceanic arcs were destroyed by subduction erosion, and maxima correspond to times of greater preservation of zircon sources leading up to and during collision. In contrast, Model 2 holds that stepwise changes in global subduction flux—and thus in zircon production at convergent boundaries—are intrinsic to supercontinent cycles. This follows because convergent boundaries are extinguished during collision; hence supercontinent tenures correspond to zircon minima.

Examination of >80 geologic secular trends reveals remarkably little empirical evidence bearing on the alternative conceptual models. The most telling evidence is provided by reconstructed sea levels. Model 1 implies no particular changes in sea level during supercontinent assembly because of the assumed constant subduction flux. If plate motion were to cease across a collisional orogen, the same amount of convergence would instantly begin elsewhere and the world population of ridges (hence ridge volume) would be unaffected. In contrast, Model 2 predicts a drop in sea level triggered by supercontinent assembly because death of a collisional plate boundary would mean death of the corresponding ridge and consequent increase in room for seawater in the ocean basins. Reconstructions of global sea level by various metrics show a major late Paleozoic to mid-Mesozoic low, which overlaps with the 0.2 Ga (Late Triassic) detrital zircon minimum and with the last stages of Pangea's assembly when convergence ceased across thousands of kilometers of plate boundary in the Uralian, Appalachian, and Ouachita-Marathon orogens. Sea level trends thus are consistent with Model 2. This finding provides hope that a carefully chosen global detrital zircon dataset will eventually yield a quantitative secular record of global subduction flux, subject to proper accounting for the other effects. **(*SY7, Thurs. 3:00*)**

Micro-X-ray diffraction and scanning electron microscopy investigation of enigmatic dun-coloured veins in the Tagish Lake carbonaceous chondrite

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The Tagish Lake meteorite, a C2 ungrouped carbonaceous chondrite, fell on a frozen lake surface in northwestern British Columbia in January of 2000. Numerous meteorite fragments were collected in January and April-May of 2000 and this material has been categorized as 'pristine' and 'degraded', respectively. Curatorial investigation of both pristine and degraded samples revealed fragments which display dun-coloured fracture-coating material, typically less than 1 mm in thickness. The dun-coloured material is very different in appearance from other reported Tagish Lake lithologies, and does not visually resemble any common carbonaceous chondrite material. Tagish Lake is a highly heterogeneous meteorite with several distinct lithologies bearing differing mineralogies and physical properties, but the dun-coloured material has not been investigated to date. Here we present a preliminary description and analysis of this enigmatic material.

The dun-coloured material coats (and likely filled) fractures that appear to have acted as structural failure surfaces during atmospheric entry; in at least two examples, fusion crust is observed to overlap or cut dun material, indicating that the dun material must predate atmospheric entry. The dun-coloured veins appear to be the youngest indigenous feature present within Tagish Lake and possibly represent a distinct, "late" water-rock alteration event experienced by the meteorite prior to its arrival on Earth.

Non-destructive *in situ* micro-X-ray diffraction analysis of degraded meteorite sample surfaces with dun-coloured material shows the major mineral phases to be polycrystalline magnetite-magnesioferrite and forsterite along with minor phases including dolomite, siderite, poorly crystalline saponite and some amount of XRD-amorphous material. These are all known to be present in the matrix of the Tagish Lake meteorite, but in different relative proportions. Further analysis by scanning electron microscopy is underway to ascertain the mineral composition and textures of the dun-coloured vein material and its context. **(*SS21, Poster*)**

New developments in the chronostratigraphy, paleoenvironment, and significance of the Pliocene Beaufort Formation and associated sediments, western and high Canadian Arctic

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The Pliocene Beaufort Formation is a wedge of mainly unconsolidated braided river deposits that stretches 1200 km along the western Canadian Arctic Archipelago (and offshore as part of the 3 km-thick Iperk Formation). The onshore sediments contain exceptionally well preserved logs, leaves, peat, insects, and vertebrate fossils, all of which provide key evidence for a boreal forest environment. In the Pliocene, the Earth was ~2°C warmer than today, but high latitude records and climate models show that the Arctic was ~15°C warmer. The IPCC predicts future global warming of ~2°C, so the Pliocene is a potentially critical analogue for the polar amplification of climate change. The wide geographic range of Beaufort Formation paleoenvironmental records (*e.g.*, the more temperate Banks Island to the south and the more depauperate Meighen Island to the north) has permitted hypotheses regarding the role of latitude, continentality, and age.

Previous dating attempts (*i.e.*, Sr isotopes and amino acid racemization on marine molluscs, foraminifera biostratigraphy, and correlation of molluscs with the opening of Bering Strait) have only been feasible on Meighen Island, because it is the only known exposure with a marine sediment unit. The Beaufort Formation on other islands has been assigned the same age based on biostratigraphic correlations. New cosmogenic nuclide ages for Meighen Island (maximum age 6.1±0.6Ma) and the High Terrace Gravels on Ellesmere Island (minimum age 3.4+0.6/-0.4Ma) indicate the potential non-synchroneity of the Beaufort Formation and related sediments across their geographic range.

In 2013, re-examination of the well-exposed stratigraphy at Ballast Brook on Banks Island revealed evidence for a Pliocene (?) distal glaciofluvial depositional environment at the base of the sequence. Quartz sand at the site was sampled for cosmogenic nuclide burial dating and, together with data from other sites (*i.e.* Meighen Island, Ellesmere Island), will provide a new chronostratigraphy for the Beaufort Formation and related sediments. Clarifying the stratigraphic and chronologic relationships among these Pliocene strata will test whether the deposition of the Beaufort, Iperk, and High Terrace sediments represent a synchronous climate-triggered (?) event, and therefore, whether they could have effectively blocked freshwater through-flow to Baffin Bay and the Labrador Sea by infilling pre-Pliocene channels in the archipelago. Refining the depositional environment and paleogeography will help elucidate the advantages and pitfalls of using the Arctic Pliocene climate system to understand future global change. **(*SS22, Thurs. 8:40*)**

Potential for lacustrine source rocks in the Middle Triassic – Early Jurassic Chignecto Subbasin, offshore Eastern Canada

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Recent discoveries of super-giant, multi-billion barrel pre-salt oil fields in Brazil's offshore basins, and related discoveries in its African conjugates, have highlighted the great importance of synrift / pre-breakup fluvial-lacustrine successions to the success and efficiency of their petroleum systems. Improvements in seismic acquisition and processing technologies were keys in imaging the architecture of the underlying rift basins, and interpreting the basin fill and internal depositional facies later confirmed by drilling.

Middle Triassic to Early Jurassic synrift basins are exposed onshore eastern North America (Newark Supergroup) and extend into adjacent offshore areas with equivalent basins in Northwest Africa. Organic-rich lacustrine successions occur in a number of the U.S. basins and although no commercial discoveries have been made, hydrocarbon shows in outcrops and a few wells are documented confirming that a working petroleum system existed.

The basin-fill model for these extensional basins' sedimentary successions defines four tectonostratigraphic (TS) units. TS-I is an unconformity-bounded, early synrift fluvial-lacustrine sequence of Late Permian age. TS-II is a dominantly fluvial (and some lacustrine) sequence believed representative of an underfilled, hydrologically-open basin (subsidence < sedimentation). This is followed by either a closed basin or one in hydrological equilibrium (subsidence ≥ sedimentation) dominated by lacustrine (TS-III), and later playa / lacustrine (and basal CAMP volcanics) successions (TS-IV). The lacustrine facies - especially in TS-III - are exquisite recorders of paleoclimate, and with paleomagnetic data refine the determination of the basins' paleo-latitudinal positions.

Seismic profiles in the Chignecto (Canada) and Newark (USA) basins reveal high amplitude, laterally continuous reflections adjacent to the respective boarder faults. They are distal to TS-II fluvial successions and interpreted as large, laterally-equivalent deep water lacustrine facies. This architecture departs from the TS model by inferring high levels of tectonically-driven extension resulting in the basins being closed from their inception (subsidence ≥ sedimentation) thus facilitating lake formation.

During TS-II deposition (approximately Late Anisian to Early Carnian), paleomagnetic data positions these basins within the north equatorial humid belt. This tropical location is thus a favourable setting for the evolution of lakes (*i.e.*, elevated precipitation coupled with tectonic extension), and most importantly, under conditions for organic matter creation and preservation. If correct, this interpretation would have a significant impact on the potential for hydrocarbons sourced from lacustrine successions in pre-salt syn-rift basins offshore Nova Scotia and Morocco. Importantly, a potential new oil-rich resource play may exist beneath the shallow waters of Chignecto Bay. **(*SS12, Fri. 9:00*)**

Collapse processes prior to melt sheet emplacement within the Manicouagan impact structure

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The Manicouagan impact structure, formed at 214 Ma, comprises a target dominated by Precambrian metamorphic rocks. A veneer of Middle Ordovician sedimentary rock was present at the time of impact. This cover provides a valuable marker horizon with which to calibrate transient cavity evolution during the excavation- to modification-stage transition of the impact process. The cover sequence was regionally eroded and largely erased from the Canadian Shield following impact, leaving only down-dropped units preserved within the impact structure. The sedimentary assembly now occurs as blocks and as smaller fragments in three settings: at the base and periphery of the main body of impact melt; in basal suevites, located between melt sheet and footwall, and within the footwall assemblage beneath the melt sheet. The latter association is revealed through field studies and the logging of drill core. These deep occurrences of sedimentary rocks must have been transported to their buried positions prior to emplacement of the overlying impact melt sheet, which is observed to intrude them. Field operations around the west flank of the Manicouagan structure, based at the edge of the main island, reveal a footwall section dominated by gneisses underlying impact melt. The gneisses are typically fractured. Intercalated with the Precambrian gneisses are Ordovician limestone blocks. The presence of the limestone in the field area is clear evidence that the rocks observed must have been emplaced by the collapse of the rim of the transient crater, and cannot represent rocks of the original basement. Drill core provides a third dimension, revealing limestone interleaved with gneiss to depths of at least 300 m below the melt sheet. In some holes limestone occurs twice, with gneiss between the two occurrences. The majority of gneiss-limestone contacts are brecciated. This observed association is best explained by assuming the geology represents large, coherent blocks, which originated at the transient crater rim and reached their current location by falling, or sliding, from the oversteepened edge. It is well established that the modification stage continues after impact melt emplacement. This work shows that considerable cavity collapse can initiate very early in the cratering process prior to melt sheet emplacement. This must occur during the late excavation to initial modification stages with the rim rocks beginning to move almost immediately to attain the speeds necessary to emplace them at significant depths beneath the melt sheet before the highly-mobile, superheated liquid comes to rest. **(*SS21, Thurs. 2:00*)**

An overview of Canada's regulatory research program on deep geological repositories

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The Canadian Nuclear Safety Commission (CNSC) has an active research program focussed on the safe long-term management of used nuclear fuel. This program was conducted in collaboration with national and international institutions with the objectives of building knowledge and strengthening staff capabilities to assess the suitability of future deep geological repository (DGR) proposals.

Historically, work focussed on the Canadian Shield as a possible repository setting; more recently this has been expanded to consider the suitability of sedimentary rocks to host DGRs.

Work will continue focussing on the assessment of a potential DGR in terms of isolating and containing radioactive waste over geologically long time frames. Specific research topics focus on characterizing issues that will help reduce uncertainty in models of long term repository performance. This will include modelling the results of shaft seal experiments (the SEALEX project, in collaboration with the French Institute for Radiological Protection and Nuclear Safety) and additional laboratory determinations of sealing material performance (*e.g.*, characterization and water injection tests, investigation of geochemical evolution, triaxial and permeability tests on specific rock types, *etc.*).

The current research program cycle is embarking on a new three year term. The previous program targeted four areas of investigation: natural tracers, gas migration, the effects of past and future glaciation, and the effect of excavation damage to the host rock. Results obtained to date are summarized and posted on the CNSC website: http://www.nuclearsafety.gc.ca/eng/waste/cnsc-research/geologic-repositories/index.cfm. The results of these investigations will inform the development of a new regulatory document on the siting of deep geological repositories, which will be developed over the next year.

This presentation will outline the current and future directions of the CNSC's internal repository research program and the results obtained so far. **(*SS8, Thurs. 9:20*)**

Recent advances on the origin and evolution of the Nashoba terrane of southeastern New England

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The Nashoba terrane is a moderately northwest-dipping fault-bounded block within the New England Appalachians of eastern Massachusetts, located between the Avalon terrane to the southeast and terranes of Ganderian affinity to the northwest. It consists of multiply-deformed and metamorphosed Cambrian-Ordovician mafic to felsic metavolcanic and interlayered metasedimentary rocks, intruded by Silurian to earliest Carboniferous granitic and calc-alkaline intermediate composition plutons. Trace element and Sm/Nd geochemistry from the mafic volcanic Marlboro Formation indicate magmas were derived from a primitive source in an early Paleozoic arc/back-arc setting. Intermediate and felsic gneisses of the Nashoba Formation incorporated older, isotopically evolved crustal material. Youngest detrital zircon grains from metasedimentary units in the Nashoba terrane are ~470-463 Ma. All units contain a dominant ~540 Ma detrital zircon population. Both the geochemistry and detrital zircon results from rocks of the Nashoba terrane indicate a Ganderian affinity.

Our recent research has focused on the Siluro-Devonian evolution of the Nashoba terrane within the context of terrane accretion. Nashoba Formation gneisses record upper amphibolite-facies metamorphism at ~423 Ma. The Andover Granite is a complex multi-phase aluminous to peraluminous granitic suite that preserves both foliated and undeformed phases that intrude the older metasedimentary rocks. U-Pb CA-TIMS zircon ages on two samples from the foliated phase are ~420 and ~419 Ma. A deformed pegmatite within the Nashoba Formation gives a similar age of ~418 Ma, indicating that Andover related magmatism was more extensive than previously mapped. We interpret the Andover suite to have originated from the subduction of oceanic crust in front of the approaching Avalonian micro-continent, which triggered anatectic melting in the underlying Ganderian basement. Sillimanite+K-Feldspar conditions were reached in the Nashoba Formation at ~395 Ma, resulting in migmatization in the northwestern portion of the terrane. We suggest the melting and migmatization of Nashoba metasedimentary rocks at this time could be the source for plutons within the overriding Merrimack belt (*i.e.* the 390±15 Ma Fitchburg Granite and/or 395±5 Ma Chelmsford Granite).

Preliminary U-Pb CA-TIMS zircon ages from leucosome within Nashoba Formation migmatite samples indicate a second melting event between ~364 and ~361 Ma. Such Late Devonian, post-Acadian migmatitic melting has not been recognized previously in the Nashoba terrane. These new ages may be related to either Neo-Acadian accretion of Meguma to the composite Laurentian margin or to decompression melts related to the exhumation of the Nashoba terrane. **(*SY1, Wed. 9:20*)**

Meteorite impacts as energy source for major mineral districts

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The three largest known impact structures on Earth host major mineral fields: Vredefort hosts the South African gold fields, the Sudbury structure hosts a world class copper-nickel-PGM mining district and the Chixculub structure on the Yucatan peninsula in Mexico hosts the Cantarell field, one of the three most productive oil fields known.

The Flin Flon, Sherridon, Reed Lake, Snow Lake, Lynn Lake and Rusty Lake areas in northern Manitoba are known for their VHMS deposits. They are Early Proterozoic in age and are grouped around the 300 km diameter Kisseynew (gneiss) Domain in Central Canada. The Flin Flon, Reed Lake, Sherridon and Snow Lake deposits occur along an east trending ellipsoid of 150 × 50 km near the southeast part of the area. The Lynn Lake-Rusty Lake areas are located along the north margin of the Kisseynew (gneiss) Domain. Several of the VHMS deposits show a close spatial association with high Fe-Ti-P basalt - gabbro and rhyolite. This bimodal suite may be the result of liquid immiscibility of an impact melt.

Intensive hematization with a characteristic greenish-black coloration occurs over several km along the Amisk-Missi unconformity near Flin Flon. Pseudotachylite is present in several areas in Amisk mafic subvolcanic rocks near the unconformity.

Narrow, structural zones of graphite and graphitic to barren sulphide can be followed for many kilometers. They represent regionally extensive faults.

A 30 × 10 km central Archean uplift area, immediately east of Deschambault Lake, trends north toward Pelican Narrows and Sandy Bay. The impact hypothesis postulates that the ore deposits of the Flin Flon-Sherridon-Reed Lake-Snow Lake ellipsoid are a part of a smaller impact structure situated on the southeast margin of the much larger Kisseynew Domain 300 km structure. The Lynn Lake-Rusty Lake deposits are located on the northern margin of the Kisseynew Domain structure. The central part of the structure, represents the transient Kisseynew Domain crater and is filled with material that flowed into the crater immediately after its excavation.

The indirect means of supporting impact hypotheses in parts of the Kisseynew gneiss domain include areas of intensive hematization. This may be derived from impact-related wuestite and native iron condensates. Other exceptional features include regionally extensive graphitized horizons and fluidized sulphide horizons.

Future work will focus on outlining the possible remnants of the transient crater structures and localizing prospective targets economic base and precious metal mineralization. **(*SS21, Poster*)**

Textural, chemical and isotopic evidence for open-system behaviour during fluid-mediated metasomatism in a rare-element pegmatite: A case study of the Little Nahanni LCT-type pegmatites, NWT, Canada

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High-T metasomatism occurs as a pervasive, fabric destructive albitization within the Little Nahanni Pegmatite Group (LNPG), a rare-element mineralized LCT-type pegmatite system. Exhibited as both a cleavelanditic- and a saccharoidal texture, albite is observed to partially replace earlier coarse K-feldspar throughout the 15 km long pegmatite system. Coincident with the albitic zones and associated secondary porosity are apatite, cassiterite, and muscovite, and to a lesser extent Nb-Ta oxide mineralization. Rare zircon in these zones also reflects alteration, as evidenced by its pitted texture, zones enriched in Ca±Fe±Al, and newly generated Th, U and REE phases that occur both within and around the zircon. A detailed SEM-EDS study of fresh and altered material indicates metasomatism was accompanied by an influx of wall-rock derived elements, including Ca, Fe, Mn, S, Pb, Zn, which formed secondary metasomatic phases (*e.g.*, apatite, garnet, sulphides). Further evidence of fluid-mediated alteration includes the presence of abundant fluid inclusions within the secondary phases and along metasomatic reaction fronts, such as at albite-K-feldspar boundaries. Microthermometric studies indicate metasomatism involved both CO_2-H_2O and H_2O fluids, both of which are low salinity (<1-2 wt. % eq. NaCl). Conventional isotopic data ($\delta^{18}O$, δD) for primary and secondary assemblages (Qtz, Kf, Alb) has been used to assess the nature of the fluid reservoirs involved during pegmatite crystallization and subsequent fluid-mediated mineralization and alteration events. The $\delta^{18}O$ silicate data (0.4 to 14.9‰) indicate metasomatism involved fluids that originated from, or equilbrated with, different reservoirs (magmatic, metamorphic, meteoric). In addition, to determine and compare potential for micron-scale ^{18}O compositional changes along alteration fronts, laser Raman was applied, taking advantage of the fact that peak shift of vibration modes for feldspar O-T-O bonds are sensitive to ^{18}O variations of the mineral. The data demonstrate that saccharoidal-textured albite is more common where meteoric fluid dominated and that the ^{18}O values of albitized samples are heterogeneous on the micron-scale. This marks the first application of the Raman method to a natural system and provides supporting evidence that albitization occurred via an interface-coupled dissolution-precipitation mechanism in the presence of an exotic fluid. Together, the data from this study suggest that the late-stage metasomatism occurs in a much more open system than is currently considered and incorporated into models for many of the described LCT-type pegmatites. Furthermore, it is evident that the rare-metal mineralization (Ta, Nb, Sn) is clearly associated with zones of pervasive albitization. **(*SS20, Wed. 2:20*)**

Geochemical aspects of nuclear waste disposal in geological repositories

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This presentation will examine various aspects of geochemistry that are important for disposal of nuclear waste in a geological repository. Of particular importance is the waste form, and its compatibility with the geochemical environment. Various examples will be examined. **(*SS8, Thurs. 10:20*)**

Keynote (40 min): Uranium mineralogy and nuclear waste disposal

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More than 200 uranyl minerals are known to occur in the oxidized regions of ore deposits, in mine and mill tailings, and in contaminated subsurface environments. Uranyl minerals also form where irradiated uranium dioxide nuclear fuel is altered in a moist, oxidizing environment. The mineral occurrences may be complex, with details depending upon the presence of various oxyanions that combine with uranyl to form complex structures. Formation of uranyl minerals in a geologic repository due to spent fuel corrosion may impact the alteration rates of the fuel, and may also control the release of various radionuclides that may be incorporated into the uranyl minerals. Towards development of a predictive understanding of the impact of uranyl minerals in a geologic repository, we have studied the structures, compositions, heats of formation, and aqueous solubility of several families of uranyl minerals. Incorporation of various radionuclides, including neptunium, have focused on experiments that probe the degree of uptake of available radionuclides during crystallization. **(*SY6, Thurs. 3:20*)**

Stratigraphy, mineralization, and alteration of the Boundary volcanogenic massive sulphide (VMS) deposit, central Newfoundland

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The replacement style Boundary volcanogenic massive sulfide (VMS) deposit (0.45Mt @ 3.4% Cu, 4.0% Zn, 1.0% Pb, 34.0 g/t Ag) is located within the Tally Pond group (~510 Ma), Victoria Lake Supergroup in central Newfoundland, Canada. Stratigraphically, Boundary consists of a semi-impermeable hanging wall composed of flow-banded, quartz-phyric flows and breccias and a permeable footwall made up primarily of lapillistones and lesser tuffs. Below the lapillistones lay aphyric rhyolite flows and breccias. Mineralization is found in two main zones (possible fault disrupted parts of the same original lens) and consists of pyrite, chalcopyrite, and lesser sphalerite. Mineralization occurs as massive lenses, stringer, bedded, and rhyolite clast-rich sulfides. Massive sulfides, pyrite-chalcopyrite in the North zone and chalcopyrite-pyrite/sphalerite in the South zone, occur primarily at the boundary between the hanging wall and footwall. Chalcopyrite stringer is common in both zones, while bedded zinc-chalcopyrite ore occurs more frequently in the South zone and is found mainly on the periphery of the deposit. The rhyolite clast-rich sulfides are very common in both zones below the massive lenses and as discreet lenses within the footwall. The clast-rich sulfides provide evidence for replacement, as the host lapillistones are often quartz-sericite/chlorite altered with sulfides surrounding the stones. Hydrothermal alteration occurs throughout the deposit and generally varies with proximity to mineralization. Proximal to mineralization, alteration is dominantly moderate-intense, sheet-like chlorite that runs parallel to the ore horizon and is likely related to replacement processes. Intense chlorite alteration sometimes extends into the hanging wall. Discordant chlorite alteration is also present and likely represents hydrothermal upflow zones. In both sheet-like and discordant alteration, intense chlorite completely replaces the host rock resulting in massive black chlorite. Variably intense quartz-sericite alteration can be found in both the hanging wall and footwall more distally from mineralization. Major element geochemistry has revealed that the deposit exemplifies relatively high alteration indices

(Hashiomoto, chlorite-carbonate-pyrite, and Ba/Sr) along with increasing anomalous Hg near the ore horizon. In general, the hanging wall shows a slightly higher affinity for quartz-sericite alteration while the footwall displays slighty higher chlorite alteration values. The footwall lapillistones show the greatest variability in element compositions among the facies and provide the best measures of alteration. **(*SS14, Poster*)**

Fingerprinting and tracing unconformity-type uranium alteration haloes through thick Quaternary sediments: An example from the Thelon Basin, Nunavut

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The Thelon Basin of Nunavut shows great potential for the discovery of unconformity-type uranium deposits. However, mineralization in the area rarely intersects the bedrock surface which limits the use of indicator mineral and traditional geochemical exploration methods. The large alteration haloes typically associated with unconformity-type uranium deposits may subcrop and are promising exploration targets, but the continuous cover of Quaternary sediments represents a challenge. The present study aims to fingerprint and trace the signature of alteration haloes through the thick till that covers much of the area. The comparison of bedrock geochemistry with that of till sampled from drill core and surficial samples allows for mapping the dispersal of alteration pathfinders in three dimensions. Multivariate statistical analysis of the dataset, including principle component and factor analysis, may reveal subtle geochemical patterns related to alteration. Geochemical data is complemented by mineralogical information from X-Ray Diffraction and Shortwave Infrared Spectroscopy. The bedrock alteration halo signatures of Na_2O depletion and B enrichment represent the strongest geochemical signature in the till samples collected from drill core at this time. However, surficial geochemical patterns are more elusive, as B values in the mudboil samples are typically an order of magnitude lower than that of borehole samples. The discrepancy may be due to the presence of a different surficial till unit <5 m thick that is not recovered in boreholes, or to a postglacial process. Dispersal trains in the study area occur in the subsurface, but the surficial till appear to be overprinted or diluted with respect to alteration derived material. Multivariate analyses will help further investigate this problem. Ongoing research also focuses on relating geochemical results to the 3D till stratigraphy and glacial dynamics evolution, and on developing innovative techniques for mineral exploration across complex glaciated terrains. **(*SS7, Poster*)**

Exsolution of semimetal liquids from sulfides: Experimental study on the solubility of Te-Bi-As liquids in monosulfide solid solution between 1050 °C and 600 °C

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Semimetals (*e.g.*, Te, Bi and As) are thought to exsolve immiscible liquids, during the crystallization of magmatic sulfide melts. Previous work has shown that immiscible Te-Bi-As bearing liquids may sequester some highly siderophile elements (HSE), particularly Au, Pd and Pt; which later, with decreasing temperature, form platinum-group minerals (PGM). To determine whether this is a feasible mechanism for HSE fractionation and remobilization, data on the Te, As, Bi content at which such immiscible semimetal liquids form are essential but little is available in the literature. To fill that gap, an experimental study was undertaken to measure the minimum semimetal concentration necessary to exsolve the semimetal liquid from the sulfides and its effects on the partitioning of HSE among sulfides, as a function of temperature. Starting materials were composed of a mixture of sulfides (70 wt.% natural pyrrhotite, 15 wt.% natural pentlandite and 15 wt.% natural chalcopyrite) in which 50 ppm of each HSE had been diluted. Semimetals were added individually in concentration of 3 wt.%. This concentration provided saturation of semimetals and was used to establish the maximum amount of semimetals that can be contained within a sulfide phase before an immiscible semimetal liquid can exsolve. Materials were sealed in evacuated silica tubes, then fused at 1200 °C for 4 hours. Temperature was reduced (2 °C/h) and different experimental sets were equilibrated respectively at 1050 °C (3.5 days), 900 °C (7 days), 750 °C (14 days) and 600 °C (28 days), then were quenched in water. Run products consisted of monosulfide solid solution (MSS), a Cu-rich sulfide phase (melt or intermediate solid solution, ISS), and a semimetal-rich phase. Analyses (SEM and EDS) show that semimetal liquids segregate and can be found with the Cu-rich liquid (or the ISS) or filling cracks within the MSS. Preliminary results (LA-ICP-MS analyses) reveal that temperature does not have an extensive effect on the solubility, but the highest semimetal content in MSS was measured for the 900 °C experiments: Te is the most soluble in MSS (4800 ± 600 ppm, 2σ) followed by As (2500 ± 120 ppm) and then by Bi (260 ± 14 ppm), for which no previous experimental data were found for comparison. Current work aims to assess the bulk concentration of semimetals that could result in the formation of immiscible semimetal liquids and affect the fractionation of the HSE. **(*GS5, Fri. 9:00*)**

A call for cross-Canada recognition of geoheritage

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The history of planet Earth that is recorded across Canada is unrivalled: it spans the breadth of geologic time and records more key events than virtually anywhere else on Earth. World Heritage Sites, national, provincial and territorial parks, and emerging Global Geoparks in Canada only hint at the depth of this record. The overarching concept of geoheritage is proving to be a highly effective portal for the general public to gain insight into the significance of Earth's history and geologic processes and how geoscience can inform us of future global change that we face as humans. The recognition of geoheritage in various provinces and territories is as varied as Canada's landscape, but systematic and comprehensive documentation is the exception. In many cases, such an inventory is known to geoscientists, but waits to be proclaimed to an eager public. In other cases, geoheritage is recognized only as a conservation measure, usually employed in the protection of fossil sites.

Geological surveys and geoscience organizations are best positioned to make public their regional geoheritage, and a transferrable template employed in Nova Scotia may be helpful in determining a list of geoheritage sites. A starting point for the cross-Canada recognition of geoheritage is to identify sites that are globally unique (GH1) and globally significant (GH2). Sites that are vulnerable may be disclosed if proper stewardship measures are in place, but can be celebrated regardless by being nonspecific about their exact locations, as in the case of the recent discovery of Burgess Shale fauna in Kootenay National Park. Cultural geoheritage, commemorating human interaction with the geological record both through historic mining sites and, with consultation, through sites sacred to First Nations, is particularly meaningful in deepening our identity as Canadians. Canada has much to offer the world, and much to celebrate as family members in this, the greatest story ever written. It falls to we geoscientists to translate and to proclaim this story. **(*SS15, Fri. 9:00*)**

Controls on syenite-hosted gold mineralization in the western Timmins camp, Timmins, Ontario

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Syenites at Lake Shore Gold Corp's Thunder Creek Deposit and Highway-144 property both host gold located approximately 20 km west of Timmins, Ontario. The former is part of the Timmins West mine and the latter is a prospect. The hosts are alkaline, similar to the Kirkland Lake camp, thus these prospects/deposits represent a new exploration target for gold mineralization in the Timmins camp. Geochemical, structural, and petrological data were collected to analyse the controls on gold mineralization and to recognize syenites that potentially are mineralized. The mineralized syenites intruded along the contact of Tisdale volcanics and Porcupine sediments. They are part of the larger Bristol Township Alkalic Complex, which is composed of pyroxenite, strongly carbonitized/mylonitized shear zone, and syenite. However, where fresh, the syenite has a quartz-monzonite composition, but its alkaline affinity is apparent from the presence of alkali amphiboles. In contrast to syenite-hosted mineralization elsewhere, the Thunder Creek syenite is relatively unaltered at the core of the mineralization, with increasing potassic and hematitic alteration in the poorly mineralized upper structural portion of the intrusion.

Approximately one hundred samples of the host syenite with disseminated pyrite, early deformed V_1 quartz-pyrite±galena veins, later V_2 extensional flat quartz-pyrite±scheelite±galena veins and the youngest V_3 subvertical quartz-pyrite veins were assayed to determine gold distribution. In the core of the Thunder Creek deposit V_2 hosts the main stage of mineralization, but disseminated pyrite, V_1 and V_3 veins are all mineralized, and the highest grades are where the four mineralizing events are superimposed. Vein density calculations made along the 695m level transect confirms vein intensity correlates to economic gold grades.

Pyrite occurs as: i) Fine to medium grained disseminated pyrite, ii) medium- to coarse-grained fracture-controlled pyrite and iii) medium to coarse corroded vein-hosted pyrite. Gold is present primarily in coarse vein-hosted pyrite grains along fractures and less commonly as inclusions. WDS mapping of trace elements in pyrite indicate that gold-bearing pyrite at Hwy-144 exhibit complex Ni and Co zoning patterns whereas in unmineralized fine- to medium-grained pyrite Co-Ni zoning is absent. The significance of these relationships is the focus of the current investigation. **(*SS23, Fri. 3:40*)**

Using portable XRF spectrometry in exploration for base and precious metals in the Mary River District, Nunavut

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The rapid development of portable X-Ray fluorescence technology in the last decade has enabled geologists to quickly acquire geochemical datasets. The portable XRF analyzer can provide "real-time" geochemical information to aid in the delineation of mineralized zones and help prioritize exploration targets in previously unexplored terrain. Geochemical datasets can be used to produce preliminary models for mineral emplacement in the context of geological and geophysical datasets.

Examples from Baffinland's 2012-2013 field work in the Mary River district will illustrate how processed geochemical data collected from portable XRF readings can contribute to a greater understanding of the relative timing and environment of mineralization. Principal component analysis (PCA) and factor analysis (FA) of robustly treated geochemical datasets integrated with geophysical and geological datasets provide the geologist with a means to begin creating preliminary models that aid in exploration planning.

The portable XRF analyser will continue to be used as a vital part of Baffinland's exploration program. Geochemical datasets generated by portable XRF readings will help geologists target mineralized zones and understand the geological processes that contribute to mineralized terrain; thus aiding in evaluation of the mineral potential of the district. **(*SS14, Fri. 2:40*)**

Sulfide-sulfate equilibria in subducted crust and the deep earth sulfur cycle over time

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Subduction at convergent plate margins returns to the mantle all rocks influenced by weathering, hydrothermal activity, atmospheric exchange, or bio-mineralization in the exosphere. The latter exogenic processes modify the long-term behaviour of certain elements in the deeper earth that are traceable over time in the chemical record of mantle-derived magmas. The redox budget of S during subduction affects the S cycle, and is tied to the evolution of oxygen and biogeochemical cycles on Earth's surface over time. One component of the deep sulfur redox and cycle is the sedimentary veneer that sits atop the subducted oceanic basalt crust. The conversion of subducted sulfide to sulfate (or vice versa) is an eight-electron change in redox state, with significant oxidation/ reduction capacity that can facilitate the mobility and/or extraction of chalcophile metals from the arc mantle into magmas by the melting process. We examine the redox controls on sulfate - sulfide stability in subducted oceanic crust of variable composition, and their disposition relative to other redox couples in the mantle along the P-T trajectories of subducted lithosphere in 'hot, warm and cold' subduction zones. We find that sulfate-sulfide equilibria greatly impact the fO_2 and fate of sulfur and chalcophile elements in subducted crust passing through the eclogite facies, depending on the Ca/Fe content of the crust and on various subduction P-T trajectories, the latter which can vary in space or time. Experimental data show the utility of Cu as a proxy as for S in subducted oceanic crust that we apply to examine the deep sulfur cycle and its role (or record) in arc magmatism over geologic time, from Archean to present. **(*SY3, Wed. 8:20*)**

Petrology and geochemistry of organic matters in early Cambrian black shales hosting Ni-Mo ores of South China: Implications for mineralization

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The Ni-Mo polymetallic deposits hosted in early Cambrian black shales of South China are well-known representatives of black-shale-hosted mineral deposits worldwide. They have been a hot research topic for decades; however their origin is still highly debated due to the extreme complexity of ore genesis. In this paper, based on a case study in the Zunyi and Sancha ore deposits from Guizhou and Hunan provinces, respectively, we address this issue through investigating the petrology and geochemistry of organic matters present in the shales. Petrologic observation on organic matters implies that the mineralization is thought to be biogenic in origin, as a type of organic clots are widespread throughout horizons that host Ni–Mo ore, but are absent in barren layers. These clots are generally elliptical, range in size from 200 to 600 µm, and have similar morphologies to modern rhodophyta. Thus, we tentatively interpret these clots to be rhodophyte cystocarps. Electron microprobe analysis indicates that these clots have differential accumulations of Ni and Mo, with Ni concentrated in the inner parts of clots, and Mo in the outer parts. This provides direct evidence for biotic controls on ore mineralization. Geochemical analyses indicate that this type of organic material (rhodophyta), as well as disseminated and amorphous organic matters, is not the sole and predominant factor controlling mineralization as implied from the nonlinear correlation between organic matter abundance/maturation and abundance of mineralized elements. Thus, other metalliferous fluid sources (*e.g.*, hydrothermal and/or seawater) also contribute to the mineralization. Ni and Mo may have mineralized independently, as suggested by their differential accumulation in different structures of the cystocarps, different relationships between organic matter abundance and thermal maturation and mineralized element concentration, as well as the large variation in element accumulation coefficients. The history of mineralization is complex, as Ni and Mo may be or not be deposited together during the same stage of mineralization. These results might also have broader implications for understanding the origin of sediment-hosted ores worldwide. **(*SS2, Wed. 9:40*)**

Application of pXRF to Cu grade estimation and igneous stratigraphy characterization: A case study at the north edge of the Eastern Gabbro, Coldwell Alkaline Complex, Canada

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pXRF is an innovative portable XRF that enables real-time data acquisition. Previous applications of pXRF have focused on elemental analysis, environmental research, and contaminated soil analysis. Recent improvements in the technology has lead to growing effort towards its utilization in exploration lithogeochemistry and geochemistry, which is exemplified by the current study.

The current study is an evaluation of pXRF in the classification of igneous stratigraphy and the estimation of Cu grade at the north edge of the Eastern Gabbro of the Coldwell Alkaline Complex. The Midcontinent Rift-related Coldwell complex, intruded into the Schreiber-White River Archean greenstone belt, which consists of low-grade metamorphic volcanic and sedimentary rocks. The Eastern Gabbro occurs along the outer margin of the Complex. It is a composite mafic-ultramafic intrusion involving three major distinctive magmatic series: the Fine Grained Series, the Layered Series and the Marathon Series. The Marathon Series hosts the majority of the Cu-PGE mineralization in the area, notably the Marathon Cu-Pd deposit, located to the southeast of the research area.

Mapping the distribution of the different gabbro units is a key to Cu-Pd exploration. However, in the field it is difficult to distinguish between the different series of gabbros, and in particular for the magnetite and plagioclase-rich augite melatroctolite in the Layered Series, and the magnetite melatroctolite in the Marathon Series. Differentiating them based upon petrography studies is nearly impossible due to their very similar petrographic features. Lithogeochemistry is a potential tool for their classification. Lab-based analytic techniques are costly and involve a time delay; instead, the small and low-cost pXRF is capable of obtaining real-time field data. Data quality from the pXRF was confirmed through a comparison of pXRF data to traditional lab-based analyses. The competency of the pXRF for Cu grade and S content estimation was evaluated by comparing down-hole pXRF and ICP-MS Cu and S variations of the same drill hole. Their similar variations and absolute concentrations indicate that the pXRF is able to quantify Cu grade down to around 100 ppm and S content down to 0.1wt%. The application of pXRF to lithogeochemical mapping consisted of plotting a number of key major and trace elements to differentiate the different igneous units. Key variables were P_2O_5, Fe_2O_3, SiO_2, TiO_2, Ba, and V. Different igneous units, of similar mineralogy and texture were successfully differentiated using these variables. **(*GS5, Fri. 8:20*)**

A Saskatchewan-based perspective of the Taltson orogen; new data from south of the Athabasca Basin and implications for the tectonic evolution of the Rae craton

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The Taltson magmatic (TMZ) and Thelon tectonic zones (TTZ) have historically been considered parts of a single orogen recording collision between the Slave craton (and Buffalo Head terrane) to the Rae craton between 2.0 and 1.9 Ga. This connection stemmed from recognition that the TMZ coincides with the Taltson aeromagnetic high that extends northward and merges with the Thelon high. Analysis of currently available data, however, indicates that this magnetic high is underlain in large part by rocks of Taltson basement complex. Additionally, both basement rocks and Taltson-age plutons can be traced eastward into Saskatchewan, below Athabasca Basin cover, and re-emerge to the south where they are truncated by the Virgin River shear zone. This paper presents new field, geochronological and geochemical data for the Lloyd domain of Saskatchewan bearing on definition of the Taltson orogen. The Lloyd domain is dominated by highly magnetic dioritic–granodioritic orthogneisses and hosts the Clearwater complex (CC), a ~300 km^2, northeast-elongate gabbro-anorthosite intrusion. While previous geochronology established that some Lloyd domain orthogneisses are of Taltson (~1.98 Ga) age, our new work has identified an appreciably older (~2.46 Ga) component. Geochemical study indicates that these older metaplutonic gneisses are distinguishable from the younger (Taltson-age) ones, but the true extent of basement rocks is difficult to evaluate. U–Pb data from the CC allow the interpretation that it was emplaced into this older basement complex at ~2.1 Ga and subsequently metamorphosed, together with surrounding rocks, at ~1.9 Ga. Geochemical study also indicates that the 1.98 Ga Lloyd domain quartz diorite suite is chemically related, but less evolved, than somewhat younger, dominantly granitic TMZ plutons of Alberta. Both reflect gradual evolution of a subduction-related continental magmatic arc, challenging previous models invoking intra-plate magmatism. Collectively, these data indicate that the Taltson orogen originally trended northwest–southeast and is a unique tectonic entity, distinct from and younger than the Thelon tectonic zone. The orogen had a breadth of at least 400 km, with 1.99–1.96 Ga arc magmatism localized along its west-southwestern edge and 1.94–1.93 Ga metamorphic overprinting of Archean and early Paleoproterozoic elements well into the interior. The dynamics of the transition to ~1.9 Ga Snowbird orogenesis remain enigmatic, but the CC age supports the notion of a late (~2.1 Ga) break-up phase of an independent, antecedent to the Rae prior to re-assembly and raises questions about age determinations for correlative mafic igneous units along strike. **(*SY3, Thurs. 9:20*)**

Intergranular solubility as a control on metamorphic equilibration

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A dramatic demonstration of the role of intergranular solubility in promoting chemical equilibration during metamorphism is found in the unusual zoning of garnet in pelitic schist of the Jewell Formation exposed at Harpswell Neck, Maine, USA. Many garnet crystals have irregular, patchy distributions of Mn, Cr, Fe, and Mg in their inclusion-rich interiors, transitioning to smooth, concentric zoning in their inclusion-poor outer rims; in contrast, zoning of Ca and Y is comparatively smooth and concentric throughout. We re-assess the disputed origin of these zoning features by examining garnet growth in the context of the rocks' thermal and structural histories, and by evaluating the record of fluid-rock interaction revealed by outcrop-scale veining and by fluid-inclusion assemblages. The transition in the character of garnet zoning correlates with the onset of a shear-dominated synkinematic phase of garnet growth and with a shift in the composition of the intergranular fluid from CO_2-rich to H_2O-rich. Compositional variations in garnet are therefore best explained by a two-stage growth history in which intergranular diffusive fluxes reflect differences in solubility in these two contrasting fluids. Interiors of garnet crystals grew in the presence of a CO_2-rich fluid, in which limited solubility for Mn and Cr (and perhaps Fe and Mg) produced patchy disequilibrium overprint zoning, while appreciable solubility for Ca and Y permitted their rock-wide equilibration. Rims grew in the presence of an H_2O-rich fluid, in which high solubilities for all these elements (except Cr) enabled intergranular diffusion over length scales sufficient for rock-wide equilibration. This striking example of partial chemical equilibrium during reaction and porphyroblast growth implies that thermal effects may commonly be subsidiary in importance to solubilities in the intergranular medium as determinants of length scales for metamorphic equilibration. **(*SS19, Wed. 4:20*)**

Geochemistry and petrogenesis of the Black Thor Intrusive Complex, McFaulds Lake greenstone belt, Ontario, Canada: Implications for magma flow and olivine-chromite accumulation

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The Black Thor Intrusive Complex is a semi-conformable sill-shaped intrusion that can be subdivided into: 1) a *lower ultramafic series* of basal olivine websterites and lherzolites, interlayered dunites and lherzolites with minor interstitial chromite, and overlying websterites, 2) a *middle ultramafic series* characterised by a basal chromitite horizon (Black Label), olivine websterites, lherzolites and dunites, and an upper chromitite horizon (Black Thor), and 3) an *upper ultramafic to mafic series* of websterites, mela/meso/leucogabbros, and lesser anorthosites. A late websterite intruded the lower and middle ultramafic series and locally brecciated the Black Label chromitite horizon.

There are two major trends on MgO variation diagrams reflecting variable mixtures of olivine-orthopyroxene and olivine-chromite. There are also clusters of Opx-rich rocks averaging 50-55% SiO_2, 27-35% MgO, 1-5% Al_2O_3 and 1-3% CaO; chromite-rich rocks (40-90 modal%) containing up to 45% Cr_2O_3, 15-30% MgO, and 5-10% Al_2O_3; and apparently co-magmatic gabbroic rocks of the upper mafic series containing 45-55% SiO_2, 25-33% Al_2O_3, **1.5-5% MgO**, and 2.5% FeO.

The lower part of the lower series exhibits an overall upward trend of increasing Mg and decreasing Si-Al-Ca, interpreted to reflect increasing accumulation of Ol-(Chr) with decreasing cooling rate away from the basal contact. The upper part of the lower series exhibits an overall upward trend of decreasing Mg-Cr, interpreted to reflect decreasing amounts of cotectic Ol-(Chr) accumulation with decreasing flow rates. The base of the middle series is marked by a major increase in Cr (Black Label), an overall upward trend of increasing Mg-Cr, interpreted to reflect increasing flow rate, and marked at the top by another major increase in Cr (Black Thor). Mg-Cr decreases through the upper series and is capped by Cr-poor gabbro.

If the variations in the degrees of Ol-(Chr) accumulation correspond to variations in magma flow-through rates, then flow rates decreased and then increased abruptly prior to the formation of Black Label (consistent with physical transport or magma mixing), but increased gradually prior to the formation of Black Thor (more consistent with physical transport of fine dispersed chromite). **(*GS5, Fri. 2:20*)**

Deciphering the multiple hydrothermal, metasomatic and structural events responsible for the formation and post-depositional evolution of the Paleoproterozoic Lalor auriferous VMS deposit, Snow Lake, Manitoba

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The Lalor auriferous VMS deposit is located in the *ca.* 1.85 Ga Snow Lake arc assemblage that is part of the Paleopropterozoic Flin Flon greenstone belt. The Snow Lake camp is host to numerous past producing Cu-Zn, Zn-Cu and Au-Zn-Cu VMS deposits and one orogenic Au deposit.

Lalor is the largest deposit of the Snow Lake camp and also the richest in gold with reserves of 15.1 Mt at 7.2% Zn, 0.6% Cu, 1.9 g/t Au and 23.3 g/t Ag and resources of 12 Mt at 2.6% Zn, 0.9% Cu, 4.0 g/t Au and 27.8 g/t Ag, for a total size of approximately 27 Mt. It potentially contains up to 75 t Au. It consists of discrete Zn-Cu-Pb±Au-Ag semi-massive to massive sulphide lenses and zones of Au-Ag-Pb-Cu disseminated sulphides to sulphide-poor lenses. The ore zones are stratigraphically and/or structurally stacked in a complexly deformed and metamorphosed succession.

The Lalor volcanic succession consists of intercalated mafic to felsic, tholeitic to calc-alkaline, extrusive to intrusive volcanic rocks. These rocks are attributed to the Chisel mature arc sequence that hosts other Zn-rich VMS deposits in the area. The Lalor volcanic succession is structurally bounded at the top and at the West by distinct volcanic successions.

Polyphased intense hydrothermal alteration, amphibolite grade metamorphism and at least three major deformation episodes have obliterated the primary composition and textures of the host volcanic rocks and the original geometry of the hydrothermal system. Five distinct hydrothermal alteration-related chemical associations can be distinguished: K, K-Mg-Fe, Mg-Fe, Mg-Ca and Ca associations. They can be further subdivided in numerous highly variable mineral assemblages characterized by variable amounts of metamorphic minerals such as amphiboles, chlorite, cordierite, biotite, muscovite, staurolite, gahnite, garnet, kyanite, sillimanite, diopside, carbonates and epidote. Crosscutting relationships and superposition of the chemical associations indicate the simultaneous development of the K, K-Mg-Fe and Mg-Fe chemical associations, which were later overprinted by the Mg-Ca association. These chemical associations are restricted to the footwall of the orebody. The Ca chemical association is widespread and related to a late overprinting metasomatic event.

While base metal-rich massive sulphide lenses are clearly associated with the initial hydrothermal events (K, K-Mg-Fe and Mg-Fe), gold-rich sulphide-poor zones seem to overprint the early chemical associations, suggesting local metamorphic remobilization and/or a late input of precious metals in the system. **(*SS14, Thurs. 4:00*)**

Characterization of porewater in low-permeability sedimentary rocks

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Characterization of porewater chemistry in low-permeability rocks can provide insight into the origin and residence times of porewater, the history of fluid movement and the nature of transport and reaction processes. However, the measurement of porewater chemistry in low permeability rocks is challenging because of small fluid volumes and the difficulty of extracting representative samples. Several techniques for porewater characterization are available, but the results provided can be affected by ion exchange and mineral dissolution, and may require independent porosity measurements. The objectives of this work are to develop and test a method of extracting representative samples of *in situ* porewater from low permeability rocks and accurately quantifying solute concentrations (Na, K, Mg, Ca, Sr, Cl, Br) in the extracted porewater. This method extracts porewater by absorption into a hydrophilic cellulosic membrane pressed between two core segments. The mass of extracted water is measured using near infrared (NIR) spectrometry, and solute masses extracted with the porewater are quantified using inductively-coupled mass spectrometry (ICP MS). Solute concentrations in the extracted porewater are determined by normalizing individual solute masses to the extracted water mass.

Laboratory experiments using controlled additions of brine to cellulosic membranes confirm that the method is capable of providing porewater solute concentrations with precision and accuracy that are within the limits suggested by USEPA Method 6020A for analysis of saline water samples by ICP-MS. Field trials were conducted on low-permeability (K < 10-12 m/s, porosity < 10 %) shale drill cores from the Michigan Basin in Kincardine, Ontario. Concentrations of major ions (Na^+, K^+, Mg^{2+}, Ca^{2+}, Sr^{2+}, Cl^-, Br^-) were quantified using the absorption method and compared to results from the crush-and-leach method obtained from paired samples.

The results of the comparison demonstrate that the absorption method provides precise porewater chemistry data that are free from ion exchange artefacts. Work to date has demonstrated that porewater, with quantifiable amounts of solutes, can be extracted from low permeability rock samples using absorption into a cellulosic membrane. Solute masses quantified by ICP-MS combined with water content measurements by NIR, make it possible to determine porewater solute concentrations that are unaffected by mineral-dissolution and ion-exchange reactions, and are independent of porosity. **(*SS8, Thurs. 2:00*)**

Sedimentology, ichnology and sequence stratigraphy of the Bakken Formation, west-central Saskatchewan: Evidence for a Paleozoic wave-dominated tidal flat

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The Upper Devonian-Lower Mississippian Bakken Formation of west-central Saskatchewan is part of a complex stratigraphic succession. A relatively thin clastic succession deposited during the middle Paleozoic, a period in which geology in Saskatchewan is dominated by the deposition of thick carbonate successions.

Although similar to its southeastern counterpart in that it is made up of a heterogeneous sandstone/siltstone middle member bounded at the top and base respectively by black shale members, upon closer examination the two are quite distinct.

Detailed core analysis has established six facies, displaying both open marine as well as brackish-water conditions, based on their sedimentological and ichnological characteristics. Of particular interest are the marginal marine facies that show potential evidence of an ancient wave-dominated tidal flat, as suggested by a combination of hummocky cross-stratification, wave-ripple cross-lamination, flaser/wavy/lenticular bedding, and mudstone drapes.

The stacking pattern of west-central Bakken records an overall transgressive system. Facies 1(black, parallel-laminated mudstone) and 2(grey-green siltstone) were deposited under open marine conditions, of which Facies 2 was deposited through progradation during a highstand. The lower open marine succession is capped by a transgressive lag (Facies 3), made up of crinoid ossicles and brachiopod shell fragments. The basal contact is being interpreted as a co-planar surface that is comprised of an amalgamated flooding surface/sequence boundary.

Facies 4(parallel-laminated mudstone/sandstone)/5(channel sandstone) displays marginal marine conditions, which can be inferred based on the sedimentological signature as well as the paucity of bioturbation. Transgression coupled with the creation of accommodation space could have allowed for marginal marine conditions to persist. Facies 6 (bioturbated siltstone) is heavily bioturbated (BI 4-5), although it has a similar sedimentological signature as is seen in underlying Facies 4, the main difference being probably an extended colonization window.

Facies 6 is being interpreted as having been deposited through further transgression, where sea level rise outpaced the creation of accommodation space, which resulted in the drowning of the tidal flat/tidal channel succession displayed by Facies 4 and 5.

Open marine conditions were re-established through continued marine transgression, displayed by the reoccurrence of Facies' 1 and 2, as seen at the base of the succession. **(*SS12, Poster*)**

Mineralogy and chemistry of tourmaline in the Woodjam porphyry deposits, British Columbia

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Tourmaline is a common accessory and gangue mineral in a diverse range of hydrothermal ore-forming systems covering a broad spectrum of pressure, temperature and chemical conditions, reflecting tourmaline's wide stability range. Previous studies, dating back into the 1960s, have shown that tourmaline can very closely track changes in physicochemical conditions within the fluid from which it is precipitated. Tourmaline's refractory and resistant physical properties mean that the mineral is able to preserve this information through numerous subsequent phases of metamorphism, alteration and weathering; in many cases tourmaline may be the only robust remaining record of original hydrothermal processes. Although tourmaline's utility in mineral exploration has been demonstrated, very few studies have attempted to measure concentrations of the ore metals themselves. In general, these limitations have been imposed by the common use of EPMA alone to interrogate mineral chemistry at high spatial resolution.

In many porphyry-related deposits of the South American Cordillera, tourmaline occurrences are abundant and extensive, and have attracted much interest for use during mineral deposit exploration. However, owing to various factors including differences in their tectonic settings and magma chemistries, porphyry-related deposits of the Canadian Cordillera rarely report significant tourmaline among their mineral inventory. Consequently, studies of tourmaline associated with Canadian deposits are limited, and almost no data exist on tourmaline occurrences associated with alkalic or hybrid alkalic-calc-alkalic systems. In this study we report mineralogical and LA-ICP-MS trace element analyses of tourmaline minerals from within the hybrid alkalic and calc-alkalic Woodjam porphyry Cu-Au deposits of central British Columbia. These minerals display significant variation in both their major and trace element compositions, reflecting both temporal and spatial evolution of the magmatic-hydrothermal fluids from which the deposit formed. Tourmaline associated with high-temperature potassic alteration has greater schorl (*i.e.* Fe-rich) component and trace element abundances characteristic of the core of a porphyry hydrothermal system, while tourmaline recovered in association with distal, lower-temperature, albite-rich alteration has an increased dravitic (*i.e.* Mg-rich) component and a distinct trace element suite. Tourmaline recovered in intimate association with chalcopyrite mineralization has a pronounced blue colour and increased copper content. Hence, within the Woodjam and other similar deposits it may be possible to use tourmaline mineralogy and chemistry as a vector to mineralization. In addition, careful analysis of tourmaline recovered from surficial samples (till, soil, *etc.*) may provide detailed information on the type and abundance of any concealed mineralized body. **(*SS3, Wed. 2:20*)**

Further Re-Os arsenopyrite geochronology from selected Meguma Au deposits, Meguma Terrane, Nova Scotia: Possible evidence for a protracted gold-forming system

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The Meguma terrane is dominated by two rock types, regionally deformed and metamorphosed Cambro-Ordovician metasedimentary rocks and *ca.* 380-370 Ma meta- to peraluminous granites. The metasedimentary rocks contain numerous orogenic-type, vein-hosted gold deposits which occur throughout the sandstone-dominated Goldenville Group rather than the overlying siltstone- and mudrock-dominated Halifax Group. These mineralized veins are dominated by quartz-carbonate-sulfide assemblages and occupy structures consistent with emplacement during late-stage fold tightening of the regional, northeast-trending, upright folds that formed during the Neoacadian orogenic event at *ca.* 410-385 Ma. Our previous work suggests vein formation, hence gold emplacement, spanned 30-40 Ma, as constrained from field observations and radiometric dating. The former indicates veins post-date cleavage formation given that cleaved wall-rock fragments occur in some veins, and that rarely; veins post-date hornfels related to 380 Ma granites. Existing absolute age dating indicates two events at 408 Ma (Re-Os aspy, $^{40}Ar/^{39}Ar$ whole rock) and 380-362 Ma (Re-Os aspy; $^{40}Ar/^{39}Ar$ amph, musc, biot, whole rock). Here we report new Re-Os geochronological data generated from arsenopyrite in gold-rich veins for two of three deposits sampled, all of which lie in the same stratigraphic-structural position in the lower part of the Goldenville Group and along the northeast-trending Moose River-Beaver Dam-Fifteen Mile Stream anticline. The Re-Os analysis of arsenopyrite from the Beaver Dam deposit, which is dominated by bedding-concordant type veins, yielded an age of *ca.* 461 Ma. In contrast, Re-Os analysis of vein-hosted arsenopyrite from the Touquoy deposit of the Moose River gold district, where mineralization occurs in a vein-poor sequence of carbonate-rich metasiltstone rocks, yielded two imprecise ages of ~375 Ma and ~440 Ma; further analyses are in progress for this deposit. The new data may indicate that in the Cambro-Ordovician metasedimentary rocks of the Meguma terrane there possibly exists more than two periods of gold mineralization, one of which occurred before the Neoacadian deformation and metamorphism of the host rocks. **(*SY5, Thurs. 2:40*)**

Linear fabrics in greenstone belts simulated by a multiscale micromechanical approach: Implications for Archean tectonics

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Archean greenstone belts have rather unique fabrics compared to Phanerozoic orogens, as recognized by many people. There is commonly a subvertical lineation defined variably by elongated minerals and deformed pebbles in certain domains. There may also be an oblique mineral lineation throughout a belt. This unique set of fabrics is commonly interpreted as reflecting a constrictional strain field which is thought to be incompatible with plate-tectonics induced tranpressional deformations. Non-plate tectonics mechanisms (*e.g.* sagduction) have been invoked to explain them. However, sagduction cannot explain pervasive subvertical foliation, asymmetric fabrics on subhorizontal planes and anastomosing network of shear zones in greenstone belts. Here we show that once more realistic deformation models capturing deformation partitioning due to rheological heterogeneities are considered, the fabric set in Archean greenstone belts are fully compatible with plate-tectonics-induced transpressional boundary conditions. We regard greenstones and granitoids as rheologically distinct rock masses. This configuration makes deformation processes in Archean intrinsically heterogeneous and multi-scale. Consequently fabrics in Archean cratons are on different scales. We use a micromechanics-based model to simulate the development of fabrics in Archean cratons. In our simulations, greenstone belts are weak domains which are embedded in granite-greenstone terrains subjected to simple shearing and transpression. We demonstrate that the strain fields within weak domains which are undergoing flattening strain can be contrictional; strong clasts can be aligned with vorticity vector by strike-slip movements; moderately to steeply plunging lineations without any systematic trend can develop in tranpressional flows. Our modelling reproduce most field-observed fabrics in Archean cratons. **(*GS2, Fri. 2:20*)**

Geomathematic analysis of sandstone compositions overlying the Phoenix U deposits and REE-rich Maw Zone, Athabasca Basin, Saskatchewan

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The Denison Mine's Phoenix deposits, with the current resources of 52.3 M lbs (indicated) and 7.6 M lbs (inferred) U_3O_8, occur both at the unconformity and along steeply dipping faults in the basement, at ~ 400 m depth. Sandstones above the deposits are variably altered to form kaolinite, illite/muscovite, clinochlore, sudoite and dravitic tourmaline. The Maw Zone, ~ 6 km SE from Phoenix Zone A, has a surface exposure of 200×200 m underlain by a breccia pipe from the unconformity. The Zone consists of highly silicified, hematitized, dravitic tourmaline-rich rocks. The Zone does not show high U (< 0.0031 %), but high REE (< 8.1% as oxides), Y (< 0.1%), and B (< 2.5%). In order to evaluate the elements associated with two different styles of mineralization, principal component analysis was carried out. For sandstones overlying the

Phoenix deposits, U is associated with REE-Y-B-Na-Mg-Ni-Cr, but inversely correlated with K-Al-Fe-Ti-Th. Additionally, distinct elemental assemblages are found in different stratigraphic units. Relative enrichment of U-Pb-Y-HREE is apparent in MFa and MFd, whereas it is less so in MFb and MFc. MFa shows relative enrichment of U- Sr-LREE-P, suggesting the occurrence of monazite and possibly Sr-rich aluminum phosphate sulphate (APS). The unit also shows an inverse correlation of U with Fe, Mn and Ti. Since sandstones were extensively hematitized during the diagenesis, this inverse correlation of U and Fe suggests the enrichment of U is accompanied by the reduction of Fe to remove hematite. The principal component analysis of the Maw Zone shows different results. REE and Y are associated with P. Enrichment of HREE-Y-P occurs in the upper sandstone units (MFb, MFc, MFd), suggesting xenotime as the host of HREE. Hematization, reflected as the enrichment of Fe and V, is positively correlated with U, suggesting that the hydrothermal fluids were oxidizing and uraniferous, but no precipitation of significant U due to the lack of a reductant in the upper part of sandstones. **(*SS7, Poster*)**

Evidence of fluid immiscibility from uranium deposits in northern Saskatchewan and Nunavut and potential relationship with uranium precipitation

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The northern part of Saskatchewan in Canada is one of the leading uranium exploration and producing regions in the world. The uranium deposits can be divided into two groups: the vein-type mineralization in the Beaverlodge district and the unconformity-related mineralization associated with the Athabasca Basin. Uranium deposits similar to the latter are also developed in the Thelon Basin in Nunavut. The Beaverlodge deposits are hosted by the 2.33-1.93 Ga Murmac Bay Group amphibolite and 1.93 Ga leucogranites, and are spatially associated with the *ca.* 1.82 Ga Martin Group redbeds. The Athabasca and Thelon deposits are located near the unconformity between the *ca.* 1760-1500 Ma sedimentary cover and the Archean to Early Proterozoic amphibolite- to granulite-facies basement rocks.

Fluid inclusion studies of quartz and carbonate veins associated with uranium mineralization in the Beaverlodge district indicate the presence of abundant monophase vapour inclusions co-existing with biphase aqueous inclusions with variable vapour/liquid ratios along growth zones and microfractures in quartz and carbonates. Raman spectroscopic analysis found only H_2O (and minor H_2 in some cases) in the vapour of the biphase inclusions, although some melting events above zero degree suggest the presence of gas hydrates; no gases including CO_2, CH_4, N_2, H_2 and H_2S were detected in the vapour inclusions. These observations suggest that two immiscible fluid phases were present during the precipitation of quartz and calcite, which are coeval with uranium mineralization. The apparent absence or invisibility of liquid phase in the vapour inclusions suggests low trapping temperatures, which is consistent with the lowest homogenization temperatures of the biphase inclusions within individual fluid inclusion assemblages being generally lower than 200°C. Similar phenomena have also been observed in the End deposit in the Thelon Basin and the Millennium and Roughrider deposits in the Athabasca basin. In these latter cases, quartz and carbonates are not well developed during the major phase of uranium mineralization; however, some quartz veins appear to be contemporaneous or overlapping with uraninite precipitation. The coexistence of monophase vapour inclusions and biphase aqueous inclusions in these deposits therefore suggests that fluid immiscibility also occurred during at least part of the mineralization period of the unconformity-related uranium deposits. Based on these observations, we propose that fluid phase separation may have contributed to uranium deposition, in addition to reaction with reducing agents. This may be related to pH increase and cooling of the liquid phase during phase separation. **(*SS7, Wed. 2:20*)**

Multispectral analysis of the Tunnunik impact structure in the Canadian Arctic using LANDSAT ETM 7+ and ASTER data

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This study investigates Visible-Near Infrared (VNIR) and Thermal Infrared (TIR) multispectral data of the ~28 km diameter Tunnunik impact structure (72°28'N, 113°56'W) recently identified on northwestern portion of Victoria Island in the Canadian Arctic. Landsat ETM 7+ VNIR (Bands 1-7) and ASTER TIR (Bands 10-14) data were analyzed to provide a spectral mineral and lithological map of the structure. Band ratio images (band5/band4, band4/band3, and band3/band2) were derived from LANDSAT ETM 7+ data and then combined into a colour composite image to classify distinct spectral units. For ASTER TIR data, a minimum noise fraction (MNF) transform was applied. An MNF-transformed ASTER TIR colour composite image, using band 2, 1, and 3, was compared to the ETM 7+ band ratio colour composite image in order to define the number of distinct spectral units in the scene. A maximum of four spectral distinct units were recognized in the MNF composite. Various techniques for deriving averaged spectra were used to extract statistically consistent and representative spectra for each of the four units. Finally, the ASTER TIR emissivity spectra were matched with spectra derived from a whole-rock spectral library provided by Arizona State University. We used two matching algorithms: spectral angle mapper (SAM) and spectral feature fitting (SFF). The best-matched spectra derived from the units were siltstone, cherty limestone, and dolomitic limestone. The results showed that the lithologies are mainly composed of siliciclastic components (*i.e.*, siltstone, "cherty" portion of the "cherty" limestone spectrum) and carbonates (limestones and/or dolostones) consistent with the target lithologies reported from the field. It is suggested that the overall chemical composition is comprised of silicates (based on absorptions in TIR bands 10, 12) and carbonates (band 14 absorption) including iron oxides components (based on VNIR observations) and the rock types represented in the data are slightly different depending on the proportion of the mixed components. Further work and analysis are planned to produce a final spectral-based mineral and lithological map based on ETM+ and ASTER data, which will be used to facilitate mapping during future field seasons at the structure. **(*SS21, Thurs. 10:20*)**

Petrogenesis and implications of tectonic setting for Cambrian suprasubduction-zone ophiolitic rocks in the central Beishan orogenic collage, Northwest China

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The ultramafic body that lies exposed in the Hongliuhe region of the Beishan orogenic collage has the signature of a supra-subduction zone ophiolite, and therefore offers distinct information on tectonic cycles and collisions within this southerly portion of the Central Asian Orogenic Belt. It is situated within a Paleozoic suture zone in Northwest China that was previously thought to have recorded a Permian ocean closure, and to have connected the Late Paleozoic Tianshan and Solonker sutures to its West and East, respectively. The ultramafic body is part of a lithological and stratigraphic sequence that transitions from highly attenuated oceanic crust with cumulate ultramafic and gabbroic rocks, to a thin, sub-conformable covering of basaltic to andesitic flows interlayered with cherts, pyroclastic and volcaniclastic deposits. The sequence continues with a thick, contiguous supracrustal covering of marginal rocks, including interlayered limestone, pyroclastic and siliciclastic rocks, and basalts. The ophiolite is internally deformed with high temperature ductile shear zones indicating a record of oceanic transform faulting. The supracrustal covering has a dissimilar structural pattern, deformed largely in a strike-slip dominated transpressive regime, marking the effects of emplacement in the suture. Geochemical analysis of the ophiolitic lava and dyke rocks provides a bimodal distribution with

one population of depleted tholeiites and another of differentiated calc-alkaline rocks. Geochemistry of plutonic rocks exhibits a refertilization of extremely depleted mantle material. Mineral chemistry of spinel from selected ultramafic lithologies shows a low Mg#, high Cr# relationship, suggesting a forearc tectonic setting for ophiolite genesis with implications of subduction inception for a juvenile intra-oceanic arc. Our efforts to constrain timing of genesis offer an Early Cambrian magmatic age from U-Pb zircon SHRIMP analysis of separates from a pegmatitic gabbro within the ultramafic body. For constraints on emplacement we provide a Devonian U-Pb Zircon SHRIMP date from an undeformed granitoid body intruded within the overlying stratigraphy. Concluding that an ophiolite exists within the Hongliuhe mélange, with these characteristics, drastically changes the interpretation of tectonics in the Beishan; ocean basin generation was active in the Early Cambrian, and supra-subduction zone modifications to the generated crust were active shortly after, creating a juvenile arc, likely the proximal Mazongshan terrane. The emplacement timing helps constrain an early collision, not related to Permian terminal closure, but between the Mazongshan arc and the South Gonpoquan arc-accretionary system. **(*SY3, Fri. 8:20*)**

Mantle plumes and the supercontinent cycle

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Supercontinents have long been modeled as insulators giving rise to either large mantle upwellings or/and numerous small plumes, which may be instrumental in fragmenting supercontinents. Although continental breakup by itself does not demand mantle plumes, the timing of breakup of Pangea is known to be associated with plumes in the Atlantic and Indian Ocean basins. However the role of mantle plumes in fragmenting or weakening the continental lithosphere in supercontinents is still a matter of uncertainty and debate. The number of precise isotopic ages of large igneous provinces (LIPs) is continually growing and can be used to monitor major mantle plume events with increasing confidence. Our existing database contains 338 precisely dated LIPs ranging in age from 3250 to 10 Ma and shows peaks in LIP activity at 2700, 2500, 2200, 2100, 1100, 800 and 100 Ma. The 2200, 2100, 800 and 100 Ma peaks correlate with known supercontinent breakups, and the 1100 Ma peak with a possible breakup or partial breakup of Nuna. Minima in LIP activity at 2600, 1700-1400, 1100-900, and 650-400 Ma appear to correlate with supercontinent assemblies.

Our results support at least two types of mantle plume events: those associated with supercontinent breakup and those not associated with supercontinent breakup. LIP peaks at 2700, 2500, 2200 and 1850 Ma may reflect periods of episodic mantle convection leading to short-term production of global mantle plumes as shown by the models of Anne Davaille. The 2700 and 1850 Ma events precede supercontinent (or supercraton) assemblies. The 1850 Ma peak is unique in that it correlates with numerous collisions between small Archean cratons that were dispersed during breakup of late Archean supercratons at 2200-2100 Ma. Widespread breakup of these supercratons may have resulted in short-term stagnation of oceanic slabs in the mantle transition zone, followed by catastrophic collapse of these slabs into the lower mantle at 1900-1850 Ma triggering a global mantle plume event. Such collapse also may have led to assembly of new supercratons over mantle downwellings, and these supercratons may have been the building blocks for the first true supercontinent Nuna beginning around 1700 Ma. Our results suggest that the supercontinent cycle is really not a cycle, but a series three (or possibly four) episodes of supercontinent assembly and breakup beginning about 1700 Ma. **(*SY7, Thurs. 4:40*)**

The Sawyer Lake iron-ore deposit, western Labrador: Potential for future high-grade iron ore deposits in the Labrador Trough

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The Sawyer Lake deposit is located in western Labrador, about 65 km southwest of Schefferville. The deposit was initially discovered in the 1930s and sporadic exploration since then has defined a significant iron-ore resource with up to 12 million tonnes of high-grade iron ore (> 60% Fe). The Sawyer Lake deposit differs markedly from other high grade Direct Shipping Ore (DSO) deposits in the northern Labrador Trough, and represents a new type of iron deposit. The main ore zone is located in the lower Sokoman Formation, below a thick sequence of volcanic rocks of the Nimish Formation. The ore forms a stratiform orebody with a saddle-reef morphology and consists of hard, massive to weakly banded high-grade hematite, containing >90% fine-grained, microplaty hematite and minor microgranular quartz. The hard hematite ore is commonly brecciated, containing angular fragments of hematite in a quartz and hematite matrix. Brecciation is associated with the collapse of hematite into open spaces created by the leaching of silica. The high-grade hematite orebody is surrounded by oxidized iron formation consisting of alternating hematite and cherty bands, and displays abundant evidence for the remobilization of hematite and quartz, and secondary hematite enrichment.

In contrast to high-grade DSO deposits in the Schefferville area, no evidence of supergene enrichment has been recorded at the Sawyer Lake deposit, and syndiagenetic iron enrichment is also considered unlikely. Macroscopic and petrographic studies and comparisons with other high-grade hematite deposits worldwide indicate that enrichment is related to hypogene processes, in which hydrothermal fluids leached silica and precipitated secondary hematite. Preliminary isotopic and geochemical analyses are also consistent with a hypogene enrichment model. Although the source of hydrothermal fluids is unknown, they may be related to dewatering of underlying shales during the Hudsonian orogeny or circulation of basinal brines during regional-scale thrusting. **(*GS5, Fri. 8:40*)**

The Albany graphite deposit: A new sub-class of igneous-hosted, hydrothermal graphite

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Globally, there are only a few known occurrences of igneous-hosted, hydrothermal (or vein) graphite deposits, with the recently discovered Albany deposit, near Hearst, Ontario, being the only example of this deposit type in Canada. The Albany graphite deposits occurs as two breccia pipes with the Albany Alkalic Complex (AAC); which is satellite syenite complex proximal to the southern margin of the Nagagami River Alkali Rock Complex (NRARC). The ACC intruded Marmion Terrane rocks proximal to the Gravel River fault, which separates the Marmion Terrain and the Quetico Subprovince. Ordovician to Devonian carbonate rocks of the Moose River basin unconformably overlie the Albany deposit. The graphite-hosting breccias are primarily comprised of angular to rounded fragments of syenite (which range in composition from diorite to granite), with subordinate number of Marmion and Quetico xenoliths. Graphite occurs both in the matrix and along fractures and crystal boundaries within fragments. In addition to graphite, the matrix consists primarily of quartz, alkali feldspar and plagioclase feldspar with minor phlogopite and amphibole and trace amounts of pyrite-pyrrhotite and magnetite. Alteration is minor, and is most pronounced as a paleo-weathering profile in the upper 20 m of the breccia pipes.

The breccia pipes are interpreted as near surface vent pipes that formed in response to brecciation induced by the ascent of carbon-rich fluids that separated from syentite magmas at depth. Plausible sources for the carbon include: i) carbon dioxide- or methane-bearing syenite magmas; and, ii) assimilation of carbonaceous Quetico metasedimentary rock. A carbon isotope study is currently in progress to discern both carbon source and carbon speciation of the fluid. Magma degassing, in response to ascent related depressurization, resulted in the segregation of a carbon-bearing fluid and accumulation of the fluid at the top of the ascending syenite intrusion(s). Continued ascent resulted in added fracturing/milling of the host syenite and surrounding country rock. Graphite deposition likely occurred rapidly in response to sudden depressurization and quenching of the carbon-fluid due to surface venting (which is evidenced from the extent of the graphite breccias to the unconformity with the overlying Paleozoic rock). This rapid depressurization would have also imploded the walls of the vent complex, resulting in the high proportion of angular syenite fragments and decreased occurrences of rounded syenite fragments and Archean xenoliths. Post-mineralization events include (in temporal succession): i) emplacement of late-stage olivine-aegirine syenite; ii) intrusion of aplite and other felsic dykes; and, iii) erosion of upper levels of the AAC complex and weathering-related alteration. **(*SS23, Fri. 4:20*)**

Keynote (40 min): Towards an improved understanding of our solar system's formation: Progress and challenges of dating meteorites and their inclusions

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Understanding the formation of our solar system relies heavily on establishing an accurate and precise record of the timing and tempo of processes related to the formation, dynamics and clearing of the protoplanetary disk around the young sun. With the lifetime of protoplanetary disks on the order of 5 million years, chronometers must have the resolution of several 100,000 years to be useful in reconstructing events in the earliest stage of our solar system's formation. Chronometers based on short-lived radionuclides (*eg.* ^{26}Al, ^{53}Mn, ^{182}Hf) can theoretically easily achieve this resolution but depend critically on the unsubstantiated assumption that the parent nuclide was homogeneously distributed throughout the lifetime of the disk. Only the U-Pb and derivative Pb-Pb methods of dating meteorites and their components have the capability to return assumption free ages with adequate precision for favourable samples for which the U isotopic composition is either known or measured.

The Pb-Pb method specifically requires accurate and precise characterization of the Uranogenic Pb component of a sample that inevitably contains other non-radiogenic Pb contributions. This is typically achieved by constructing an array of analyses in ^{204}Pb/^{206}Pb *vs.* ^{207}Pb/^{206}Pb space where the y-intercept of the array represents the required radiogenic ^{207}Pb/^{206}Pb composition. The array can be defined by analyses of mineral separates with different U/Pb ratios and/or by parsing a two component Pb reservoir into aliquots of different proportions of radiogenic Pb by step-wise acid dissolution of a mineral or whole rock sample. Substantial improvements in the precision of Pb-Pb ages have been made in the past decade, primarily based on lower laboratory blanks, improved instrumental mass bias correction schemes, more sensitive and stable mass spectrometers and innovative sample handling that have collectively led to the current possible precision of ±200,000 years or better.

Multiple laboratories are now producing Pb-Pb ages with this precision using different methods to define Pb arrays as well as different mass spectrometers, instrumental mass bias corrections, data reduction schemes, error regressions and means to measure U isotopic compositions. Following the example of the NSF-sponsored EARTHTIME project, a community-based initiative called EarlyTime has been undertaken to verify consistency of age results from participating laboratories and to work cooperatively to improve methods for U-Pb and Pb-Pb dating of meteorites and their components. **(*SS17, Wed. 10:20*)**

Challenges in the interpretation of U-Pb data for zircon in meta-anorthosite: Examples from the Scandinavian Caledonides

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Proterozoic anorthosite suites are found at various tectonic levels of the Scandinavian Caledonides. The oldest suite (1800-1790 Ma) is hosted in the Caledonized basement of Lofoten-Vesterålen, a younger *ca.* 1500 Ma suite dominates the Espedalen Nappe, and several *ca.* 970 Ma anorthosite-gabbro massifs are present in the Lindås, Jotun and Dalsfjord nappes. The latter have been subjected to Sveconorwegian high temperature and then Caledonian high pressure metamorphism, and also predated the *ca.* 930 Ma Rogaland anorthosite suite in the Caledonian foreland of southern Norway. Additional occurrences, for example in the Western Gneiss Region, remain undated. Geochronological investigations of anorthosites can be challenging for a number of reasons. A first difficult step is finding zircon at all, due to the generally low abundances of Zr in such rocks, combined with their cumulate nature, which concentrates specific minerals in specific sites depleting them in the rest of the bodies. The other difficult task is interpreting the genesis of the recovered zircon grains properly, finding diagnostic features that can identify magmatic, metamorphically modified magmatic or entirely metamorphic grains. In low grade metamorphic suites, such as in Lofoten, the task is relatively straightforward, especially because a number of associated lithologies provide a firm age framework for the interpretation of the age. By contrast, high-grade metamorphic suites such as in the Lindås, the Jotun and the Dalsfjord nappes present bigger challenges. The difficulties include the proper interpretation of zircon textures in terms of magmatic or metamorphic processes, the superposition of multiple metamorphic overprints which partially reset older zircon and / or create new overgrowths, and the effect of younger Pb loss during the Caledonian orogeny. In general the final assessment of the data has to reconcile all lines of evidence within the existing age framework. **(*SS17, Wed. 8:20*)**

The Folster Lake formation: Vestige of a Paleoproterozoic-age delta fan deposit?

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The Folster Lake formation unconformably rests on Archean basement of the Prince Albert Group on Melville Peninsula, Nunavut, above a regolith that locally includes corestone. Its stratigraphic base is up to a few metres thick and consists of a polymictic pebble conglomerate that is dominated by quartzite and iron-formation clasts. Locally, the conglomerate is overlain by specularite- and hematite-rich iron-formation in quartz-rich arenite. This is overlain by marl, up to a few tens of metres thick, likely derived from arkosic arenite and siltstone with carbonate cement. The marl is interlayered with arkosic arenite that shows decimetre to metre-scale trough cross-beds likely deposited in a distal braided stream or delta environment. The marly layers give way up section to thick arkosic arenites sequences that feature giant (up to 30 m thick) foreset beds separated by metres-thick foreset and bottomset beds, perhaps representing eolian or Gilbert-type delta fan deposits, as suggested by the scale of the sedimentary structures and the lack of fine-grained sediments such as silty or muddy beds. The arkosic sandstone beds are overlain by relatively more quartz-rich arenites. The entire sequence is deformed into upright open folds with a steeply-dipping cleaveage, the latter visible mainly in the more metamorphically fertile marly layers, and a likely effect of the Trans-Hudson (*ca.* 1.80 Ga) orogeny. U-Pb SHRIMP dating of detrital zircon from the lower conglomeratic to arkosic basal sequence shows a dominantly local provenance from a source with a 3.25 to 2.61 Ga age range, and a major population at *ca.* 2.705 Ga. Stratigraphically higher beds yield zircon populations ranging from *ca.* 3.77 Ga to 1.91 Ga, with major age peaks at *ca.* 2.50 Ga, 2.49 Ga, and 1.99 Ga. The youngest concordant age of 1905 ± 8 Ma provides an upper age limit for deposition. This maximum age is similar to that obtained from the Longstaff Bluff formation, representing a deep, rapidly filled greywacke-turbidite basin that outcrops approximately 100 km to the south, within the Penrhyn-Piling group. The Folster Lake formation is therefore (pene?)-contemporaneous with the Longstaff Bluff formation and likely represents a distal fan related to the latter. The contemporaneous uplift and exhumation observed along the western and southern margins of the Rae Craton (Thelon-Talston and Snowbird orogenies, respectively) may have provided a source of detritus for the Longstaff Bluff and Folster Lake formations, at least in part. **(*SS13, Thurs. 2:40*)**

Origin of disseminated Au-Cu mineralization in pervasively albitized synvolcanic-pluton: Example of the archean Boyvinet stock, Abitibi belt, Québec

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Gold mineralization within an intrusion can be ascribed to numerous genetic models, such as intrusion-related, porphyry, thermal aureole gold, syenite-related, volcanogenic and late orogenic overprinting existing plutons. Ore control would be very different depending on the origin of mineralization and consequently this is a fundamental parameter for gold exploration. Cryptic and disseminated gold-copper mineralization occurs in the Boyvinet stock (known as the Lac Shortt property: SOQUEM & MDN) located within the north-eastern part of the Abitibi Greenstone Belt, Québec. Consistent with the previously syenitic interpreted composition, the intrusion is mainly composed of ±40% albite, ±10% quartz, plagioclase, epidote, chlorite and ±5% magnetite, pyrite, hematite, K-feldspars and sphene. However, geochemical characterizations indicate that the intrusion is calc-alkaline (La/Yb = 22) with a classical arc signature (Nb & Ta negative anomaly). Furthermore, the surrounding seafloor–related basalts share the same geochemical characteristics, hence supporting a co-genetic link and consequently a syn-volcanic origin rather than a late-tectonic alkaline stock. This revised origin has a profound impact on ore genesis and control, which was previously interpreted as magmatic-related, as it is the case for other gold deposits in the district (Lac Shortt and Batchelor). The pervasive albitization seems to be related to a widespread hydrothermal event, which also induced martitisation. The origin of this major hydrothermal event remains to be established. Hydrothermal alteration associated with gold-copper mineralization, although weakly developed, occurs as impregnation of carbonate-quartz-albite-pyrite-chalcopyrite in association with millimeter-scale idiomorphic crystals of magnetite. Fluid inclusions in quartz veins were analyzed by solid-probe mass spectrometry. Preliminary results reveal CO_2-rich and H_2O-poor fluids, with traces of CH_4 and N_2, more compatible with an orogenic origin for the gold mineralization. With these orogenic overprinting fluids, the presence of magnetite could be a key factor for precipitating gold by changing the oxygen fugacity of the fluids. The origin of the magnetite remains to be established, as magmatic or hydrothermal, with the latter being related to the pervasive albitization event. In such a scenario, the albitization event would have played two roles: 1) a physical change in the rheological behavior of the stock accounting for the less focalized orogenic-related fluid flow, and 2) a chemical change, related to the precipitation of gold induced by interaction with magnetite. In this case, the use of aeromagnetic surveys could lead to indirect mapping of magnetite-rich zones in the intrusive rock, potentially indicating areas of gold-enrichment formed during later orogenic fluids flux. **(*SY5, Poster*)**

Sm–Nd and U–Pb geochronological evidence for a newly identified metasedimentary sequence in the Thompson Nickel Belt, Manitoba: The "missing" cratonic margin rift sequence?

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Nickel exploration in the Thompson Nickel Belt (TNB) typically targets ultramafic bodies hosted by sulphidic metasedimentary rocks of the Paleoproterozoic Ospwagan Group, a passive margin sequence deposited along the Superior craton margin. Detritus for the Ospwagan Group was sourced from the adjacent and underlying craton, whereas other Paleoproterozoic metasedimentary sequences along the western margin of the belt (Burntwood and Grass River groups) were sourced from arc rocks of the Reindeer Zone of the Trans-Hudson Orogen (THO). Detailed re-mapping of parts of the TNB, supported by Sm–Nd isotope studies and U–Pb laser ablation–multi collector–inductively coupled plasma-mass spectrometry (LA–MC–ICP-MS) dating methods, have resulted in the recognition of at least one additional metasedimentary sequence in the TNB. The new sequence, informally termed the Paint sequence, consist largely of metawacke and meta-arenite with subordinate meta-iron formation, and metapelite. The Paint sequence occurs along the eastern margin of the TNB over a strike-length of at least 50 km with the most extensive exposures occurring at Paint Lake. Neodymium model ages for Paint sequence metawacke range from *ca.* 3.57 to 3.22 Ga, which is generally older than Ospwagan Group model ages of *ca.* 3.22–2.82 Ga. A limited dataset (n = 19) of detrital cores to metamorphic zircon in the Paint sequence yield U–Pb ages ranging from *ca.* 2850–2060 Ma with a dominant Archean population at *ca.* 2675–2650 Ma and a smaller Paleoproterozoic population at *ca.* 2440 Ma. In comparison, detrital zircon grains contained within the Ospwagan Group are almost exclusively Archean, 3000–2550 Ma, with prominent modal peaks at *ca.* 2700–2660 Ma and rare Paleoproterozoic detrital grains as young as *ca.* 1975 Ma.

The available detrital zircon data suggest a Paleoproterozoic age for the Paint sequence; however, its stratigraphic position relative to the Ospwagan Group remains unknown. Archean populations of detrital zircon in the Ospwagan Group and the Paint sequence are similar to the *ca.* 2700–2650 Ma metamorphic and igneous ages of the Pikwitonei Granulite Domain, which borders the TNB to the east; however, model ages for the two sedimentary sequences suggest different sources. Model ages for the Ospwagan Group are similar to the North Caribou Superterrane (3.28–2.97 Ga), whereas model ages for the Paint sequence are more similar to the North Superior Superterrane (3.64–3.09 Ga) and basement gneiss to the TNB (3.7–3.14 Ga). Both of these superterranes were affected by the granulite-facies event that led to the formation of the Pikwitonei Granulite Domain. Does the Paint sequence represent a portion of the "missing" rift sequence along the northwest margin of the Superior craton? This and other possibilities for the stratigraphic significance of the Paint sequence and its relationship to the Ospwagan Group will be explored over the course of the presentation. **(*SS17, Wed. 2:20*)**

Towards successful CO_2 flooding for EOR in Bakken Formation reservoirs: Assessing the critical interplay of lithological framework, mineralogy and geochemical fluid-rock interaction

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The Upper Devonian–Lower Mississippian Bakken Formation of the Williston Basin is an important hydrocarbon reservoir. In the Canadian Province of Saskatchewan, it is estimated that Bakken Formation reservoirs are endowed with some 25 to 100 billion barrels of original oil in place. The primary recovery factor in the various Bakken Formation lithologies, however, remains rather low due to a high degree of capillary trapping. Furthermore, the rate of primary production is known to decline drastically over the first one-two years of operation. Enhanced oil recovery methods are considered key to the further development of the significant resources within Bakken reservoirs. While water-flooding could result in unfavourable injectivity issues, carbon dioxide (CO_2) miscible flooding provides a promising option for significantly boosting the recovery factor.

The Middle Member of the Bakken Formation, that is oil-bearing, has extreme lithological variability both vertically and along strike; it is commonly also host to highly saline formation brines. Complex geochemical reactions from CO_2–rock–brine interactions under reservoir conditions — and the many physical and chemical processes that are expected to result — have to be accounted for in any design of a CO_2 flooding process in Bakken reservoirs. For example, reaction of CO_2-saturated brine with calcite and/or anhydrite cements may result in grain dissolution, framework-repacking and fluid-compositional changes, that ultimately affect rock permeability and porosity. As well, carbonic acid may react with cations present in formation brine to precipitate new carbonate mineral cements. These two mechanisms can induce both positive and adverse effects on reservoir behaviour and CO_2 flooding performance.

In this research, complex interactions among CO_2, rock, and brine in Bakken reservoirs are investigated and presented. Experimental, CO_2 core-flooding was conducted on Middle Member core plugs that represent a variety of lithologies and mineralogies present within the Bakken Formation (including siltstone, sandstone, and dolomitic/calcitic sandstone). Scanning electron microscopy-energy dispersive spectroscopy (SEM-EDS) and X-ray diffraction (XRD) were performed to analyse morphological and mineralogical changes on pre- and post-flood core samples. Experimental results highlight important modifications to both grain-framework and the pore cements, particularly where this is calcite, or the lithology contains pyrite. The data point to a need to understand more fully the implications of fluid–rock interactions that could affect porosity, permeability, relative permeability, and wettability, which will help oil producers determine the viability of, and select optimal locations for, CO_2 flooding in Bakken Formation reservoirs. **(*SS12, Poster*)**

Temperature constraints during emplacement of the Parkin Offset dyke, Sudbury impact structure, Canada

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The Sudbury impact structure is widely recognized as a 1.85 Ga 200- to 250-km tectonically altered multi-ring impact basin located in central Ontario, Canada. There are now twelve known offset dykes surrounding the Sudbury Igneous Complex (SIC). There are seven radial dykes, three concentric and two discontinuous dykes. The radial dykes are often linked to the SIC via an embayment structure(s) that typically contains abundant sulfides. The Offset dykes are traditionally separated into quartz diorite and inclusion bearing quartz diorite phases that vary compositionally between quartz monzodiorite, granodiorite and tonalite. The inclusion-bearing phase is associated with disseminated to massive Ni-Cu-PGE sulfide; however, there are also few mineralized examples of inclusion free quartz diorite.

The Whistle-Parkin is a 12 km radial Offset dyke located in the northeast corner of the impact structure. The Whistle segment of the dyke is connected to the SIC via a 0.5 km long and 250 m wide embayment. The Whistle extends for 1.5 km from the embayment where it is then apparently displaced ~2 km to the northwest. Beyond the displaced fault zone is the Parkin portion of the dyke, which is known for another ~10 km to the northeast. The Parkin cross cuts the Espanola Formation of the Huronian Supergroup at ~6 km from the SIC at the Milnet Mine Zone, which is an ascending sequence of limestone, siltstone and dolostone. S- and Z-folds are common in the Espanola Formation along contacts with the dyke indicating some level of deformation. Samples taken from the contact between the Espanola Formation and the dyke were analyzed via powder- and micro-X-ray Diffraction. A variety of minerals;

Åkermanite, Hedenbergite, Pargasite and Richterite, typical of thermally metamorphosed limestones in contact metamorphic zones were discovered in close proximity (< 1 m) to the dyke within the Espanola Formation. Cristobalite was also found in close proximity to the dyke, indicating the Espanola Formation was heated to high temperatures (> 1470°C) due to contact metamorphism from the dyke. Several control samples were analyzed at various distances (up to 2 km) away from the dyke to ensure that this was not a regional metamorphic event. **(*SS21, Thurs. 3:00*)**

Acicular calcite fabrics, Syros Greece: Pseudomorphs after aragonite or not?

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Acicular calcite occurs in marbles at all tectonostatigraphic levels on Syros. The acicular calcite was interpreted by Brady *et al.* (2003) as a pseudomorph after aragonite that preserved a blueschist-facies fabric that formed by aragonite (001)<010> glide. The acicular calcite occurs as needles that are mm's in width and up to 10 cm long. The needles are straight to curved and are generally at a high angle to foliation. Each needle is a calcite polycrystal with a strong shape fabric (aspect rations of crystals are commonly >5:1) and moderate to strong lattice preferred orientation with calcite c-axes sub-parallel to the long axis of the needles. The acicular calcite overgrows a foliation defined by bands of white-mica and a mica shape fabric (mica inclusion foliation).

In most samples, the needles have been deformed since inverting to calcite and exhibit macroscopic to grain-scale calcite deformation fabrics. At an outcrop scale, there are shear bands, defined by a grain-size foliation that are approximately parallel to the mica inclusion foliation. Deformation twins are common in the needles with a transition from thin-twins to thick-twins to curved thick-twins with increasing strain. The least deformed needles have patchy undulose extinction. With greater strain, subgrains develop. The subgrains have progressively greater angular mismatchs with increasing strain. Grain boundaries between low-strain needles are straight to gently-curved. With increasing strain, the grain boundaries develop a roughness similar to that of the boundaries between subgrains within a needle.

At the highest strains, the acicular fabric is gone and the marbles are calcite mylonites with alternating bands of coarser and finer grained calcite. The coarser calcite is heavily twinned with thick and curved thick-twins common. Subgrains are common in the coarse calcite. The finer bands are composed of dynamically recrystallized untwinned calcite.

Calcite in all samples has a moderate to strong LPO dominated by c-axes that are nearly perpendicular to both the mica foliation and the calcite shear bands. Topotaxial inversion of aragonite to calcite should preserve c-axis orientation so the LPO may preserve aragonite (001) glide. However, this LPO is also common in calcite deformed by dislocation glide. Topotaxial replacement of calcite by aragonite should transform aragonite <010> to calcite <120>. Calcite <120> has a weak to strong LPO does not correlate with the degree of preservation of the acicular calcite habit. **(*SY3, Thurs. 2:00*)**

Teaching the geology and awareness of natural disasters to a large university class of non-science majors

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Natural disasters, including tsunami, earthquakes, floods, and volcanic hazards, are an important component of the course curriculum for a large (>200 students), introductory geoscience class at the University of Calgary. The students have varied backgrounds, and many have had little formal education on the topics of geologic processes, timescales, and materials. Experiential data indicates that the concept of natural disasters and their consequences for human society are easier for students to comprehend than Earth processes such as sedimentation and metamorphism. There are several reasons for this: 1) natural disasters commonly occur over a short time span of seconds to days, compared to the millions of years necessary to form a sedimentary or metamorphic rock, 2) the impact on society of natural disasters is a topic that students can relate to, and 3) the ubiquity of videos on television and the internet that instantly show geologic phenomena that may be occurring thousands of kilometers away.

Natural disasters are not abstract topics; the students do not need an extensive geological background to know what a tsunami or volcanic eruption looks like. In contrast, the diagenesis of sedimentary rocks or the solid-state phase changes in metamorphic petrology are much more abstract, in that the students cannot actually observe them. Natural disasters are the geologic events that often appear as news items, which make them a topic of interest to students. Data shows that although students are familiar with the imagery of natural disasters, most do not understand the Earth processes that cause the disasters. Observations of students in the large, non-science majors class suggest that many students have pre-conceived misconceptions about the ability of geologists to predict natural disasters, the geologic timescales involved in the frequency of disasters, the types of Earth materials produced and involved in disasters, and the role of the public in hazard awareness. Preliminary conclusions suggest that location-based and collaborative learning are meaningful, significant tools that aid in enhancing student understanding of the geological origin of natural disasters. **(*SS9, Poster*)**

The New Brunswick Energy Institute: A new voice in the scientific community

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The New Brunswick Energy Institute (NBEI) is a new voice in the scientific community of New Brunswick. Established in 2013, the Institute was created by the provincial Department of Energy and Mines to serve as an advisory body to government and as a credible source of scientific information for the public on the issues surrounding energy development in the province.

As a research institute, its objectives are to foster scientific research related to energy extraction, development and production in the province and to provide independent scientific review and assessment of the environmental, social, economic and health issues related to energy.

The governance structure of the NBEI consist of a Chair, who serves as President and CEO, an Executive Director, to oversee the day-to-day operation of the Institute, and a Scientific Advisory Council who serve as its board of directors and determine the scientific direction of the institute.

Working with a network of scientists, the Institute will ensure that evidence-based research and monitoring are conducted by using expertise from New Brunswick's universities, as well as recognized experts from outside the province.

Although there are many areas the NBEI could focus its efforts on over time, from oil and gas pipelines to wind or hydropower, the current research focus is on understanding the science behind hydraulic fracturing and both the positive and negative implications shale gas development may have in the region.

While much can be learned from studies being undertaken in other jurisdictions, there are certain questions unique to New Brunswick's geology and environment that can only be answered by New Brunswick based research and monitoring. **(*SS4, Thurs. 2:00*)**

Lithostratigraphy and palynology of crater infill from the Fifty kimberlite, Northwest Territories: Insights on volcaniclastic processes and paleoecology

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The Fifty kimberlite is one of over 150 pipes located in the Lac de Gras kimberlite field within the Slave Structural Province of the Northwest Territories. Previous modeling has shown that kimberlite pipes in this area are characterized by small, steeply-dipping morphologies and dominated by re-sedimented volcaniclastic infill. The current study examines drill core collected from approximately 70m to 150m depth through the uppermost levels of crater infill.

The core does not show an overall trend in grain size distribution with depth, alternating between kimberlitic mudstone, siltstone, sandstone, and conglomerate lithologies throughout. The kimberlitic mudstone is dominated by a dark, possibly organic-rich, mud-rich matrix with less than 10% angular to sub-rounded grains of quartz, alkali feldspar, plagioclase feldspar, crustal xenoliths, microcrystalline quartz, and cryptocrystalline lithic fragments. At the other end of the grain size scale, the kimberlitic conglomerate is composed of very fine to fine pebble-sized, sub-rounded to rounded mudstone and lithic clasts in a matrix of sand-size grains of quartz, plagioclase feldspar, white mica, and mud. Kimberlite indicator minerals, such as garnet, olivine, and clinopyroxene, are present between 123m and 148m depth, and are found in greatest concentrations in consolidated volcaniclastic kimberlite. The lithology of the pipe infill is consistent with explosive fragmentation and pipe excavation resulting in re-sedimentation of volcaniclastic material at deeper levels in the core, and deposition of allochthonous sediments derived from Archean granitoid host rocks at shallow levels.

Palynological data, including the presence of fresh water algae, suggests that a crater lake occupied the eruption pipe for a period of time. These microforms are found in the 115m to 137m depth range in the core, and contrast with the large percentage of terrestrial angiosperm pollen (*e.g.* Quercoidites, Momipites, Caryapollenites) found between 70m and 80m depth. The most notable change in palynoflora is the transition from an abundance of pollen from coniferous taxa, such as Taxodiaceae-Cupressaceae-Taxaceae, deeper in the core to pollen from hardwood taxa in the upper core. Spores are found throughout the core, however there are far fewer at shallow depth compared to deeper. The age of the identified palynomorphs ranges from Late Cretaceous to Early Oligocene, and the transition from coniferous to hardwood pollen may indicate a local warming trend, possibly associated with Early Eocene climate change. Further work will involve detailed interpretation of paleoclimate in the Lac de Gras area during the Early Cenozoic. **(*GS4, Poster*)**

Alternative ways to date zircon

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Zircon U-Pb dating is the most useful method for documenting events over geologic history. *In situ* approaches such as ion microprobe and laser ablation are important but cannot yet attain the part per thousand age precision that is routine with isotope dilution (ID). ID is however laborious because of the requirement for maintaining ultra-clean bombs and processing environments. Secondary Pb loss is the most important problem with ID analysis of zircon but has been solved for most samples using the chemical abrasion (CA) treatment. A second problem is avoiding inheritance, which can still only be done with total assurance using *in situ* methods.

Because U-Pb contains a double decay, age information is over-determined meaning that full analysis gives a criterion for closed system behavior (concordance) as well as an age or, assuming concordance, U measurements can be dispensed with. This is generally only practical in the Precambrian, because the depletion of relatively short-lived ^{235}U in more recent times means that only $^{206}Pb/^{238}U$ ages can furnish precise age information. Precambrian ID ages are determined almost entirely using $^{207}Pb/^{206}Pb$ ratios because these can generally be measured more accurately than $^{206}Pb/^{238}U$ ratios. Because U/Pb proportional errors increase only slowly with decreasing age, absolute errors can be quite low for Mesozoic and younger ages, approaching the age of a magma chamber (<100 Ka), whereas Pb/Pb errors much less than ±1 Ma are unusual for Precambrian samples, a limit that is largely set by uncertainty in Pb fractionation during analysis.

The ability to rely only on $^{207}Pb/^{206}Pb$ ratios means that ID is not inherently necessary for dating older samples. This provides an opportunity to obtain far better precision using less laborious methods than are necessary for younger time scale work. This potential has only received limited attention, largely through use of the Kober Pb evaporation method. A number of alternative approaches will be presented including extensions of Kober method with double-Pb spike, thermal extraction of Pb from zircon into silica melt, and micro-flux fusion methods on the filament. While these can produce sub-Ma precision with less effort than conventional ID, they each have their own problems. The ultimate method would provide the ability to continuously extract Pb vapour from zircon with simultaneous analysis of its isotopic composition. Several possible approaches to this will be discussed. **(*SS17, Wed. 8:00*)**

Precambrian plate tectonics - a thermodynamic perspective

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The ultimate goal of geochronology is to understand how Earth works. Arthur Holmes was dedicated to this effort and, in addition to pioneering geochronology, he was among the first to suggest a viable mechanism for plate tectonics. It is now sixty years since the development of methods for reasonably accurate dating on a wide variety of rocks. Data accumulated over this period have consistently shown a distribution of magmatic ages over geologic time characterized by peaks and gaps in activity. This pattern has generally been ascribed to amalgamation and breakup of supercontinents but it is not clear that this explains episodicity in arc magmatism.

Continuous plate tectonics occurs at present because the mantle potential temperature is low enough that oceanic lithosphere produced at ridges cools to the point where it can subduct on a time scale shorter than required for global-scale spreading. This is only the case over a limited temperature range. Modest increases in mantle temperature result in substantial increases in the depth of partial melting producing thicker low density crust and melt residue, which requires more time to develop a lithospheric density inversion. The early Hadean crust is likely to have been derived from solidification of the last melt fraction of a magma ocean and contained most of the incompatible heat producing elements presently sequestered in continental crust. It may have required the entire span of the Hadean eon to cool a thick and dense enough lithosphere to allow subduction. Once subduction began, this crust would have completely recycled into the mantle, accounting for the lack of an extensive Hadean rock record. Subduction would only have lasted long enough to remove dense older lithosphere and replace it by thick buoyant crust with mantle lithosphere requiring long periods to thicken by conductive cooling. This suggests that ancient plate tectonics was episodic with periods of subduction during which mantle cooling was rapid separated by periods characterized by a stagnant lid regime during which cooling was governed by the slow decay of radioactive elements.

The period of largest production of juvenile felsic crust was around 2.7 Ga and is the first to show clear evidence for large-scale plate interactions. The subsequent Proterozoic igneous record suggests that magmatism continued to be episodic with at least three major gaps in activity. If this is due to episodic plate tectonics, the continuous Wilson cycle may be a unique feature of the Phanerozoic eon. **(*SS17, Wed. 3:00*)**

Keynote (40 min): Fracture-controlled hydrothermal alteration at the Canadian Malartic deposit: Toward a multiphase model for Archean intrusion-related low-grade bulk tonnage gold deposits

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The Canadian Malartic gold deposit (P&P reserves 10.1Moz, 311Mt@1.01 g/t) is hosted by subvertical clastic metasedimentary rocks of the Pontiac Goup and ≤2678 Ma sub-alkaline to transitional, fine- to medium-grained porphyritic monzodiorite located immediately south of the Larder-Lake–Cadillac Fault Zone. The main cleavage (S_2) in the Pontiac Group is NW-striking and axial-planar to F_2 folds. Ore zones are dominantly oriented sub-parallel to S_2 and to the E-W-striking Sladen Fault. Ore minerals comprise pyrite+native gold+tellurides with traces of sphalerite+chalcopyrite+galena and molybdenite that yielded a Re-Os age of *ca.* 2664 Ma. The assemblage Bi-Te-W-S-Ag±Pb±Mo defines the bulk metallic signature of the ore. Monzodiorite in the footwall of the Sladen Fault shows an early distal alteration consisting of a reddish-coloured calcite+hematite+biotite±pyrite assemblage associated with quartz+pyrite+galena+biotite veins. This assemblage is overprinted by proximal pink- to greyish-coloured replacement zones comprising microcline+carbonate+albite+rutile±biotite. These alterations show K_2O, CO_2, and S progressive mass gains in the distal to proximal assemblages. Mineralized coarse-grained "pegmatitic" quartz-carbonate-feldspar-biotite-muscovite-tourmaline-scheelite veins, also present in the greywacke, are locally superimposed on these alteration assemblages. In the hanging-wall of the Sladen fault and along NW-SE ore zones, the greywacke shows distal, dark pervasive calcite-biotite alteration and proximal, light-colored albite-microcline-quartz-pyrite±biotite±calcite alteration assemblages. These occur as bedding- and shear zone-controlled replacement zones, and as thin selvages of quartz-calcite-biotite veinlets. NW-SE-oriented mineralized shear zones and veinlets are preferentially developed in the hinge zone and faulted short limbs of F_2 folds. The distribution and composition of alteration assemblages in the sedimentary rocks is strongly influenced by protolith composition and competence contrasts (greywacke/mudrock). Nevertheless, these alterations show Na_2O, CO_2 and S show consistent gain, whereas K_2O is characterized by variable gain/loss behaviour. Laminated quartz-pyrite-galena veins and breccia with visible gold are locally overprint these earlier alterations. Biotite in the mineralized alteration zones in the greywacke and monzodiorite is F- and Mg-rich, contrasting with the background biotite, defining hydrothermal and exploration vectors. This study reveals that the deposit resulted of the superposition of hydrothermal and structural events including a ≤2678 Ma syn-Timiskaming magmatic-hydrothermal phase of mineralization inferred by the Bi-Te-W-S-Ag±Pb±Mo metallic signature, the presence of mineralized stockworks, and potassic alteration (biotite/microcline). This magmatic-hydrothermal phase shares analogies with Archean oxidized syenite porphyry-associated disseminated gold deposits. However, at least part of the mineralization (or remobilization) and its actual distribution and geometry are controlled by a syn-D_2 event, as indicated by the nature and chronology of alteration/deformation and the *ca.* 2664 Re-Os molybdenite age. **(*SY5, Wed. 2:00*)**

Magnetite paragenesis associated to IOCG systems, Great Bear Magmatic Zone, Canada

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Magnetite is a minor to major constituent of veins, breccias and incipient to intense alteration in iron oxide-copper gold systems of the Great Bear magmatic zone, Northwest Territories. Prevalence of magnetite in most of the known IOCG systems makes it a key mineral to understand and monitor their evolution and development. Multiple magnetite paragenesis associated with numerous textures are observed in these magmatic/hydrothermal systems that are able, through metasomatism processes, to completely modify the chemistry of precursor rocks. Macroscopic and microscopic observation of magnetite-bearing paragenesis is used to understand the processes that have generated the spectrum of textures observed. Mineral assemblages and associated textures can be used as exploration vectors to mineralized zones so distinctions between different paragenesis are essential in the comprehension of IOCG systems.

Prevailing paragenesis consists of 1) magnetite (Fe alteration), 2) amphibole-magnetite ± apatite ± albite (high temperature Ca-Fe±Na alteration), 3) K-feldspar-magnetite ± biotite or biotite-magnetite (high temperature K-Fe alteration), with common overprint by hematite. Replacements and veins of transitional high temperature Ca-K-Fe and subsequent high temperature K-Fe alteration are commonly followed by the mineralization stage, in which a wide variety of metal can be concentrated (*e.g.* Cu, Au, Ag, Bi, Co, *etc.*). In volcanic rocks, magnetite replacement is preferentially formed around phenocrysts, within vesicules and in groundmass. In bedded or layered rocks, magnetite alteration can form selective stratabound replacements of specific horizons. These habits suggest that magnetite replacement forms by metasomatism where fluids circulate through porous and permeable rocks and/or minerals. Each type of paragenesis and textures exert a control on the aspect that will take subsequent alteration. As an example, amphibole-magnetite alteration forms veins that cross-cut albitized volcanic rocks and replaces metasedimentary rocks. Magnetite also crystallizes as breccia cement or fills veins. Microprobe analysis performed on magnetite from different paragenesis (mineralized and barren) show that concentration of traces elements varies through the evolution of the hydrothermal system. Moreover, concentration of traces elements is distinct between hydrothermal and magmatic/volcanic magnetite and from mineralized and barren paragenesis. Discriminant diagram has been developed to separate different paragenesis and mineralized ones. Ultimately, the main objective of the project is to produce an atlas of alteration associated to IOCG systems and a discriminant diagram based on the chemistry of magnetite that will provide exploration tools and a framework for geologists during the exploration of under-explored terranes. **(*SS20, Wed. 10:20*)**

Keynote (40 min): Archean crust formation in cool exosphere

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Speculations about climate variability on our young Earth are based on models that trade-off elevated concentrations of greenhouse gasses against lower solar radiation from a *ca.* 23% fainter sun; as well as on geological observations that imply surface water on our planet as far back as 3.8 Ga (and possibly 4.3-4.4 Ga), and a temperature range of this hydrosphere that is in dispute. Some temperature estimates of surface water range between *ca.* 40° to 80°C, primarily based on stable isotope proxies measured on early Archean cherts. Others suggest that the temperatures of the atmosphere and oceans (exosphere) were relatively cool at *ca.* 2.8 and 3.5 Ga based on diamictites with drop-stones that resemble glacial deposits. Archean climate reconstruction is therefore controversial. The Barberton Greenstone Belt, South Africa contains at least two unrelated hydrothermal systems: 1) 3.47 Ga deep water fossil hydrothermal fields with silica-fuchsite pipes that formed at about 200°C on seafloor *ca.* 2 km below sea-level, followed by discontinuous waning hydrothermal activity whilst the ocean floor cooled and deepened to *ca.* 4 km over *ca.* 5 Myrs; 2) 3.46-3.32 Shallow water hydrothermal fields in island arc settings dominated by hydrothermal systems at temperatures ranging between 40° to 270°C in water depths less than 70 m, and in places terrestrial. Thus oxygen isotope values on regional cherts can be interpreted as either reflecting hot exosphere or hot springs. Independent field observations of sub-aerial diamictites; and authigenic gypsum abyssal muds formed at relative low latitudes (20-40°; based on paleomagnetism) suggest that the temperature of the exosphere was relatively cool *ca.* 3.4-3.5 Ga, and again around 2.8-2.9 Ga. This suggests that Archean surface temperatures and climate fluctuations were comparable with those of more recent times. The absence of an overall warming trend despite increase in solar heating implies a broadly stable climate for near 4 Gyrs that can only result from concurrent biochemical cooling. **(*SY3, Thurs. 10:20*)**

Emerging sustainability issues in the Mines & Minerals sector in India

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The mineral sector is the key driver for the country's industrial growth. However, it has brought in its wake severe environmental repercussions and social conflicts in recent years in India. After sticking to an average growth rate of 4.8% between 2006-2011, the sector has witnessed negative growth of 0.6% for the next two consecutive years. Mining projects, mainly of iron ores and bauxite, have remained stalled across the country owing to legal, regulatory, environmental and land acquisition issues as well as Naxalite violence in pockets along the "Red Corridor". While in the states of Odisha, Andhra Pradesh and Chattisgarh, which contribute the highest to the mining sector and through which the Red Corridor runs, the population has remained very backward with low values of Human Development Index (HDI), the situation is quite different in states like Goa and Karnataka, where HDI is much higher, but mining is fraught with several other issues.

The Korean steel producer, POSCO, proposed to set up a 12 Mt steel SEZ with an investment of $12 billion, the largest FDI project, at Jagatsinghpur in 2005 spreading over 4004 acres, but scaled down to 8 Mt and 2700 acres in 2012 due to the Odisha Government's inability to acquire the required land. The project is held up over the last 8 years due to delays in various environmental clearances and local communities' severe resistance to land acquisition. The Indian Government has recently turned down the UK-based Vedanta Resources' proposal to mine the 70 Mt reserve of bauxite in the Niyamgiri hills in Odisha to feed its Rs.50 billion Lanjigarh aluminium refinery. It was based on the decision of 12 village councils across Raygara and Kalahandi districts to protect the sacred hills of the threatened Dongria Kondh and Kutia tribes in terms of their social, cultural and religious rights. In the states of Karnataka (Tumkur, Chitradurga and Bellary districts) and Goa, the Supreme Court recently banned iron ore mining due to widespread illegal extraction which caused irreversible damage to the environment (Bellary having lost 45% of its green cover), affected village communities and public health, and brought huge revenue losses (Rs 160 billion in Karnataka) to the state exchequer. Thus the greatest challenges facing the mining sector in contemporary India is how to make mining environmentally and socially acceptable as well as viable in terms of intra- and inter-generational equity and the political economy of natural resources. **(*SS10, Wed. 10:20*)**

The use of shock data to define the transient cavity of a simple impact crater

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Two drill holes, each ~1065 m deep, that penetrate the centre of the 3.8 km-diameter Brent simple impact structure, Canada, provide constraints on the original shape of its transient crater. The distribution of shock metamorphic effects within breccias underlying its deep lens of impact melt rocks indicate that the transient cavity profile was hyperbolic not parabolic, as has generally been assumed; this interpretation is supported by Chappelow's recent work observing small, pristine lunar impact craters by oblique illumination.

Core from the two holes comprise post-impact sediments overlying 560m of late-stage collapse breccias covering the floor of the transient crater, beneath which each has a similar relatively undisturbed sequence forming the crater lining and autochthonous basement. The melt lens preserves traces of the projectile, an underlying ~15m thick hornfelsed breccia comprising strongly shocked and partly recrystallized clasts, then ~50 m of fine grained clastic breccia with clasts recording diminishing levels of shock metamorphism overlying fractured, locally brecciated, country rocks with rare shatter cones.

The melt zone is ~42 m thick in the central hole, but only sporadically present over ~3m in the other hole, 200 m towards the rim. Significantly, the underlying breccias in the central hole are ~50m deeper than their equivalents in the rim-ward hole. The average apparent shock attenuation rate recorded beneath the melt in the central hole is -60 to -35 until the level where shock is between 10 and 5 GPa; the rate then drops abruptly to about -7. A more marked change is observed in the other hole. In both, the abrupt change coincides with the transition from breccia to fracturing, which is taken as the base of the "true" crater. The ~50m difference in the depth of this fragmentation limit over a lateral distance of 200 m can be modelled as a parabola with a focus about 200 m above the base, in contrast to a parabolic focus ~500 m above the base determined by restoring slumped material to the cavity walls. These two sets of data can be reconciled if it is accepted that the transient cavity was hyperbolic in profile, with an eccentricity of about 1.5 like small lunar craters, and, at Brent, a hyperbolic focus about 100 m above the "true" base, placing it within the melt zone. The result highlights differences between impact and explosion craters which has direct implications for the modeling and understanding of impact cratering processes. **(*SS21, Thurs. 10:40*)**

Detection of deeply buried uranium deposits using radon gas: A case study in the Athabasca Basin

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The Athabasca Basin, Saskatchewan, hosts Proterozoic age world-class high-grade uranium deposits and many occur along the unconformity between the crystalline basement and Athabasca sandstones. The unconformity is at shallow depths in the eastern part of the Athabasca Basin (500 m), but it is at deeper levels (<1.5 km) towards the center of the Basin. Many of these deposits occur below thick sandstones and overburden up to 900 m deep which poses a challenge in finding deposits. This study examines the behavior of radon (Rn) dissolved in groundwater at Cameco's Millennium deposit: a high-grade (~4-5 % U_3O_8), basement-hosted uranium deposit, which has 68.2 M lbs (indicated resource) and 22.3 M lbs (inferred resource) U_3O_8 at a depth of approximately 750 m. In August 2013, samples (n = 32) of gas dissolved in groundwater were collected from cased and cemented drill holes (n = 11) and shallow monitoring wells (n = 2). Sample locations were chosen based on varying proximity (0 - 700 m) to the surface projection of the deposit. Groundwater shows neutral pH (6.9 - 7.5), low conductivity (134 - 287 µS/cm), low Cl (8 - 11.3 mg/L) and ^3H concentrations (< 8.8 TU). Three different techniques (water, mineral oil extraction, gas diffusion sampler) were employed to measure the specific activity of dissolved Rn and they yielded similar results. Turbidity of water and colour appear to not affect the counting efficiency of Rn with liquid scintillation spectroscopy. All samples in a 1.5 square km area show detectable activities of Rn, varying between 0.8 and 277.6 Bq/L. The highest was observed in DDH CX-40, directly above the deposit and the lowest was in DDH CX-44, approximately 300 m from the surface projection of the deposit and upslope of groundwater flow. A depth profile from 10 m - 50 m of DDH CX-40 shows Rn concentration is highest at 10 m below surface (278 Bq/L), and lowest at 30 m (189 Bq/L). The contents of U increase from 1.7 ppb at 10 m depth to 46 ppb at 50 m, suggesting that U is not causing the increase in Rn at shallow depth. The variation in Rn activities does not correlate with other parameters of water such as pH, conductivity, and halogen contents. This study indicates that the measurement of Rn provides information useful in exploring for deeply buried uranium deposits. *CMIC-NSERC Exploration Footprints Network Contribution 025.* **(*SS7, Wed. 10:20*)**

Preliminary field and petrographic study of the leucogranite within the Norumbega fault zone in The Horseback quadrangle, Maine

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Recent mapping in The Horseback 7.5' quadrangle has revealed that the "Passagassawakeag Gneiss" shown on the current Maine bedrock geologic map is composed predominantly of mylonitized leucogranite dikes and garnet-bearing, spangled muscovite quartz schist. The protolith of the schist was greywacke and slate of the Fredericton Trough. Both the leucogranitic mylonite and the schist are products of the early Norumbega ductile shearing. The leucogranite is composed of quartz, plagioclase, and K-spar with minor muscovite and biotite. It occurs as multiple phases of medium-grained and pegmatitic dikes that are intruded in the metasedimentary rocks and that contain abundant metasedimentary xenoliths. Outcrop-scale, pervasive diking within the metasedimentary rocks demonstrates a migmatic appearance along with local assimilation. Based on structural fabrics the leucogranite could be either pre-ductile shearing or syn-ductile shearing. In the more favorable syn-ductile shearing model, the ductile shearing could either facilitate ascent of leucogranitic magmas produced at depth or generate leucogranitic magmas by anatexis of metapelite due to elevated geotherms caused by "shear heating". **(*GS2, Poster*)**

Sulfur geochemistry in black shales and iron-formations, Temagami, ON

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The 2.72 Ga Temagami Algoma-type banded iron-formation (BIF) has been extensively mined for iron ore in the 1970s and 80s and has been the subject of numerous studies that improve our understanding of Archean iron formation and the development of marine and atmospheric redox conditions. A combined mapping and multiple sulfur isotope study of the BIF and associated black shales reveals atmospheric sulfur as a major sulfur source in both lithologies. This contradicts the traditional interpretation of a juvenile sulfur source as an explanation for sulfide-$\delta^{34}S$ values in the Temagami BIF (varying around 0‰). Multiple sulfur isotope results in coeval black shales and BIF as well as $\delta^{34}S$ *vs.* $\Delta^{33}S$, argue against hydrothermally recycled marine sulfate as the dominant sulfur source, whereas studies of Archean VMS deposits of similar age indicate variable input of recycled, mass-independently fractionated (MIF) seawater sulfate in the sulfur budget of the hydrothermal system. These findings are consistent with very limited mobility of sulfur entering the water column from seafloor vents responsible for BIF and deposition of iron distal from the hydrothermal source. This coherence may allow to develop multiple sulfur isotopes into a useful indicator of proximity to hydrothermal vent sources. The multiple sulfur isotope results also inform the oxidation pathways for Fe^{2+} to Fe^{3+}, thought to be fundamental in the formation of BIF. A loss of the MIF-sulfur signal would be expected if a process capable of oxidizing reduced sulfur along with ferrous iron was the major pathway for BIF formation. Metal enrichment in coeval black shale units by hydrothermal fluids would have been accompanied by a sulfide input, but this was not found, requiring a different process to explain metal enrichment in these rocks. **(*SS2, Wed. 8:20*)**

Ichnofabrics in a meander loop: Control factors and environmental implications

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Ichnofaunas recorded in meandering channels show a heterogeneous distribution, ranging from sparse bioturbation preserved in point bar deposits to intense bioturbation in deposits of overbank areas. This spatial heterogeneity reflects a variety of processes taking place in a meander loop and controlling the colonization window. Assessing the links between ichnofabric distribution and stratal architecture allows inferring depositional processes, detecting subtle stratigraphic gaps and evaluating paleoenvironmental controls. In this work we use the ichnofabric approach to study the tide-influenced meandering channels recorded in Upper Cretaceous deposits of the Tremp Formation (South-Central Pyrenees, Spain) with the purpose to better understand the ichnology and the dynamic of a tide-influenced meander loop.

The studied deposits are constituted by hybrid components (carbonate and siliciclastic) and are grouped in overbank facies and interbedded point bar deposits with inclined heterolithic stratification (IHS). The ichnofauna shows low diversity but typically high, albeit irregularly distributed, abundance. Eight ichnofabrics have been identified which, based on their distribution are grouped in three associations: ichnofabrics of lower IHS point bars (IA1), ichnofabrics of upper structureless point bars (IA2) and ichnofabrics of overbank (IA3). The eight ichnofabrics identified differ from each other in the bioturbation index (higher in IA2 and IA3), preservation of primary sedimentary fabric (typically preserved in IA1), inferred behaviour (common dominance of dwelling structures in IA1 and feeding structures in IA2 and IA3), substrate penetration, ichnotaxonomic composition, presence or absence of root traces and/or mottling, and the number of superimposed suites. Moreover, the colonization windows inferred from the ichnofabric analysis differ in both duration (long-short) and frequency (episodic-continuous).

The deduced environmental factors intrinsic to the tide-influenced meander loop that control the development of the ichnofabrics are: a) geometry of the colonization window or lateral accretion surface of the point bars, b) helicoidal flow, c) water level change (tidal or/and fluvial discharge-controlled), d) time (taphonomic pathways during meander loop development), and e) salinity fluctuations. In addition, early diagenesis (shallow dissolution and/or cementation processes) can be a determinant environmental factor related with the hybrid nature of the deposits. Some environmental implications inferred for the tide-influenced meandering channels of the Tremp Formation are: dominant subaqueous conditions in both the upper part of adjoined point bars and overbank areas, water level oscillation in the upper point bar and early cementation. **(*SS18, Thurs. 9:20*)**

The "chessboard" classification scheme of mineral deposits - A tool for application, research and training in geosciences

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Economic geology is a "*mixtum compositum*" of all geoscientific disciplines focused on one goal, finding new mineral deposits and enhancing their exploitation. The keystones of this "*mixtum compositum*" are geology and mineralogy whose studies are centered on the emplacement of the ore body and the development of its minerals and rocks. In the present study, mineralogy and geology act as x- and y-coordinates of a classification chart of mineral resources called the "chessboard" (or "spreadsheet") classification scheme. Magmatic and sedimentary lithologies together with tectonic structures (1-D / pipes, 2-D/ veins) are plotted along the x-axis in the header of the diagram representing the columns in this chart diagram. 63 commodity groups, encompassing minerals and elements are plotted along the y-axis, forming the lines of the spreadsheet. These commodities are subjected to a tripartite subdivision into ore minerals, industrial minerals and gemstones/ ornamental stones. Further information on the various types of mineral deposits, as to the major ore and gangue minerals, current models and mode of formation or when and in which geodynamic setting these deposits mainly formed throughout the geological past may be obtained from the text by simply using the code of each deposit in the chart. This code can be created by combining the commodity (lines) shown by numbers plus lower caps with the host rocks or structure (columns) given by capital letters. Each commodity has a small preface on the mineralogy and chemistry and ends up with an outlook into its final use and the supply situation of the raw material on a global basis, which may be updated by the user through a direct link to databases available on the internet, *e.g.*, the database of the US Geological Survey. The internal subdivision of each commodity section corresponds to the common host rock lithologies (magmatic, sedimentary, metamorphic) and structures. Cross sections and images illustrate the common ore types of each commodity. Ore is given priority over the minerals. The minerals are listed by their chemical composition and may be viewed by the reader by clicking on-line the pertinent databases, where the "showroom" varieties, seldom found in a mine, are on display. A metallogenetic-geodynamic overview is given at the bottom of each column in the spreadsheet. It is the "sum" and "mean" of geodynamic models and ideas put forward by the various researchers for all the deposits pertaining to a certain clan of lithology or structure. This classical or conservative view of metallotects related to the common plate tectonic settings is supplemented by an approach taken for the first time for such a number of deposits, using the concepts of sequence stratigraphy. This paper, so as to say, is a "launch pad" for a new mindset in metallogenesis rather than the final result. **(*GS5, Poster*)**

Keynote (40 min): Orecretes linking geosciences and life sciences

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The study of supergene mineralizations encountered in the field as metalliferous encrustations or orecretes is more than a distinction of true and false gossans. Orecretes develop on or near the earth surface in the oxidized zone. They include oxicretes (oxide plus hydrate), carbocretes (carbonate), silicacretes (silica), halcretes (halogenides: Cl, J, F, and Br), sulcretes (sulfate plus APS minerals/ aluminum phosphate sulfate minerals), phoscretes (phosphates), arsenocretes (arsenates), vanadocretes (vanadates) and some rare species accommodating Mo, Cr and Se in the anion complex. Orecretes may contain Pb, Cu, Zn, In, Fe, Mn, Ni, Co, W, REE, U, and Ag, as qualifier, that are added as a suffix to the afore-mentioned terms, *e.g.*, carbocretes-Cu containing malachite and azurite or vanadocretes-U made up of carnotite, tyuyamunite or francevillite. The varied spectrum of supergene minerals form(ed) under near-ambient conditions at the interface of different spheres on the globe: Atmosphere, biosphere, lithosphere, pedosphere, hydrosphere. There is a catena from geogene to anthropogenic orecretes with supergene oxidized minerals bridging the gap between geosciences and life sciences. At one end of the "metalliferous supergene catena", the gossans, also called "chapeau de fer", "Eiserner Hut", "canga" or in case of *e.g.* Zn termed "calamine", attract the attention of exploration geologists in search of ore deposits (applied) or of geoscientists studying the supergene alteration of mineral deposits (genetic economic geology). Anthropogenic mining residues (post-mining mineral assemblages) resulted from descending meteoric waters in galleries and opencasts. Effervescence is triggered there by ventilation and the exposure of minerals to the subaerial processes. Well-crystallized chemical compounds (minerals) cover the stopes. They may be used to determine the most recent physical-chemical regime and chronological constrain (radiocarbon-dating) and trace back these ocrecretes to the Bronze Age in Greece, Cyprus and the Middle East, using Cu humate-oxalates. Mineralogical, geochemical and microbiological processes in the tailings ponds (*e.g.* Matchless, Namibia, produce(d) sulcretes, halcretes and phoscretes. The slag heaps in Germany and pyrometallurgical remains of Cu-enriched VMS deposits, Cyprus, have been covered with sulcretes since 1600 AC and the Chalcolithic Age. Archeometallurgy is not the end of the catena. In places, the mining residues were not only exposed to the atmospheric processes but also to man-made physical-chemical processes such as blazes in the miners´ settlements. These artificial processes gave rise to mixed sulcrete-phoscretes or pure phoscrete-bearing aggregates. Supergene alteration is controlled by the parent material, the landforms (geology *vs.* geomorphology) and the (paleo)climate. More than 80 sites of supergene mineralization around the globe, covering all morphoclimatic zones from the periglacial through the humid tropical zones have been studied to tackle the issue to what extent nature and man have contributed to the built-up of orecretes. **(*SY4, Wed. 8:00*)**

Keynote (40 min): The built-up and alteration of pegmatites in the Central European Pegmatite Province – Exploration tools from geodynamics to weathering

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Pegmatites are among the most looked-for target areas when it comes to the exploitation of rare elements (*e.g.* Li, Nb-Ta, Be, Sn), ceramic raw materials (*e.g.* feldspar, kaolin, quartz) and gemstones (*e.g.* topaz, tourmaline). Their metallogenetic evolution throughout the Variscan orogeny in Central Europe is typical of an ensialic mobile belt with subfluence rather than subduction, leading from an initial stage of rifting into a collisional stage. Plate convergence gave rise to a complex subhorizontal thrustal movements followed by the intrusion of felsic magmatic bodies during the late Paleozoic, all of which resulted in a series of pegmatites, metapegmatites, and pegmatoids. The pegmatitic rocks are located in Upper Proterozoic country rocks amphibolites, metabiolites, marbles, and calcsilicates, forming part of the Moldanubian core zone, with the largest bodies located in the Hagendorf-Pleystein-Pegmatite Province. The estimated P–T conditions in the meta-psammopelitic rocks are compatible with those of the low-P facies series, considering the prevalence of cordierite in medium-grade schists (temperature: approx. 650°C, pressure: 3 to 4 kbar). During the early pegmatitic stage (302.1±3.3 Ma), columbite-(Fe), Mn apatite, triplite, wolfeite, triploidite, and monazite are associated with Zr-Sc phosphate-silicates and K-Sc-Zr-Ba phosphate (Hagendorf, Waidhaus, Pleystein). There is little or no zonation as to the feldspar-quartz distribution and the aplites and pegmatites are held to be emplaced by a single-stage process. The quartz aplites and quartz dykes contain aggregates with rutile-ilmenite intergrowths ("nigrine"). In the rose quartz pegmatite at Pleystein apart from the Fe-Mn phosphates common to all aplites and phosphates of the Hagendorf pegmatite province, a Ti-Zn-Bi phosphate mineralization composed of benyacarite, parahopeite, schoonerite and xemingite was detected. The stocklike feldspar-quartz pegmatites exploited at Hagendorf North and Hagendorf South among others mined for the Li phosphate triphylite were emplaced around 299.6±1.9 Ma. The hydrothermal/ epithermal stage brought about a group of variegated Fe-Mn-Ca-Zn-Sc-Li phosphates which evolved in the various aplitic mobilizates and pegmatite plugs from the primary phosphates under hydrothermal conditions (< 200°C) and strongly fluctuating redox conditions. Primary Sc phosphates sparked the formation of kolbeckite; Li phosphates gave rise to ferrosicklerite and tavoite. Opposed to the zonation where mineral assemblages in pegmatites and aplites are separated in space and time, these minerals developed side-by-side at low temperature and by a hydrothermal system emplaced at shallow depths of less than1 km similar to what is called an epithermal system. The epithermal phosphate mineralization is post-Coniacian in age and bridges the gap between hypogene and supergene mineralization. The presence of autunite and torbernite accompanied by wavellite, beraunite, cacoxenite, churchite and kaolinite allow for a precise determination of the supergene alteration at 4.55±0.02 Ma, when a subtropical weathering on a vast peneplain similar to modern-day morphoclimatic zones in Central Africa was at full swing. The geomorphological and sedimentological Cenozoic evolution controls the unroofing of the pegmatites and provides a tool for the exploration of this type of pegmatites using placer-type accumulations of "nigrine" in the alluvial-fluvial drainage system. Alluvial-fluvial Ti ("nigrine") and Sn (cassiterite) accumulations may help to reconstruct that part of the pegmatite being unroofed. Inclusions in "nigrine" (*e.g.*, columbite, pyrochlore, aeschynite, and pseudobrookite) may help draw picture of the apical parts of the pegmatites, while twinned cassiterite aggregates abundant in "internal sediments", *e.g.*, plumbogummite, florencite, goyazite are of assistance when it comes to the description of the chemical weathering during the late Mesozoic and Cenozoic. Both heavy minerals may be used as an ore guide to pegmatites/aplites which in general are poor in minerals stable under pervasive chemical weathering and hence suitable for placer deposits that can be used for stream sediment exploration. **(*SS25, Thurs. 2:00*)**

Geology of the Eastern Ultramafic North Lac des Iles intrusion of the Lac des Iles Complex, Ontario

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The Lac des Iles Complex comprises the mafic Mine Block Intrusion (MBI), South Lac des Iles Intrusion, Camp Lake Intrusion and the ultramafic North Lac des Iles Intrusion (NLDI-I). Although the MBI has been extensively studied due to Pd-Pt mining over two decades, little is known about the other intrusions and their PGE occurrences. Previous work identified two distinct circular intrusive centers within the NLDI-I; the Northern Ultramafic Center (NUC) and the Southern Ultramafic Center. North American Palladium's integration of historical geological data with recent geophysical surveys indicates NLDI-I is a multi-phase intrusive complex composed of more than five nested intrusions. This study, focused on the eastern flank of the NUC, has identified a series of shallow to steeply dipping funnel-shaped intrusions within tonalitic country rock. NUC exhibits much fewer penetrative deformation features than observed in the MBI and is cut by gabbro and granodiorite dykes. NUC is broadly composed of basal gabbro overlain by a lower-pyroxenite dominant zone and upper peridotite-dominant zone. Pyroxenite and peridotite zones comprise alternating layers of variable thicknesses of fine grained chrome-spinel bearing serpentinized peridotite and clinopyroxene-rich websterite with minor gabbronorite and dunite. Contact transitions between serpentinized peridotite and clinopyroxene-rich websterite layers are either thin (< 10cm) or thick (rarely up to 1m) and are fine grained olivine websterite. Downhole mineral chemical variations depict both normal and inverse variation trends. Olivine relicts have a composition which range from Fo_{75} to Fo_{90} with NiO contents varying between 0.2 and 0.3 wt %. Orthopyroxene compositions range from En_{74} to En_{86} and parallel the evolution of clinopyroxenes. Clinopyroxenes are dominantly Ca-rich augite and show Mg-numbers ranging from 92 to 79, much higher than in orthopyroxenes (from 77 to 62). Chrome-spinels have Cr_2O_3 ranges from 25 to 45 wt % and show a wide range of Cr:Fe ratios (from 0.6 to 1.3). Mineral chemistry variations and geologic data indicate that NUC has undergone a complex history of magma emplacement under dynamic and open system conditions. **(*SS24, Thurs. 4:00*)**

Detrital zircon geochronology of the Fredericton Trough, New Brunswick: Constraints on the Silurian closure of a remnant of the Iapetus Ocean

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The Fredericton Trough cover succession, in the Appalachians of southwestern New Brunswick, consists of the Silurian Kingsclear Group, and lies between the Ganderian St. Croix and Miramichi terranes, which represent crust rifted from Amazonia on the margin of the Iapetus Ocean. South of the Fredericton Fault, which bisects the trough, the Kingsclear Group unconformably overlies the Kendall Mountain Formation of the St. Croix terrane, interpreted to have been deposited on the Ganderian passive margin of the Tetagouche-Exploits backarc basin. To the north of the Fredericton Fault, the Kingsclear Group is in faulted contact with rocks of the Miramichi terrane, including the Brunswick subduction complex. The Fredericton Trough has thus been interpreted to represent a marine foredeep formed during Salinic orogenesis, filling as the Tetagouche-Exploits seaway closed to bring together northern and southern components of Ganderia. Detrital zircon samples were collected, where possible, from known fossil localities in four formations of the Kingsclear Group for U-Pb dating by LA-ICP-MS.

South of the Fredericton Fault, detrital zircon populations in the early Llandovery Digdeguash Formation include a prominent statistical peak in the late Neoproterozoic – typical of peri-Gondwanan detritus – with a minor peak in the Paleozoic, and a small proportion of zircons in the 1.0 to 1.9 Ga range. The overlying late Llandovery to Wenlock Flume Ridge Formation shows a strong peak in the Paleozoic, and an asymmetric peak at 1.0 Ga with a tail of older Proterozoic zircons, indicative of Laurentian input. North of the Fredericton fault, the early Llandovery Hayes Brook Formation shows a dominant peak in the Paleozoic, and a peak at 1.0 Ga with a range of Proterozoic zircons (*ca.* 1.0 to 1.8 Ga), similarly consistent with Laurentian provenance. The Burtts Corner Formation, of Wenlock to Ludlow age, has a mixed signature including peaks in the Paleozoic, late Neoproterozoic, and in the Proterozoic (*ca.* 1.0 to 2.2 Ga), suggesting that later input from an uplifted Miramichi terrane added material to the Laurentian sources. Contrasting detrital zircon signatures between synchronous formations suggest a significant role for the Fredericton Fault. To the south of the fault, where the relationship of the Fredericton Trough with underlying Ganderian basement (St. Croix terrane) is exposed, Laurentian detritus is not observed until at least the late Llandovery, indicating that a remnant of the Iapetus Ocean separated Laurentia from southern components of Ganderia until this time. **(*SY1, Wed. 2:20*)**

From Siccar Point to Brimstone Head: Implications of some Silurian-Devonian (?) stratigraphic, structural and intrusive relationships from Fogo Island, Newfoundland

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The northeastern section of the eastern Dunnage Zone in Newfoundland is a key area in understanding the mid-Paleozoic ("Salinic" to "Acadian") tectonic evolution of the Appalachian Orogen. On the Change Islands, previous work recognized an angular unconformity between steeply dipping and cleaved greywackes of the pre-433 Ma Badger Group (Samson Formation) and flat-lying volcanic and pyroclastic rocks of the Botwood Group (Lawrenceton Formation). The latter are now dated in nearby areas at *ca.* 421 to 418 Ma. On nearby Fogo Island, undated shallow-marine sedimentary rocks containing volcanogenic intervals (Fogo Harbour Formation) are traditionally correlated with younger terrestrial sedimentary rocks of the Botwood Group (Wigwam Formation) that elsewhere sit above the Lawrenceton Formation. The Fogo Harbour Formation has always been thought to pass abruptly but conformably into undated felsic ignimbrites and pyroclastic rocks termed the Brimstone Head Formation. The Fogo Harbour Formation is also intruded by both mafic and felsic phases of the bimodal Fogo Island Intrusion, for which sparse U-Pb zircon data indicate an age of *ca.* 420 Ma. The Brimstone Head Formation is largely free of granitic or mafic dykes, but is itself affected by penetrative deformation associated with high-angle reverse faults. Detailed mapping of the boundary between the Fogo Harbour and Brimstone Head formations in the summer of 2013 suggests that it is not conformable and may instead be a subtle angular unconformity. This idea is further supported by the recognition of complex folding and local low-angle structural inversion within the underlying Fogo Harbour Formation.

These findings lead to at least two working hypotheses. The evidence indicates recumbent folding of the Fogo Harbour Formation, followed by eruption and deposition of the Brimstone Head Formation, which is then affected by later deformation. This implies that two important unconformities might exist within a restricted time interval. It is also possible that the Fogo Harbour Formation does not belong to the post-420 Ma Botwood Group, but is instead a previously unrecognized shallow-marine facies of the older Badger Group. In this model, the Brimstone Head formation could sit beneath or adjacent to the Lawrenceton Formation, and both could represent extrusive equivalents of the Fogo Island Intrusion. These hypotheses are readily testable through field work and geochronology, and the confirmation of either (or some other interesting possibilities) should constrain the timing of mid-Paleozoic orogenic events. **(*SY1, Wed. 9:00*)**

Ron under the Sun: Professor Ron Pickerill and the genesis of Antillean ichnology

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Antillean ichnology was essentially a blank book when Ron Pickerill of the University of New Brunswick, Fredericton (UNB), made his first research visit to the University of the West Indies (UWI), Jamaica, in February 1990. This lack of previous studies was not due to any lack of material, but to a dearth of interested bodies. The first Jamaican trace fossil research team, led by Ron, included SKD and the late Hal Dixon. Starting with the Paleogene flysch succession in the east of the island (=Richmond Formation), subsequent fieldwork moved on to examine the diverse sedimentary formations of the Neogene Coastal Group.

Ron's encyclopedic knowledge of ichnotaxonomy and enthusiasm for fieldwork led the Jamaican team in many directions, and our investigations were integrated with new studies of the island's sedimentology and paleontology. One example among many was the description of the ichnology and sedimentology of the Upper Pliocene Bowden Formation, including the internationally famous Bowden shell bed, as part of a much wider study. The mid-Tertiary was largely ignored, because the case-hardened rocks of the White Limestone Group discouraged detailed study until DJB, a UWI graduate who researched his Ph.D. under Ron at UNB, took the bull by the horns and attacked the diverse ichnobiota of these user-unfriendly rocks with gusto.

Carriacou in the Grenadines was the other island to receive detailed study by Ron *et al.* The east coast of this small island provides a near-continuous exposure of the deep water succession of the Grand Bay Formation. This provided a fascinating contrast between deeper water burrows and borings in allochthonous bioclasts derived from the shallow shelf. **(*SS18, Thurs. 8:20*)**

Revisiting the importance of residual material (restite) in granite petrogenesis: The Cardigan Pluton, New Hampshire

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The Cardigan Pluton of New Hampshire exhibits a positive correlation between peraluminosity with maficity, with as much as 8 percent normative corundum in rocks with 53 wt. % SiO_2. No mafic magmas of these compositions exist; the whole-rock compositions reflect high concentrations of garnet. The mafic rocks have higher CaO concentrations than garnet and require the accumulation of plagioclase as well. The presence of melt depleted, restitic garnetites in the pluton that are in isotopic equilibrium with the host rocks provide evidence for the textures and compositions of peritectic garnet and restitic plagioclase that can be compared to garnet and plagioclase in the host rocks. Peritectic garnet is inclusion-rich and has flat chondrite-normalized HREE patterns. The HREE elements incorporated into peritectic garnet were continuously supplied by zircon during the melting process. Once the melt separated from the source, fractionation of zircon and garnet depleted the melt in the HREE and phenocrystic garnet shows a progressive depletion in HREE from cores to rims. Peritectic garnet entrained in the host rocks show the same textural and chemical characteristics as garnet in the garnetites, but is mantled by inclusion-poor, HREE depleted, phenocrystic garnet. Some restitic grains of plagioclase in the garnetites contains needles of rutile and ilmenite. Plagioclase crystals with these same inclusions are also present in the host rocks. Inclusion-bearing plagioclase in both settings have identical Sr, Ba, Eu, Pb, and Ga concentrations, indicating these crystals in the host rock are also restite. Most host plagioclase crystals that lack inclusions have higher Ba concentrations resulting from the fractionation of Ba which was an incompatible element until K-feldspar crystallized; these are phenocrysts. The Cardigan Pluton thus contains both peritectic garnet and restitic plagioclase, the retention of which in variable amounts can account for the whole-rock compositional range of the pluton. If retention of relatively high density peritectic garnet occurs in other granitic plutons, then retention of lower density restitic phases such as plagioclase must occur as well. Hence, peritectic mineral entrainment cannot occur without retention of lower density restitic phases, lending legitimacy to the restite/peritectic phase unmixing model in peraluminous plutons. **(*SS5, Wed. 3:40*)**

The Vault gold deposit, Meadowbank area, Nunavut: Preliminary results on the nature and timing of mineralization

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The Vault deposit (~1.4 Moz Au in reserves and resources) is located about 7 km north of the BIF-hosted Meadowbank world-class gold deposit in Nunavut, in a ~2711 Ma succession that is part of the Woodburn Lake Group. The host succession at Vault consists mainly of highly strained, altered volcaniclastites composed of polymictic blocky (footwall only), lapilli and fine-grained tuffs intercalated with thin BIF layers. The volcaniclastites are divided into suites of intermediate (andesitic), intermediate-felsic (andesitic-dacitic), and less abundant felsic compositions (rhyodacitic to rhyolitic) based on their major and trace elements signature. Quartz and feldspar porphyry dikes intruding the volcaniclastites are present in the ore zone and hanging-wall succession, and their composition is very similar to that of the most fractionated, arc-style calc-alkaline felsic volcaniclastic rocks.

The host rocks are moderately to intensely altered, and rocks from the ore zone are characterized by a tan coloured alteration mostly due to the presence of fine-grained sericite, carbonates (calcite and ankerite), chlorite and local biotite partly retrograded to chlorite. Enrichment in potassium, calcium, iron and magnesium are the main characteristics of the hydrothermal footprint. Felsic rocks close to ore show an albitization trend. The chemistry of carbonates, chlorite, sericite and biotite from ore samples shows a decrease in the Fe# associated with an increase in pyrite abundance. Enrichment in F contents of micas is another example of chemical variations towards gold mineralization. The hydrothermal alteration is largely restricted to the ore zone and hanging-wall rocks, regardless of the geological units.

The main ore zone consists of very fine-grained, disseminated pyrite and partly transposed quartz-carbonate veinlets in a few meters-thick, NE-trending and shallowly ESE-dipping panel of strongly altered and intensely foliated rocks. Preliminary results suggest a complex ore paragenesis with a late-, syn-main deformation pyrite recrystallization event that might have locally remobilized part of the gold. Systematic correlations between alteration mineral assemblages and chemistry, alteration distribution and ore are present, allowing for the development of exploration vectors. The strong contrast between the footwall and hanging-wall successions, the geometry of the ore zone and its location in a high strain zone strongly suggest a genetic relationship between mineralization and high-strain corridors in the area. Although the ore style at Vault strongly contrasts with the predominantly BIF-hosted mineralization at Meadowbank, proximity and similarities in their lithotectonic setting suggest common tectonic and hydrothermal processes in generating these two gold deposits and demonstrate the potential of the area for various styles of syn-deformation gold mineralization. **(*SY5, Poster*)**

Geochemical and isotopic signatures as proxies for source mantle composition in a post-collisional tectonic setting: An example from SW England

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The geology of SW England has long been interpreted to reflect Variscan collisional processes associated with the closure of the Rheic Ocean and the formation of Pangea. The Cornish peninsula is composed largely of Early Devonian to Late Carboniferous volcano-sedimentary successions that were deposited in pre- and syn-collisional basins and were subsequently metamorphosed and deformed during the Variscan orogeny. Voluminous Late Carboniferous granitic magmatism (Cornubian Batholith) is broadly coeval with the emplacement of *ca.* 290-300 Ma lamprophyric dykes, sills and flows. Although these lamprophyres are well mapped and documented, the processes responsible for their genesis and their relationship with regional Variscan tectonic events are less understood.

Syn-rift basalts have intra-continental alkalic affinities, and have REE profiles consistent with derivation from the spinel-garnet lherzolite boundary. εNd values for the basalts range from +0.37 to +5.2 and TDM ages from 595 Ma to 705 Ma. The lamprophyres are extremely enriched in LREE and LILE, and depleted in HREE suggesting a deep, garnet lherzolite source that was previously metasomatised. They display εNd values ranging from -1.4 to +1.4 and TDM ages that from 671 Ma to 1031 Ma, suggesting that metasomatism occurred in the Neoproterozoic.

Lamprophyres and coeval granite batholiths of similar chemistry to those in Cornwall occur in other regions of the Variscan Orogen, including Iberia and Bohemia. By constraining the evolution of the mantle beneath SW England and the processes associated with the formation of these post-collisional rocks, we may be able to gain a more complete understanding of mantle processes during the waning stages of supercontinent formation. **(*SY3, Wed. 9:40*)**

The geomorphological characteristics of a catchment are key in developing forest management strategies to augment or minimize seasonal river-flows

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Canada's population and water demands are increasing with time. In addition there is a growing awareness of climate change and its impacts on our water resources. The adequacy of our water supply (both current and future) is quickly becoming a significant issue in many parts of the country including its forested areas.

Forests are powerful biological agents that significantly alter the amount of precipitation (both rain and snow) that ultimately makes its way into our lakes, rivers and streams. Our forests are also changing both in response to climate and reforestation and afforestation programs. In a forested catchment, river discharge in any season can be either decreased or augmented by appropriate species selection and retention and forest management practice.

Fluvial geomorphologists and forest hydrologists can augment the efficacy of any such strategy in either new plantations or existing forests by identifying and considering the distribution of the key hydrological functions in the catchment. Managing our forests for increased water-yield may become a key adaptive response in some catchments, as we deal with a changing climate. **(*SS22, Thurs. 9:00*)**

High arsenic pyrite associated with the uranium mineralization in the McArthur River deposit, Athabasca Basin, Saskatchewan

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The McArthur River deposit is the largest high grade U deposit in the world. The deposit occurs along the P2 fault near the unconformity between the basement rocks and the Athabasca sandstones. Pyrite is abundant in the basement rocks, especially in graphitic metapelites. The overlying sedimentary rocks contain very minor amounts of pyrite along fractures near the unconformity. Samples were collected from Zone B ore (n=2), metapelites (n=12), pegmatites (n=4) and from sandstones (n=3) along the P2 structure. For comparison, samples far from the ore were also collected such as pelites ~3 km W of the mine. Pyrite in these samples forms fine-disseminations (<0.05 mm), euhedral cubes (<10 mm), isolated grains in clay and monominerallic veinlets and films along late fractures (1-2 mm in width).

Pyrite shows a large range in $\delta^{34}S$; from -30 to +20 ‰ (median=8 ‰, n=10) for disseminated/ euhedral grains in pelites, and from +5 to +40 ‰ (median=10 ‰, n=12) along fractures in pelites. Although the spread is large, the median values are similar. The values close to the ore (< 100 m) are in a narrow range from 0 to +15‰ (median=9 ‰, n=19) which are close the median values for all pyrite. Pyrite in the ore shows an even more restricted range from -1 to + 3‰ (median=1.5‰, n=4), suggesting well mixed source for S and high fluid/rock ratios.

Pyrite far from the mineralization has the stoichiometric composition, whereas pyrite from the ore shows a large compositional variations due to varying concentrations of As (< 4.0 wt%). As-poor pyrite grains are coated and cemented by later As-rich pyrite. As rich pyrite contains ^{206}Pb (<2.0 wt%) indicating that the As rich pyrite formed after uraninite. Contents of As are inversely correlated with those of S, indicating that As is forming AsS dianion in pyrite. It has been known that the U ore contains considerable As, but no As mineral has been found. This study suggests that pyrite is the most likely host of As in the ore. Intragrain compositional variation and zoning of pyrite suggests little recrystallization, if any, after its original deposition. **(*SS24, Poster*)**

Volcanic reconstruction of the productive VMS ore interval in the Paleoproterozoic Chisel sequence, Snow Lake, Manitoba

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The Chisel sequence is a 3 – 5 km thick succession of volcanic rocks that occurs within the Snow Lake arc assemblage of the Paleoproterozoic Trans-Hudson Orogen. It is host to six economic Zn-Pb-Cu-Ag-Au VMS deposits (the Chisel Lake, Lost Lake, Ghost Lake, Chisel North, Photo Lake, and Lalor deposits). With the exception of the Photo Lake deposit, all of the deposits occur at the contact between the Lower Chisel and Upper Chisel sequences. This contact marks a break in voluminous, continuous emplacement of volcaniclastic material. The stratigraphy of the ore interval and its bounding units consists of, in ascending order, the Powderhouse dacite, the Chisel-Ghost (-Photo?) rhyolite, and the Threehouse mafic volcaniclastic rocks. VMS deposits occur at the contact between the Chisel-Ghost rhyolite and Threehouse unit (*e.g.* Chisel Lake deposit) and, where the rhyolite does not occur, at the contact between the Powderhouse dacite and the Threehouse unit (*e.g.* Lost Lake deposit).

Where it is exposed in outcrop at the Chisel Lake and Ghost Lake deposits, the contact between the Upper and Lower Chisel sequences is conformable and defined by a volcaniclastic interval up to 10 m in thickness that represents a transition from felsic to mafic volcanism. At the Lalor Lake deposit, the ore interval is visible in drill core as a pyrrhotite- and biotite-rich, fine-bedded to laminated intermediate tuff that also represents a conformable transition from felsic to mafic volcanism. At a large stripped outcrop approximately 125 m west of the Lost Lake deposit (the Lost Lake outcrop), a sequence of volcaniclastic rocks (~20 m thick) records a period of volcanic quiescence accompanying deposition of volcaniclastic rocks and significant subsidence that is synchronous with the ore interval. Here, synvolcanic faults cut mass flow deposits of tuff, lapilli tuff, and tuff breccia that are intercalated with suspension sedimentation deposits of fine-bedded tuff. Blocks of material from units occurring stratigraphically below and laterally to this outcrop (*e.g.* basalt, felsic tuff, rhyolite, and Powderhouse dacite) indicate that this area represents a depositional basin and that accumulation of volcaniclastic material occurred during ongoing subsidence. The Chisel sequence ore interval thus represents a period following rhyolite dome development during which volcanic quiescence and subsidence were ideal for VMS formation. **(*SS6, Thurs. 9:40*)**

Geologic setting, mineralogy, and geochemistry of the Paleoproterozoic Photo Lake VMS deposit, Snow Lake, Manitoba

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The Photo Lake deposit at Snow Lake, Manitoba, is a Cu-Zn-Au-Ag volcanogenic massive sulfide (VMS) deposit that occurs within the Chisel sequence of the Snow Lake arc assemblage of the Paleoproterozoic Trans-Hudson Orogen. It consists of two stacked massive sulfide lenses; a Cu-rich lens 1 (5.71 wt% Cu) and a Zn-rich lens 2 (10.98 wt% Zn). The Photo Lake deposit differs from most VMS deposits in the Chisel sequence because of its high average Au grade (4.9 g/t at Photo Lake versus 0.4 to 1.8 g/t in the Chisel, Chisel North, Lost and Ghost deposits) and stratigraphic position. While all of the other VMS deposits occur at the contact between the Lower Chisel sequence and Upper Chisel sequence, the Photo Lake deposit has been interpreted to occur within a thick section of coherent rhyolite in the Upper Chisel sequence. This is significant because the Photo Lake horizon may represent a relatively unexplored productive VMS interval. As such, an understanding of the processes responsible for Au enrichment at Photo Lake is critical for further exploration in the area. Field mapping, ore petrography, sulfur and lead isotopes of the ores, and trace element geochemistry of the ores and minerals associated with Au at the Photo Lake deposit are used to determine the processes responsible for Au enrichment.

Gold occurs in mercurian electrum and is associated with magnetite in lens 1 and with gudmundite (FeSbS), galena, and cassiterite in lens 2. At the deposit scale, Au grades exhibit a strong positive correlation with Cu in spite of potential metal remobilization during deformation associated with peak, middle almandine-amphibolite facies, regional metamorphism. This indicates that Au was introduced into the system at the time of chalcopyrite precipitation during the main VMS mineralizing event. This also suggests that Au was dominantly transported as $AuCl^{2-}$ in a high temperature, low pH hydrothermal fluid. Locally, Au exhibits a positive correlation with Zn in lens 2, suggesting that Au was also present in lower temperature hydrothermal fluids and was precipitated throughout the duration of deposit formation. Gold enrichment at Photo Lake may be due to one or a combination of: (1) boiling of the hydrothermal fluid in order to facilitate a large precipitation of gold; (2) an input of magmatic volatiles into the hydrothermal system; and (3) a hydrothermal fluid composition that was favourable for high Au solubility and transport. **(*SS14, Poster*)**

A textural and lithological examination of the Camp 26 Medial Moraine Atlin, British Columbia, Canada

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Bedrock mapping studies in glaciated, high relief terrains typically identify exposed bedrock (nunatak) geology; however, few have determined to what extent bedrock is transported down glacier, or how the clasts are modified by the transportation process. Mapping moraine clast lithology, morphology and distribution in medial moraines will aid in the understanding of the regional bedrock geology of ice covered terrain, and may provide a more logistically accessible medium for study. This project was a reconnaissance survey of the Camp-26 Medial Moraine (C26MM) located in British Columbia on the Juneau Icefield. By mapping the medial moraines on the Juneau Icefield gaps in the regional bedrock geology and the nature of local transport mechanisms can be elucidated. The C26MM was chosen due to the variable regional bedrock geology and it's ease of access. According to previous studies the Camp 26 Nunatak is composed of volcanic, igneous (diabase), and meta-sedimentary rocks. If the clasts are transported significantly far down glacier than they will have little lithological affinity to the nunatak, and they will have experienced significant physical and chemical weathering. Twenty sites were sampled at approximately one hundred meter intervals. Over thirty clasts were analyzed at each site for lithology (diabase, gneiss, granite, greenstone, meta-sedimentary, schist, and volcanics), shape (measurement of long, medium and short axis) and roundness (*ca.* Benn and Ballantyne 1994 classification). Preliminary analysis indicates that as distance increases from the Camp 26 Nunatak lithologies sourced from the nunatak decrease in abundance. As the distance from the nunatak increased clasts on average decreased 11-26% in size (length of the long axis), and became 10-29% more rounded; these trends elucidate data that can be used to estimate clast transport distance. Clast transport curves were created by comparing the distance from the Camp 26 Nunatak and measured clast shape, and roundness. The results of this study provide field estimates of transport distance of clasts, and indicate that medial moraine mapping could be used, in reconnaissance geological surveys in glaciated terranes, to fill in gaps in bedrock geology. Future studies could focus on the mapping of clast lithology and morphology of other moraines, including nearby Marble Mountain Medial Moraine, in order to test the clast transport curves and construct more accurate maps of regional bedrock geology. **(*SS22, Thurs. 10:20*)**

Revisiting structure and gravity of the Howley Basin

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The Howley Basin, located in western Newfoundland, is a fault bounded Carboniferous sedimentary basin of entirely non-marine, fluvial to lacustrine origin with a dominantly siliclastic composition. Previous studies of the basin have alluded to the potential presence of migrated hydrocarbons, good effective porosity, vertical depths capable of bringing hydrocarbons into the oil window, and the possibility for stratigraphically controlled structural traps. Despite Howley's known potential for hydrocarbon production, there has been limited exploration within the basin. Several researchers that have studied the area have had conflicting interpretations of basin formation processes, timing of deformation, basin stratigraphy and true vertical depth.

As part of Nalcor's Petroleum Exploration Enhancement Program (PEEP), a detailed structural mapping project combined with a high precision gravity survey was conducted. The purpose of the surveys is to evaluate the potential of the Howley Basin for presence of hydrocarbon traps by confirming timing and results of deformation mechanisms, basin stratigraphy and true vertical depth of the basin. This detailed work with modern equipment and techniques, is expected to guide industrial companies on how and whether to pursue hydrocarbon exploration within the Howley Basin. **(*GS2, Poster*)**

The Large Igneous Provinces Industry Consortium Project: U-Pb dating campaign funded by industry

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For the past four years a consortium of Industry Sponsors (mining and oil) has provided funding ($1.5 million) for research, mainly U-Pb dating, on Large Igneous Provinces (LIPs), especially their dolerite dyke and sill swarms, from around the world and back through Proterozoic time (www.supercontinent.org). The main goal has been dating of all major dolerite suites on all major crustal blocks to use this record to fast track progress in pre-Pangea continental reconstructions using the LIP barcode method. From the industry perspective the goal is improved exploration strategies in two ways: 1) by providing reconstructions that allow known major ore deposits (of any type) to be traced into greenfield areas on blocks that were formerly attached; and 2) by providing improved targeting within LIPs given that they can be a direct host of magmatic deposits (*e.g.*, Ni-Cu-PGEs), and indirectly contribute to other ore deposit types (*e.g.*, hydrothermal deposits), and that they also have a role for the oil industry in hydrocarbon generation (anoxic events) and maturation. In return for their investment the sponsors receive data in reports which have a one year confidentiality period in order to allow sponsors time to use the results to their competitive advantage.

Most of the dating has been with the U-Pb ID-TIMS method on baddeleyite (+zircon). Given the current efficiency of baddeleyite separation, sample sizes less than 1 kg are often sufficient. Collaborators from around the world both provide the samples, and participate in the interpretation, preparation of reports, and subsequent publication of results. For samples with minute baddeleyite grains (<25 microns) or with significant rimming of baddeleyite grains by secondary zircon, *in situ* techniques have been applied such as LA-ICP-MS, SHRIMP and IN-SIMS dating (*e.g.*, Söderlund *et al.* 2013, Lithos, 174:101; Chamberlain *et al.* 2010, Prec. Res. 183:379).

The generous industry funding has allowed production of 171 U-Pb dates from all parts of the world, to provide the first robust barcodes for blocks such as the West Africa, Siberia, Amazonia, and Sarmatia. More than 10 Proterozoic LIPs of scale comparable to the Siberian LIP have been discovered. In other cases dating has provided a decisive barcode match with another block (*e.g.*, *ca.* 725 Ma mafic-ultramafic magmatism in southern Siberia, provides a critical support for a reconstruction link with the 725-715 Ma Franklin LIP of northern Canada). **(*SS17, Wed. 9:00*)**

The 1498-1503 Ma Kuonamka LIP of northern Siberia; new precise U-Pb baddeleyite dating

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Siberia is best known for the 250 Ma Siberian Trap Large Igneous Province (LIP) which hosts the important Ni-Cu-PGE Noril'sk deposits. However, comparable-scale Proterozoic LIPs are being discovered through a campaign of U-Pb dating of dolerite dykes and sills through the LIPs-Continental Reconstruction-Project (www.supercontinent.org). Here we profile the 1498-1503 Ma Kuonamka LIP of northern Siberia, which can also potentially be linked with sills in the formerly attached São Francisco – Congo craton (Ernst *et al.* 2013, Prec. Res., v. 230, p. 103-118) to produce an event 2000 km across. (Ages below are by U-Pb TIMS on baddeleyite unless otherwise noted).

The Kuonamka event was originally recognized in the Anabar shield. An E-trending dyke was dated at 1503±5 Ma with additional E-ESE-trending dykes correlated via paleomagnetism (Ernst *et al.* 2000, J. Geol., v. 108, p. 381-401). A new date (1502±6 Ma) allows the swarm to be traced into the Riphean sediments on the western slopes of the Anbar shield for a distance of 270 km. A dolerite sill province also cuts these Riphean sediments and yields new ages of 1498±2, 1502±6, 1503±2, 1502±8, and 1493±9 Ma. A slightly younger age of 1466±14 Ma was obtained for a sill by U-Pb SIMS. Several hundred km further east in the Olenek uplift a Sololi sill yielded an imprecise SHRIMP age of 1473±24 Ma (Wingate *et al.* 2009, Prec. Res., v. 170, p. 256-266) that within uncertainty would match the Kuonamka event further west. Overall these data suggest that the Kuonamka LIP extends E-W for 700 km from the western slopes of the Anabar shield to the Olenek uplift. Convergence of the E-ESE trending Kounamka dykes with SSW-trending dykes in the Olenek uplift would define a *ca.* 1500 Ma plume centre on the northeastern margin of the Siberian craton. The age of Kuonamka LIP can be summarized as 1501 ± 3 Ma (95% confidence), based on the weighted average of the seven U-Pb TIMs results.

Platinum group minerals have been found in placers along the Anabar River (eastern side of Anabar shield) which are linked to layered intrusions recognized by geophysics along the Anabar River (Okrugin, 1998, Int. Geol. Rev, v. 40, p. 677-687; Okrugin *et al.*, 2009, Otechestvennaya Geologiya no. 5, p. 3-10). Given the prominence of the 1501 Kuonamka LIP in northern Siberia, it should be considered that these undated intrusions and the associated placer PGEs could belong to the Kuonamka LIP. **(*SY7, Fri. 3:00*)**

Long term reconstruction of southern Siberia and northern Laurentia (Slave-Rae craton) margins, based on multiple LIP barcode matches over the interval 1.9–0.7 Ga

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New precise U-Pb dating from southern Siberia and northern Laurentia provides multiple matches between the Large Igneous Province (LIP) records of both crustal blocks. Most important is the recognition of two dominant Proterozoic events of northern Canada (725-715 Ma Franklin and 1270 Ma Mackenzie events) in southern Siberia, as well as recognition in both blocks of 1350 Ma and 1750 Ma intraplate magmatism. These, along with more speculative comparisons at the other times, yield a robust match of the magmatic barcodes of southern Siberia and northern Laurentia between 1750 and 725 Ma, affirming a close fit of these blocks. Earlier speculative comparisons at *ca.* 1900 and 1885-1870 Ma, prior to the final assembly of Laurentia or Siberia, suggest a similar fit between southernmost blocks of Siberia and the Slave-Rae craton of northern Canada. On the basis of the barcode matches, and associated dyke trends, we propose that the Irkutsk promontory of southern Siberia was near Banks Island of northern Canada. This reconstruction is broadly consistent with paleomagnetic evidence (*e.g.*, Pavlov *et al.*, this conference). Details on the magmatic correlations are given below (ages by U-Pb methods except where noted; strongest age matches are starred):

1.90 Ga:	Snowbird event of Slave-Rae craton *vs.* Angual dykes of Irkutsk promontory.
1.88–1.87 Ga:	Ghost dykes, and Morel and Mara River sills/sheets of Slave craton*vs.* 1.86 Ga volcano-plutonic units of Akitkan belt, Kalaro-Nimnyrskidykes (Ar-Ar ages) of Aldan shield and gabbro-anorthosite massifs of southeastern Siberia.
*1.75–1.74 Ga:	Cleaver, McRae Lake, and Hadley Bay dykes, and granites of northern Laurentia *vs.* giant radiating dyke swarm of Siberia (in part Ar-Ar ages).
ca. 1.70 Ga:	Pelly Bay dykes of Boothia Peninsula area *vs.* Ulkan-Bilyakchan rift magmatism of southeastern Siberia.
1.64–1.62 Ga:	Melville Bugt swarm of western Greenland *vs.* Biryusa sills of Irkutsk promontory.
1.38 Ga:	Midsommerso–Zig Zag Dal event of northern Greenland *vs.* Chieress dykes of northern Siberia and probable equivalents in southeastern Siberia.
*1.35 Ga:	Wellington Inlier sill of Victoria Island *vs.* Listvyanka dykes of Irkutsk promontory.
*1.27 Ga:	Mackenzie LIP of northern Laurentia, dominated by a giant radiating dyke swarm, *vs.* 1.26 Ga Srednecheremshanskii dyke of Irkutsk promontory.
0.780 Ga:	Gunbarrel event of western North America *vs.* volcanic rocks of Yenesei uplift.
*0.72 Ga:	Franklin LIP of northern Laurentia *vs.* dykes and sills of Irkutsk promontory (Ar-Ar ages), bimodal volcanism near Lake Baikal, and coeval mafic-ultramafic intrusions including Dovyren and Upper Kingash.

(***SY7, Fri. 2:40***)

Keynote (40 min): Neoarchean to Paleoproterozoic transition from supercratons to supercontinents?

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The Archean to Proterozoic (Ar-Pt) transition included such momentous events as global atmospheric oxidation, low-latitude ice ages, and possibly eukaryote origination. Insofar as growth and demise of supercontinents may be considered as a key link between deep-Earth and surficial processes at long timescales, accurate reconstructions of Ar-Pt paleogeography are of paramount importance for understanding the evolving Earth system through that interval. Currently, however, our understanding of these ancient landmasses is poor. Global scarcity of the little-metamorphosed volcano-sedimentary record, no doubt, contributes to this lack of knowledge, but recent strategies working around such limitations have led to initial breakthroughs in global Ar-Pt paleogeographic model development. First, the integrated study of geochronology and paleomagnetism on relatively abundant, cratonic mafic dyke swarms, dominantly of Paleoproterozoic age, can demonstrate linkages among Neoarchean cratons at the time of their breakup, and hence permit "clan" assignment of extant cratons into their original supercraton entities. Second, integration of global databases in geological/geophysical mapping, geochronology, orogenesis, stratigraphy, and mineral deposits, permits identification of terranes and their relative kinematic histories. Third, new visualization software such as GPlates provides immediate feedback on whether proposed reconstructions seem dynamically feasible according to rates and styles of the modeled plate motions. Thus far, several supercratons can be reconstructed at the beginning of the Ar-Pt transition, though it is not known whether those blocks were assembled further into a single supercontinent, Kenorland, or whether late Paleoproterozoic Nuna was the first full-fledged supercontinent. (***SY7, Thurs. 3:40***)

Keynote (40 min): Projecting risk into the future: Geologic repository failure and the sinking of the Titanic

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This year marks the 102nd anniversary of the sinking of the “unsinkable” Titanic when it struck an iceberg in the North Atlantic Ocean on its maiden voyage from Southampton, UK, to New York City. Often, repository performance is analyzed within the framework of the failure analysis of engineered structures, such as nuclear reactors, bridges, aircraft, and even the tragic loss of the Titanic. In this presentation, I reflect on the essential differences between analyzing the failure of engineered structures *vs.* a "failed" geologic repository for nuclear waste. Perhaps, the most important difference is that for most countries there will only be a single repository, and we will never see the repository "in operation," as the operational phase of a geologic repository comes long after it has been filled with waste and sealed.

Based on these differences, I will argue that scientific and engineering demands for proof-of-performance should change and be adapted to different time frames. Also, the structure of the standard and implementing regulations, as well as the standard-of-proof for compliance, should not extend beyond what is scientifically possible and reasonable. The demonstration of compliance must not only be compelling, but is must also be able to sustain scientific scrutiny and public inquiry. We can benefit from the sobering reality of how difficult it is to project the future behavior of a geologic repository over extended spatial and temporal scales that stretch over tens of kilometers and out to a hundreds of thousands of years. **(*SS8, Thurs. 8:00*)**

Mineralogy and petrogenesis of Ni-Cu-PGE mineralization in the Black Thor Intrusive Complex, McFaulds Lake greenstone belt, Ontario

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The 2.7 Ga Black Thor Intrusive Complex (BTIC) is located in the James Bay Lowlands of northern Ontario and is composed primarily of dunite, lherzolite, olivine websterite, websterite and chromitite (Black Thor and Black Label horizons) with mela/meso/leucogabbro and minor anorthositic gabbro. A late websterite intruded the lower and middle ultramafic series rocks and locally brecciated the Black Label chromitite horizon. Ni-Cu-PGE mineralization within the BTIC can be subdivided into four different styles (basal contact style, magmatic breccia style, reef style, and vein style) occurring within the following zones: 1) AT-12 Extension (hosted primarily by lherzolite along the contact between the feeder and adjacent granitoids), 2) Basal Contact (hosted primarily by lherzolite along the contact between the BTIC and underlying granitoids), 3) NW Breccia (hosted primarily by websterite in a magmatic breccia zone along the SW contact between Black Label and the late websterite), 4) F2 (hosted primarily by websterite in a magmatic breccia zone along the NE contact between Black Label and the late websterite), 5) an unnamed zone (hosted by websterite between the F2 and NW Breccia), 6) Black Label chromitite (hosted primarily by websterite interlayers), and 7) Black Thor Chromitite (hosted primarily by talc schist interlayers). Sulfide textures include: interstitial disseminated (<20% sulfide), blebby (5-20%), patchy net-textured (20-30%), net-textured (20-40%), ragged (20-40%), vein (30-100%), semi-massive (50-90%), and massive (>90%). AT-12E and Contact Zone are dominated by vein, disseminated, patchy net-textured, and blebby textures; NW Breccia and F2 are dominated by patchy net-textured and blebby textures; Black Label is dominated by patchy net-textured and vein textures, and Black Thor is dominated by disseminated textures. The predominant mineral assemblages are: 1) pyrrhotite-pentlandite-chalcopyrite-magnetite, 2) chalcopyrite-pyrrhotite-(pentlandite), and 3) chalcopyrite-(magnetite). Platinum-group minerals (PGMs) are commonly spatially associated with sulfide-bearing minerals and secondary silicates. The principal PGMs identified thus far include sperrylite (PtAs2), paolovite (Pd_2Sn), and minor PGE tellurides and arsenides. Two main magmatic mineralizing events appear to have occurred within the BTIC: an early event forming basal contact style mineralization in the Basal Contact and AT-12 Extension zones, and a later event forming magmatic breccia style mineralization in the F2 and NW breccia zones. **(*GS5, Poster*)**

Keynote (40 min): Kinetic and equilibrium isotope effects and their implications for the formation of sandstone-type uranium deposits

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Sandstone-type uranium deposits represent a major strategic source of uranium in the world. They are widespread and are primarily hosted in Carboniferous to Tertiary age rocks, and constitute approximately 30% of the world's uranium resources. They can be broadly defined as low-temperature, epigenetic deposits that likely derive their uranium supply from adjacent, exposed granitic bodies and interbedded or overlying uraniferous tuffaceous sediments. There are four sub-types: (a) Tabular deposits; (b) Roll-front deposits; (c) Basal channel deposits; and (d) tectonic/lithologic deposits. The two highest producing ore types are classified as tabular and roll-front; they are recognized on the basis of the shape of the ore body, and relationship to depositional and structural environments.

Historically, the most economic sources and reserves of uranium in the United States occur in sandstone-type uranium deposits of two types, the Wyoming-Nebraska roll-type and the Colorado Plateau peneconcordant (tabular) type deposits. Roll-type deposits are also important sources of uranium in China. Although the geology and geochemical processes involved in the genesis of these types of uranium deposits have been described in numerous studies, these deposits have been largely ignored for over 15 years. The major similarities and differences between deposits and some of the genetic problems relating to these differences have been examined, however, due to the fine-grained nature of mineralization, understanding the key processes involved in the genesis and subsequent alteration of these deposits has been challenging.

Our on-going research on roll-type deposits from the Yili Basin, China and Crawford sub-Basin, Nebraska represents one of the few recent studies on sandstone-type deposits. Stable isotopic systematics of sulfides and uranium minerals show that there are differences between the deposits from China and those located in the USA. Microbial processes are largely responsible for uranium mineral precipitation and sulfur isotopes can be used as an exploration-vectoring technique. U-series isotopes and U-Pb geochronology were used to determine the age of uranium mineralization and to track roll-front migration. U-series isotope analysis of uranium minerals from the nose and the limbs of the deposits show that although the mineralization at the nose of the deposits may be in secular equilibrium, the limbs are not in secular equilibrium, and uranium was re-mobilized by recent (<1 Ma) fluid events. **(*SS7, Wed. 8:20*)**

Four billion years, four thousand hours, four hundred people

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Canada's diverse geology underpins a landscape that ranges from towering Cordilleran peaks to Prairie plains, from the fertile farmlands of the Great Lakes and St. Lawrence Lowlands to the rugged cliffs of the Atlantic shore. Although the modern Canadian landscape has largely developed over the past 20,000 years, this interval is only the latest episode in an epic story over four billion years in the making, as revealed by Canada's geological record. During this time and fundamental to modern Canada's growth and well-being, minerals were concentrated by usually subsurface processes and future hydrocarbons were generated in stagnant seas. Plate-tectonic forces have caused continents and oceans to move and change such that, for example, all of what is now Canada was south of the equator until about 250 million years ago, some of it at the South Pole; and a great ocean once roughly separated Saskatchewan and Manitoba. Canada's rocks also preserve a rich trove of fossils, affirming life's evolutionary development from microbes to humans. Fossil sites include the Burgess Shale in British Columbia, Dinosaur Provincial Park in Alberta, Miguasha National Park in Quebec, and the Joggins Fossil Cliffs in Nova Scotia, all recognized as UNESCO World Heritage Sites. The upcoming book Four Billion Years and Counting: Canada's Geological Heritage (FBY) ties all these elements together as a continuous narrative. The narrative also encompasses social issues such as climate change, hazards such as landslides and earthquakes, and environmental factors. Some one hundred specialists have contributed to the text, which is intended to be accessible to an interested non-specialist audience. FBY will be richly illustrated by exquisite photographs drawn from several thousand images, artwork, and explicit schematics. There will be English and French editions, both expected to be available in 2014, as well as a website with many of the illustrations from the book available for downloading for educational purposes. The project has been sponsored by private and public institutions, as well as individuals, and could not have been completed without volunteer and professional contributions. At $39.95 for the paperback English edition and $49.95 for the hard-cover French edition, the book will be a good buy for those interested in gaining new insights into how Canada came to be, and as a case study that elucidates the evolution of our planet. **(*SS15, Fri. 8:40*)**

Late Neo-Proterozoic epithermal-style Au mineralization of the Burin Peninsula, Newfoundland: U-Pb geochronology and deposit characteristics

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The Burin Peninsula, in southeastern Newfoundland, lies along the western margin of the Avalon Terrane, which extends along the Eastern coast of North America from Newfoundland through New England. The terrane originated in an extensional arc setting along the margin of Gondwana during the Neo-Proterozoic. Epithermal-style gold mineralization is present throughout the Avalon in Newfoundland, as well as in the neighbouring, correlative peri-Gondwanan terranes, Ganderia and Carolinia. The most notable deposits include the Hope Brook Mine (Southern Newfoundland) and the Brewer, Haile and Ridgeway Mines (South Carolina).

The Burin Peninsula is predominately underlain by the 590-565Ma Marystown Group - consisting of subaerial flows and volcaniclastics, and their plutonic equivalents. Overlying this group to the west and north is the 570-550Ma Long Harbour Group - composed primarily of felsic volcanic rocks. To the east and north lies the post-570Ma Musgravetown Group - composed primarily of marine to terrestrial epiclastic sedimentary rocks.

Both high- and low-sulfidation styles of epithermal mineralization are present. The high-sulfidation occurrences are characterized by extensive zones of advanced argillic alteration including variable amounts of pyrophyllite, alunite, quartz, specularite, and local vuggy silica. The most significant high-sulfidation examples occur at Stewart, located centrally on the peninsula, and at Tower and Hickey's Pond in the north. Nominally, all of these are hosted within Marystown Group volcanic rocks. The low-sulfidation occurrences are characterized by epithermal textures that include brecciation, blading, and crustiform and colloform banding, as well as silica and adularia alteration. These include Heritage on the southern tip of the peninsula, Big Easy, just north of the peninsula proper, and Long Harbour, along the neighbouring shoreline to the west. These deposits are nominally hosted by the Marystown, Musgravetown, and Long Harbour groups, respectively.

Here we report new zircon U-Pb (CA-TIMS) ages for volcanic and plutonic rocks hosting, or associated with, the high- and low-sulfidation epithermal systems at Stewart and Long Harbour, respectively. At Stewart: the Bat Zone granite, 576.0±2.7Ma; unaltered intermediate tuff, 575.9±2Ma; altered, felsic Caribou Tuff host rock, 576.7±2.5Ma; unaltered, felsic Stewart Tuff, 575.2±2.1Ma; and altered felsic porphyry, 575.6±1.7Ma are indistinguishable, and overlap with ages of the proximal Swift Current Granite (580-570 Ma). At Long Harbour: the flow-banded rhyolite hosting the mineralization is 564.6±3.4Ma. This is currently interpreted as a separate, later mineralizing event from that which occurred at Stewart. **(*SY5, Poster*)**

A Radarsat-2 and Landsat 7 investigation of the Manicouagan structure, Quebec: Impact versus regional tectonics

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It is known from the Sudbury Basin in Ontario, and other meteorite craters, that these types of impact structures have the potential to hold vast amounts of valuable mineral deposits. In order to search for natural resources within these craters, geological maps, in conjunction with other data types, are generally used. To assist in the search for natural resources at the Manicouagan crater in Quebec, Canada, a terrain map and mineral property map were created.

The terrain map was created from a Digital Elevation Model (DEM) and satellite data from Radarsat-2 (SAR) and Landsat-7. Four Landsat-7 bands were used to generate a multispectral image which was then integrated with the Radarsat-2 SAR data. The DEM was used to create a shaded relief, which was then integrated with the multispectral/SAR data. The resulting terrain map revealed noticeable grains running north to south. These grains may be glacial in origin or a result of the ground slowly rebounding from the impact 214 Ma. Fine lines, that may be stress fractures or fault lines created from the impact, were also noted in the south-west (but are prevalent everywhere). The location of these grains and lines may be used for targeted mineral exploration.

The mineral property map was created from a DEM, Radarsat-2 SAR data and aeromagnetic data. The SAR and DEM data were integrated first then infused with the aeromagnetic data. Reviewing the resulting mineral property map, relationships between different magnetic signatures of rocks and their corresponding topographic and surficial properties may be studied. This information may then be used to assist in targeted mineral exploration projects. It may also be used in conjunction with other subsurface geological information to create a 3-D model for petrography.

The terrain and mineral property maps created for the Manicouagan crater offer an effective tool in the support of geological and lithological interpretation, which may be used in the search for valuable ores or other minerals. **(*SS11, Fri. 8:40*)**

Shear zones in the Grenville Front Tectonic Zone Part 1: Causes of orogneic strain localization

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Although the processes leading to strain localization are known, there is very little information available about which processes dominate in the real Earth. Towards that end, we document microstructural and compositional features across several amphibolite facies strain gradients at the boundaries of granitoid units in the Ontario segment of the Grenville Front Tectonic Zone. We document these shear zones in order to determine the degree of similarity across shear zones in the GFTZ and whether a wide range of microstructures and interacting weakening mechanisms operated. These strain gradients are marked by at least six-fold increases in the aspect ratios of magmatic enclaves, indicating substantial deformation. The studied gradients represent three of the many NNE-SSW trending, steeply dipping shear zones within the Grenville Front Tectonic Zone. Across all of the studied gradients, deformation resulted in significant grain size reduction. The fabric develops from anastomosing to a straight morphology with increasing strain. Finer grained quartz and amphibole, as well as quartz ribbons in high strain samples, wrap plagioclase porphyroclasts. Preliminary microstructural analysis indicates that deformation was dominated by dislocation creep, although diffusive processes played a role. Whole rock and electron microscopy results from two of the shear zones indicate little modal and bulk compositional change with strain. However, microprobe analyses in at least one shear zone show an evolution of both biotite and garnet compositions across the gradients. To this point, the granitoid shear zones exhibit a moderate to great degree of similarity. **(*SY2, Poster*)**

Roberto gold deposit, Eleonore project, Superior Province, James Bay, Quebec, diversity of styles related to structural-metamorphic settings

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The Roberto gold deposit is the main gold discovery in James Bay area with 3.03 Moz at 7.56 g/t (proven and probable reserves) and 4.17 Moz at 10.60 g/t (inferred resources). The production of this new world-class deposit is scheduled to start in 2014. The underground access offers a new opportunity to study the complex structural and metamorphic setting of the deposit and its polyphased nature. Located a few km south of the boundary between the volcano-plutonic La Grande sub-province and the migmatites and intrusions of the Opinaca sub-province, the main orebody is hosted by <2675 Ma Timiskaming age clastic sediment enclosed within a structurally complex ≤10 m wide «N-S» trending mineralized envelope that hosts various styles of mineralization. The main ore zones are associated with potassic alteration and an Au-As-B signature. They are characterized by quartz-dravite-microcline-phlogopite-arsenopyrite stockwerk and associated replacement zones and by quartz-diopside-arsenopyrite laminated veins. The bulk of the gold mineralization is confined within a steeply plunging ore shoot coaxial with F_2 fold hinge. Gold deposition is interpreted as pre- to syn-D_2. However, the complexity of several ore zones needs to be integrated in the complex tectono-metamorphic history and the timing of the deposition of the bulk of the ore remains to be better define. The quartz-diopside-arsenopyrite laminated veins are located near a brittle-ductile fault that is folded by F_2 fold. These high-grade zones (20 g/t Au) are located in the hinge of a F_2 fold but S_3 schistosity influence plunge axis and create interference pattern marked by sheath folds.

New mapping reveal that several en-echelon veins compatible with D_3 deformation are often associated with main ore bodies while some of them show boudinaged and sinistral shearing in response to layering-parallel extension during D_2. In the north part of the deposit, four types of ore zones are present: (i) quartz-dravite-arsenopyrite veins hosted by sandstone layers, (ii) calcium-bearing breccia, (iii) quartz-feldspar-arsenopyrite veins, and (iv) arsenopyrite-bearing pegmatites (up to 19.5 g/t Au). Type (i) and (ii) are stratigraphically controlled by sandstone layers while (iii) and (iv) are strongly transposed by S_2. Paragneiss (<2685Ma) exposed 1km east of the main ore zone illustrate the steep metamorphic gradient towards the Opinaca sub-province to the north. The paragneiss have recorded complex D_2 deformation characterized by the S_2 regional E-W schistosity axial planar to F_2 folds. D_3 is characterized by F_3 folds deforming the pegmatites injected parallel to S_2 (1-2 interference pattern) and S3 crenulation cleavage.

We suggest that metamorphic gradient, competence and anisotropy play a role on style and complexity of deformation and ore bodies. Although complex and metamorphosed, the deposit is hosted by Timiskaming-age sediments, near the boundary between two sub-provinces and as such share analogies with most Archean gold deposits. **(*SY5, Poster*)**

Ground truthing of the 'Eastern Athabasca Basin' regional airborne gamma-ray survey: Context for exploration of deeply buried unconformity type uranium deposits

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With uranium exploration shifting to greater depths and more indirect targets, new tools and better use of existing data are needed to maximize exploration efficiency and quantify both “hits” and “near-misses”. Recent and historical research has demonstrated that although deeply buried beneath Athabasca Group sandstones, unconformity type uranium deposits still may be targeted by understanding subtle surficial geochemical anomalies. Expressions of these anomalies in surficial media reflect a variety of processes from regional diagenetic-mineralogical alteration patterns, through hydrothermal alteration halos more directly associated with the deposits, to specific sites where mobile metals including decay products were brought to the surface along structural pathways.

Airborne gamma-ray spectrometric surveys can be used for effective surficial geochemical mapping of K, U and Th over large areas, and have been conducted by the Geological Survey of Canada across much of the Canadian Shield over the past 50 years, notably in partnership with Saskatchewan over the Athabasca Basin. To apply the results of these surveys to uranium exploration, the effects of deposit-related geochemical anomalies on airborne gamma-ray measurements must be predicted. And, just as importantly, the background in terms of K, U and Th above which these anomalies have to be detected, has to be quantified and its genetic linkages understood.

The 'Eastern Athabasca Basin' airborne gamma-ray survey was conducted in partnership with the Saskatchewan Geological Survey in 2009. This regional survey was ground-truthed along the corridor between Key Lake and the McArthur River mine site, during the summer and fall of 2013. High-resolution helicopter-borne gamma-ray acquisition, ground gamma-ray spectrometry, surficial material mapping, sampling and laboratory analysis were performed. Preliminary results indicate that the relationships between subsurface processes, glacial dispersal and airborne gamma-ray measurements are very intricate and responsive to detailed local surficial geological processes that have modified elemental dispersion from bedrock sources. Changes in background levels are related to multiple factors including drumlins, surface and shallow subsurface water, and multiple ice flow events with concomitant multiple tills. The gamma-ray data thus need to be mapped in the context of surficial geological domains. By working within domains, quantitative analysis of the airborne data, integrated with surficial geological knowledge, can differentiate between the complex patchwork of background domain levels and deposit-related surficial geochemical anomalies. **(*SS7, Wed. 2:00*)**

Geochemistry and water quality of surface waters in New Brunswick

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New Brunswick has some of the most famous rivers in the world, including the Miramichi and Restigouche Rivers, notable for their recreational salmon fishery. Protection of rivers is vital to the people of New Brunswick and to the government acting on their behalf. Chemical monitoring of rivers throughout New Brunswick has been on-going for many years. Over the last ten years, a consistent monitoring program has been designed and carried out that includes 56 stations located on various rivers throughout New Brunswick. Each of these stations is sampled at least four times per year and the samples are analyzed for a variety of parameters including major ions, trace metals, nutrients, pH, specific conductance and others.

In general, water chemistry reflects the major underlying lithological units. In northern New Brunswick, water chemistry is strongly controlled by the limestone-rich rocks throughout the area. It is not uncommon that pH in these waters is greater than 8.0 and aluminum, iron, and manganese concentrations are very low. In contrast, rivers in south-central New Brunswick have chemistries indicative of large bogs and wetland areas and they are generally characterized by high organic carbon, and comparatively higher iron and aluminum concentrations. In the southern part of New Brunswick, waters can be very low in pH and reflect the very low buffering capacity of the rocks throughout the area.

Throughout New Brunswick, water quality is generally interpreted as good to excellent using the Canadian Council of Ministers of the Environment Water Quality Index. However, the interpretation of water quality must take into consideration the wide range of water chemistry and appropriate water quality guidelines must be developed. In some cases, national water quality guidelines can be used to interpret water quality. In other cases, site-specific water quality guidelines should be developed for specific rivers in order to reflect their naturally high background concentrations. **(*SS16, Wed. 9:00*)**

Martian Soils: Lithospheric Probe or just "Dirt"

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The “soils” of Mars range from dark sands and silts dominated by primary igneous minerals to bright dust, rich in secondary sulfates. Despite this apparent diversity, they all have a remarkably uniform mafic composition indicating that, despite the effects of weathering, Martian soils have suffered little in the way of chemical leaching. The composition of Martian soils thus represents a global sampling of the Martian crust, and may provide the kinds of constraints for the Martian interior that the composition of MORB provides for the Earth.

The paradox that the reflectance spectra of the dark Martian soils indicate the presence of significant olivine, but olivine is not present in their calculated normative mineralogy has been attributed to the soils being mechanical mixtures between primary igneous minerals and secondary detrital quartz, sulfates, and clays produced by weathering. The program ALPAMELTS, however, predicts olivine to be the sole crystallizing phase for more than 60°C below the liquidus of the soil’s composition, before saturation with a low-Ca pyroxene. The absence of olivine in the soil’s normative mineralogy may thus reflect the existence of an olivine reaction relationship, and not the admixture of secondary weathering products. Accepting this interpretation, ALPAMELTS calculations suggest that the relatively low Ca and Al contents of Martian soils reflect melting of a pigeonite-bearing peridotite mantle source with an Mg no. of ~ 0.80, rather than the effects of weathering or chemical secondary.

Furthermore, the pressure of multi-phase saturation along the calculated liquidus of Martian soils requires derivation from a minimum depth of ~ 100 km, and implies the existence of a thick lithospheric lid on Mars. In this regard, the Martian soils differ from MORB, and Venusian lowland basalts, which are both multi-phase saturated at shallow depths, but do resemble Lunar Mare basalts, which have multi-phase saturation pressures indicating derivation from depths of 200-500 km. **(*SY3, Wed. 8:00*)**

Monitoring land subsidence and groundwater levels in the Kanto groundwater basin, Central Japan

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Over 40 million people live on and exploit the groundwater resources of the Kanto Plain. The Plain encompasses metropolitan Tokyo and much of Chiba Prefecture. Useable groundwater extends to the base of the Kanto Plain, some 2,500 to 3,000 m below sea level. Much of the Kanto Plain is at sea level. By the early 1970’s, with increasing urbanization and industrial expansion, local overdraft of groundwater resources caused major ground subsidence and damage to commercial and residential structures as well as to local and regional infrastructure. Parts of the lowlands around Tokyo subsided to 4.0 m below sea level; particularly affected were the suburbs of Funabashi and Gyotoku in western Chiba. In the southern Kanto Plain, regulations, mainly by local government and later by regional agencies, led to installation of about 500 monitoring wells and almost 5000 bench marks by the 1990's. The monitoring systems are costly, but the resulting data provide continuous measurement of the "health" of the Kanto Groundwater Basin, and thus permit sustainable use of the groundwater resource. **(*SS10, Wed. 10:40*)**

Sedimentological criteria for distinguishing stacked dune-trough muds from muds in inclined heterolithic strata in the subsurface – Insights from McMurray Formation outcrops, cores and modern analogues

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Both dune-trough (also known as dune-bottomset) mud deposits (DTMD) and muds in inclined heterolithic stratification (IHS) are deposited in the same depositional systems including fluvial, tidal and tidally influenced fluvial systems. Although their geometries and structures are fundamentally different, recent observations from McMurray Formation outcrops and cores suggest that stacked cross-beds with preserved DTMD may easily be misinterpreted as IHS.

Our detailed outcrop logs and sketches are from a recent road cut exposure in the Abasand area and from the McMurray Formation Type Section, both located in the vicinity of Fort McMurray, Alberta, Canada. In both studied locations, the interbedded sand and mud are characterized by several centimeters thick (up to 0.2 m), non-bioturbated mudstone bounded by up to 0.2 m thick sand. Mud layers are comprised of multiple mud laminae whose number progressively decreases in the toesets, perhaps as a result of neap-spring cyclicity superimposed on the slower forward migration of a large to very large dunes; and are gradationally overlain by sand without mud layers. These observations are in the line with recent findings in modern environments (BITE Consortium, unpublished data).

The criteria for distinguishing in a narrow core may include: (i) if present, the high-angle foresets in overlying sands are more likely an indication of DTMD; (ii) depositional dips (when FMI available), being inclined and unidirectional in IHS and (sub) horizontal and scattered in stacked DTMD; (iii) when described in a broader geological context, the lower series of mud layer above the channel-base contact in the core is very likely a DTMD, whereas those that are higher in the core are less certain, and/or more likely IHS; (iv) an upward transition over a short vertical distance from flat-lying mud layers to progressively more steeply dipping mud layers likely indicates the upward increase in slope from the bottomsets to the toesets and sometimes even into the foresets of the dune characteristic of DTMD, versus lack of this phenomena and rather constant dips of muds within the IHS; (v) a lateral change in a number of thinly interbedded mud-silt layers (from numerous in bottomsets to less numerous in toesets) is diagnostic of DTMD whereas a consistent number of thinly interbedded mud layers is more likely to be indicative of IHS deposition.

Since the DTMD are not and the IHS are, of concern for reservoir developments, the importance of distinguishing between the two in the subsurface is paramount. **(*SS1, Fri. 9:20*)**

Canadian Malartic gold deposit footprint: Preliminary investigation of geological, geochemical and mineralogical features

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Canadian Malartic (Québec) represents a major example of a large-tonnage, low-grade gold deposit in the southern Superior Province, and a relatively unique setting in Archean terranes worldwide. It is located in the Pontiac Subprovince, in contact with, and immediately south of the east-west trending Cadillac-Larder Lake fault zone (CLLFZ), marking the contact with the Abitibi Subprovince. Most gold deposits in the Abitibi Greenstone Belt are of orogenic type and are typically associated with albite-carbonate alteration. Canadian Malartic contrasts with these deposits in that the gold is disseminated in pervasively altered (pyrite-K-feldspar-biotite-calcite-ankerite) quartz monzodiorite porphyries and adjacent clastic metasedimentary rocks (metagreywackes). Gold also occurs in quartz-biotite-carbonate-microcline±pyrite veinlets with potassic alteration haloes (mainly as biotite selvages). These veinlets are generally subparallel to the S_2 foliation. The gold occurs in elongated, lens-shaped orebodies, strongly controlled by faults and lithological contacts. Hydrothermal alteration in the quartz monzodiorite porphyry stocks was accompanied by mass gains in S, C and K, consistent with the mineralogical characteristics of the alteration assemblage, as well as an increase in loss on ignition. Gold mineralisation in quartz monzodiorite was associated with substantial mass gains in Ag-Te-Bi-Mo-Pb-W-Cu. Core-logging, pXRF data (*e.g.*, K_2O content) as well as gold grades, show that the intensity of the hydrothermal alteration is decreasing sharply away from the deposit. Preliminary results indicate that the visible alteration halo (*e.g.*, pyritisation, carbonation or potassic alteration) does not extend more than 500 meters south of the southern limit of the pit. Subordinate mineralisation occurs as late "pegmatitic" veins (coarse-grained quartz-muscovite-biotite-tourmaline-orthoclase-albite-calcite-pyrite assemblage), mostly in quartz monzodiorite porphyry. The composition of tourmaline from these veins indicates growth from a solute-rich solution, in marked contrast to fluids inferred from tourmaline for the orogenic-type gold deposits elsewhere in the Abitibi. *CMIC-NSERC Exploration Footprints Network Contribution 013* **(*SY5, Poster*)**

Gold mineralization in the Canadian Malartic deposit, Canada: Insights from textural and quantitative elemental mapping of pyrite

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Pyrite is one of the most common sulphide minerals present in gold-bearing ore assemblages of a wide diversity of deposit types. Gold commonly occurs as sulphide lattice-bound gold, nanoparticle inclusions or filling fractures in pyrites (Deditius *et al.*, 2011; Hough *et al.*, 2011; Cook *et al.*, 2013). In addition, elements that are commonly associated to gold mineralization, including As, Hg, Sb, Te, W, Bi, Cu, Zn and Pb, can be partitioned into pyrite. Thus, the chemical composition of pyrite can provide key information on the timing of gold deposition within the ore assemblages and genetic processes involved.

The Canadian Malartic gold deposit (311Mt@1.01 g/t) is hosted by subvertical clastic metasedimentary rocks of the Pontiac Group and porphyritic monzodiorite. It locates immediately south of the Larder-Lake–Cadillac Fault Zone. Textural and quantitative elemental mapping of pyrites from Canadian Malartic indicate a complex evolution characterized by five types of pyrite (Py1 to Py5) that represent three generations of pyrite crystallization. Py1 is a diagenetic porous pre-mineralization pyrite, yielding high Co-As-Se and low Ni-Te-Sb-Bi-Pb values. Py2, py3 and py4 are contemporaneous with gold deposition and have consistently variable Co and Ni contents and high Au-Ag-Te-Bi- Pb values. Py5 crystallized after gold deposition. It is enriched in Co and Ni, but is depleted in most other metals. At Canadian Malartic, gold enrichment is generally associated with potassic alteration (microcline and biotite) and Au in pyrite is positively correlated to Te, Bi and Pb. These features are compatible with an intrusion-related auriferous fluid.

Field relationships reveal that the deposit resulted from the superposition of hydrothermal and structural events including a magmatic-hydrothermal phase of mineralization that shares analogies with Archean oxidized syenite porphyry-associated disseminated gold deposits. However, at least part of the mineralization (or remobilization) and its actual distribution and geometry are controlled by a syn-D_2 event. Elemental mapping also reveals that the Canadian Malartic deposit was formed by two stages of gold mineralization. The early stage is likely to be the result of fluid degassing as recorded in Py2, whereas the latter stage, crystallized Py3 and Py4 and associated with potassic and hematite alteration, is related to the evolution of the hydrothermal system. **(*SY5, Poster*)**

Parameterizing orogenically significant shear zone formation

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Because km-scale shear zones play a first-order role in lithospheric kinematics, accurate conceptual and numerical models of orogenic development require predicting when and where they form. A review of tectonically significant shear zones worldwide and more detailed investigations in the Central Gneiss belt of the Ontario segment of the Grenville Province reveal no clear systematics of km-scale shear zone formation mechanisms, aside from their dominant occurrence at lithological boundaries. For example, the relatively flat-lying Twelve Mile Bay shear zone in the western Central Gneiss belt, containing paragneiss and mafic and felsic orthogneiss, formed in the core of the orogen and is likely the product of both localized anatexis and later retrograde hydration with attendant metamorphism. In contrast, moderately dipping shear zones in grainitoids of the Grenville Front Tectonic Zone apparently resulted from cooperation among several complementary microstructural processes, such as grain size reduction, enhanced diffusion, and crystallographic changes. Because extensive areas of deep crustal levels can experience broadly distributed high strain, the rheological changes required to form high strain zones cannot be due to strain alone. Instead, localization into shear zones requires the operation of other spatially restricted processes such as stress concentration, metamorphism/fluid access, textural evolution, and thermal perturbation. Although stress concentrations, such as form at rheological boundaries, may be sufficient to nucleate high strain gradients, they are probably insufficient to maintain them because the stress perturbations will disspate with deformation. Metamorphism can unquestionably cause sufficient rheological change, but only under limited circumstances. For example, under deep crustal conditions, granitoids have much less capacity for metamorphically induced rheologic change than do mafic rocks. Because of the magnitude of variation observed in natural systems, topological change (*e.g.*, interconnection of weak phases) likely has little direct affect on strength changes. Although other textural factors related to diffusion paths and crystallographic orientation could play a significant role, experimental data are insufficent to draw firm conclusions. Thermal perturbation, mainly in the form of shear heating, remains potentially powerful, but inconclusive. Taken together, these observations indicate that parameterizing shear zone formation remains imperfect. It may be that the inherent lithologic variation at the km scale, such as observed in the Central Gneiss belt, prevents the development of self-organizing strain patterns that would form in rheologically more uniform systems. **(*SY2, Thurs. 9:00*)**

Very high pressure metamorphism in the Canadian Cordillera: Tectonic links between blueschists and low-temperature eclogites

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Blueschist facies rocks are of tectonic importance; they are indicators of subduction-related metamorphism at plate margins. They have also been used to determine the polarity of subduction and to estimate the geothermal gradients attending the metamorphism. Eclogites in the Canadian Cordillera include both lawsonite- and epidote-bearing types (classified as low-temperature eclogite). The occurrence of eclogite with pressure estimates near the P-T stability of coesite occur in subduction complexes with possible links to the blueschists. Estimation of P-T conditions for blueschist facies rocks is difficult due to the lack of geothermobarometers. Limits on P-T conditions can be estimated using the equilibria, albite=jadeitic pyroxene + quartz; laumontite=lawsonite + H_2O and calcite = aragonite. Constraints on the P-T trajectory to the surface can be estimated from the survival of metamorphic aragonite, suggesting the temperature never exceeded about 250-350 °C. This suggests a metamorphic gradient of about 10°C km^{-1} or less. The blueschists at Pinchi Lake, B.C. are associated with tectonic blocks of eclogite. The blueschists contain lawsonite, jadeitic pyroxene +quartz and aragonite. Geothermobarometry of lawsonite eclogite at Pinchi Lake suggest P/T of~ 500 °C /24 kbar. Eclogites from the Yukon are hosted by metasedimentary rocks and range in $^{40}Ar/^{39}Ar$ Ar dates from 220 to 345 Ma. Some of the Yukon host garnet-mica schists crystallized at similar temperatures to the eclogites. Blueschists from the French Range contain lawsonite and albite, with clinopyroxene + quartz in veins. No aragonite was detected. Blueschists occur in fault-bounded blocks within the Bridge River Complex. Lawsonite and epidote occur with blue amphiboles and clinopyroxene contains up to 55 mol% jadeite (no aragonite). Minimum pressure of metamorphism was about 8 kbar at 200 °C. The blueschist metamorphism in the Bridge River Complex is dated at 230 Ma. The French Range blueschists have $^{40}Ar/^{39}Ar$ dates on white micas in the early metamorphic fabric at 174 Ma. At Pinchi Lake $^{40}Ar/^{39}Ar$ dates on white micas are 221 to 224 Ma which overlap those in eclogite tectonic blocks. Calculations using metamorphic temperatures, closure temperatures, geothermal gradients and exhumation rates suggest that the lawsonite eclogites could have been at similar depths to the Pinchi Lake blueschists at about 220 Ma. **(*SS19, Thurs. 9:20*)**

Keynote (40 min): The lunar impact record and regolith development via Diviner thermal radiometer observations

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The Lunar Reconnaissance Orbiter's suite of instruments has provided new insights into fundamental properties of the lunar surface. The Diviner thermal radiometer, in particular, reveals details of the vertical structure and lateral variation of the lunar regolith that are paving the way for newly quantitative estimates of important parameters such as the rate of regolith accumulation. In this talk, I will outline several of Diviner's most significant findings regarding the thermophysical properties of the lunar surface, and will discuss their implications for our understanding of regolith production and overturn, space weathering, and variations in the impactor flux. These processes are important to our understanding of Earth's early evolution because the Moon's regolith bears a record of the past 4.6 billion years of bolide impacts. Though Earth must have experienced a similar history of bombardment, with profound effects on early terrestrial geological processes, most of the impact record on Earth is lost. Therefore, we endeavor to use the history of impacts on the Moon to unravel the complexities of the impact process and its effects on the target body. **(*SS21, Thurs. 8:00*)**

Extensive remobilization and reprecipitation of copper during phyllic overprint in Miduk porphyry system, south Iran

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The Miduk porphyry Cu-Mo-Au deposit lies in the southern section the Cenozoic Urumieh-Dokhtar magmatic belt, Iran. The deposit is associated with a Miocene shallow quartz-diorite to quartz-monzodiorite body intruded into Paleocene-Eocene lavas and pyroclastics. The intrusion consists of plagioclase, biotite, and minor K-spar, hornblende and quartz phenocrysts in a quartz-feldspar matrix. Hydrothermal alteration is characterized by a central potassic assemblage, distinguished by abundant biotite and K-spar, grading outward and upward into a phyllic assemblage distinguished by sericite and subordinate chlorite that in turn is enclosed in rocks with propylitic alteration.

A thick leached cap is underlain by an irregularly developed oxide ore, grading downward into a high-grade supergene enriched blanket. Recent deep diamond drill holes by the National Iranian Copper Industries have indicated that hypogene ore at economic grades extends vertically for over 1000 meters from the current workings in the enriched blanket. A distinct feature with increasing depth in the central part of the deposit is the scarcity of pyrite and common occurrence of bornite, associated with chalcopyrite.

The intrusion is intruded by a hornblende-diorite stock and several late and post-ore diorite dykes. The late dykes display alteration assemblages comparable to those in the enclosing rocks. The post-ore dykes, however, are characterized by propylitic alteration dominated by chlorite, even where cutting rocks with potassic alteration; they are distinguished by near total replacement of hornblende and biotite by chlorite and minor carbonates, and rimming of plagioclases by calcite and minor epidote. A rather unusual feature is that the dykes contain economic copper assays.

The widespread phyllic alteration in Miduk appears to be mostly of overprint nature, as evident from increasing replacement of the original potassic assemblages by sericite, chlorite and quartz, laterally and vertically away from the potassic core. A distinct feature in rocks with phyllic alteration is the common occurrence of gypsum/anhydrite as veinlets associated with sericite, chlorite, calcite, sulfides, as well as scattered grains, implying that fluids involved in the phyllic overprint were relatively oxidized. Reequilibration of the earlier potassic assemblage and associated mineralization with the oxidized fluids was associated with partial to complete dissolution of sulfides and remobilization of copper. This is supported by cross-cutting relations, as well as textures indicating partial replacement of sulfides by sericite, chlorite, and gypsum. Mass balance approximations suggest that during the overprint, Cu was depleted from 20% to 40% below the original assays. The copper, and possibly gold, released during the overprint, was reprecipitated at some distance from the depleted rocks. The impregnation of the post-ore dykes might be attributed to the process. **(*SS3, Poster*)**

Analysis of extensional deformation in coastal Makran molassic deposits and its situation in Makran Accretionary Wedge, SE Iran

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Makran, geologically defined, is one of the largest accretionary wedges on Earth. It is located in SE Iran and South Pakistan and is an uplifted, Eocene–Recent accretionary complex that extends over *ca.* 1,000 km between the dextral Minab Transform Fault through the Strait of Hormuz, to the west, and the sinistral Chaman Transform Fault, along the Kirthar Range to the east. The ophiolite-bearing imbricate zone separating the Jaz-Murian Basin, to the north, from the Makran Accretionary Wedge (MAW) to the south is accepted as a segment of the Tethys orogenic system. The MAW is a key orogenic feature produced from the convergence between the Arabian and Eurasian plates taking place since at least the Late Cretaceous. The MAW is now associated with the ongoing subduction of the oceanic lithosphere flooring the Gulf of Oman at a present-day rate of about 2 $cm.a^{-1}$ in a roughly N–S direction, beneath the Iran and Afghan Blocks. Shortening and abundant sediment supply led the low-taper wedge to grow seawards by frontal accretion and underplating of trench fill sediments. The modern MAW developed since the Early–Middle Miocene, leading to a typical thrust-and-fold belt with forward propagation of thrusting, sediment underplating at the front and subsequent thickening and uplift of the accretionary complex.

On the basis of field observations and seismic data interpretation in outer fore-arc domain of MAW, the extensional deformation of coastal Makran molassic deposits which is contemporaneous with the subduction of the Oman oceanic plate beneath the Eurasian plate has been analyzed. The most important evidences of normal faulting are fault plans solutions accompanied with almost dip-slip displacements of Miocene to Pleistocene marl-mudstone and sandstone sequences with repeated/lost strata. Generally, the Makran outer fore-arc domain including the coastal uplifted range and fore-arc basin has been affected by extensional deformation since approximately Miocene. This deformation is analyzed in two phases. Firstly, the syndepositional formation of southward listric normal faults that is due to marginal gravitational collapses and could lead to northward imbricate thrust faults in accretionary wedge zone. Secondly, the post depositional high angle extensional deformation in uplifted coastal range that is probably related to local uplift resulting of active underplating. **(*GS2, Poster*)**

“Acadian” magmatism in Maine and New Brunswick; petrology and tectonic setting

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Acadian magmatism produced voluminous felsic and mafic magmas, the plutons of which group into two main igneous provinces or belts. The coastal lithotectonic block of Maine is host to the Coastal Maine Magmatic Province, which continues into southwestern New Brunswick. The Piscataquis Magmatic Belt, located across central Maine, is a group of ~ 40 plutons which were emplaced at differing crustal levels. A possible third group of Devonian plutons forms a distinct linear belt from central and western New Brunswick to southeastern Maine, including the central Gulf of Maine.

This “Acadian” magmatism was a prolonged event, beginning in the Late Silurian (~ 420 Ma) and continuing to the Late Devonian (~ 360 Ma). It is unclear whether magma production was continuous or episodic during this interval due to the uneven coverage of reliable ages for many of the plutons. The granitic plutons are petrographically diverse, display different emplacement styles, magmatic processes, and variable interaction with mantle-derived mafic magmas. The plutons display both I- and S- type mineralogies and alumina saturation independent of their age. This heterogeneity suggests that melts were derived from various crustal sources and that the orogenic events varied in style. Trace element discrimination diagrams indicate variable tectonic settings from volcanic-arc and within-plate signatures to upper crustal melts. With available data, trends of composition and tectonic signature with age are not yet apparent to further elucidate the petrogenesis of granitic magmas during this period of crustal assembly. **(*SS5, Wed. 4:20*)**

Reconstruction of the ore interval and environment for the Paleoproterozoic, Lost and Ghost Lake VMS deposits, Snow Lake, Manitoba

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The Lost and Ghost Lake volcanogenic massive sulphide (VMS) deposits (590,233Mt @ 8.6% Zn, 1.33% Cu, 3.83 g/t Au, 32.61 g/t Ag) are located at the contact between the Upper and Lower Chisel Sequences of the Paleoproterozoic, Snow Lake VMS district of Manitoba. The Chisel Sequence is a mature-arc, bimodal, felsic-mafic, volcaniclastic dominant, submarine succession that records three deformation events and has been metamorphosed to mid-amphibolite facies. The Lower Chisel Sequence consists of voluminous, felsic and lesser mafic volcaniclastic and flow lithofacies. The Upper Chisel sequence consists of felsic flow/dome lithofacies (*e.g.*, Ghost rhyolite) and voluminous mafic volcaniclastic (*e.g.*, Threehouse unit), and lesser mafic flow lithofacies. The ore interval consists predominately of volcaniclastic lithofacies and is host to the Chisel, Chisel North, Lost, Ghost and Lalor VMS deposits; the latter three are anomalous in gold.

At Lost and Ghost, the ore interval ranges up to 9 m in thickness and consists of a uniformly fine felsic tuff, with lesser coarser lithofacies, which are massive to thinly plane bedded. The tuffs are syneruptive deposits that were emplaced via suspension sedimentation (non-erosive) and mass flow (erosive). Bedding within the tuffs is finer and better developed towards the top of the interval. The tuffs are intercalated with mafic tuffs of the overlying Threehouse unit indicating a conformable transition to mafic volcanism. A monolithic rhyolite breccia bed within the intercalated mafic and felsic tuffs is a mass flow deposit derived from over steepening/collapse of the nearby Ghost rhyolite dome and is the time-stratigraphic equivalent of the Lost-Ghost VMS deposits. A 50 m thick, synvolcanic basalt sill, with well-developed peperite along its upper and lower contacts, intrudes the base of the Threehouse unit. The Threehouse mafic tuff and plagioclase ± pyroxene crystal tuff, products of violent, phreatomagmatic to magmatic pyroclastic eruptions, are thinly to thickly bedded and based on an interval containing abundant trough-hummocky cross beds, symmetrical ripples with mud drapes, and accretionary lapilli define an upward shoaling to inter-tidal environment, that abruptly reverted to a deeper water environment. The Lost and Ghost deposits are interpreted to have formed within a shallowing marine basin (cauldron) that was undergoing subsidence and during a relatively quiet volcanic hiatus marked by the deposition and resedimentation of felsic tuffs, and con-commitment dome growth that preceded voluminous mafic pyroclastic volcanism and renewed subsidence. The hydrothermal fluid that formed the VMS deposits may have boiled. **(*SS6, Thurs. 9:20*)**

Mineralogy, metal zoning and genesis of the Cambrian-Ordovician Zn-Pb-Cu-Ag-Au Lemarchant volcanogenic massive sulphide (VMS) deposit, Newfoundland

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The Lemarchant deposit, located in the Tally Pond volcanic belt, Newfoundland, is a bimodal felsic volcanogenic massive sulphide (VMS) deposit with anomalous gold, silver, and epithermal suite elements (*i.e.* As, Sb, Ba, Ge). Currently, the deposit has a geological resource of 2.58 Mt at 0.49% Cu, 4.51% Zn, 1.01% Pb, 54.62g/t Ag, and 1.00 g/t Au. The roughly stratiform massive sulphide zone and underlying stockwork zone comprising the Lemarchant deposit are hosted in footwall rhyolite breccia, flows and volcaniclastic rocks, and are overlain by a dominantly exhalative pyritic mudstone. The stratiform massive sulphides are divided into 3 mineral assemblage types. Type 1 mineralization consists of barite, massive red (high-Fe, <7 mole%) to white (low-Fe, <1 mole%) sphalerite, recrystallized fine-grained pyrite, galena and chalcopyrite. Type 2 mineralization cross-cuts the lower type 1 mineralization and is subdivided into thin Type 2a bornite-galena-stromeyerite stringers and thick Type 2b bladed barite-coarse-grained tetrahedrite-galena-colusite-electrum stringers. Type 3 stockwork mineralization is found below type 1 and type 2 assemblages and consists of orange sphalerite-chalcopyrite-euhedral pyrite stringers. Sulphur isotope values ($\delta^{34}S$) are relatively lower in galena, pyrite and chalcopyrite from the type 2 assemblages than the upper type 1 and type 3 assemblages. Type 2 assemblages are enriched in trace elements relative to type 1 and type 3 assemblages, and are zoned from proximal As-Cu-bearing sulphosalts to more distal Sb-Ag-bearing sulphosalts. Lead isotopes in galena indicate that lead in the hydrothermal fluid was derived from a mixture of eroded continental crust and depleted mantle material. Paragenetically, deposition began with type 1 sulphides, followed by deposition of type 2a and penecontemporaneous type 2b mineral assemblages. Type 3 sulphides were deposited last, with coincident zone refinement and recrystallization of the stratiform massive sulphides. The low-Fe sphalerite, low $\delta^{34}S$ sulphides and epithermal suite sulphide mineral assemblage (*i.e.* tetrahedrite, bornite, colusite, electrum) in type 1 and type 2 assemblages suggest that mineralizing fluids were likely low temperature (<250°C), oxidized and had high sulphur activity; hydrothermal fluid conditions especially suitable for gold transport and deposition. The type 3 assemblage is indicative of relatively higher fluid temperatures (>300°C). A direct contribution of magmatic volatiles to the hydrothermal fluid may have been responsible for the contribution of lead isotopes to the Lemarchant deposit from a depleted mantle source and for trace element enrichment of the type 2 assemblages, and might provide an explanation for the lower $\delta^{34}S$ values found in these assemblages. **(*SS14, Fri. 8:20*)**

Using process ichnology for high-resolution sequence stratigraphy

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Trace fossils have proven to be useful in sequence-stratigraphic analysis. Ichnological applications in sequence stratigraphic analyses have centered on the use of substrate-controlled ichnofacies to identify strata-bounding discontinuities. It has been also demonstrated by many workers that trace-fossil assemblages can be used to assess relative salinities, sedimentation rates, episodicity of sedimentation, duration of colonization windows and overall oxygenation at the time of sediment colonization. Taken as a whole, trace fossils thus provide the requisite information to identify discontinuities as having a transgressive or a regressive nature. In marginal-marine settings, trace-fossil assemblages reflect highly variable depositional conditions, so the sequence-stratigraphic resolution resulting from the ichnological analysis can be exceptional.

This work focuses on characterizing the character of transgressive and regressive ichnological patterns in embayed and sheltered settings. In proximal locales, transgressive deposits are typically dominated by high-diversity assemblages of trace fossils that range in size from 1mm to 50mm in diameter. These assemblages comprise many common marine trace-fossil forms and, because sedimentation rates are lower, bioturbate textures can be highly reworked. Regressive deposits contain low-diversity to monospecific trace-fossil assemblages that range in size from 1mm to 20mm diameter (there are exceptions to the upper size range). Moreover, by comparing trace-fossil diversity and size trends above and below suspected discontinuities, relatively small shifts in the sedimentary system can be discerned, especially in estuary deposits. Thereby, a surface can be inferred to encapsulate a landward or seaward shift of facies.

This work is supported with examples from Cretaceous strata of the Western Canadian Sedimentary Basin and Pleistocene examples from Willapa Bay, Washington. **(*SS18, Thurs. 9:00*)**

Determining the primary iron precipitate in Algoma-type banded iron formation: Mineralogy and geochemistry of the Sherman Mine, Temagami, ON

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Banded Iron Formation (BIF) is the most widely mined source of iron ore, yet is poorly understood in terms of its genesis and depositional history. This project will examine Algoma-type BIF, an Archean chemical sediment associated with sequences of volcanic rocks and greywacke, considered to be a direct product of hydrothermal venting on the seafloor. Despite decades of mining at the Sherman Mine in Temagami during the 1970s and 80s, little is known about the ore types and their origins other than their classification as Algoma-type BIF. More than 10 million tons of iron ore from the Sherman Mine was excavated from three large open pits. Around 300 massive blocks of ore were left at the edges of the pits from which they were removed, providing an excellent archive of the ore types in the mine. A world-class outcrop of Algoma-type BIF outside the mine has provided samples for studies of Archean ocean chemistry and will be mapped and sampled in detail as part of this project.

Ore types will be categorized by the trace element geochemistry, sedimentary features and mineral composition of more than 200 samples. Of particular interest is whether hematite, magnetite or ferrous hydroxide was the primary iron oxide precipitate and how those minerals have been transformed into the present-day assemblage. These conditions have particular bearing on the redox state of the Archean ocean. We will approach this question using petrographic methods to establish the mineral paragenesis, including links to silicate alteration (*e.g.*, epidote), trace geochemistry (*e.g.*, trace metals and REE as indicators of hydrothermal activity) and isotopic compositions (*e.g.* sulfur isotopes to determine euxinic character of the Archean ocean). Our field mapping in the Sherman Mine has yielded a general ore classification based on the common mineral assemblages observed. Mapping will provide insight into the area's tectonic history when considered alongside archived data from the Geological Survey of Canada. **(*GS5, Poster*)**

Feldspar triclinicity, superheating and mineralization

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The association of hydrothermal alteration and gold mineralization with Archean porphyric felsic dykes swarms is a well-known feature. Examples are abundant in the Abitibi greenstone belt, such as Fenn-Gibbs or Lamaque. It has been frequently observed by the authors, in the course of routine petrographic work, that feldspar phenocrysts from such dykes ("FP" or "QFP") are monoclinic sanidine or anorthoclase, rather than the more usual orthoclase. It is estimated that about 50% of the "QFP" occurrences are apparently sanidine bearing, suggesting an underlying process. Preservation of the high temperature structure of feldspar requires rapid heat dissipation in order to avoid inversion to triclinic feldspar or perthite. In hypabyssal or mesozonal conditions, it requires abundant fluids percolation. Such fluid inflow necessitates permeability, likely by fracturation, as indicated by the coeval pervasive sericite dominated hydrothermal alteration invading in the wallrock of the dyke swarm. Porphyritic felsitic dykes can be seen as the uppermost expression of larger magmatic chambers, linking it with the eruptive complex Superheating evidences are abundant, such as phenocrysts resorbtion, similar to what is commonly seen in rhyolite and dacite.

Feldspars, under magmatic conditions, are monoclinic and form a complete solid solution between albite and orthose. Their inversion into triclinic structure occurs at about 700°C, where microcline and albite end-members exsolve into perthites. Orthose can preserve pseudomonoclinic structure and variable obliquity. The magnitude of this obliquity is potentially related to the cooling history of the intrusion, and is envisaged as a proxy of the cooling gradient.

Recognizing sanidine or anorthoclase from orthoclase can be done under the petrographic microscope, while accurate measurement of obliquity needs time-consuming 5-axis Federov's stage manipulations. The relation between optical obliquity and $d_{(13\bar{1})} - d_{131}$ spacing by XRD are under evaluation, as well is the development of more efficient procedures. The effectiveness of the method is currently tested on a well-documented mineralized system at Osisko's Canadian Malartic deposit. In the event the premise works, it may provide a new tool to test the fertility of porphyritic intrusions. **(*SS3, Wed. 4:00*)**

Keynote (40 min): Orogenic gold: Regional perspectives and space-time correlations

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Orogenic gold deposits represent the main source of gold in deformed Phanerozoic metasedimentary or Precambrian metavolcanic terranes, typically having formed 20-200 million years after their host rock terranes. These deposits are characterized by a post-peak metamorphic timing, changing far-field stresses in a dominantly subduction/active margin setting; structural siting in a metamorphosed fore-arc or back-arc locations; a broad thermal equilibrium with country rocks, as indicated by alteration assemblages and lack of telescoped zonation; hydrothermal addition of K, CO_2, Au, As, Sb, Te, and/or W; low base-metal contents; and broadly similar over-pressured H_2O-CO_2-CH_4-N_2-H_2S ore fluids that commonly undergo phase separation. Differences in the Earth's thermal budget and tectonic processes between the Phanerozoic and Archean explain the greater complexities of the latter, such as spatial overlap of orogenic gold with other deposit types, some giant orogenic gold overprinted by younger metamorphism, and a more episodic nature to ore deposition. Historically, these were relatively high-grade deposits, with gold-bearing quartz-carbonate veins mined underground at grades from 5 to >10 g/t. With any significant increase in gold price, many of these deposits are now mined by large open-pit operations, recovering both high-grade veins and surrounding lower-grade hydrothermally altered country rock that were previously considered waste, or just distal geochemical anomalies (*i.e.*, <1 g/t).

Whereas our ability to measure many parameters of the ore-forming fluid for orogenic gold continues to improve, and a relatively consistent fluid chemistry continues to be recognized, the interpretation of these data remains equivocal. A magmatic hydrothermal model for orogenic gold, although recently coming back into favor in many studies, still is incompatible with geochronological data from many gold-rich regions. Similarly, large gold endowments in numerous juvenile oceanic terranes, indicates an enriched subcontinental lithospheric mantle cannot be the direct gold source in many regions. A crustal metamorphic model remains the most viable ore genesis model that can be applied globally, with sulfur and gold released from prograde metamorphism of pyrite at depth. In Phanerozic terranes, metasedimentary rock sequences are well proven to be an important fluid and metal source; in Archean greenstone belts, it remains unclear as to whether the metasedimentary or metavolcanic rocks were the main source. The giant Cretaceous orogenic gold deposits in Archean terranes of the North China block indicate that, in some examples, the subducting slab or the fertilized mantle wedge must be a metal and ore fluid source. **(*SY5, Wed. 8:00*)**

Carbonatites and alkaline magmas at the margins of the North Atlantic Craton in Greenland: A vital resource of the critical metals

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Alkaline magmas, and associated carbonatites, are recognised as the most important repositories of certain 'critical metals', particularly the Rare Earth Elements (REE) and niobium. The critical metals are those metals used in a range of new technologies, for which demand is increasing and there are potential threats to security of supply. Currently, much of the world's supply of REE and Nb comes from carbonatites and associated rocks, in China and Brazil respectively. In Europe, extensive exploration is ongoing, and major research projects such as EURARE aim to understand the European resources of these metals.

Perhaps the region of greatest interest for REE and Nb in Europe lies in West Greenland, at the margins of the North Atlantic Craton. The southern margin is marked by the Mesoproterozoic Gardar alkaline igneous province, where large alkaline igneous complexes such as Ilimaussaq contain abundant resources of REE and Nb. In this area, carbonatites and lamprophyres offer a 'window' into the mantle sources of the magmas, but have thus far seen limited exploration. In contrast, the northern part of the craton has seen several episodes of alkaline magmatism and emplacement of carbonatites, most notably in the Neoproterozoic and again in the Jurassic, but lacks large alkaline silicate complexes. Two of these carbonatites are being actively explored for the REE and Nb: Sarfartoq (Neoproterozoic) and Qeqertaasaq or Qaqarssuk (Jurassic).

Our previous work has shown that the parental magmas of the Gardar Province were derived from a mixture of sources, including small-degree partial melts from the asthenospheric mantle, and larger-degree partial melts of lithospheric mantle. That lithospheric mantle had been enriched in fluids and a range of incompatible elements during Palaeoproterozoic subduction around the margins of the North Atlantic Craton. This talk will present new work on the Qeqertaasaq phoscorite-carbonatite complex, which contains several pulses of carbonatitic magmatism. The latest intrusions in this complex are highly enriched in the REE and Nb, forming a significant resource of these critical metals. Our ongoing work will compare the Qeqertaasaq carbonatite with Gardar Province carbonatites to understand the mantle sources of critical metal enrichments around the North Atlantic Craton. **(*SS23, Fri. 10:20*)**

Development of a 3D geological model of the Athabasca Basin in the area of the McArthur River and Millennium uranium deposits, northern Saskatchewan, Canada: First step in Footprint detection

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The Paleoproterozoic to Mesoproterozoic Athabasca Basin in northern Saskatchewan, Canada, contains the highest grade uranium deposits in the world. The basin and the underlying deformed and metamorphosed Archean and Paleoproterozoic rocks of the Hearne and Rae Provinces host unconformity-type uranium deposits which are spatially associated with faults that cut the unconformity between the unmetametamorphosed basin-fill sedimentary rocks and the underlying metamorphic basement rocks. The study area, which is the focus of the uranium site component of the CMIC-Footprints Project, is 50 km long by 17 km wide and extends from the high-grade McArthur River deposit to the basement-hosted Millennium deposit, parallel to major NE-SW anastomosing structural corridors. The sandstone in this part of the basin consists of the Manitou Falls and Read Formations, and overlies the boundary between the

Mudjatik and Wollaston domains of the Hearne Province. The initial part of the project has involved the compilation of various public domain datasets in GoCAD™ and the construction of nearly 200 NW-SE to WNW-ESE cross-sections through the basin to the unconformity using geological logs from more than 900 drill-holes. This provides an image of the 3D sedimentary layering and structural architecture of the basin within the area of interest, which will be refined by using legacy geophysical data (courtesy of Cameco) and inversions (*i.e.* gravity, resistivity, EM, and seismic data). The ultimate goal will be the construction of a 3D common earth model integrating various geological, geophysical, geochemical, and petrophysical interpretations to define the footprint of a basement-hosted (Millennium) and unconformity-hosted (McArthur River) uranium ore-system. *CMIC-NSERC Exploration Footprints Network Contribution 026.* **(*SS7, Poster*)**

Tectonic setting and structural control of the polymetallic VMS deposits, Hackett River greenstone belt, Slave Craton, Nunavut, Canada

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The eastern domain of the Archean Slave Craton, located in the northwestern Canadian Shield, comprise the Yellowknife Supergroup which host the Hackett River (HR) greenstone belt (2687 to 2660 Ma), an arc-like bimodal volcanic sequence hosting significant polymetallic Zn-Pb-Cu-Ag-Au volcanogenic massive sulphide (VMS) deposits. The larger VMS occurrences of the HR group are, from west to east, East Cleaver, Boot Lake, Main and Jo deposits. Theses deposits occurences are near the contact between the HR group and the tectonically overlain turbiditic metasedimentary rocks of the Beechey Lake Group (2.65Ma, Burwash Basin). A striking feature of the HR stratigraphy is an overwhelming abundance of felsic pyroclastics, both proximal to VMS deposits and, as well, in distal meta-limestone (*e.g.* calcitic marble).

A particular exploration challenge of the HR district is that it is largely affected by superposed folding and thrusting of all the sequences and by a later post-tectonic brittle evolution. Specific marker-horizons were selected to trace-back polyphased deformation. These are 1) the contact between HR felsic volcanics and the overlying Beechey Lake Group, 2) a gabbro sill intruded in between these two stratigraphic groups and, 3) marble units. Structural field survey and 3D geological modeling using drill hole logs show at least two major sets of ductile folding that affected VMS deposits under mid-amphibolite metamorphic conditions. First (F_1), NNE thrusting of Beechey Lake Group on top of HR Group, results in tight isoclinal folding and tectonic stacking. A strong lineation oriented N220° to N250°, plunging 60° southwest is thus generating a 10 to 1 flattening and stretching ratio. F_1 foliations and lineations are refolded by F_2, which is mainly oriented E-W, isoclinal and overturned to the north, producing regionally, a crescent type interference fold pattern. The second schistosity (S_2) appears to be locally distorted by a late crenulation (F_3). Mineralization is remobilized in fold hinges. Late brittle conjugated structures are affecting the deposits in a dextral Riedel type system. Structural interpretation suggest a complex early active extension, tectonic subsidence of an arc at the eastern edge of the Archean Slave Craton and strong compressionnal D_1 and D_2 ductile deformation followed by late brittle strike slip deformation. **(*SS14, Fri. 2:20*)**

The geochemistry of banded iron formation (BIFs) at the Meadowbank gold deposit, Churchill Province: Implications for the origin of gold mineralization in BIF deposits

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Among mineral deposits in Archean cratons, gold mineralization is important with >20 000 metric tons of gold produced from greenstone belts in 2001. Of the Archean-early Paleoproterozoic gold deposits, several different types of mineralization are known including Algoma-type Banded Iron Formation (BIF) where gold is associated with localized sulfide-facies zones within the regionally extensive oxide-facies. It is commonly accepted that the shale-normalized chemical signature of REE+Y of chert bands in Algoma-type BIFs may reflect one of three processes which may be relevant to the nature and origin of the gold mineralization: (1) direct seawater precipitation, (2) contribution of hydrothermal fluids, and (3) replacement. An essential question in regards to the mineralization is, therefore, whether the gold mineralizing fluids have a preference for one geochemical type of iron formation versus another. In order to assess the relevance of these competing models, we report herein the results of a LA ICP-MS study of chert samples within different Algoma-type BIFs from the Meadowbank deposit (24.5 Mt proven/probable ore reserves grading 2.8 g/t (2011) hosed in the Neoarchean Woodburn Lake Group of the Rae Domain of the western Churchill Province, Canada. This study used 39 carefully selected and characterized (*i.e.*, petrography and SEM-EDS imaging) chert samples from both the main deposit, the Central BIF, and four additional BIFs, the Far West, West, East and Grizzly zones, with data collected using line traverses across the chert bands. The geochemical data, indicate that an ambient seawater signature (characterized by enrichment in HREE relative to LREE, positive La, Gd and Y anomalies) dominates the samples with a lesser hydrothermal component (characterized by a positive Eu anomaly), but that the influence of both crustal contamination and overprinting hydrothermal fluids can also be detected. These initial results indicate that the methodology employed provides a reliable means to assess and interpret the chemical signature of BIFs hosting gold mineralization. In the present case the results for the Meadowbank deposit suggest that chert from mineralized BIF units do not record an unusual chemical signature that may be used as a vector for potential gold mineralization. **(*SY5, Thurs. 9:40*)**

Trace element fingerprinting of hydrothermal magnetite from porphyry Cu-Mo-Au deposits of British Columbia, Canada

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Recent work (Dupuis & Beaudoin, 2011 Min. Depos.; Nadoll *et al.* 2012 Econ Geol) has explored the composition of magnetite as a means of discriminating between various ore deposit types. In this way, magnetite, which occurs in a variety of rocks and settings, could be widely used for mineral exploration in glaciated regions. The trace element composition of magnetite may also bear on the processes involved in its formation. In this study, we explore the range of composition within hydrothermally produced magnetite from five different granitoid-hosted porphyry copper deposits (PCD's) in the Canadian Cordillera. We studied magnetite in a variety of parageneses (disseminated, vein, breccia, replacement) to investigate whether hydrothermal magnetite has specific trace element patterns that differ between deposits, or from other sources (igneous and metamorphic rocks). Laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) shows hydrothermal magnetite from PCD's is nearly pure (~99%) Fe_3O_4 with little solid solution. The main trace elements are Sc, Ti, V, Cr Mn, Ni, Co, Cu, Nb and Sn which covary in abundnace. Hydrothermal magnetite from PCD's can be discriminated from plutonic and volcanic rocks by its relative abundances of Sn and Nb, and to some degree Mn. Other variations in magnetite chemistry (*e.g.*, Mn, V) within different PCD's, however, are related to variations of temperature, oxygen fugacity, host rock composition or ore solution chemistry. **(*SS24, Fri. 9:20*)**

Petrology, geochemistry and age of the Crevier alkaline intrusion (Québec)

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The Crevier alkaline complex, located in the Grenville Province, north to the Lake Saint-Jean, is composed of massive nepheline syenite cut by dykes of layered nepheline syenite, ijolite, and biotite-carbonate bearing nepheline syenite, carbonatites and lamprophyres. The mineralized pegmatitic nepheline dykes crosscut the previous units. Fractional crystallization occur from ijolite towards nepheline syenite, mica bearing nepheline syenite and nepheline and sodalite pegmatites with a progressive Na_2O and Al_2O_3 enrichment *vs.* SiO_2, and a MgO and TiO_2 decrease *vs.* SiO_2. REE similarly increase during differentiation. Carbonatites, formed by liquid immiscibility between carbonate and silicate melts, are more or less contemporaneous with the pegmatite dykes.

The late-grenville age (957.5±2.9 Ma U-Pb age) is linked to a rifting process due to relaxation after the Grenville collision. The Lu-Hf gave a Labrador age of 1700 Ma corresponding probably to the initial extraction age from the upper mantle. **(*SS23, Fri. 10:40*)**

Fluorcalciopyrochlore mineralization within the pegmatitic nepheline syenitic dyke swarm from the Crevier alkaline intrusion (Québec)

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The Crevier alkaline intrusion, located in the Grenville Province (North to the Lake Saint-Jean, Québec), is composed of a massive nepheline syenite cut by dykes of layered nepheline syenite, ijolite, biotite and biotite-carbonate bearing nepheline syenite, carbonatites and lamprophyres. The pegmatitic nepheline dykes swarm oriented N320° crosscuts previous units and hosts the Nb-Ta mineralisation. Three types of fluorcalciopyrochlores have been observed:

- The earliest euhedral fluorcalciopyrochlores show Ti enrichment and occur in micro-nepheline syenite and pegmatitic nepheline syenite.
- They are sub-contemporaneous with fluorcalciopyrochlores exhibiting a Ta enrichment in carbonate-mica bearing nepheline-syenite.
- The largest euhedral fluorcalciopyrochlores (≥ 1mm) are associated with late sodalite rich nepheline syenitic veinlets.

Primary fluorcalciopyrochlores are often associated with Sr bearing fluorapatites, and show always resorbption and recrystallization features indicating that primary magmatic crystals underwent chemical changes during interaction with a F rich fluid. The secondary anhedral fluorcalciopyrochlores occur within late veinlets associated with pyrrhotite, fluorapatite, ilmenite and REE carbonates. The alteration product of the fluorcalciopyrochlores is an acicular unnamed Nb silicate. **(*SS23, Fri. 2:20*)**

Metallogenic and structural study of the « Montagne d'Or » Au deposit, Paul Isnard Sector, French Guyana

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In French Guyana, the "Montagne d'Or" gold mineralization, a mining property of Columbus Gold Corporation, has inferred resources of 5.37 M oz Au at 1.43 g/t. The mineralization is hosted by the Proterozoic Paramaca Greenstone Belt (PGB), a gold-bearing metallogenic province of the Guiana Precambrian shield. The PGB represents the remnant of a volcanic island-arc sequence formed between 2.18 to 2.13 Ga, which has been structured during the Transamazonian Orogeny, interpreted as the result of plate convergence between the West African Craton and the Guiana shield. In French Guyana, the PGB is divided into northern and southern domains separated by tonalite-trondhjemite-granodiorite (TTG) intrusions. Three main tectonic events have been identified, one of them being related to the formation of several pull-apart basins on the northern domain, known as the North Guiana Trough. Three types of gold deposits are recognized within the PGB, (1) gold-bearing conglomerates, (2) orogenic gold deposits, and (3) minor stratiform/stratabound ore deposits. The third (and oldest) type includes the "Montagne d'Or" deposit, which preserved evidence for the three tectono-metamorphic events. Two genetic hypotheses for the origin of gold are under consideration for this deposit, (i) a syn-genetic magmatic origin, and (ii) a late hydrothermal deformation-related origin. We present here a summary of the "Montagne d'Or" geological environment, and of the main features of gold mineralization, and its alteration and structural characteristics.

Preliminary observations indicate that "Montagne d'Or" deposit is hosted by a bimodal volcano-sedimentary sequence bounded to the south by a major, steeply-dipping left-lateral shear zone. The entire rock sequence is affected by a penetrative, E-W trending and south-dipping regional schistosity. At the property scale, the rock sequence is facing southward and seems to define an isoclinal fold. Many minor folds have been observed on drill holes over the area. The orebody is composed of pyrite, pyrrhotite and chalcopyrite with minor sphalerite, magnetite and arsenopyrite. The sulfides mineralisation is polyphased, showing both pre- and syn-deformation patterns, and is marked by three distinct facies, (1) stratiform disseminated sulfides, (2) stockwork sulfide veinlets and (3) tectonically-transposed layers of semi-massive sulfides. Visible gold occurs within chlorite-rich zones or is spatially related to sulfides mineralization. Geochemical interpretations have shown alkali depletion and aluminous rich altered rocks with zonal alteration by iron chlorite surrounded of sericite. Following these preliminary observations, a metamorphosed auriferous volcanogenic massive sulfide is presently envisioned for the "Montagne d'Or" deposit. **(*SS14, Poster*)**

Seep-related microbial carbonate accumulation in the tectonically active Mesoproterozoic Borden Basin (NU)

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The Mesoproterozoic Borden Basin (Nunavut; Nanisivik Zn-Pb district) contains unusual, deep-water dolostone mounds (Ikpiarjuk Formation) that formed during fluid-venting along subaqueous faults. Mounds are hundreds of metres thick, extend for kilometres along mapped faults, and consist of featureless pelagic dolomudstone and benthic clotted dolostone. The faults were active during accumulation of mounds and coeval black shale.

Trace element analysis of the mounds indicates that they formed in an anoxic environment at the base of a stratified water column. Results, from all mounds but one, show REE + Y patterns that are characteristic of Proterozoic seawater. An unusual Eu anomaly, present in most samples, is interpreted to indicate that the basin was restricted and that local weathering-derived solutes influenced the REE composition. Subtle differences in the REE + Y patterns between mounds cannot be attributed to diagenesis or contamination by detrital material. These differences are instead attributed to subtle differences in the vent fluid at different mound locations; it appears that there was little mixing of bottom-water between the subaqueous sub-basins.

The mounds consist of both thrombolitic and massive dolomudstone. The thrombolitic fabric consists of millimetric clots of medium-crystalline dolomite with rare spheroidal micrite microstructures (~ 100 μm; grumeaux) and laminated, irregular patches of micrite; thrombolitic material is interpreted to have precipitated on the seafloor as a direct result of fluid seepage, probably in the presence of microbes. The clots form a framework in which marine isopachous cement lines voids. Cement is bladed and inclusion-rich; in some mounds this cement phase is also hematite-rich. Dolomudstone fills remaining void space in the thrombolite framework and is also present as thick, massive accumulations of featureless dolomudstone in parts of the mounds. The dolomudstone is interpreted to have formed in the water column through the reaction of vent fluids with seawater. The composition of the vent fluid remains uncertain, although the mounds share petrographic features with several types of fluid seeps, including methane seeps, hydrothermal carbonate accumulations, and spring water (tufa) seeps. If the thrombolitic texture present through the mounds is of microbial origin, then these mounds represent a type of benthic microbial community that has yet to be documented in rocks of this age. (***SS13, Thurs. 2:20***)

Environmental effects monitoring using LA-ICP-MS of calcified structures in fish

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Metabolic transformation and tissue re-compartmentalization of trace elements in muscle or visceral tissue limits their use in environmental effects monitoring because they only indicate recent exposure. Biominerals on the other hand are often metabolically inert and typically have incremental mineralized structures formed on time scales from days, to seasons to years. Biominerals can be used to 1) establish background chemical/trace element levels in aqueous environments and 2) monitor environmental changes, sometimes over long periods of time. Otoliths (earbones of teleost fish made of $CaCO_3$) are particularly good at storing a chemical record of a fish's exposure to contaminants and relatively easy to analyze using LA-ICP-MS.

Sr, Ba, Mn, Zn, are detected in many species at the ppm to ppb level, Cu, Pb, Ni, Cr, Cd, Se and Hg are detected at the ppm to ppb level in some species in specific settings. While Mn can be associated with mine waters, Mn is found in otoliths from a wide range of settings suggesting Mn can record both effluence and local redox conditions. Zn, a potential contaminant, is biologically mediated and necessary for growth and reproduction is species specific, so requires careful interpretation. Cu, Pb, and Zn being geochemically coherent, when found together in a specific annulus in an otolith is more likely to indicate exposure to contaminants.

Analytical data from burbot sampled from Great Slave Lake when compared with samples take from Inuvik and Aklavik show burbot in Great Slave Lake have been repeatedly exposed to Cu, Pb and Zn. Grayling otoliths from the Keno Hill silver district, Yukon territories, show a mixed population with significant variations in Mn and Zn concentrations consistent with resident and non-resident fish being exposed to similar histories. Sculpin sampled in Nuuk fiord, Greenland, can be used to establish a regional chemical background for the proposed Isua iron mine. (***SS16, Wed. 9:40***)

Iron oxide copper-gold Systems of the Mazenod Lake region, Great Bear Magmatic Zone, NWT

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The Mazenod Lake region is located in the southern Great Bear Magmatic Zone (GBMZ) between the Proterozoic NICO (gold-cobalt-bismuth) and Sue-Dianne (copper-silver) IOCG deposits. The Mazenod region comprises a series of rhyodacite and dacite ignimbrite sheets and volcaniclastic rocks, associated sub-volcanic porphyritic diorite and monzodiorite intrusions, and regionally extensive granitic rocks of the Marian River Batholith. The area is characterized by a complex and regionally extensive array of hydrothermally altered volcanic and plutonic rocks including varying combinations and degrees of albite, K-feldspar, garnet, pyroxene, actinolite, chlorite, sericite, epidote, allanite, titanite, tourmaline, carbonate, silica, hematite, magnetite and pyrite alteration. The extensive hydrothermal system at Mazenod Lake has several different styles of mineralization exposed locally at surface, including: (1) magnetite and/or hematite breccia and stockwork with or without pyrite ± chalcopyrite, (2) tourmaline breccia and stockwork with or without pyrite ± chalcopyrite, (3) magnetite-chalcopyrite skarn, and (4) disseminated pyrite with minor copper. Locally, enrichments of uranium, cobalt and rare earths also occur in minor amounts. This presentation examines the hydrothermal alteration using petrographic analysis, geochemistry, the analytical scanning electron microscope and field relationships. The principal purpose is to provide a preliminary assessment of the various alteration types and zones present in the region and their paragenetic relationships to each other, potential source intrusions, and to known and potential mineralization. (***SY5, Poster***)

Fluid inclusion and stable isotope evidence for mixing of magmatic- hydrothermal fluids with meteoric water in vein-type Cu-Au-Bi deposits, southern New Brunswick, Canada

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Vein-type Cu-Au-Ag-Bi mineralization in the Caledonian Highlands, southern NB, Canada, is hosted within quartz-carbonate-rich shear zones cutting felsic lithic tuffs, intermediate intrusives and interbedded felsic and mafic flows of the Neoproterozoic Broad River Group. Mineralization in the veins consists of bornite-chalcocite-hematite, coprecipitated with electrum and bismuthinite; ore minerals post-date quartz and REE-rich carbonates in the veins, with later supergene oxidation and hydration of the ores to cuprite-malachite. Wall-rock alteration is characterized by albitization and paragonitization. Replacement of bornite by chalcocite-hematite indicates changes in fluid redox with mineralization progression.

Trails of secondary fluid inclusions in the quartz veins are two-phase liquid-vapour at room temperature. Homogenization occurs by vapour bubble disappearance between 150-270°C for all assemblages; individual assemblages show relatively narrow ranges (*e.g.*, 173-191°C, n=22). Bulk salinities from final ice melting range from 4 to 13 wt% NaCl eq. with individual assemblages showing similarly narrow ranges.

Stable isotope data (bulk separates, and *in-situ* by secondary ion mass spectrometry [SIMS]) for vein-stage quartz ($\delta^{18}O_{bulk}$ = 13.7-15.1‰; $\delta^{18}O_{SIMS\text{-}qtz}$ = 10.8±1.5‰, 1σ, n=32) and carbonate ($\delta^{13}C_{bulk}$ = -4.4 to -4.6‰) combined with microthermometric data rule out unmodified, heated seawater and meteoric water as the dominant fluid components, and suggest that the metal-bearing fluids were magmatic in origin or represented saline formation waters modified through fluid-rock interaction with the host volcanic rocks (calculated $\delta^{18}O_{fluid}$ ~ 6-7‰). However, significant variations in $\delta^{18}O_{SIMS\text{-}qtz}$ are observed within single quartz crystals across growth zones and in massive quartz texturally predating sulfides and gold (from as low as 8.2‰ to 14.8‰ in quartz enclosed entirely within bornite-chalcocite). This indicates either (i) localized mixing of the metal-bearing fluid with low latitude meteoric water (calculated $\delta^{18}O$ = -1.0 to 0‰), or (ii) fluctuations in fluid temperature during vein formation, with the lowest T portions of the vein associated with base metal-gold precipitation, or (iii) both. The isotopic composition of coeval quartz-carbonate predict a crystallization/final equilibration T of vein-stage at ~250-270°C; if inclusions are primary, then a maximum $P_{trapping}$ = ~1.5 kbar, based on the lowest T assemblages, is estimated.

Significant fluctuations in fO_2, fluid temperature or fluid composition during vein precipitation highlight the importance of fluid mixing for mineralization. These characteristics, combined with the style of mineralization, link these deposits in NB genetically to much larger vein Cu deposits worldwide (*e.g.*, Churchill, Davis-Keays, and Mamainse Point, Canada; Inyati, Zimbabwe; Copper Hills, Australia; Messina, South Africa; Cornwall, UK). (***SS3, Wed. 10:20***)

(U-Th)/He thermochronology of Mont-Tremblant, Quebec: Insight into an ancient landscape

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Mont-Tremblant is one of the tallest and steepest peaks (875 m) within the southwestern Grenville Province. It is composed of 1.2 Ga Mesoproterozoic granulite facies orthogneiss and host to a 1.15 Ga AMCG suite. The region is situated at the transition from a thick to thin mantle root and is located off-axis to the Mesozoic Great Meteor hotspot track within the Western Quebec Seismic Zone. Advancements in thermochronology have made it possible to study the cooling and uplift history of the Mont-Tremblant region through crustal depths of <10 km with the application of zircon and apatite (U-Th/He) thermochronometry. Samples were collected along a ~650 m vertical traverse on Mont-Tremblant for age-elevation profiles as well as from the adjacent distal regions. From four equally spaced vertical samples, (U-Th/He) ages were obtained for 20 individual prismatic to elongate subhedral zircon grains and 20 barrel shaped apatite grains. The zircon ages are notably scattered, exhibiting a positive correlation of younger ages with higher effective uranium concentrations (eU). The eU is a proxy for radiation damage within the zircon and can alter He diffusion kinetics. Samples with eU values <300 ppm yield preliminary (U-Th/He) ages of *ca.* 650 Ma at the highest elevation (875 m) to *ca.* 560 Ma at the base (235 m). Apatite ages from the same suite of rocks yield *ca.* 290 Ma at the highest elevation, and *ca.* 190 Ma from structurally low levels. By incorporating the (U-Th/He) data with regional geology into the thermal modeling program HeFTy, viable time-temperature paths for the area can be determined. Resolvable thermal episodes as defined by our data correspond with post-Grenville cooling (Neoproterozoic) or cooling and exhumation of the orogen during rifting and passive margin formation associated with the Iapetus Ocean (Early Cambrian). Moreover, this indicates that the rocks from the area have not experienced sufficient heating (>200°C) to reset the zircon He systematics since the Proterozoic-Cambrian transition. Apatite (U-Th/He) ages of *ca.* 290-190 Ma suggest no significant post-Carboniferous burial and may reflect far-field tectonism related to Alleghanian collision to the east. Surprisingly, neither the cooling ages nor topography were influenced by the hot spot. By combining apatite and zircon (U-Th/He) thermochronometers in one model, we provide a unique look at the low-temperature history of the Mont-Tremblant region and insight into ancient landscapes. **(*SS17, Poster*)**

Keynote (40 min): Experimental alteration of zircon using akali- and Ca-bearing solutions: Metasomatic resetting of the zircon geochronometer during high-grade metamorphism

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In nature zircon is one of the principle accessory minerals used for the dating of geologic processes. As a consequence, the stability of zircon in the presence of various possible metamorphic and igneous fluids under a range of P-T conditions and its subsequent alteration with respect to some of these fluids has begun to be explored experimentally as well as speculated upon in a series of natural studies of metasomatized zircons (see review in Geisler *et al.*, 2007 Elements 3, 43-50). Natural alteration of zircon takes place either via dissolution coupled with overgrowth or via fluid-aided coupled dissolution-reprecipitation (Putnis, 2009 Rev Mineral Geochem, vol 70, 87-124). This process results in the zircon being partially or totally replaced by new compositionally re-equilibrated zircon or a new mineral phase or both.

In this study, fragments (50 to 200 microns) from a large, inclusion-free, clear, light brown, relatively non-metamict euhedral zircon collected from a nepheline syenite pegmatite (Seiland magmatic province, northern Norway) were experimentally reacted in 20 mg batches with a series of alkali-and Ca-bearing fluids plus a Th + Si source (5 mg ThO_2 + $ThSiO_2$ + SiO_2) in sealed Pt capsules at 900 °C and 1000 MPa for 6 to 11 days in the piston cylinder press using a CaF_2 setup with cylindrical graphite oven. Fluids included 5 mg 2 N NaOH, 5 mg 2 N KOH, 10 mg $Na_2Si_2O_5$ + 5 mg H_2O, 1 mg NaF + 5 mg H_2O, and 1 – 5 mg $Ca(OH)_2$ + 5 mg H_2O. In each experiment, the fluid reacted with the zircon. This reaction took the form of partial replacement of the zircon with compositionally altered zircon via coupled dissolution-reprecipitation plus varying amounts of overgrowth. The reacted zircon is characterized by a sharp compositional boundary between the altered and original zircon as well as, in some cases, by a micro-porosity and/or inclusions of ZrO_2 or $ThSiO_4$. LA-ICPMS and SIMS analyses of the replaced zircon indicates that it is strongly enriched in Th, heavily depleted in U, and heavily to moderately depleted in (Y+REE). If YPO_4 replaces (Th + Si) in the system, the altered zircon is enriched in YPO_4 and heavily depleted in Th and U. TEM of FIB foils taken across the reaction front indicate no change in the crystallography of the altered zircon compared to the unaltered zircon. In all experiments radiogenic ^{206}Pb (3 to 5 ppm in the unaltered zircon) is strongly depleted in the altered zircon to below the SIMS and LA-ICPMS detection limits. Hafnium concentrations in the altered zircon retain the same value as in the original zircon. The results from these experiments indicate that zircon can be compositionally altered via alkali- and Ca-bearing fluids via coupled dissolution-reprecipitation processes under high-grade conditions and that their internal geochronometer can be reset due to the massive loss of radiogenic Pb.

In experiments where the zircon was metasomatized in $Ca(OH)_2$ + H_2O, inclusions of baddelyite (ZrO_2) are seen outlining the reaction front between the altered and unaltered zircon. The baddelyite-zircon textures from these experiments replicate similar, highly-localized zircon-baddelyite textures seen in albitized, 2.9 to 2.7 Ga, amphibolite- and granulite-facies granitoid rocks from SW Greenland (Windley and Garde (2009) Earth Sci Rev 93, 1-30). Here Ca was released into the fluid during the albitization of plagioclase. Baddelyite should not be stable in the presence of SiO_2 (present in both the experiments and in the granitoid rocks) but rather react with SiO_2 to form zircon. However, if sufficient Ca is present in the fluid, it appears to complex with the SiO_2 as $CaSiO_3$ thereby lowering the SiO_2 activity such that baddelyite is stable with co-existing zircon and quartz. The experiments also demonstrated that, with sufficiently high enough concentrations of SiO_2 in the fluid, not all of the SiO_2 will complex with Ca allowing for the activity of SiO_2 to remain at 1. In this case baddelyite did not form in or with the altered zircon. **(*SS20, Wed. 8:00*)**

Detecting and mapping gossans using remotely-sensed data: A review

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Gossans are surficial deposits that form by the oxidation of sulphides in host rocks where acidic and oxidizing fluids are available. In a classic gossan profile, primary sulphides are replaced by iron-bearing pseudomorphs such as ferrihydrite, goethite and jarosite. The soils typically accumulate as surficial deposits and form an oxide cap. Most gossans have a distinct colour ranging from red to orange to yellow due to the presence of ferric iron and in some cases can be black due to weathering of manganese oxides. Gossans are important vectors to buried ore deposits but they also impact the polar environment if the resulting acid solution transfers transition metals into the permafrost and local catchment basin.

Remote sensing can be used not only to detect and map gossans but, with the advent of hyperspectral imaging, uniquely identify iron-bearing minerals. This presentation reviews image processing techniques developed for detection and identification of gossan mineralogy using a variety of moderate resolution spectral/spatial sensors as well as more advanced high resolution instruments. A number of northern Canadian study areas will illustrate these image processing techniques. In addition, ground and laboratory spectra of the various iron-bearing minerals are used to compare and verify the signatures derived from the remotely sensed data. **(*SY4, Wed. 8:40*)’**

Keynote (40 min): A comparison of different remotely sensed data for classifying lithology in Canada's Acrtic: Application of the Robust Classification Method and Random Forests

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Over the past three decades, the increasing availability of space-borne sensors imaging the Earth's surface using increasingly higher spatial and spectral resolutions has evolved geologic remote sensing from being primarily a qualitative discipline to a quantitative discipline based on the computer analysis of digital images. The Geological Survey of Canada under the Remote Predictive Mapping (RPM) project part of the Geo-mapping for Energy and Minerals (GEM) program, Natural Resources Canada, has the mandate to produce up-to-date geoscience maps of Canada's territory north of 600. Classification of remotely sensed data is a well-known and common image processing application that has been used since the early 1970's concomitant with the launch of the first LANDSAT (ERTS) earth observational satellite.

In this study we apply supervised classification using a new algorithm known as the Robust Classification Method (RCM) and a Random Forest (RF) classifier to a variety of remotely sensed data including LANDSAT-7, LANDSAT-8, SPOT- , ASTER and airborne magnetic imagery producing predictions (classifications) of primarily bedrock lithology and quaternary cover in central Victoria Island, Northwest Territories. We compare and contrast these different data types and evaluate how well they classify various lithologies and surficial materials using confusion analysis (confusion matrices) as well as comparing the generalized classifications with the newly produced geology map of the study area. In addition we propose some new ensemble classification methods that leverage the best characteristics of all remotely sensed data used for classification.

Both RCM and RF provide good classification results. However, RF provides the highest classification accuracy because it used all 43 of the raw and derived bands from all the remotely sensed data. The ensemble classifications based on the generalized training dataset showed the best agreement with the new geology map for the study area. **(*SS11, Fri. 8:00*)**

Composition of metamorphic olivine formed by dehydration of serpentine

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Olivine is the most abundant mineral in the upper mantle and olivine in the mantle has a narrow range in composition (De Hoog *et al.*, 2010). Olivine near the surface environments hydrates to form serpentine and magnetite. Hydrated olivine-rich rocks (peridotites) are commonly exposed on the oceanic lithosphere formed at slow spreading ridges. Serpentine formed on the ocean floor are enriched in fluid-mobile elements as they incorporate them from sea water and sediments. These serpentinites are subducted to form secondary metamorphic olivine at ~ 150 m depth in subduction zones. Studies of such secondary olivine in high pressure and ultra high pressure terranes show that the metamorphic olivine has significantly different compositions from mantle olivine.

Samples of secondary metamorphic olivine were collected from the Voltri (Italy), Zermatt (Switzerland) and Western Himalayas. Olivine grains contain significant NiO, as the primary mantle olivine, but the NiO contents do not positively correlate with MgO. The contents of MnO in metamorphic olivine are variably high (<0.43wt% in Voltri, <0.3 wt% in Zermatt and W. Himalayas) compared to the contents (~ 0.1 wt%) of mantle olivine (De Hoog *et al.*, 2010). Arsenic contents vary; 1-15ppm in the Himalayan olivine and 0.1-0.3ppm in the Zermatt olivine. The high values in the former reflect the occupation of high As(V) in the Si site of the precursor serpentine (Hattori *et al.*, 2005). Other notably enriched elements in olivine include Li (<60ppm in Voltri; <1.3ppm in Zermatt), F (<137ppm; <1.9ppm) and B (<23 ppm; <8ppm). Boron isotope compositions of olivine shows significant enrichment in ^{11}B, up to + 23 permil. The values may be compared to the primitive mantle value of less than – 5 permil (Vils *et al.*, 2009). Since olivine is stable under high P and T, secondary olivine can transport ^{11}B, volatiles and other highly incompatible elements into the deep mantle. Furthermore, magnetite in serpentinites are stable during the dehydration reaction and metamorphic olivine commonly contain dust-like fine-grained magnetite inclusions. Magnetite is enriched in high field strength elements and these elements are also transported into the deep mantle together with the host metamorphic olivine. **(*SS24, Fri. 9:40*)**

U-Pb Dating of Fossils

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The geochemistry and isotopic compositions of fossils (bone, teeth) have been used with limited success both as a chronometer to date the time of fossilization and as a proxy for paleoenvironmental conditions. A major challenge in these studies is that original biogenic apatite experiences a number of changes during fossilization and is geochemically modified during diagenesis and post-fossilization fluid-mediated processes. For example, modern bioapatite contains trace amounts of U and Pb (typically < 1 ppm), incorporated during *in vivo* growth, and generally has homogeneous, typically low U/Pb (<0.1). Fossil bone on the other hand is enriched in U (up to 1650 ppm), Pb (up to 40 ppm) and has variable U/Pb ($^{238}U/^{204}Pb$ up to 51,000). If any part of the fossil bone preserves the record of U-enrichment during initial diagenesis, *i.e.* within ~1000 years post-mortem, then the U-Pb method could be a powerful tool to constrain absolute dates for the fossil record. In this study the veracity of U-Pb fossil dates has been evaluated by high-spatial resolution techniques including *in situ* LA-MC-ICPMS and micro-sampling ID-TIMS. The accuracy of the ICPMS analyses was monitored using fragments of Durango apatite characterized to have relatively consistent uranium (13.6-14.9 ppm) and thorium (275-343 ppm) contents, high Th/U (20.2-23.0), and a weighted average ID-TIMS $^{206}Pb/^{238}U$ date of 33.1±0.2 Ma ($^{206}Pb/^{238}U$= 0.005148±31; 2σ; MSWD=0.19, n=3).

Examples of U-Pb fossil dating will be presented illustrating that, at high spatial resolution (on the scale of individual osteons), the ages of fossilization and secondary U-enrichment events can be established. An important finding is that fossil bone can also provide a faithful record of the timing of fluid-mediated U-mobilization events in sedimentary basins. **(*SS17, Wed. 2:00*)**

Semi-metals concentrations in black shales: The development of a new analytical method extraction from humic substances

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Concentrations of semi-metals in organic matter-rich mudstones (black shales, coals and peats) are of interest for a number of reasons: A) They trace important events in Earth's history; B) The semi-metals are associated with ore grades of Ni, Mo and PGE in a few black shales; C) In many magmatic Ni-Cu-PGE deposits the PGE are present as Te, As, Bi or Sb bearing PGM, and the black shales are believed to be the source of S in these deposits, which raise the possibility that they are also the source of the semi-metals; D) Some of the semi-metals such as As are pollutants and their dispersion must be carefully monitored.

The combination of the volatile nature of the semi-metals, the presence of the organic material and their very low concentrations, represents an analytical challenge to developing an efficient analytical method. We have developed a dissolution method for organic rich rocks which is based on a procedure outlined by the International Humic Substances Society (IHSS). This method does not require heating or aggressive acid attack, and does not require long and complex procedures. After the digestion process, the solution can be analyzed directly by ICP-MS. We selected two international reference material black shales (SDO-1; SCHS-1) and our own in house black shale to test the method. The results for As, Se and Sb match working values. For Te and Bi there are no working values to compare, but our obtained results are similar for others black shales in the literature.

	SDO-1					SH-19			
	V (ppm)	SD (1σ)	WV (ppm)	SD (1σ)		V (ppm)	SD (1σ)	WV (ppm)	SD (1σ)
As	61.44	0.38	68.50	8.60		39.42	4.30	21.88	2.15
Se	1.46	0.08	1.50	0.20		2.90	0.62	3.03	1.20
Sb	3.63	0.04	4.42	0.35		1.34	0.08	1.48	0.14
Te	0.13	0.03	nr	_		bld	_	nr	_
Bi	0.12	0.01	<2	_		1.39	0.27	nr	_

V = obtained values bld = below limit of detection
WV = working values nr = non reported SD = Standard deviation

This method of analysis permits us to determine which fraction, organic or clastic, the semi-metals are associated with and it appears that they are found mainly in the organic fraction. Suggesting that, humic substances are main syngenetic agents capable of concentrate semi-metals in black shales, remaining a minor importance for the hydrothermal fluids during the transport and fixation of these elements in anoxic/alkaline sedimentary environments. **(*SS2, Wed. 2:40*)**

Lost, locked out and left wondering: Geotourism challenges

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Several years of practical work in geotourism has revealed significant challenges to the meaningful application of geoheritage ideals—challenges that need to be addressed if geoheritage programs are to have the wished-for impact on public understanding of and interest in earth science. Efforts that fall short can leave tourists both figuratively and literally "lost, locked out and left wondering": figuratively, by language barriers and other failures of communication; and literally, by factors such as park closures, privatization of access and poor site conditions.

Intellectual access to geoheritage depends heavily on the existence of thoughtful, accessible and engaging content that invites visitors to understand appropriate sites. The vocabulary of earth science presents special challenges and so does a penchant for cataloguing rather than storytelling. Professional development and graduate programs in communicating geoscience concepts to the public could help build the necessary skills. Such programs could draw upon the tenets of Plain Language as well as upon research-based best practices for print and multi-media communications.

Physical access can be affected by change of ownership and poor site maintenance or other unwelcoming site qualities. Some of these issues fall into the sphere of public policy—for example, land use frameworks, laws governing trail rights of way, policies that address the sale of public lands, and budget allocations for public park operations. Geoscience societies should be vocal advocates on many fronts for the continued public access on which our geoheritage enterprise depends. **(*SS15, Fri. 10:40*)**

Predicting the geometry of mineralization in shear-zone-hosted orogenic gold deposits

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Shear-zone-hosted orogenic gold deposits in the Archean Superior Province of northern Ontario have several characteristics in common. They typically occur within steeply dipping, regional-scale ductile shear zones where lithological competence differences have produced heterogeneous strain. Although strongly developed mylonitic foliation indicates strain that was dominantly flattening, gold mineralization is not uniformly distributed within the plane of flattening. Instead, mineralization is concentrated in elongate plunging zones. Predicting the orientation, shape and spacing of these mineralized zones is key to exploration success. Defining these elements is also key to development of these deposits.

Both shape and orientation of the mineralized zones is controlled by heterogeneous three-dimensional strain. Steeply dipping mylonitic foliation defines the plane of flattening. Stretching lineations and the long dimensions of sheath folds define the direction of maximum elongation. The direction of maximum elongation in shear zones hosting gold deposits is typically subhorizontal to gently plunging, indicating a dominantly strike-parallel sense of displacement across the shear zone. Subhorizontal displacement across the shear zone may be critical to formation of these deposits by maintaining relatively constant conditions for mineralization over an extended period of active deformation.

The elongated mineralized zones lie within the plane of flattening. They commonly plunge moderately to steeply, and do not lie parallel to the maximum elongation direction. Within the three-dimensional geometry of strain for these shear zones they lie closer to the steeply dipping intermediate principal axis of strain. This geometry suggests large-scale boudinage of competent lithologies as a controlling factor in concentrating gold, with mineralization concentrated in elongate zones lying between and parallel to the long axes of boudins.

The shape and orientation of mineralized zones can be predicted based on strain geometry, and strain geometry can be determined by structural and microstructural analysis. Spacing will be a function of competence differences and the thickness of competent lithologies. The structural relationships observed in Archean gold deposits in northern Ontario may be generally applicable to orogenic gold deposits elsewhere and provide a tool to understanding the geometry of high-grade mineralized zones. **(*SY5, Wed. 9:00*)**

Petroleum potential of the Paleozoic Magdalen Basin in the western Gulf of St Lawrence and Northumberland Strait, Atlantic Canada

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The Magdalen Basin is part of the Upper Paleozoic Maritimes Basin and underlies the southern Gulf of St. Lawrence and adjacent onshore areas in five provinces in eastern Canada. A previous assessment by the Geological Survey of Canada indicates the Maritimes Basin has high potential for conventional oil and gas resources. A new study of marine seismic data in the undrilled western part of the Magdalen Basin is providing additional insights into petroleum potential for offshore eastern New Brunswick and western Prince Edward Island. This region encompasses areas of interest for marine environmental protection and a federal-provincial offshore petroleum accord.

The Magdalen Basin contains up to 12 kilometres of continental and shallow marine strata, deposited in three main tectono stratigraphic packages: a Lower Carboniferous succession of alluvial and lacustrine clastics in fault bounded subbasins (Horton Group), a widespread Lower Carboniferous succession of carbonates, evaporites and nonmarine clastics (Windsor Group), and a thick Upper Carboniferous-Lower Permian succession of alluvial and fluvial clastics (Mabou, Cumberland, and Pictou groups). Petroleum system elements in the Magdalen Basin include abundant reservoir intervals and large volumes of thermally mature source rocks, including lacustrine shales in the Horton Group and Upper Carboniferous coal measures. Known exploration plays include Horton sandstones in combined structural-stratigraphic traps, Windsor carbonate reefs, and Upper Carboniferous sandstones in salt structures or inversion folds.

In the offshore western Magdalen Basin, Horton strata are variably preserved, with thick sections indicated in seismically mapped subbasins. Windsor and younger strata comprise a more uniform, westward thinning succession. The most prospective petroleum plays in the study area are associated with strata within or above the Lower Carboniferous subbasins.

Producing oil and gas fields in onshore New Brunswick (Stoney Creek and McCully) provide petroleum-system models for the Horton Group play. Gas chimneys, seafloor pockmarks and other hydrocarbon indicators interpreted in marine seismic data provide indirect evidence of petroleum migration and entrapment in the western Magdalen Basin. **(*SS12, Fri. 9:40*)**

Quaternary stratigraphy and till provenance of a thick drift area, central Nunavut with implications for drift prospecting

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Mineral exploration in glaciated terrains is shifting to deeper targets, sometimes under thick sediment cover with multi-till stratigraphy overlying altered rocks. This represents an important challenge and drift prospecting approaches need to adjust to this change by integrating surface and subsurface data as well as the recent advances in glacial geoscience and mineral exploration. Understanding the Quaternary stratigraphy of a prospective region and relating it to the surficial glacial record is an important step towards the successful application of drift prospecting in areas of thick drift. This study focuses on an area southeast of Aberdeen Lake, a region of central mainland Nunavut characterized by crosscutting glacial streamlined landform flowsets and near continuous till blanket. Detailed logging of 62 continuous cores of Quaternary sediment from Cameco Corp., totaling over 1000 m, facilitates in a major way the study of the Quaternary record of this remote region. Detailed sedimentological and stratigraphic analyses of these cores are coupled with mapping of outcrop ice flow indicators, river bluff investigation, remote mapping of glacial lineations and clast analysis to understand the glacial dynamics and till provenance of the region. Ice flow indicator mapping across the study area reveals a complex ice flow record reflecting the migration of the Keewatin ice divide. Core logging reveals variable Quaternary sediment thickness throughout the study area, with till thickness reaching a maximum of 37 m. This investigation has revealed multiple till units over drilling targets with varying till provenance reflecting the complex surficial ice flow record. Despite the complex stratigraphy, it is interpreted that northwesterly ice flows are responsible for the majority of the till production. These findings are being incorporated into tracing dispersal trains in 3D from known subcropping alteration zones associated with uranium mineralization and will have future implications for drift prospecting in the region. **(*SS22, Thurs. 9:40*)**

Preliminary geochemical analysis of the Nipigon Bay granites, northern Lake Superior

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The Neoarchean granitic basement to exposed, overlying Mesoproterozoic Sibley Group sedimentary rocks in Nipigon Bay, northern Lake Superior, was first identified by diamond drilling in 1997. A series of three, prominent magnetic anomalies delineates these magnetite-bearing granitoids in the subsurface. These granitic intrusions occur at a confluence of three regional-scale structures: the northeast-trending Gravel River fault; the north-northeast-trending Jackpine River fault; and the west-southwest-trending North Shore fault, which forms the base of the Osler Group volcanic rocks of the Mesoproterozoic Midcontinent Rift.

Granitic rocks underying Nipigon Bay are characterised by enriched LREE (La/Smn = 2.9 to 7.7) and flat to weakly fractionated HREE (Gd/Ybn = 1.4 to 3.1) with pronounced negative Nb anomalies (Nb/Nb* = 0.1 to 0.2). The granites are metaluminous and when compared to other granite suites in the area, the Nipigon Bay granites most closely resemble the I-type granites of the Dog Lake chain rather than the S-type Neoarchean granites of the Pukaskwa batholith and nearby Georgia Lake area, or the Mesoproterozoic anorogenic English Bay granites in the Nipigon Embayment.

The granites of the Dog Lake chain, 80 km west-southwest of Nipigon Bay, appear as a series of distinct aeromagnetic "highs" along the southern boundary of the Quetico subprovince. They have been interpreted to have formed within a suprasubduction mantle and were subsequently emplaced along crustal-scale faults that form terrane boundaries. Similarities in geochemistry, magnetic signature and regional tectonic setting suggest that the Nipigon Bay and Dog Lake granites may have formed in a similar manner. Recently, however, the Trout Lake Intrusion in the Dog Lake chain yielded a U-Pb age of 2679 ± 1.6 Ma, whereas the Nipigon Bay granite was dated at 2636 ± 1 Ma. This suggests that the temporal relationship between the granites is more complex than suggested by the similarities in geochemistry. Pending geochronologic, geophysical and geochemical analyses of granitoids situated between the Trout Lake and Nipigon Bay intrusions will help to elucidate the temporal relationships and tectonic setting of these intrusive rocks. **(*SS5, Wed. 3:20*)**

Textural and compositional constraints on re-equilibration processes of hydrothermal magnetite from iron skarn deposits

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Recent studies have raised concerns that magnetite could be re-equilibrated with subsequent hydrothermal fluids, forming secondary magnetite domains during re-equilibration processes (*i.e.*, the dissolution and re-precipitation process). New textual and compositional data of magnetite from seven iron skarn deposits ranging in age from Paleoproterozoic to Cenozoic are presented to further demonstrate such processes. BSE images show that magnetite grains from most deposits have been replaced due to re-equilibration processes, including the dissolution and re-precipitation process, and oxy-exsolution process. The former is the majority process and exists in most of the magnetite samples, whereas the latter occurs only in the high Ti magnetite, accompanied by the Fe-Ti oxide inclusions. Some of the high Ti magnetite grains are also re-equilibrated by the subsequent dissolution and re-precipitation process. In addition, magnetite grains from some samples have the triple junction texture which demonstrates that they have been recrystallized and completely replaced by late hydrothermal fluid. Thus, it is likely that some magnetite grains from iron skarn deposits represent the final product of the mineralization, with the precursor phase being completely obscured during the re-equilibration processes. EMP data of magnetite shows these re-equilibration processes have significantly modified the composition of trace elements of magnetite, particularly Si, Mg, Ca, Al, Mn, and Ti. Indeed, analyses of secondary magnetite from skarn deposits are partly plotted in the field of IOCG and porphyry deposits in the Ti+V *vs.* Ca+Al+Mn diagram. Thus, geochemical characteristics of secondary magnetite of the skarn deposits may not be applicable in distinguishing from high Ti magnetite from porphyry, and Kiruna deposits. Mixing of external saline fluids, local decreasing of pH and pressure have been considered the potential causes for the dissolution and re-precipitation process. In addition, primary magnetite from some skarn deposits has also larger variation of compositions than previously thought, and some samples are spuriously plotted in the field of BIF deposits in the Ti+V *vs.* Ca+Al+Mn diagram. Our studies show that textures and compositions of magnetite could well record such re-equilibration processes, suggesting textural characterization should be conducted before *in situ* compositional analysis of magnetite grains and is unlikely to discriminate different type of ore deposits using the Ti+V *vs.* (Ca)+Al+Mn diagram. **(*SY6, Fri. 3:00*)**

Titanite as a record of magma mixing in the Mangling granitoid pluton, Eastern Qingling Orogen, China: Textural, geochronological, and geochemical evidence

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The Mangling plutonic granitoid complex is located at the south margin of the North China Craton (NCC). This pluton consists mainly of monzogranite with lesser diorite, and contains abundant mafic microgranular enclaves (MMEs), providing an excellent opportunity to study magma mixing and its role in the formation of the granitic pluton. In this paper, we present *in situ* analysis of U-Pb isotopes and trace elements of titanite from the MMEs and the host monzogranite, using Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICPMS). Titanites from the MMEs (type 1) are typically rhombic to sphenoidal in shape with simple zoning, whereas the equivalents from the host monzogranite are euhedral to subhedral crystals and can be classified into two varieties (type 2 and type 3). Type 2 titanite has oscillatory or sector zoning without Fe-Ti oxide inclusions which is the dominated type of titanite in the monzogranite, whereas type 3 titanite commonly have Fe-Ti oxides inclusions in the core, which are rimmed by overgrowths with weak oscillatory zoning. Titanite grains of the three types yield indistinguishable U-Pb ages of 148 ± 1 Ma (type 1; MSWD = 0.93), 149 ± 1 Ma (type 2; MSWD = 1.7) and 147 ± 1 Ma (type 3; MSWD = 1.2). The reproducibility of the titanite U-Pb ages is consistent with the coeval formation of the MMEs and the host granitoid intrusion, thus demonstrating a magmatic, rather than extraneous or restitic origin for the MMEs. Titanite grains from the MMEs (type 1) have much lower Al_2O_3, Fe_2O_3, REE, Nb/Zr, Y/Zr and Lu/Hf, but higher (Ce+Nd)/Y and La/Ce ratios compared to the varieties from the monzogranite (type 2). This composition difference indicates that titanite grains from the MMEs and the host granitoid intrusion crystallized from melts of different origin. Type 3 titanite with Fe-Ti oxide inclusions is characterized by dissolution and regrowth textures; its core have trace element compositions similar to the type 1 and rim similar to the type 2 titanite. The compositional variation observed in the type 3 titanite indicates that titanite grains were re-equilibrated with high temperature, mafic magma and then continued to crystallize in the granitoid magma with low fO_2. The textural, geochronological, and geochemical data of titanite grains are best interpreted as evidence for magma mixing. It is therefore concluded that both the fine-grained MMEs and the host granitoid intrusion are hybrid products of mafic and felsic end-magmas. **(*SS20, Poster*)**

Application of Canadian Geoscience Maps: Susceptibility of terrain and geohazards to extreme weather and climate change; and vulnerability of natural resources and critical infrastructure in northeastern British Columbia

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Future changes in permafrost regime, landslide activity, surface and groundwater conditions, magnitude and frequency of flooding, wind erosion and other geohazards positively or negatively affect our ability to access both existing and potential mineral and energy resources in Canada's North. Mitigation and adaption to future extreme weather and climate change will require innovative geotechnical and cultural solutions based on fundamental geoscience knowledge. New digital Canadian Geoscience Maps include critical information on surficial and bedrock geology, landforms and geohazards. Maps and databases are useful tools for assessing the susceptibility of terrain to geological hazards, and the vulnerability of natural resources and infrastructure to extreme weather and climate change. For the Maxhamish Lake map area (NTS 92O), northeastern British Columbia, three terrain susceptibility classes are recognized. Least Susceptible Terrain is blanketed by till, bedrock and eolian deposits on gentle to moderate slopes, and modified by two or fewer active geomorphic processes. Existing and potential natural resources and infrastructure in classified polygons are expected to be largely unaffected by geohazards influenced by extreme weather and climate change. Moderately Susceptible Terrain is blanketed by alluvial, organic and glaciofluvial deposits, and modified by up to three active geomorphic processes. Existing and potential natural resources and infrastructure in classified polygons are expected to be somewhat vulnerable to the impacts of geohazards triggered by extreme weather and climate change. Highly Susceptible Terrain is modified by up to four active geomorphic processes, and includes organic and glaciolacustrine sediments with sporadically discontinuous permafrost, and colluvial deposits derived bedrock and surficial deposits on moderate to steep slopes. Existing and potential natural resources and infrastructure in classified polygons are vulnerable to the impacts of geohazards triggered by extreme weather and climate change. When used by government agencies, industrial and academic partners, land-use decision-makers, elected officials, communities and other interest groups, this Terrain Susceptibility Map will help to reduce the risks for sustainable investment, exploration and development of natural resources and critical infrastructure in this part of Canada's North. **(*SS9, Thurs. 8:40*)**

Instrumental monitoring, terrain mapping and geophysical investigations of an active landslide near Ashcroft, British Columbia: Tools to better understand, engineer and manage the risks of railway ground hazards

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Landslides in the mountain valleys of western Canada have challenged the development and operation of railways since the late 19th Century. In the 21st Century, pronounced economic and environmental repercussions can occur when rail service is disrupted by landslide activity. A vital section of the national railway transportation corridor runs through the Thompson River valley in southern British Columbia. This is a unique area where complex glacial geology, active geomorphic processes and rail infrastructure intersect and are affected by a history of slope instability. To better understand and manage landslide geohazards along this section of the railway corridor, an international multi-year project investigating a small, slow-moving landslide that is adversly impacting CN and CPR infrastructure and operation is now underway. Tracks are lifted and ballast is added when needed during the year to accommodate lateral and vertical displacement across the main body of the slide. Sagging is also observed in a lock-block retaining wall separating the main landslide body and toe. An extensive array of innovative monitoring technologies have now been installed and are monitoring activity across the landslide, including: permanent global positioning stations; piezometers and ShapeAccelArray inclinometry in observation wells; fiber Bragg grating and Brillouin optical time domain reflectometry networks on the retaining wall; InSAR corner reflectors for RADARSAT-2 interferometry; and ground-based SAR and LiDAR. Field observations and surficial geology mapping provide information on the spatial and vertical distribution of earth materials, landforms and geomorphic processes involved in the landslide. Electrical resistivity tomography, electromagnetic (EM-31, EM-34), ground penetrating radar (50 MHz), reflection, and refraction seismic surveys were undertaken to provide insight into the subsurface nature of the landslide. Knowledge of the internal architecture and composition of the landslide as revealed by field mapping and geophysical surveys is essential for interpreting results from the other monitoring programs. All techniques confirm movement across the main body, with the greatest displacement at the south end of the landslide in the vicinity of retaining wall. This is where geophysical surveys indicate a high relief bedrock surface overlain by a 10 m to >60 m thick package of clay, till and saline groundwater-rich gravel, diamicton and bedrock. Planar physical sub-surface features revealed in geophysical profiles include tabular bedding and terrain unit contacts. Profiles also show discrete curvilinear features interpreted as rotational and translational failure planes in clay-rich beds comprising the main body of the slide beneath the rail ballast and retaining wall. **(*SS9, Thurs. 9:20*)**

From Mars to Earth, non-destructive testing for geochemistry

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Northern ANI is proud to be part of the GAC-MAC 2014 taking place at the University of New Brunswick in Fredericton. Our company provides analytical solutions that are used in a wide range of different industries and the Mining market is one that benefits the most from their use. We will cover the latest development in the use of portable analytical instruments that include X-Ray Fluorescence (XRF), Near-Infrared (NIR) and X-Ray Diffraction (XRD). These technologies will be compared, and benefits and limitations will be investigated. Examples of relevant case studies will be discussed, including but not limited to the Mars Curiosity Rover project.

Our superior suite of analytical equipment provides qualitative and quantitative material characterization for detection, identification, quality control, and process control in mining and mineral exploration. Our portable XRF and XRD analyzers give real time quantitative data for immediate, on-site decision making reducing costs greatly and in the same manner showing a short term return on investment. The utilisation of these instruments gives you immediate element (XRF) and mineralogical (XRD) concentration helping you to quickly decide what the next course of action will be. Their efficiency can be used at any level of a mine development whether at the exploration level, ore grade/process control or environmental sustainability at the mine closure. Their use with GPS-GIS allows real-time mapping, saving substantial time and money.

Our near-infrared (NIR) portable spectrometers are a cost-effective tool for identifying minerals, optimizing processes and managing costs. It allows identification of minerals within seconds and helps to quickly determine material's properties. Analyzing the wavelength from 350 nm to 2500 nm, NIR is especially useful for the identification of clays mineral that can be really useful during metal recovery processes in mining.

Northern ANI provides analytical solutions to improve the efficiency of these methods used in the mining industry. We are focused on the safe, responsible and effective utilization of NIR, RAMAN, XRF and XRD technologies. **(*SY5, Thurs. 2:20*)**

Metallogenesis of the North Australian Element: Links to tectonic evolution

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The North Australian Element (NAE) is one of the most richly endowed cratonic blocks in the world, containing major Zn-Pb, U, Cu-Au, diamond and Au deposits as well as smaller deposits with a range of other commodities. This richness results from a complex tectonic history extending from the Archean through to the Paleozoic.

The NAE largely assembled before ~1840 Ma through accretion of the Kimberley and Pine Creek provinces from the northwest, the Numil-Kowanyama Province from the east and Aileron Province from the south onto a proto-NAE comprising the Tanami-Tennant and Isa provinces. The last major growth of the NAE occurred during accretion of the Warumpi Province from the south at ~1640 Ma. This overlapped development of the North Australian Basin System along the eastern flank between ~1800 Ma and 1540 Ma. Since then the NAE has been affected by 1540-1500 Ma A-type magmatism, Meso- to Neoproterzoic alkaline magmatic events, and the development of the intracratonic Neoproterozoic-Paleozoic Centralian superbasin, which was terminated by Paleozoic inversion associated with accretion in the Tasman Element to the east.

The oldest significant mineral deposits — VHMS, orthomagmatic Ni-Cu-PGE and REE deposits — relate to convergence and docking of the Kimberley and Pine Creek provinces at

1865-1830 Ma. The ~1850-1845 Ma Tennant Creek IOCG event may relate to convergence of the Aileron Province. Small VHMS (1810-1765 Ma) deposits and, possibly, the Tanami and Pine Creek lode gold provinces (1810-1795 Ma) relate to north-dipping subduction along the southern margin of the NAE. Syn- to post-collisional magmatism associated with the Strangways event, which terminated subduction, produced widespread but relatively minor W-Mo and Sn deposits at 1740-1720 Ma.

Development of the North Australian Basin System was accompanied by U (1740-1610 Ma) and Zn-Pb (1690-1575 Ma) events, many of which correspond in time to bends in the apparent polar wander path. The last Mesoproterozoic mineralising events in the NAE occurred at 1540-1500 Ma, involving IOCG, sediment-hosted Cu, and apatite-REE-U-Th vein deposits.

Between ~1500 Ma and initiation of the Centralian Basin System at ~850 Ma, mineralisation was associated with alkaline magmatism, including one of the world's the world's largest diamondiferous diatreme at ~1180 Ma. The most recent period of mineralisation accompanied inversion of the Centralian superbasin and included ~360 Ma MVT and ~320 Ma lode gold deposits. **(*SY7, Fri. 2:00*)**

Keynote (40 min): Zinc metallogeny through time: Links to secular changes in the hydrosphere and tectonics, and the supercontinent cycle

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The secular distribution of zinc deposits is episodic and related to the supercontinent cycle and hydrosphere oxygenation. Peaks in deposits hosted by volcanic-dominant successions (*aka* VMS deposits) are associated with supercontinent or supercraton assembly, particularly Kenorland (2740-2680 Ma), Nuna (1900-1760 Ma), and Pangea (550-300 Ma), although no peaks are associated with Rodinia assembly. Outside these periods, formation and/or preservation of these deposits was poor. These deposits form along introverted convergent margins, and this distribution probably results from high heat flow, rapid obduction and a greater likelihood of preservation.

The distribution of stratiform deposits hosted by clastic-dominated sequences (*aka* "SEDEX" deposits) differs from that of volcanic-dominated deposits. Although both are characterized by peaks during Pangea assembly, their Precambrian distributions differ. There are no examples of clastic-dominated deposits before 2100 Ma, and Proterozoic clastic-dominated deposits are associated with breakup, not assembly, of Nuna and Rodinia.

Low temperature deposits hosted by carbonate-dominated successions (*aka* MVT deposits) are mostly associated with Pangea assembly. Precambrian examples are uncommon; none are known before 2100 Ma.

Preserved higher temperature, carbonate-hosted deposits that are coeval with magmatism (skarn and related deposits) are mostly geologically young, generally Tertiary in age, although older deposits (to ~1820 Ma) are known. This distribution may be related to preservation as these deposits commonly occur in arcs that are eroded during later orogenesis.

Most zinc deposits are temporally associated with the assembly of supercontinents, except Rodinia. Zinc deposits not associated with supercontinent assembly are hosted by clastic-dominated successions, which can occur in extensional environments associated with supercontinent stability and break-up. The association with supercontinent assembly is probably related to the presence of magmatic (mostly back-arc, but arc for skarn deposits) and orogenic environments critical to formation/preservation along convergent margins. The lack of deposits associated with Rodinia assembly may relate to the dominance of advancing accretionary orogenesis and extroversion during Rodinia assembly. The lack of clastic-

dominated and low temperature carbonate hosted deposits prior to the early Paleoproterozoic may relate to the reduced nature of the hydrosphere prior to the Great Oxidation Event at ~2400 Ma. (***SY7, Fri. 8:20***)

The Nolans Bore REE-U-P deposit, Northern Territory, Australia: A mineral systems perspective

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Nolans Bore is a REE-U-P deposit (47 Mt grading 2.6% REO, 186 ppm U_3O_8 and 11% P_2O_5) hosted by apatite veins and breccias within the ~1805 Ma Boothby Orthogneiss of the Aileron Province, Northern Territory. Allanite SHRIMP U-Pb analyses indicate a vein crystallisation age of 1525±40 Ma, but mineral system processes necessary to the development of the deposit commenced before 1800 Ma and continue today.

Processes leading to the formation of Nolans Bore began with north-dipping subduction along the south margin of the Aileron Province at 1820-1750 Ma, producing a metasomatised, volatile-rich lithospheric mantle wedge. About 200 Ma later, towards the end of the Chewings Orogeny, this reservoir became a source of alkaline low-degree partial melts which passed into the mid- and upper-crust. Among these alkaline products was a phosphate-rich magmatic-hydrothermal fluid which deposited the Nolans Bore apatite veins by local fluid-rock interaction and/or fluid mixing at ~400°C.

The deposit then became a radiogenic heat source, owing to its size and high concentration of Th, raising the local ambient temperature to ~300°C, above the closure temperature of some mineral isotopic systems. For example, vein apatite U-Pb ages are in the range ~1240 to ~960 Ma, significantly younger than initial emplacement. The system finally cooled below 300°C (the ^{40}Ar-^{39}Ar closure temperature of biotite) at ~370 Ma, possibly in response to unroofing during the Alice Springs Orogeny.

Subsequent to surface exposure, weathering of fluorapatite produced acidic fluids and intense, near-surface kaolinitised zones that form high-grade, supergene-enriched cheralite-rich ores. This groundwater-mediated process continues today.

The local heat production of Th- and/or U-rich deposits is an important feature that may be partly responsible for the arrays of post-emplacement isotopic ages which characterise such mineral systems. Other physical and chemical processes continue to be generated by the high abundances of reactive and heat-producing elements at Nolans Bore, with significant effects on the economic, isotopic and geochemical characteristics of the deposit and its host, an observation that may apply to other such deposits. (***SS25, Thurs. 4:00***)

West African/South American origin for the European Variscan

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The Variscan Orogen in western Europe, which preserves the late Paleozoic suture between Laurussia and Gondwana, has a circuitous trace including very tight, large-scale folds (‘oroclines’). Hypotheses to explain its form include deformation around promontories on the colliding continental margins, lateral extrusion from within the collision zone, deformation in a transform zone between orthogonally-converging zones in the Mauritanides and the Urals, and deformation of a former ribbon continent that lay between the two converging supercontinents. Continental collision in the European Variscides was well under way by 350 Ma, but convergence in the Mauritanide/Alleghenide sector continued until 250 Ma. Paleomagnetic data for the interval 310-250 Ma show that the relative positions of the two supercontinents are not well constrained, but that the continents were probably not sutured until 250 Ma. First contact between the continental margins was therefore followed by a long period of relative motion. Any significant relative motion between the supercontinents in this interval would, because of latitudinal constraints imposed by the paleomagnetic data, have required a dextral component, and this is strongly supported by widespread evidence of dextral shear along the orogen. Dextral shear would potentially transport terranes westward on the Laurentian margin – which is clearly evident in the geological record - and eastward on the Gondwana margin. The almost complete absence of Paleozoic continental-margin assemblages of northern Gondwana in the Mauritanides west of the Moroccan Meseta requires either that all were thrust over the continent and subsequently eroded, with no trace of them preserved, or that they have been transported along the orogen. Given the arguments above, any such transport would likely have been eastward with respect to Gondwana. I suggest that the tortuous form of the Variscan belt in Europe arises from detachment of the northern margin of Gondwana in a dextral transpressional environment, and its transport eastward along the convergent orogen. The detached margin, probably initiated along zones of weakness in the margin developed during protracted rifting in an upper-plate environment, would have had a ribbon-like form, and been susceptible to the folding evident in the oroclines. This scenario would require that much of the European Variscan comes from significantly west of where it is now, so that a possible source of Grenville-age zircons in some of the detrital rocks of the Gondwana margin may have been Grenvillian terranes in South America rather than in eastern north Africa. **(*SY3, Wed. 4:00*)**

The Canadian Space Agency Planetary Analogue Materials Suite

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The Canadian Space Agency has recently commissioned the development of a suite of over fifty well-characterized planetary analogue materials. These materials are terrestrial rocks that are similar to rocks known or suspected to occur on the lunar or martian surfaces. These include: Mars sedimentary, hydrothermal, igneous and low-temperature alteration rock suites; lunar basaltic and anorthositic rock suites; and an impactite rock suite featuring samples from the Haughton, Lake St. Martin, and Mistastin impact structures.

Representative thin sections of the materials have been characterized by optical microscopy and electron probe microanalysis (EPMA). Modal mineralogy has been measured using Rietveld refinement of high-resolution powder X-ray diffraction (XRD) data. Reflectance spectra have been collected in the ultraviolet, visible, near-infrared and mid-infrared, covering 0.2-25 µm wavelength. Thermal infrared emission spectra were collected from 5-25 µm. Raman spectra with 532 nm excitation, and UV fluorescence spectra with 365 nm spot lamp excitation were measured. Bulk chemical analysis was carried out using X-ray fluorescence, with Fe valence measured by wet chemistry. Chemical and mineralogical data were collected using a field-portable Terra XRD-XRF instrument similar to CheMin on the MSL Curiosity rover. Laser-induced breakdown spectroscopy (LIBS) data similar to those measured by ChemCam on MSL were collected using a LIBS instrument at MBP robotics. Three-dimensional laser camera images of rock textures were collected for selected samples.

Sample powders (at <45 µm and 1000-45 µm grain sizes), thin sections, and bulk rock samples will be made available to the research community through the CSA. All analytical data collected as part of the initial characterization and description are also available through CSA.

The CSA planetary analogue material suite is a new resource for planetary scientists. We envision many potential applications for these materials in the development and testing of new analytical devices for use in planetary missions and the calibration and ground-truthing of remote sensing data sets. **(*SS21, Poster*)**

Geology of the banded iron formation-hosted Meadowbank gold deposit, Nunavut, Canada

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The Meadowbank banded iron formation (BIF)-hosted world-class gold deposit is hosted in the polydeformed and metamorphosed *ca.* 2711 Ma Pipedream-Third Portage volcanic sequence of the Woodburn Lake Group that comprises several similar BIFs, of the most significant of which being the East BIF, the Central-BIF and the West-BIF. Despite their similarity, only the Central BIF contains economical gold mineralization. The deposit host succession consists of greenschist to amphibolite grade intermediate volcaniclastic rocks, BIFs, intermediate to felsic volcaniclastic rocks, mafic and ultramafic rocks, and quartzite. The pronounced negative Nb, Ta and Ti anomalies of the intermediate and intermediate to felsic units indicate an arc-like affinity. Notwithstanding cryptic and strongly overprinted Archean tectonism, four phases of Trans-Hudsonian (Proterozoic) deformation, have been recognized in the Meadowbank deposit area: isoclinal F_1 folds and early shear zones, strongly overprinted by coplanar N-trending isoclinal F_2 folds and associated D_2 shear zones that cut the stratigraphy and mineralized zones. Shallowly to moderately-inclined, open to tight, chevron-style F_3 folds and open to closed SW-plunging F_4 folds further affect the deposit, resulting in a complex polyphase geometry. The bulk of the gold at Meadowbank is hosted in iron-formation occurring at or near the contact with sheared ultramafic rocks and is associated with pyrrhotite ± pyrite and traces of chalcopyrite and arsenopyrite. Gold-rich quartz-pyrrhotite ± pyrite veins are locally present in intermediate to felsic volcaniclastic rocks intercalated with BIFs. The ore-associated mineral assemblages include grunerite/cummingtonite and chlorite in BIF layers, whereas sericite ± chlorite and carbonates dominate in altered volcaniclastic rocks. The metamorphic grade increases southward along the deposit, where biotite, Fe-Mg amphibole and garnet occur in variable proportion. Crosscutting relationships suggest that the bulk of the gold was introduced prior to D_2, preferentially along the sheared contact between BIFs and ultramafic rocks, and was later locally remobilized during D_2. Deposit- and regional-scale lithogeochemistry and new U-Pb zircon ages indicate that the Meadowbank deposit is located at the boundary between two distinct lithological assemblages (2711 Ma and 2717 Ma) separated by long-lived shear zones that potentially have controlled gold deposition and distribution. The study demonstrates that integrated structural analysis, lithogeochemistry and geochronology are essential aspects to understand BIF-hosted gold deposits in order to develop better genetic and exploration models. **(*SY5, Thurs. 9:20*)**

Calcalkaline to alkaline metallogenic transition, from Archean to Present

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Late orogenic period are characterized by a variety of magmatism from calkalcaline to alkaline that are associated with numerous epigenetic gold mineralizations. Although is have been long known for Phaneroic magmatism, the discovery of a strong association of economic gold mineralizations with late Archean intrusions both in the Yilgarn (Australia) and the Abitibi (Canada) terranes have renew the interest for plutonic related hydrothermal systems. Detailed chronology shows that these mineralizations could be associated with both calcalkaline and true alkaline, undersaturated volcano-plutonic systems.

In the Archean rocks of the Abitibi greenstone belt, the transition occurs between 2685 and 2675 Ma, during the formation of Temiskaming clastic basins. Both sanukitoid and alkaline plutons are associated with the deformation along major E-W and NE-SW corridors. The shape

and the magnetic signature of these plutons reveal a syn- to post tectonic emplacement, with a local extrusive component In the Cenozoic, such transition have been studied in the West Mediterranean basin. Calcalkaline magmatism peaks in the Tran-Alboran region at *ca.* 16-15 Ma whereas the main alkaline occurrences emplaced after 6 Ma. The calcalkaline magmatism shows migration in space and time within the West Mediterranean basin. During these transition, a rapid uplit is associated with transtensional to extensional structures, inversion of the stress, and is responsable for abundant clastic sedimentation in intramontane basins.

Numerous gold mineralization are associated with this transition: Late Archean gold is both associated with calcalkaline (Malartic deposit) and alkaline plutons (Beattie, Douay, Lake Bachelor...); Mineralizations appears during the convective hydrothermal events and related to late brittle ductile faulting. In the recent Mediterranean environment, Miocene to recent epithermal gold-silver deposits have been recognized in Toscana, Sardinia, Spain, Morocco, Algeria and Tunisia, associated with calcalkaline calderas and late alkaline plutono-volcanism. Present CO_2 streaming is responsible from earthquake activations that recall the location of Au-bearing secondary faults and regional carbonatation in older orogens.

The transition from calcalkaline to alkaline magmatism reflects the evolution from collision to orogenic collapse, induced by slab breakoff and modification of the geothermal gradient. **(*SS23, Fri. 4:00*)**

Keynote (40 min): The Nuclear Waste Management Organization: Geosciences research and development in Canada

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The Nuclear Waste Management Organization (NWMO) is responsible in Canada for implementation of the Adaptive Phased Management (APM) approach, the long-term strategy for the management of Canada's nuclear used fuel. The APM approach envisions the nuclear used fuel ultimately being emplaced in a Deep Geologic Repository (DGR) in a suitable crystalline or sedimentary geologic setting. In this role, the NWMO manages and directs an APM technology program focused on advancing repository engineering, geosciences and safety assessment techniques and methods as related to the design and safety of a DGR for used nuclear fuel. This presentation will provide an overview of the NWMO's Geosciences Research and Development activities during the last decade. These activities are multidisciplinary in nature and broad in scope with intent to advance the understanding of deep seated groundwater system evolution and stability at time frames relevant to DGR safety in low permeability sedimentary and crystalline environs. The recent application and integration of such Geoscience methods within a recently completed Environment Assessment for a proposed DGR for low and intermediate level radioactive waste within an 840-m thick Palaeozoic age sedimentary sequence beneath the Bruce nuclear site, located in Kincardine Municipality, Ontario is described. **(*SS8, Thurs. 8:40*)**

A multiscale computational approach to link structural geology and tectonics

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Structural Geology is concerned with small structures and fabrics in rocks adopted by their constituent elements in response to deformation. How to use small structures to gain information about past tectonic-scale deformation boundary conditions and rheology has been hampered by the lack of a rigorous framework. Existing models do not capture the rheological heterogeneities in Earth's lithosphere and the resulting variability in deformation history in rheologically distinct domains. A self-consistent multiscale model is proposed to address the heterogeneous deformation and multiscale fabric development in Earth's ductile lithosphere. The model is based on micromechanics, principally an extension of Eshelby's classic work on an elastic inhomogeneity in an infinite elastic solid. Three scales are considered. The tectonic-scale (macroscale) deformation field at a point is represented the average deformation of rock masses of a representative volume element (RVE), which consists of an assemblage of structural-scale (mesoscale) rheologically distinct phases (RDPs). The tectonic-scale rheology is that of the RVE and is approximated by an ideal homogeneous effective medium (HEM) and is obtained from rheological properties of the constituent RDPs by homogenization methods based on micromechanical principles. The interaction between a RDP with HEM is governed by the extended theory. Partitioning, homogenization, and self-consistent equations are derived and solved numerically to obtain the mesoscale, partitioned flow fields, which form the boundary conditions for the development of microscale structures in mesoscale RDPs. This multiscale computational approach is a rigorous link between Structural Geology and Tectonics. An application of the approach to the Cascade Lake shear zone in the east Sierra Nevada of California shows that outcrop scale fabrics of the shear zone suggest a transpressional deformation with the boundary convergence angle of 15°. The strike-slip displacement is about 15 km. Further the strength evolution of the model zone suggests that a transpression zone is a weakening system with respect to the simple shearing component and hardening one for the pure-shearing component. This is consistent with slip partitioning in obliquely convergent plate boundaries – boundary-normal convergence tends to spread over a broad area which boundary-parallel shear tends to localize in major strike-slip zones. **(*GS2, Fri. 2:00*)**

Coseismic damage and strain localization in large displacement, strike-slip fault/shear-zone systems: Observations from near the base of the seismogenic zone

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Large-displacement, seismogenic strike-slip fault zones transition to middle crustal shear zones across the frictional to viscous transition (FVT). Near the surface, these faults are characterized by an unusually extensive damage-zone of fractured rocks with widespread microcracking and fragmentation to the micron scale. These damage zones carry valuable information about earthquake mechanics and near-field rheological response of rocks to seismic energy release, and are important in seismic hazard analysis because they channel seismic waves. Seismological experiments suggest that microstructural damage around these faults diminishes significantly at depths greater than ~5 km. The question arises as to whether or not similar damage continues deeper into the crust, but is rapidly healed at depth making it transparent to seismological investigations. The answer to this question is of fundamental importance owing to the influence of fault zone structure at depth on overall fault strength.

Here we use novel microstructural observations and data from the Paleozoic Norumbega fault system in Maine, USA, to show that coseismic damage can extend to the FVT in large displacement strike-slip faults, but is quickly masked from seismological investigation by microcrack healing and other thermally activated microstructural processes at depth. The shear zone divisions that arise from our microstructural data allow us to propose a correlation with the pattern of damage around active strike slip faults at the surface. In addition, the repeated cycles of damage with intense grain-size reduction, dilatation and fluid flow facilitates localization of viscous deformation. This rheological feedback among different deformational and recovery processes over the earthquake cycle suggests that this cycle may facilitate strain localization in shear zones that floor major seismogenic faults, and this deeper localization may in turn facilitate long-term localization in the brittle upper crust leading to mature seismogenic faults. **(*SY2, Thurs. 9:40*)**

Crustal tilting in the Haida Gwaii: Structural analysis and tectonic implications

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The magnitude 7.7 2012 Haida Gwaii earthquake (HWE) raised questions regarding the seismic risk and tectonic setting of transform Queen Charlotte plate margin. Plate motion models imply a component of convergence in the vicinity of the HWE. Models explaining how the convergence is accommodated include 1) strain-partitioning into orthogonal subduction of Pacific lithosphere (Yorath & Hyndman, 1983; explaining the HWE as a subduction-megaquake), and 2) transpressive distributed shear (Rohr *et al.*, 2000; explaining the HWE as an expression of lithospheric thickening). Complicating the debate are paleomagnetic data (Irving *et al.*, 1992, 2000) showing that Eocene to Miocene dykes are characterized by a primary remanance that yields steep inclinations relative to the cratonic reference pole. Anomalous tilts could reflect local crustal tilting or translation. Near-sided poles require translation away from the pole (to the south). However Eocene strata on Vancouver Island and in Alaska yield concordant paleopoles implying no latitudinal displacement with respect to cratonic North America since the mid-Tertiary, and plate motion models are inconsistent with southerly displacements. N- tilting of the crust by 10° is therefore the preferred interpretation, but begs the questions how was tilting accommodated, and what are the implications for the tectonic setting of the margin. We collected structural orientation data on Louise and Moresby islands from Mesozoic strata, dykes, joints, and veins and brittle shear zones. Our data show that strata were folded and then tilted. Most structural domains are tilted 5 - 10° to the northwest. Dykes dip steeply and strike E-W to NNE-SSW. No systematic pattern was recognized for fracture zones and joints. S- to ESE-dipping brittle shear zones (n=13) are characterized by normal displacement. Our data imply post-Cretaceous tilting of a NW-SE striking fold belt to the N, consistent with the paleomagnetic data. Irving *et al.* explained N-tilting as a product of rotation of domino blocks bound by south-dipping normal faults. Support for their interpretation includes identification of candidate faults, the presence of E-W striking topographic lineaments, and down-plunge projections that show that the crust is divisible into isolated blocks separated by steeply-dipping, E-W striking faults. Modeling of transpressive margins has, however, shown that similar geometries can be achieved by thrusting out of zones of distributed shear. A normal-fault explanation supports a model of strain partitioning (strike-parallel σ1); a thrust-fault explanation supports a model of distributed shear (strike-perpendicular σ1). Microseismic and kinematic data constraining shear sense constitute tests of these models. **(*SY3, Fri. 9:40*)**

Geovisualization of the New Brunswick Coastal Erosion Database on the GeoNB web site

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A large amount of data on coastal erosion and coastal habitats have been and are being produced in New Brunswick since the development of GIS, as part of studies on coastal erosion and/or climate change impacts on the coastal zone. Although coastal erosion rates are now systematically added to the New Brunswick Coastal Erosion Database [NBCED] (Department of Energy and Mines), up to now public access to the data has only been granted upon request or through published maps and reports. It is in this context that a recent initiative to publicise and broaden the use of existing data on coastal erosion and habitats in New Brunswick has been developed, with the collaboration of Service New Brunswick and the financial support of the Environment Trust Fund. A first step of this project will migrate the NBCED on the GeoNB web site (Spring of 2014). The cartographic interface will ultimately grant access to all published erosion rates. Provincial maps showing analogically-derived data or numerically-derived (geomatics) data will also discriminate rates according to the nature of the coast (natural/artificialized) and its evolutionary trend (erosion/neutral/progradation). At larger scales, pop-up windows will provide the following information for every rate : period covered (years and lenght), coast type, reference line used (coastline or shoreline), margin of error, mean provincial rate measured for this coast type; mean regional rates (Chaleurs Bay, Gulf of St. Lawrence, Northumberland Strait or Bay of Fundy) will also be included. When several erosion rates are available for a given location (*e.g.* more than one time period), additional pop-up windows will open successively, showing the rates for intermediate periods (from the most recent to previous ones). Links to access the NBCED (spreadsheet file) and the published documents (maps, reports) for each location will be included. With the growing interest for data on coastal erosion and habitats, the inclusion of the NBCED data to the GeoNB web site is a way to publicise such information to stakeholders and the public. While its content does not have legal force and should be used for information purposes only, the deployment of the New Brunswick Coastal Erosion Database on the GeoNB site is a powerful web-based tool for public education on coastal mobility, coastal hazards and coastal zone management. It is also a way to ensure public access to data that was produced with public funds. **(*SS22, Poster*)**

Oxygen isotopic composition and REE patterns of uranium mineralization at the Kiggavik uranium deposit, Nunavut, Canada

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The Thelon Basin, Nunavut is similar in age, size, and geology to the Athabasca Basin, and may share similar economic potential. Presently, the fluid history and metallogenesis of the uranium deposits associated with the Thelon Basin is poorly known.

Uranium mineralization associated with the Thelon Basin in the Kiggavik area is located immediately south of the current extent of the Thelon Basin. It occurs in a series of deposits that follow a northeasterly trend, within which trend the northernmost deposit is the Kiggavik Deposit, comprising three separate ore zones (Main, Centre, and East Zone). The Main Zone is associated with brittle structures that occur at the interface between a granite and metasediments of the Woodburn Lake Group and the Ketyet Group, while the East and Centre Zones occur solely within these metasedimentary units. The current work is focusing on the mineral paragenesis and fluid history of the Main Zone.

There are three generations of uranium minerals at the Main Zone: Stage 1 uraninite, stage 2 coffinite, and stage 3 uranophane. Although stage 1 uraninite has a wide range of relatively high SiO_2 and CaO contents (2.5 to 7.8 wt%, 2.2 to 4.2 wt%, respectively), there is no correlation between uraninite mineral chemistry and the range in $\delta^{18}O$ values (8.3‰ to 4.7‰). There are two generations of muscovite and three generations of illite. They are: (1) prograde metamorphic muscovite (M1) in the host rocks, (2) a later generation of hydrothermal muscovite (M2), (3) pre-ore, retrograde metamorphic illite (I1) resulting from the alteration of feldspars and muscovite (M1, M2), (4) illite (I2), which is coeval with precipitation of uraninite, and (5) illite (I3) that is coeval with formation of coffinite. The two generations of illite that are coeval with the first two stages of uranium mineralization have significantly different $\delta^{18}O$ values of 0.8 ±2.9‰ (I2) and 13.7 ± 3.7‰ (I3).

Chondrite-normalized REE plots show that uraninite from the Kiggavik deposit has a similar REE pattern to apatite from the host metasedimentary units, whereas apatite from the granite immediately below the deposit is slightly more LREE-enriched. Florencite (REE-phosphate) present at the granite-metasediment contact is even more LREE-enriched and HREE-depleted, relative to metasediment apatite.

Based on our preliminary paragenesis, chemical and isotopic data, the Main Zone experienced two main fluid events: a fluid that interacted with the metasediments above the deposit and precipitated uraninite, and a subsequent event that altered uraninite to coffinite. **(*SS7, Wed. 2:40*)**

Zirconium mobility and constraints on partial melting and melt segregation within the contact metamorphic aureole of the 1.85 Ga Sudbury Igneous Complex, Ontario, Canada

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The geochemistry and microscopic textures of pyroxene hornfels rocks within the southern contact metamorphic aureole of the 1.85 Ga Sudbury Igneous Complex (SIC) record Zr-loss related to partial melting. Fe-rich tholeiitic rocks of the 2.45 Ga Elsie Mountain Formation (EMF) comprise the dominant lithology in the southern footwall of the SIC, and include a ≥ 725 m (true thickness) two-pyroxene zone that can be traced for over 1.5 km along strike. Within *ca.* 500 m of the SIC the two-pyroxene zone is dominantly composed of hornfelses with only minor amphibole present. Based on geochemistry the hornfelses can be subdivided into two subzones: 1) a *ca.* 250 m-thick outer zone characterized by higher Cs-Rb-K and Ba, higher Th-U-LREE and W, and less pronounced negative Zr-Hf anomalies (Zr/Zr* >0.68), and 2) a *ca.* 250 m-thick inner zone characterized by lower Cs-Rb-K and Ba, lower Th-U-LREE and W, and more pronounced negative Zr-Hf anomalies (Zr/Zr* <0.68). Petrographic examination of the samples within the inner zone reveals the presence of semi-continuous *ca.* 10 um wide films of zircon at silicate-silicate, silicate-oxide and oxide-oxide interfaces with low dihedral angles against the surrounding phases (approaching 0°). These textures are interpreted to reflect liberation of Zr either via exsolution from or melting of Zr repository phases during high temperature metamorphism. While some Zr was mobilized and lost in partial melts, the rest crystallized as zircon films when melts became Zr-saturated. In combination with the geochemistry, this suggest that the thickness of the zone that records melting and melt segregation on the South Range (at least 250 m) is much greater than that reported on the North Range (~25 m), consistent with the greater thickness of the Main Mass of the SIC on the South Range (~3 km) than that on the North Range (~2 km), and the significantly greater thickness of the pyroxene hornfels zone on the South Range (~500 m) than reported on the North Range (~200 m). Sharp-walled Cu-Ni-PPGE-rich veins in the North Range footwall rocks appear to be restricted to within 200-300 m of the SIC contact, reflecting the maximum depths that molten sulfides could penetrate. Because footwall Cu-Ni-PPGE-rich veins appear to be much less common in the South Range footwall rocks, their emplacement may have been inhibited more by the rheology of the footwall mafic and sedimentary rocks on the South Range than by the thickness of the high-temperature part of the contact metamorphic aureole. **(*SS20, Poster*)**

Identification of uranium sources in alluvial aquifers: An example from the Khan and Swakop rivers, Namibia

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Namibia is an arid country that depends on groundwater for almost 60% of its population. As such the identification of deleterious elements such as uranium and other radionuclides in aquifer systems is of prime importance. The Rossing uranium mine is located on the banks of the Khan River while the Langer Heinrich mine is on the southern bank of the Swakop River. It was important to trace the source of uranium as either from tailings or of natural origin from the rocks in both rivers. This study looked at identifying the origin of elevated uranium (as a trace element as well as a radionuclide) and other radionuclides such as thorium and radium concentrations in the Khan and Swakop River alluvial aquifers. A fingerprinting method was used where the $^{234}U/^{238}U$ and $^{235}U/^{238}U$ ratios were used to distinguish natural from anthropogenic sources for the uranium sources. The $^{234}U/^{238}U$ ratio is above unity (1.3 – 1.7) whereas the $^{235}U/^{238}U$ ratio is 0.045 ± 0.015. All elevated uranium and other radionuclides concentrations in groundwater of the study area are as a result of natural dispersion from the mineralized rock formations rather than results of anthropogenic sources. Uranium increases in the lowest part of Swakop Rivers. There is no gradual change in uranium concentration thus indicating that concentration is related to local factors such as lithology, Eh and pH for each borehole along the two rivers. The secular disequilibrium between elements in ^{238}U decay series is natural due to different fractionation processes that include the decay of radioactive elements. The water in the area is not suitable for human consumption and agricultural usage, as most components such as TDS which has values up to 11123 mg/l and ^{228}Ra which has activities up to 278 mBq/kg exceeded the Namibian and WHO guideline values respectively. **(*SS10, Wed. 2:20*)**

Development of broad crustal flexures as a ductile response to the slowdown of an ongoing NW-shortening trend during the Holkerian and the early Asbian (mid-Viséan) in Atlantic Canada; evidence from basin-fill sedimentology

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Atlantic Canada has been steadily affected by NW-shortening from the beginning of the Devonian until the onset of a clockwise rotation of paleostresses near the Mississippian-Pennsylvanian boundary. Open folds with a SW-NE axis developed during the Early and Middle Devonian Acadian Orogeny, followed by the development of large E-W dextral strike-slip faults in Late Devonian times (the Grand-Pabos and Minas fault systems) in response to the migration of orogenic deformation towards New-England. From then on, in Late Devonian and Mississippian times, Atlantic Canada evolved as a series of pull-apart basins (the composite Maritimes Basin) with high, fault-controlled sedimentation rates except for a brief period in Holkerian to early Asbian times, when fault activity seemingly came to a halt. During this period, sedimentation was sourced not only from basement highs, but also from marginal parts of the early Mississippian basins, and was deposited as a monotonous succession of fine sheetflood deposits (the Tennycape Formation of Nova Scotia and equivalent Poodiac and Cap d'Espoir formations of New Brunswick and eastern Quebec) in broad areas of crustal flexures with a SW-NE axis. This event eradicated much of a formerAtxhly more extensive cover of Arundian (early Viséan) evaporites, which are now mainly constrained below Holkerian to Asbian synclinal depocentres. The broad depocentres of the Tennycape Formation and equivalent units possibly developed due to a temporary slowdown of NW-shortening, which promoted a very gradual ductile deformation, whereas a re-increase of shortening rates resumed brittle deformation and fault-controlled sedimentation during late Viséan and early to middle Serpukhovian times. **(*SS13, Thurs. 4:20*)**

The Archean Côté Gold intrusion-related Au (-Cu) deposit, Ontario, Canada: A large-tonnage, low-grade deposit centred on a magmatic-hydrothermal breccia

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The recently discovered (2009/2010) Côté Gold deposit, located in the Archean Swayze greenstone belt, Abitibi Subprovince is a large-tonnage, low-grade Au (-Cu) deposit with an indicated resource of 269 Mt averaging 0.88 g/t Au (7.61 M oz) and an inferred resource of 44 Mt averaging 0.74 g/t Au (1.04 M oz) at a 0.3 g/t Au cut-off grade. The deposit is hosted by the Chester intrusive complex, a high-level, multi-stage composite intrusion consisting of gabbro, diorite and tonalite; these phases are constrained to 2741 ± 1 Ma based on U-Pb high-precision zircon dating. Field relationships indicate that two leucotonalites occur; tonalite I is cut by diorite whereas tonalite II contains <1% - 40% dioritic enclaves. Tonalite II locally displays autobrecciation and UST textures, chilled contacts and miarolitic cavities. Gold mineralisation is associated with disseminated sulphide and quartz-sulphide ± carbonate vein arrays. A maximum age for this mineralisation, provided from Re-Os dating of molybdenite, including an auriferous sample, is 2739 ± 8 Ma which overlaps with the age of magmatism. Mineralisation is hosted by a multi-phase magmatic-hydrothermal breccia that intrudes tonalite and diorite. The breccia is a largely continuous, discrete body containing variably sized (<1 cm to rarely 1 m) and shaped (angular to rounded), biotite-altered tonalite clasts within a dark, fine-grained hydrothermal matrix (biotite ± amphibole-chlorite-quartz-carbonate ± apatite ± sulphides) or magmatic matrix (plagioclase-quartz-biotite-chlorite ± sulphides). Biotite alteration (biotite ± magnetite ± epidote ± pyrite), the earliest type, occurs as dissemination or veins. Silica-sodic alteration (quartz-albite), a texturally destructive alteration, occurs as vein- and fracture-controlled alteration that coalesces to form a pervasive replacement with rare, localised episyenites due to silica leaching. Sericite alteration (sericite ± quartz ± carbonate ± pyrite) occurs as haloes surrounding veins and fractures and also coalesces into pervasive alteration. Rare, vein- and fracture-controlled propylitic alteration is also documented. This apparent *ca.* 2741 Ma mineralisation age is significant for several reasons: (1) it establishes a new, pre-main stage deformation, metallogenic event in the Abitibi Subprovince; (2) globally represents a rare example of an intrusion-related, Archean-age large-tonnage, low-grade Au deposit; and (3) the nature and style of mineralisation and alteration, and the overlap of magmatic and hydrothermal events suggests possible affinities to younger porphyry-style Au (-Cu) mineralisation, although the paleo-tectonic settings may differ. **(*SY5, Wed. 3:40*)**

Chemical fingerprinting of the Archean Côté Gold deposit: A large-tonnage, low-grade intrusion-related deposit system, Ontario, Canada

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The Côté Gold intrusion-related Au (-Cu) deposit, in the Archean Swayze greenstone belt of the Abitibi Subprovince, is a large-tonnage, low-grade deposit hosted by *ca.* 2741 Ma tonalite and diorite of the Chester intrusive complex which formed in a high-level sub-volcanic setting. The deposit contains a resource (indicated + inferred) of 8.3 M oz Au that is centered on a magmatic-hydrothermal breccia. Mineralisation occurs as disseminations or is associated with quartz ± carbonate vein arrays, and is broadly coincident with biotite, silica-sodic and sericite alteration zones. Lithogeochemical and petrographic/SEM-EDS studies (>600 samples) across the deposit are used to assess the petrogenesis of the magmatic host rocks, distinguish between magmatic versus hydrothermal breccia, differentiate alteration types, determine the precursor rock where alteration is most intense, and chemically fingerprint the deposit. Preliminary observations indicate the following: (1) the tonalite suite is characterised by unfractionated CN REE patterns and reflects melt generation in a low-P regime; (2) protolith rocks are best discriminated using CaO, TiO_2 and Zr/ TiO_2; (3) the magmatic-hydrothermal breccia is characterised by an Au-Cu-F-Te-Zn association; (4) biotite alteration, often with intergrowth of chalcopyrite, is characterised by Ba and LREE enrichment often accompanied by the presence of allanite-euxenite-bastnaesite; (5) zones of intense sodic alteration, up to 40 m thick and approaching 10 wt.% Na_2O are characterised by a red-pink colour and a vuggy texture due to quartz dissolution. In thin section albite is pitted, contains abundant fluid inclusions and is mantled by clear albite. These rocks are considered to be episyenites; (6) sericite alteration zones, up to 150 m and cutting silica-sodic alteration, are characterised by an F ± Au ± Cu association; and (7) the chemistry of biotite in the breccia unit shows a reversal in Mg# after fractionation from diorite to tonalite (*i.e.*, decreasing Mg#) which may indicate either injection of a new primitive melt or an oxidation-sensitive event coincident with formation of the breccia. Many of the features of the Côté Gold deposit suggest derivation of mineralisation and alteration by the flux of high-temperature fluids enriched in K, Fe, F, LREE, CO_2, and Ba, in addition to Au, Te and Cu. The association of Au-Cu mineralisation with a magmatic-hydrothermal breccia and a chemical signature that is atypical for Archean orogenic-type gold deposits indicates a possible affinity with a spatially and temporally related intrusive centre. **(*SS3, Wed. 4:20*)**

Ichnology of transgressive lacustrine shoreface successions in the Eocene Green River Formation, northeastern Uinta Basin, Utah, USA

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Trace fossils have been observed in sandstone of the Green River Formation exposed at Raven Ridge on the northeastern side of the Uinta Basin, close to the state border of Utah and Colorado. Based upon the facies interpretation of the host sandstone beds and of adjacent strata, these trace fossils are considered to represent a rare recording of bioturbation from relatively high energy lacustrine shoreface environments (Skolithos ichnofacies).

In the study section, the lower Green River Formation has been interpreted to be almost entirely of siliciclastic offshore to shoreface strata, with minor interfingerings of foreshore and carbonate shoal deposits. Overall, there appears to be a gradual development of a steeper gradient lake shoreline system over time. Structureless sandstones in the lower part of the section probably represent prolonged bioturbation during periods of limited accommodation space generation with respect to sediment supply. Two 5 m-thick, coarsening-up sandstone packages in the medial section contain storm-dominated traction deposits and upper shoreface and foreshore deposits. At the top of the ridge, a 6.5 m-thick sandstone package is an almost archetypal coarsening-up shoreface succession. In these units, bioturbation is more sporadic and ichnotaxonomic assignments are possible.

Many burrows are encountered in complex association with one another, including cf. *Thalassinoides*, cf. *Psilonichnus*, *Skolithos*, *Planolites* and *Palaeophycus*. Some cf. *Ophiomorpha* have an irregular lumpy appearance to the outer surface that appear to be a slightly weathered "pelletal" lining. This would be consistent with the currently accepted definition of this ichnotaxon, which requires the recognition of pellets (or if less distinctive, peloids); the implication being that an organism produced its own wall material. However, in thin-section, peloids represent only a minor fraction of the wall material and the majority of "pellets" are found to be ostracode-cored ooids. Coated grains also form menisci in examples of *Taenidium barretti*, and the entire fill in some *Planolites*. **(*SS18, Thurs. 9:40*)**

Keynote (40 min): How subduction broke up Pangea

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It is well-established that the supercontinent Pangea broke apart in the latest Triassic-early Jurassic. What remains uncertain is why? Broadly, there are two end-member possibilities, either a mantle-driven process (bottom-up plate tectonics) or a subduction-driven process (top-down plate tectonics). This study demonstrates the many tight links between Mesozoic subduction zones active along the periphery of Pangea and its net motion and internal rifting through this period. These include: (1) northward rollback of the trans-Arctic/Eurasian subduction zone with northward motion of Pangea in the Middle Triassic, which slowed and ended as Eurasia progressively collided with Amuria and Cimmeria, (2) clockwise rollback of the Paleo-Tethys subduction zone with clockwise spin of Pangea during the early Triassic, which became disrupted by the full arrival of Amurian and Cimmerian blocks, and (3) rifting of the central Atlantic that was symmetric with the continued closure of the Paleo-Tethys in the early Jurassic. Evolving subduction rollback – mediated by continental collision – can provide a single mechanism for the kinematic and geometric connections. The synchroneity and geometry of these events would be fortuitous, if a mantle drive was responsible for the early rifting in the Atlantic instead. Thus, the kinematic data provide strong support for a subduction-driven mechanism for the breakup for Pangea. **(*SY3, Wed. 2:00*)**

Tectonic switching in a neutral arc: The Devonian-Jurassic record of southern Mexico

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The Devonian—Jurassic geological record of southern Mexico preserves three cycles of periarc/passive margin removal by massive subduction erosion followed by channel flow extrusion through the upper plate back to the surface of Earth. The onset of subduction erosion and the return of each package to the surface of Earth are constrained, respectively, by U-Pb geochronology from detrital zircons and the extrapolation of metamorphic cooling ages. The three cycles of consist of: (1) removal of forearc and lower Paleozoic passive margin rocks to a depth of *ca.* 35—40 km where they underwent eclogite/blueschist metamorphism at 350 Ma followed by extrusion by 330 Ma (Late Devonian—Mississippian), (2) post-339 Ma subduction erosion of Carboniferous periarc rocks followed by amphibolite facies metamorphism at a depth of *ca.* 20 km followed by extrusion between 250 and 210 Ma (Triassic), and (3) subduction erosion of a Jurassic, backarc, passive margin after 192 Ma, migmatization/amphibolite facies metamorphism at 170 Ma at a depth of *ca.* 20 km followed by exhumation by 150 Ma (Late Jurassic). This cyclic record of subduction erosion and extrusion suggests alternating contraction and extension (*i.e.* tectonic switching) has taken place during ongoing subduction. A comparison with modern analogues suggests that temporal variations in slab dip, convergence rate, convergence angle, and/or trench rollback are possible drives for the documented kinematics. Examples of tectonic switching in Cenozoic western South America, late Paleozoic southern Mexico, and Cenozoic eastern Australia appear to define a spectrum of behaviour consistent with positive, neutral, and negative intra-arc deformation, respectively. **(*SY3, Wed. 3:40*)**

Holmes and the indelicate question: Measuring the depth of time with the clocks of the Earth

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The development of geology involved several great controversies, long-standing conflicts with the forces of organized religion, and with the dogma of other scientific disciplines. The fierce and acrimonious debate about the true age of the Earth was perhaps the most important and lengthy of such conflicts, because so many other ideas in science - notably evolution - depend upon this foundation. One hundred years ago, long before his career was established, a young geologist named Arthur Holmes wrote an eloquent book in which he evaluated the ideas of the times, and outlined the principles for what we now call *geochronology*. Holmes was the very first timekeeper of the Earth and although remembered mostly as the father of geological time scales, he had a profound influence on many other aspects of our science. As a noted supporter of Alfred Wegener's radical ideas, he helped to lay the foundation for the plate-tectonic revolution.

The debate around the age of the Earth involved some famous names, such as James Hutton, Charles Darwin, Lord Kelvin, Henri Becquerel, Marie Curie and Ernest Rutherford. It pitted the fluid observational science of geology against the firm bastion of 19th century physics, which was then ruled by intransigent dogma. But in the end its resolution actually came from within physics, with the world-changing discoveries of radioactivity and subatomic particles. Ironically, the clock that gives us the power to unravel the history of the Earth is the very same substance that gave us the potential to destroy ourselves. Interestingly, much of the technology and methodology of modern radiometric dating was first developed through the Manhattan Project. This lecture traces the course, characters and ideas of this great debate, and also touches upon the remarkable innovations of more recent times. Arthur Holmes died almost fifty years ago, but his legacy remains vital even in our 21st century, when fundamental scientific knowledge continues to be challenged by 'creationism' and 'intelligent design'. The age of our

Earth is without question one of the most important pieces of knowledge gained within the last century, and it is a cornerstone of modern geoscience. **(*Plenary Address, Fri. 11:30*)**

Geoscience outreach, education and related adventure tourism in a five-star all-inclusive context: The evolving "Geology at the Edge" program on Fogo Island, Newfoundland

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Fogo Island has a special place in Newfoundland's rich identity. It is justly renowned for its long history, spectacular scenery, superb natural environment and a strong cultural heritage expressed in literature, music and art. It is also a place where geology is written in large letters upon the landscape, and anecdotes of geological time and process are laid bare in exquisite detail along hundreds of kilometres of wave-washed and ice-scoured coastline. In short, it is a natural place for sustainable geotourism in both the broad and specific sense, and for geoscience education at multiple levels. The established artist residency programs, followed by the 2013 opening of the innovative and award-winning Fogo Island Inn, have now given the island and its people a much wider profile. In turn, this provides a chance to use this natural framework to promote wider awareness of our links with and responsibilities to the modern environment, and our place in the much vaster context of planetary history and time. Ideally, such insights need to be packaged and subtly imparted within unforgettable outdoor experiences. This approach applies not only to the somewhat restricted clientèle of the Inn, but to the increasing numbers of independent visitors drawn to these shores, and to the residents of Fogo Island and Change Islands. Such a challenge might seem to some to call for extensive preanalysis and scoping studies, but in our view an honest and unabashed trial-and-error approach will work out better in the long run.

In 2013, the "Geology at the Edge" program was established. This allows professional Earth Scientists to spend time on the island, pursue independent research goals, and interact with both visitors and residents. Some key activities included guided hikes in areas of geological interest, marine excursions, public lectures at a non-specialist level, school initiatives, and community workshops on topics of societal interest such as climate change. This presentation recounts some of our experiences as the first "geologists-in-residence" with this program. It outlines developing plans for 2014, and also ongoing efforts to secure additional funding for amenities and future activities. "Geology at the Edge" is very much alive after year one, and is seeking interested and committed individuals for years to come. For the right people with the right motivation, there is much to be gained in terms of outdoor enjoyment, professional scientific growth and changed perspectives on the use and value of geoscience knowledge. **(*SS15, Fri. 2:00*)**

Notes: Andrew Kerr is also with the Geological Survey of Newfoundland and Labrador, St. John's, NL; Sheridan Thompson is also with the Department of Geography, Memorial University, St. John's, NL.

The south Newfoundland granophile mineral district: Features and opportunities for research on blind deposits

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The south coast of the island of Newfoundland is a diverse and potentially important district of granophile mineral deposits, in which several mineralized intrusive complexes span contrasting tectonostratigraphic zones of the Appalachian Orogen. In addition to molybdenum and tungsten deposits that represent potential producers, the district includes one of the world's largest producing fluorspar deposits, at St. Lawrence. The settings of mineral deposits vary, as do their associated commodities, but there is a common magmatic thread throughout the district. All major deposits are associated with evolved, alkali-calcic, siliceous granitoid rocks emplaced within a short time interval from *ca.* 388 Ma to *ca.* 375 Ma. Coherent U-Pb and Re-Os geochronology links these deposits to spatially associated plutons, even where direct physical connections are lacking. There are common geochemical themes that link prospective magmas, but these are not always easily visible through the geochemical and isotopic diversity connected to the contrasts in basement terranes along the belt. There is a dire need for other types of diagnostic data (*e.g.*, Pb isotopes, accessory mineral chemistry) that can better unravel the respective contributions of magma sources, contaminants and fractionation histories to regional prospectivity.

There are contrasts in the erosional levels revealed in individual complexes, from endocontact disseminated mineralization in high-level granites, to sheeted vein complexes and related hydrothermal lodes associated with hidden subsurface plutons. The Grey River - Moly Brook area provides the best example of the latter setting, and has all of the expected characteristics of a large zoned hydrothermal system. This area is of particular interest in the context of exploring such blind systems, because high-resolution geophysical data provide potential 3D information to augment the direct data from drilling. Exploring for targets associated with hidden intrusions is never going to be easy, so examples such as this, for which multiple data sets exist, are obvious priorities for expanded research. **(*SS3, Wed. 2:00*)**

Lawrence Head volcanics and Dunnage Mélange, Newfoundland Appalachians: Ordovician ridge subduction or back arc rift?

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We review the geological setting and report new geochemical trace element data from the Ordovician Lawrence Head Volcanics (LHV), the underlying gabbro sills of the Exploits Group, and mafic blocks and dikes in the Dunnage Mélange. In combination with existing published analyses and ages of these rocks, the volcanics and sills are indistinguishable in composition and age, and the data are consistent with the hypothesis that they represent the same (mostly E-MORB composition) magmatic event in the early-mid Darriwilian (~465 ± 2Ma). The LHV and their enclosing strata show regional evidence for: 1) decline of volume and grain size of arc-derived volcaniclastics over the uppermost turbidite sediments below the LHV; 2) change to shallow marine conditions locally by the end of LHV volcanism, followed immediately by significant subsidence and 3) no evidence of coarse-grained clastic input, nor of normal faulting, during or immediately after LHV volcanism. Ridge-trench interaction (ridge subduction) at a NW-dipping subduction system is consistent with all of these features, but a rift (back-arc) origin over a SE-dipping subduction zone can only accommodate the compositions, and is inconsistent with the geological evidence. The Dunnage Mélange (DM) has been interpreted either as olistostromal in a developing backarc rift basin, or as a subduction accretionary prism. Peraluminous intrusions in the Mélange (Coaker Porphyry - CP) are more readily explained by ridge subduction, and a previously reported zircon age (469±4) is reasonably consistent with the age of the LHV and gabbro sills. Blocks of volcanics and gabbro in the DM are lithologically similar to the LHV and related gabbro sills, but some blocks, mainly from the eastern half of the DM, do not resemble them geochemically. Localization of the CP in the eastern area of DM, and of most of the large LHV-derived volcanic blocks in the western DM, suggests a slightly younger age, and perhaps a different mechanism (olistostromal versus accretionary), for the origin of the western DM. **(*SY1, Poster*)**

New geochronological constraints on the history of the Otish Basin and implications for uranium mineralization

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The intracratonic Paleoproterozoic Otish Basin of the southeastern Superior Province hosts several uranium deposits, including Camie River and Matoush (586,000 t at 0.95 % U^3O^8). The uranium mineralization is complex but some deposits ($^{eg.}$ Matoush) are spatially related to mafic dykes and sills, leading to the suggestion that the intrusion of the Otish gabbros triggered uranium mineralization. Otish Supergroup sediments unconformably overlie Archean basement and the late Archean (2.5 Ga; U-Pb, baddeleyite) Mistassini mafic dyke swarm, constraining a maximum age of basin formation. The clastic rocks are intruded by three principal, olivine-bearing, Otish gabbro sills (Novet, Margat and Conflans) and NE- and NW-trending dykes. The Otish gabbros comprise two geochemical suites. Group 1 is characterized by relatively high REE abundances and fractionated REE profiles with lower Mg-numbers. Group 2 has lower REE concentrations and a flatter REE profile with higher Mg-numbers. Chemical differences between the two are consistent with a simple model involving differential accumulation of plagioclase and clinopyroxene. Physical evidence for internal, *in situ* fractionation also exists; rhythmic layering features from the gabbros sills, and local ultramafic portions and feldspathic cumulates are present. Differentiated thicker sills can locally carry minor quartz. The gabbro dyke associated with uranium at the Matoush deposit forms a third type of mafic intrusive characterized by steep REE patterns and an alkaline affinity. Moreover, the Matoush dyke has an uncommon N-S strike and narrow width (<5m) compared to the more widespread and prevalent NW- and NE-trending, thicker Otish gabbro dykes (which are interpreted to feed the sills).

Precise U-Pb dating of baddeleyite constrains the emplacement and crystallization of the lower (Novet), middle (Margat) and upper (Conflans) sills, including Group 1 and 2 chemical types, narrowly between 2172-2166 Ma, implying that sediment deposition must be older than 2172 Ma. Re-Os dating of molybdenite finely intergrown with the second generation of uraninite at the Camie River deposit yields an age of 1724 Ma, identical to a previous Pb/Pb uraninite age, and an Sm-Nd age for altered gabbro. Mineral resource drilling at the Matoush deposit suggests that the Matoush alkaline dyke is younger than the nearby Coonishish dyke, which geochemically belongs to the Otish gabbro suite. The geological and geochronological evidence therefore indicates the Otish basin filled with sediments between 2515 and 2172 Ma. The uranium mineralization formed ~ 450 million years later *ca.* 1720 Ma following intrusion of the alkaline Matoush dyke. **(*SS7, Wed. 3:40*)**

Pliocene to late Pleistocene magmatism in the Aurora Volcanic Field, Basin and Range province, Nevada and California, USA.

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The Aurora Volcanic Field (AVF) is Pliocene to late Pleistocene (3.9–0.1 Ma) that covers about 325 km^2 east and southeast of the Bodie Hills, along the northern margin of Mono Lake, near the California-Nevada border, USA. The AVF lies within the Basin and Range province, adjacent to and overlapping the Miocene Bodie Hills Volcanic Field (BHVF); it is immediately northwest of the late Pliocene to Holocene Long Valley magmatic system, which energizes the Casa Diablo geothermal power plant.

Aurora Volcanic Field rocks have bimodal compositions; intermediate (trachybasalt to trachydacite) and felsic (high-silica rhyolite) compositions are separated by a prominent gap between 66 and 77 wt. % SiO_2. The intermediate composition rocks are weakly to moderately porphyritic (1-30%); phenocryst assemblages include variable combinations of plagioclase, hornblende, clinopyroxene, and lesser orthopyroxene, olivine, and/or biotite. Microphenocrysts are dominantly plagioclase but include opaque oxides, clinopyroxene, and apatite. The high-silica rhyolites are sparsely porphyritic and contain trace to 10% phenocrysts of quartz, sanidine, plagioclase, biotite, (± hornblende), and accessory opaque oxide minerals, titanite, allanite, (± apatite, zircon). Plagioclase phenocrysts in AVF rocks are oscillatory-zoned and commonly sieve textured. Amphibole pheonocrysts have distinct opacite rims. Xenocrystic quartz and plagioclase are present in some samples.

The AVF rocks have high-K calc-alkaline to shoshonitic compositions and are metaluminous to weakly peraluminous. They are rare earth element (REE) enriched, especially light REEs. Although AVF rocks erupted in a post-subduction, extensional tectonic setting, primitive mantle-normalized incompatible element patterns maintain arc- or subduction-related signatures, including Ba and Pb enrichment and Nb and Ta depletion; these patterns are indistinguishable from those of older, subduction-related BHVF rocks. Neither $^{206}Pb/^{204}Pb_{initial}$ (18.974-19.246) nor $^{143}Nd/^{144}Nd_{initial}$ (0.51238- 0.51260), ratios and εNd_t (-0.74 to -5.00) covary systematically with silica content. Initial strontium ratios ($^{87}Sr/^{86}Sr_{initial}$ = 0.70511-0.70693) are moderately well positively correlated with silica. Pb, Nd, and Sr isotope compositions do not vary systematically in a temporal context. The AVF rocks have significantly higher initial $^{86}Sr/^{87}Sr$ and lower εNd than the BHVF rocks, and radiogenic Sr and SiO_2 variation are better correlated, which suggests that the AVF rocks contain a considerably larger crustal component than the BHVF rocks. Granitic rocks of the Sierra Nevada batholith and associated metavolcanic rocks are likely contaminants.

Ongoing investigations are designed to constrain sources for the AVF and BHVF rocks; we will employ new radiogenic isotope data for basement rocks to define the magmatic processes responsible for compositional characteristics of the respective lavas. **(*SS6, Thurs. 2:00*)**

Remote predictive mapping of base metal gossans associated with evaporite diapirs, South Fiord, Axel Heiberg Island, Nunavut

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Base metal gossans are the surface expression of weathered mineralized zones and may be used as indications that concealed sulphide deposits exist at depth. Remotely-sensed predictive mapping in unvegetated areas of Canada's North provide an effective tool to highlight gossans and other types of alteration zones prior to field work. For example, Landsat-7 TM (Thematic Mapper) contains seven spectral bands which are sensitive to different wavelengths that are characteristic of materials that reflect in different parts of the electromagnetic spectrum such as soils, rocks and vegetation.

A geological field expedition to Axel Heiberg Island, Nunavut required advance mapping of meter-scale gossans using remote sensing. The geology in the study area of South Fiord (centred at N 79.372, W 93.639) is dominated by dykes, sills and basaltic lava flows that forms part of the Canadian component of the Cretaceous High Arctic Large Igneous Province (HALIP) as well an extensive network of salt diapirs which influence regional tectonics.

Applying ratios from spectral bands sensitive to Fe-oxide and clay reflectance on Landsat-7 TM imagery was used to help predict the distribution of base metal gossans in the South Fiord and East Fiord areas. As a result, I utilized Landsat-7 TM imagery to construct simple and composite band ratio maps to highlight regions that display spectral signatures of elevated Fe-oxides and clay, which are key indicators of the presence of gossanous deposits. The results of the remote predictive study are presented in the context of ongoing work at the Geological Survey of Canada using a range of sensors such as SPOT5, GeoEye and WorldView-2. **(*SY4, Wed. 9:00*)**

The effects of silica activity and viscosity on the dissolution kinetics of sapphire in CaO-Al_2O_3-SiO_2 melts

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Minerals picked up by magma on its way to surface are typically not in equilibrium with their host resulting in their partial to complete dissolution. Details of the pathways and processes involved are important because if the assimilation rate is slow relative to the cooling rate, the added materials may never be completely assimilated, despite the predictions of phase equilibria. In addition, complex diffusion pathways during dissolution may result in production of exotic melts not predicted by the equilibrium phase relations.

Previously, dissolution has been interpreted to be controlled by diffusion of the released cations through the solvent melt with the dominant cation controlling the overall rate. Recent studies show that there are a number of complications. First, in simple melts the dissolution rate of quartz is controlled by interface reaction for hundreds to thousands of seconds rather than the <1 second predicted by the diffusion model. Second, there are viscosity and activity controls on dissolution rate not accounted for in the model.

We performed experiments in which sapphire was dissolved in three different melts in the CAS system at 1.5 GPa and 1600 °C. The melts used range in $aSiO_2$ from 0.21 to 0.56 and all three have approximately the same aAl_2O_3. Dissolution amounts were determined by mass balance from compositional profiles.

Our results show sapphire dissolution is most rapid in melts with low $aSiO_2$ and low viscosity and slows significantly when $aSiO_2$ and viscosity increases. In all three melts there is a long period of interface control. Since Al is a network forming cation, its incorporation into the melt is controlled by the initial degree of polymerisation. In the dissolution reaction, Al_2O_3 is change balanced by SiO_2 and CaO diffusion implying that as Al_2O_3 is added, the concentration of SiO_2 should decrease away from the crystal – melt interface while the charge balancing CaO should increase. SiO_2 shows the expected behaviour in all three melts. However, CaO shows evidence of uphill diffusion, *i.e.* diffusion against its concentration gradient, in melts with moderate and high $aSiO_2$.

Our results confirm the importance of $aSiO_2$ and melt viscosity as the dominant controls on dissolution, regardless of the composition of the dissolving crystal. Our data also highlight the ubiquity of uphill diffusion during mineral dissolution even in very simple systems. It is this uphill diffusion that leads to the development of small volumes of exotic melts with compositions not predicted by phase equilibria. **(*GS3, Poster*)**

Petrography and geochemistry of the Rome-Norridgewock pluton, west-central Maine; evidence for two distinct intrusive events

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The 378 Ma Rome – Norridgewock pluton (RNP) is one of a group of five intrusions that outcrop in west-central Maine and are related to the Acadian orogeny. The RNP covers an area of approximately 370 km^2 and is depicted as a single homogeneous granitic intrusion on the 1985 Maine bedrock geology map. However, preliminary fieldwork has revealed that there are distinct petrographic and geochemical variations within this intrusion.

In the northern outcrops of the RNP the rocks are medium grained granodiorite to granite in composition and contain normally zoned plagioclase, biotite, hornblende and sphene, with possible epidote. However, in the southern and southwestern exposures of the pluton the granite contains both biotite and muscovite along with microcline, lacks hornblende and sphene, but displays microscopic deformation features. The two phases of the RNP are also geochemically distinct with the northern phase being metaluminous whereas the southern two-mica granites are peraluminous.

Contact relationships between the two phases are obscured and relative ages of the two phases cannot be resolved. In addition, the 378 Ma age is for the two-mica granite of the southern phase of the pluton. While it is not impossible that the RNP is an asymmetrically zoned pluton or a composite body, the variance in deformation features suggest it is more likely that it is two separate intrusive events, the age relations of which remain unclear. **(*SS5, Poster*)**

Textural, chemical and isotopic evidence for pervasive high-temperature metasomatism in type examples of the Cretaceous Mongolian ongonites

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The *ca.* 120 Ma ongonite dike rocks from their type locality at Ongon Kkairkhan, central Mongolia, are variably described as pristine topaz-bearing albite-quartz-keratophyres with <4 wt. % F with phenocrysts of euhedral albite, K-feldspar, quartz and rare mica in a similar groundmass with topaz microlites. Detailed petrographic observations and SEM-EDS studies reveal that whereas macro-scale (≤5 mm) textures indicate a magmatic origin, on the micro-scale (<10 µm) textural evidence for metasomatism is pervasive, as is also suggested from mineral chemistry. Integration of observations reveal: (1) quartz euhedra rarely contains albite (Ab_{100}) in a snowball texture; (2) primary topaz only occurs as small (≤150 µm) acicular grains; (3) plagioclase is albitic (Ab_{98-100}) and mantled or replaced by orthoclase (Or_{100}); (4) K-feldspar is rarely perthitic with point (Ab_{98-100}) and bulk (*i.e.*, raster; Or_{96-98}) analyses similar; (5) feldspars are intensely pitted due to dissolution-precipitation reactions; (6) primary muscovite (<2 wt. % FeO, 6-8 wt.% F) is replaced (to 90%) by secondary muscovite (6-8 wt. % FeO, 3-4 wt.% F) with fluorite along cleavage traces; (7) secondary phases along grain boundaries and in pores (*e.g.*, muscovite, fluorite, monazite, xenotime, zircon (±Hf), U-Th oxides, Nb-Ta(±Sn, W) oxides, Bi phases); and (8) the presence of abundant secondary fluid inclusions (L-V, L-V-solids) in both quartz and feldspars. LA ICP-MS analysis of intergrown primary and secondary muscovite document dramatic chemical changes such that the LILEs (≤45,000 ppm Li, ≤25,000 ppm Rb, ≤1000 ppm Cs) are enriched in primary muscovite and relatively depleted in secondary muscovite, whereas the reverse occurs for both the transition metals (≤25,000 ppm Mn, ≤4,000 ppm Zn, ≤500 ppm Ti), and the HFSEs (≤1200 ppm Sn, ≤250 ppm Nb, ≤100 ppm Ta, ≤50 ppm W); the muscovite chemistry records, therefore, the ingress of metal-enriched fluids coincident with alteration. The nature of fluid:rock interaction is addressed through $\delta^{18}O$ analysis, both whole-rock (+0.7 to +7.5‰, n=10) and SIMS on quartz (+7.9 ± 1.3‰, n=16), which through mass balance indicates $\delta^{18}O_{feldspar}$ is -3.5 to -1.2‰ for the ^{18}O-depleted samples. Modelling of the $\delta^{18}O$ data indicates metasomatism occurred at a high T (>350ºC) and involved incursion of two diverse fluids, one of magmatic origin and the other meteoric with $\delta^{18}O$ = -5‰. Thus, this study shows that whereas the ongonites owe their macro-textures to magmatic processes, their micro-textures and mineral chemistry, except for the LILEs in primary muscovite, reflect extensive fluid:rock interaction. **(*SS20, Wed. 2:00*)**

Zircon is not always robust: A case example of dissolution-reprecipitation and variable discordance in zircon from syn-tectonic Neoproterozoic granitoids in the Gavilgarh-Tan shear zone, central India

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Zirconium is a trace element, but its HFSE chemistry causes it to be excluded from the common rock forming minerals which enhances its ability to instead form zircon, a common accessory phase in many igneous rocks and due to its high U content prized for use in geochronology and, more recently, petrochronology. In addition, the usual immobility of Zr has led to its widespread use in petrogenesis and rock classification (*e.g.*, Zr/TiO_2 *vs.* SiO_2). Here we present the results of an integrated SEM-EDS and *in situ* U-Pb LA ICP-MS study, in addition to pending SIMS $\delta^{18}O$ and LA ICP-MS trace element chemistry, which challenge these general assumptions. The zircon-bearing samples used represent previously undated suites of syntectonic, amphibole and/or biotite granitic rocks from the Gavilgarh-Tan Shear Zone (GTSZ) in central India, which holds vital clues for a comprehensive understanding of the tectonic evolution of the central Indian craton during the Meso-Neoproterozoic. Although meaningful U-Pb zircon ages of *ca.* 900 Ma were yielded for most of the samples, which indicates emplacement of granites into the GTSZ during the Neoproterozoic amalgamation of Rodinia, the presence of common Pb and, hence, discordance is noted. Significantly, the lack of concordance equates to an increasing degree of intricate textures (*e.g.*, zoning) imaged in the zircons in addition to their non-stoichiometric chemistry. This complex oscillatory zoning, commonly with multiple domains present, in addition to the presence of wt. % levels of Ca, Al, and Fe, equates to features previously observed in zircon from both natural settings and replicated under experimental conditions and related to a dissolution-precipitation mechanism (DPM). Further evidence of this DPM is the presence of minute accessory phases (*e.g.*, uraninite, thorite, galena) as inclusions in zircon enriched in the non-stoichiometric elements. Where this DPM was most prevalent, all of the Neoproterozoic history of the zircons analyzed (n=38) was erased and instead the zircons record a Cretaceous (*ca.* 106 ± 50 Ma) resetting event. We relate the latter age to circulation of heated basinal fluids thermally driven by either the Narmada-Tapti rifting in response to break-up of Indian plate from East Gondwana or to the voluminous effusion of Deccan Trap basaltic volcanics. Thus, this study provides evidence for the abundant occurrence of the DPM in a mineral generally considered to be robust and furthermore suggests that widespread resetting events may be overlooked where only gem-quality zircons are selected for U-Pb dating. **(*SS20, Wed. 8:40*)**

Syngenetic gold: An update

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New observations to support and extend syngenetic formation models for lode gold veins (LV) include: 1) subdivision of the Abitibi belt into 7 discrete autochtonous volcanic stratigrapic episodes that are separated by sedimentary interface zones. 2) classifying LV occurrences with a proposed “Gold Cycle” (GC). Similar to Bouma cycles, footwall volcanic or sedimentary lithologies (A) fine upwards into foliated chloritic tuff or pelagic/pelitic chlorite-carbonate interflow sediments (E) and are capped by hydrothermal quartz -gold “veins” (Q). Q-E-A asymmetry is geopetal and survives metamorphism. GCE units are often “shear zones”, “lamprophyre” (L) or “mafic dikes”. GC “A” division lithologies include gabbro, diorite, syenite, TTG suite and volcano-sediments. 3) recognition that L in gold camps are “E” units of the Gold Cycle (GCE). In the 2.74 Ga Chester felsic Complex (CC), which hosts the > 8 M oz Iamgold Côté Gold deposit in Ontario, a minette (L) cross-cuts GCE, which it resembles in hand specimen and mineralogy. Both have broadly similar calc-alkaline affinity and a high degree of fractionation, elevated LREE and incompatible trace elements. L also show significant depletion of Nb, Ta and Ti, higher concentrations of LREE and considerably lower Au. Reflecting a volcano-sedimentary origin, basaltic GCE are more primitive (higher Mg, Cr, Ni & Ca) and show widely variable whole rock chemistry, higher LOI, gold and base metal contents and lower Si, Al, Na and P, than L. K/Rb, Rb/Sr, Th/La and mg# are also different. L and GCE plot separately on petroplots, but discriminators must be field based. Averages (N=7) are:

	L_{avg}	1σ	GCE_{avg}	1σ
Al_2O_3/TiO_2	21.9	0.6	14.9	3.0
Sr/Nd	0.186	0.012	6.7	4.7
V/Cr	2.9	0.3	0.73	0.58
Zr/Sc	11.3	1.9	3.7	3.2

Probable GCE (L in the literature) occur in these gold camps: Abitibi, Bourlamaque, Laowangzhai, Maskwa, Hillsdale, Syama, Yilgarn. 4) GCE in felsic host rocks means they are extrusive. In the CC bi-modal flows with SiO_2 contents range from 51-77%. Strata can be correlated over > 400m using Sc as proxy for SiO_2. 5) GCE chemistry resembles mafic enclaves in the TTG suite implying extrusive origins. 6) “stylolite” graphite textures, common in LVs, are abiotic carbon generated in sea-floor hydrothermal vents. Meguma LV textures suggest sea-floor deposition from silica gel. GCs underlie asymmetric alteration, stable isotope disequilibrium between LV and host rocks and provide a link between TTG, felsic and bi-modal volcanism and early crustal processes. LV deposition occurs at sea-floor vents or seeps. **(*SY5, Thurs. 4:20*)**

The mechanical behaviour of synthetic calcite-dolomite composites: An experimental investigation

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The mechanisms and styles of deformation associated with many tectonic belts in variably dolomitized limestone layers are strongly controlled by strain partitioning between relatively strong dolomite and weak calcite. Here, we present experimental results based on four composite starting materials designed to address the role of dolomite on the strength of limestone. The composites were synthesized by hot isostatic pressing of homogeneous mixtures consisting of dolomite (Dm) and calcite powders (% Dm: 25%-Dm, 35%-Dm, 51%-Dm, and 75%-Dm). In all composites, calcite is finer diameter) than dolomite (~100 µ diameter). The synthesisedµgrained (~ 5 µ materials were deformed in torsion at constant strain rate (3×10^{-4} and 1×10^{-4} s^{-1}), high confining pressure (300 MPa), and high temperature (750°C) for variable finite shear strains. Mechanical data show an increase in yield strength with increasing dolomite content, however, all composites have significantly lower yield strengths than anticipated for 100% dolomite. Conversely, 25% dolomite composites have significantly higher yield strengths than anticipated for 100% calcite. Microstructural analysis shows no intracrystalline deformation in dolomite irrespective of its relative abundance and finite shear strain. Brittle deformation of dolomite grains by Mode I cracks and shear fractures is observed in samples with % Dm > 51; at low (<35%) dolomite remains undeformed. In contrast, the microstructure of the fine-grained calcite aggregates suggests grain boundary sliding, accommodated by diffusion creep and dislocation glide in all samples.

We propose that for natural limestone-dolomite composites, rocks with <75% dolomite (with the remaining being calcite), may accommodate significant shear strain at much lower shear stresses than pure dolomite, mostly as a result of strain localization into thin, interconnected fine-grained calcite layers. Conversely, even at low concentrations (*i.e.* 25%), the presence of coarse-grained dolomite in a micritic calcite matrix has a profound effect on the strength of composite materials as dolomite grains limits the superplastic flow of calcite aggregates, thereby strengthening the rocks. **(*SY2, Thurs. 2:40*)**

Preliminary investigations of the Fe-Ti-V-P mineralization associated with the Thunderbird and Butler gabbroic intrusions within the McFaulds greenstone belt, Superior Province, northern Ontario, Canada

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The McFaulds Lake area (*i.e.*, Ring of Fire) located in northern Ontario (Canada) has been the site of recent exploration leading to the discovery of several mineralization types including chromite and nickel sulfide deposits. Although the majority of exploration has been focused on chromium, the area also contains significant Fe-Ti-V-P mineralization associated with gabbroic intrusions, of which the Thunderbird and Butler occurrences are the best defined.

The gabbroic intrusions are widely distributed throughout the McFaulds Lake area and can be grouped into two main types: (1) large mafic-dominated intrusions and (2) subconcordant to slightly discordant mafic-dominated sills/dikes characteristic of the Thunderbird and the Butler intrusions respectively. Both intrusions are composed of an evolved mafic suite termed the 'Ferrogabbro' characterized by the presence of Fe-Ti oxides. Detailed core logging has shown that both intrusions are largely composed of very similar lithologies including iron-rich gabbros, leucogabbros, and anorthosites. Two types of Fe-Ti oxide mineralization occur within these intrusions: (1) Fe-Ti-V and (2) Fe-Ti-P mineralization. Fe-Ti-V mineralization has been intersected within both intrusions, whereas the Fe-Ti-P mineralization has only been identified within the Thunderbird intrusion. The mineralization occurs dominantly as disseminated magnetite and ilmenite (1-10%), but is also present as semi-massive (50-80%), to massive layers (>80%). These layers typically contain distinct sharp, stratigraphically lower contacts and gradational upper contacts typical of primary igneous layering. The ilmenite occurs as anhedral to subhedral crystals and to a lesser extent, as very fine-grained exsolutions within anhedral magnetite grains.

The ferrogabbroic intrusions may be petrogenetically related to the abundant ultramafic rocks within the McFaulds Lake area, and could possibly represent the late stage end member of a magmatic sequence as has been suggested for the Bushveld complex. However, the overall absence or rare ultramafic components spatially associated with these ferrogabbroic intrusions, combined with some ultramafic units cross-cutting the ferrogabbroic units within the Butler intrusion, may suggest that they could represent two distinct magmatic events rather than a dismembered layered intrusion as proposed by previous workers. **(*GS5, Fri. 10:40*)**

Novel geochemical techniques in exploration for uranium deposits

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Mineral deposits are geochemical anomalies, and as such their detection and assessment of their impact on the environment must include geochemical techniques. Although geochemistry has been used indirectly in shaping deposit models, the novel applications of geochemistry and integration with other data can be effective in formulating exploration and remediation strategies. The use of geochemistry in detecting uranium deposits at depth should involve more effective integration of geochemical with geophysical data to refine targets, document element distributions in and around deposits to assess the primary and secondary dispersion of specific elements associated with the deposit, use both elemental concentrations and isotopic compositions to detect specific components that have migrated to the surface from uranium deposits at depth, and understand the effects of micro-environments on element mobility across the geosphere-biosphere interface to enhance exploration using select media for uranium at depth.

Drill core from near the deposit, clay-size fractions separated from soil horizons and vegetation over and far from the deposit record element migration from the deposit as radiogenic He, Rn and Pb unique to uranium-rich sources. Isotopic compositions of C and N indicate microbial interactions with the uranium deposits, which are involved in the process by which elements are mobilized out of the deposits and into the surrounding environment for us to use as vectors to ore. Correlations among pathfinder elements occur in fractures in core, but also in various surface media. Multi-element analyses including Pb isotopes of the clay-sized fractions of all soil horizons and vegetation provide compelling evidence that a robust geochemical signature exists. All types of uranium deposits undergo similar processes so that geochemistry should be integrated into learning curves for effective exploration of uranium. **(*SS7, Wed. 8:00*)**

Petrology, geochemistry, and geochronology of the granitic pegmatite-aplite dykes and sills of the Repulse Bay block, Melville Peninsula, Nunavut

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The Repulse Bay block (RBb), Melville Peninsula, Nunavut is host to a number of post-Trans-Hudson peraluminous pegmatite-aplite dykes and sills that provide information on events that followed the orogeny. These weakly to undeformed intrusions cut the Meso to Neoarchean upper amphibolite-facies to granulite-facies migmatites and gneisses forming the block. Pegmatites and aplites are biotite-magnetite-allanite-syenogranitic in composition, approximately 5–10 m wide, and randomly orientated. Pegmatite dykes contain localized graphite textures and mineralogical zoning with a quartz-rich core. Megacrystic allanite displays concentric radial fractures related to positive volume change during alpha-decay induced amorphization. The pegmatite-aplite system has a chondrite-normalized LREE-HREE ($(La/Yb)_N$ = 25–72) fractionated profiles with negative Eu anomalies and contains trace element enrichments typical of fertile granites (K/Rb = 153–295, Ba/Rb = 0.2–6.1, Nb/Ta = 5–33). When extended trace element diagrams are normalized to the average Neoarchean continental crust of Condie (1993), the samples demonstrate positive Th, U and Pb anomalies. An enrichment in Pb is also a common feature of the RBb gneisses. U-Pb zircon geochronology of an aplite dyke yields an age of crystallization at 1.78 Ga, 40 m.y. after peak metamorphic conditions and the onset of partial melting within the block. Pegmatites and aplites intruded the RBb following isothermal decompression and cooling to 650 –700 °C. We interpret the chemical composition of pegmatite-aplite system to reflect derivation from crustal melts and were emplaced in an extensional environment in response to *ca.* 1.82–1.80 Ga orogenic collapse and lateral extrusion of the RBb. **(*SY3, Poster*)**

Neoarchean mantle-derived magmatism within the Repulse Bay block, Melville Peninsula, Nunavut: Implications for Archean crustal extraction and cratonization

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The Repulse Bay block (RBb) of southern Melville Peninsula, Nunavut, lies within the Rae craton and exposes a large (38,000 km^2) area of middle to lower crust. The block is composed of *ca.* 2.86 Ga and 2.73–2.71 Ga tonalite-trondhjemite-granodiorite (TTG) gneisses and sheets of diorite that were extracted from the mantle at 3.25–3.10 Ga. This period of TTG generation was followed by the emplacement of *ca.* 2.69–2.66 Ga enderbite, charnockite and granitoid intrusions with entrained websterite xenoliths. These voluminous batholith-scale bodies (dehydrated and hydrated intrusions) and the associated websterite xenoliths have similar whole rock geochemical properties including fractionated light rare earth element (LREE)-heavy (H)REE whole rock patterns and negative Nb, Ti, and Ta anomalies. Additionally, large ion lithophile and transition elements (*e.g.*, Ni, Co, Ba, and Sr) and Mg# suggest a systematic trend when compared to immobile Zr. Dehydrated intrusions and websterite xenoliths also contain similar mineralogy (two pyroxene, biotite, interstitial amphibole) and similar pyroxene trace element compositions. Based on geochemical and mineralogical properties, the two lithologies are interpreted to be related by fractional crystallization, and the product of a cumulate-type intrusion. Reworking of the crust in a *ca.* 2.72 Ga subduction zone setting was followed by *ca.* 2.69 Ga upwelling of the asthenospheric mantle and the cumulate intrusion of massif-type granitoids. Based on a dramatic increase in FeO, Zr, Hf and LREE content of the most evolved granitoid components of the 2.69–2.66 Ga cumulate intrusion, we determine partial derivation from a metasomatized mantle source enriched by fluids from the subducting oceanic slab that underwent further hybridization (via assimilation) with the crust. Large-scale, mantle-derived Neoarchean sanukitoid-type magmatism played a role in the development of a depleted lower crust and residual subcontinental lithospheric mantle, a crucial element in the preservation of the RBb. **(*SY3, Thurs. 8:20*)**

Gold mineralisations along the Porcupine-Destor Fault; the Duquesne-Ottoman property, Abitibi greenstone belt, Quebec, Canada

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Gold mineralizations in Abitibi's Archean greenstone belts occur in a wide range of style and geological context. In the Duparquet district (Quebec), volcanogenic, intrusive-hosted felsic porphyry (Beattie Mine) and orogenic gold models coexist along the Porcupine-Destor fault. This area is therefore a key area where the relationship between these different models may be deciphered. The Duquesne-Ottoman Property is being explored and developed by Globex Mining Enterprises Inc. for its gold potential.

The area is located approximately 30 km northwest of the city of Rouyn-Noranda, and 10 km east of the town of Duparquet. The rocks of this area are mainly volcanic in origin and Archean in age (2722 to 2718 Ma). The property is located in the volcanic Kinojévis group, north of the Porcupine-Destor fault. The Kinojévis group is interpreted as a volcanic arc and was subsequently deformed during continental collision. The studied sector is composed of mainly intermediate to mafic volcanic rock with the relative presence of ultramafic and felsic volcanic rock, quartz-feldspar porphyry and minor alkaline intrusions. A large polymict breccia is also present on the property and demonstrates the existence of early hydrothermal processes associated with a high level of volcanism.

A shear zone cuts across the property's volcanic sequence. This fault zone is part of the Porcupine-Destor fault system. It has an average width of 5-10m and is generally oriented 070N to 090N with a 75° to 90° dip. Within this shear zone are slivers of feldspar-quartz porphyries who emphases, by rheological contrast, the shearing of the intermediary to mafic volcanic sequence. This east-west fault displacement displays a dextral inverse movement.

The three principal auriferous zones on the Duquesne-Ottoman Property (Liz, Shaft and Fox), are located within this, east-west trending, fault zone. Mineralizations are discordant with the stratigraphy and are structurally controlled. Multiple quartz- carbonate veins are associated with a proximal sericite–ferriferous dolomite-pyrite alteration. The alteration intensity is maximal in the intermediate to mafic host rock, near quartz-feldspar porphyries contacts and proximal to the fault. The main gold carrier is native gold and to a lesser extent, electrum, Au Telluride and Au-Ag Telluride. The average diameter observed for the precious metal grains vary marginally from 2 to 4 µm. The very fine-grained particles occur predominately at silicate-sulphide (pyrite) grain boundaries or locked in gangue minerals, especially pyrite. **(*SS25, Thurs. 3:00*)**

Physical properties of the Canadian Malartic ore body and host rock: Preliminary results

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The Canadian Malartic gold deposit apparently shows no specific magnetic or electromagnetic signature that would allow prospecting for that type of deposit in similar geological environments. Physical properties of the ore and host rock are dependent on their mineralogical composition and textures which relates to their original composition, deformation, metamorphism and fluid-rock interaction history. This study aims at measuring the physical properties of the various rock types from the core of the mineralized system to the outer zones of the gold deposit to help anticipate the geophysical signals that could be detected in surface or airborne surveys. Laboratory measurements were carried on 217 core samples representative of the various rock types and styles of alteration and mineralization. Since it is highly related to porosity, mineralogy and alteration content, the density of each sample was measured. Magnetic susceptibility was also measured to investigate how alteration affects the magnetic signature. Additionally, spectral induced polarization measurements were performed on the core samples; gamma-ray spectrometry will soon be applied to estimate potassium and uranium content. The preliminary results are presented in the form of cross-plots in order to better identify relationships between some physical properties, rock type, and styles of alteration and mineralization. Similar surveys were also conducted at the outcrop scale using handheld equipment and typical time-domain induced polarization gear to better understand the scaling effect between laboratory measurements and large-scale geophysical surveys. These results are presented in the form of geophysical maps correlated with geological maps of the outcrop surfaces and are fundamental to understand the spatial relationship between the geophysical data and the rock compositions and structures. A subset of 25 samples that showed remarkable physical properties will be studied in detail to determine their mineralogy using Mineral Liberation Analysis. *CMIC-NSERC Exploration Footprints Network Contribution 016.* **(*SY5, Wed. 3:20*)**

Isotopic and chemical alteration of zircon crystals by hydrothermal fluids within the Horseshoe Greenstone Belt (Superior Province) using trace element and U-Pb depth-profiling techniques

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Hydrothermal fluids play an important role in heat transfer and reaction kinetics, and act as a transporting medium for the movement of soluble material. New advances in zircon geochronology allow the potential to date thermal and recrystallizing events of a rock through the analysis of submicron mineral domains caused by coupled dissolution-recrystallization of the mineral. However, it has proven difficult to resolve the timing of fluid infiltration due to complex chemical interactions between hydrothermal fluids and chronometers. Here we develop microanalytical techniques to help determine the timing and nature of crustal fluid flow and study fluid-zircon interaction. U-Pb isotopic and trace element analyses on unpolished zircon were conducted using laser ablation-inductively coupled plasma-mass spectrometer (LA-ICPMS) depth-profiling methods. Zircons were separated from lower greenschist facies Neoarchean metasediments from the Central Domain in the Horseshoe Greenstone Belt of the Western Superior Province. Although broadly deformed into a km-scale fold, metasediments preserve relict sedimentary structures and possess cross-cutting *ca.* 2730 Ma porphyritic plagioclase-rich felsic dikes. Chlorite and sericitization of feldspar are commonly observed in thin section and suggest post-metamorphic fluid alteration. The equant zircons (and quartz grains) are generally euhedral to subhedral, which suggests that sedimentary transport was minimal and the source of these sediments is proximal. U-Pb geochronology coupled with trace element depth-profiling techniques uncovered ≤3 μm thick distinct chemical domains preserved along the margins of zircon. Normalized zircon/chondrite versus REE (La-Lu) diagrams indicate the ultrathin domains are enriched in LREE, and isotopic analyses suggest that these chemical domains are also enriched in U. In a third of the zircons analyzed, these chemically distinct zircon exteriors are *ca.* 100 m.y. younger than the zircon interior ages (*ca.* 2950 Ma *vs.* 3040 Ma, respectively; single spot age errors are ±5 Ma).

Surprisingly, our rim ages are dissimilar to the local and adjacent *ca.* 2730 Ma porphyritic plagioclase-rich felsic dikes which cross cut the outcrops. The zircon's morphology and geochemical signatures infer that the alteration event may have occurred prior to deposition since the age of the greenstone belt is believed to be 2860 Ma. Therefore, Mesoarchean geological processes are responsible for the distinct chemical domain preserved in the zircon crystals in the Horseshoe Greenstone Belt and are yet to be understood. Our results are consistent with a paucity of mineralization in this greenstone belt compared to the neighboring North Caribou belt. **(*SS17, Wed. 2:40*)**

Integrating terrestrial and marine archives of Late Wisconsinan ice stream dynamics in the western Canadian Arctic

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During Late Wisconsinan glaciation the northern Laurentide and Innuitian ice sheets converged over the Canadian Arctic. This ice sheet complex included multiple regional ice-flow divides that sourced several large ice streams draining through the major marine channels of the archipelago. These ice streams were a primary control on ice sheet mass balance and ice age sedimentation on adjacent continental margins, including the Arctic Ocean basin. Recent field research on the islands of the western Canadian Arctic Archipelago and in the adjacent Beaufort Sea aboard the CCGS Amundsen has yielded a substantial compilation of geomorphological, sedimentological, geophysical, and geochronological data bearing on the maximum extent, timing, and behaviour of former ice streams in M'Clure Strait, Viscount Melville Sound, and Amundsen Gulf. Of particular relevance are new data highlighting complex patterns of past ice stream flow during regional deglaciation, when the region was undergoing rapid glacioisostatic, climatic, and oceanographic changes. These new results contribute to a better understanding of the causal mechanisms that occasioned retreat of the terrestrial and marine sectors of the Laurentide and Innuitian ice sheets. As well, this research helps gauge the magnitude of past iceberg fluxes to the Arctic Ocean, which has implications for assessing the origin of ice-rafted sediment and deep iceberg scours in the Arctic Ocean basin, as well as past climatic oscillations. Future field research will continue clarifying the Late Wisconsinan sedimentary record and further contribute to an emerging chronostratigraphic framework for the Beaufort Sea shelf and slope. **(*SS22, Thurs. 10:40*)**

Alteration and Cu-Zn mineralization of the Turgeon volcanogenic massive sulfide (VMS) deposit (New Brunswick, Canada)

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The Turgeon deposit is a mafic-type Cu-Zn volcanogenic massive sulfide (VMS) deposit hosted in the middle Ordovician volcano-sedimentary rocks of the Elmtree-Belledune Inlier (EBI), located 20 km northwest of Bathurst in northern New Brunswick. The deposit is hosted in the tholeiitic pillow basalts of the Devereaux Formation of the Fournier Group. The Fournier Group consists of the gabbros and sheeted dykes of the Devereaux Formation at its base, stratigraphically overlain by the pillow basalts and sedimentary rocks of the Pointe Verte Formation.

The Turgeon deposit consists of two lens-shaped Cu-Zn massive sulfide mounds (100m Zinc zone, 48-49 zone) underlain by Cu-rich stockwork zones. Mineralization is found at the contact between the sheeted dykes and pillow basalts of the Devereaux Formation. Trace element geochemistry indicates that the host rock is composed primarily of tholeiitic basalts with mid-ocean ridge basalt (MORB) signatures. Petrographic studies show that the host footwall basalts distal to mineralization have undergone greenschist metamorphism and consist of plagioclase microcrystals, with minor sericite, in a chloritized volcanic glass matrix ± epidote. Alteration mineral assemblages of the footwall basalts proximal to mineralization are dominantly chlorite ± quartz in the stockwork zone, and carbonate ± pyrite ± talc near the massive sulfide lenses. Geochemical alteration box plots show a hydrothermal alteration trend between that of chlorite - pyrite – (sericite), and chlorite - carbonate. Footwall basalts are characterized by mass gains in Fe, Mg, and Mn, and mass losses in Na, Ca, and Si. In the extensively chloritized stockwork zone, mineralization is present in the form of chalcopyrite – quartz veins overprinting pyrite veins. Trace element geochemistry shows a linear relationship between Cu - In and Cu - Se. The "100m Zinc" zone lens features a distinct sulfide breccia unit consisting of subrounded to subangular pyrite, chalcopyrite, and basalt fragments in a pyrite ± quartz matrix. The "48-49" lens is zoned with a base characterized by chalcopyrite – pyrhottite - quartz ± magnetite, whereas towards the top, the lens is characterized by massive euhedral pyrite ± magnetite in a carbonate and talc matrix. Similarly to other Phanerozoic VMS deposits, sulfides at Turgeon have an average $\delta^{34}S$ of 6.9 ‰, indicating that sulfur was primarily derived from thermochemical reduction of seawater sulfate. **(*SS14, Fri. 9:20*)**

Characterization of gold occurrences with respect to metamorphism at the Lalor deposit, Snow Lake, MB

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The Lalor Au-rich VMS deposit is located on the eastern flank of the Paleoproterozoic Flin Flon greenstone belt, within the Snow Lake arc assemblage. A regional metamorphic event at 1.81 Ga, up to middle amphibolite facies, resulted in a variety of mineral assemblages in the hydrothermally altered rocks. The diversity of mineral assemblages indicate a complex metamorphic fluid evolution including processes that could facilitate the mobilization of metals. The extent of which metals were remobilized or introduced to the system during metamorphism is uncertain.

To investigate the role of metamorphism with respect to mineralization, drill core and petrographic studies were undertaken to identify the environments of Au-enrichment, focusing on relationships between Au and metamorphic assemblages, fabrics, textures, and sulfide associations. Four environments of Au-enrichment exist at the Lalor deposit: massive sulfides, unaltered to weakly altered mafic volcanics, calc-silicates to carbonate silicates, and Fe-Mg altered rocks. Disseminated-stringer chalcopyrite and pyrrhotite are common to all four Au environments. Gold occurs in the massive sulfide environment with euhedral-subhedral pyrite with interstitial sphalerite as well as fine, blebby galena. In the unaltered to weakly altered mafic rocks, gold is found with disseminated-blebby sphalerite, galena, or arsenopyrite. In the calc-silicates to carbonate silicates, calcite-tremolite-chlorite ± diopside ± epidote is host to gold that is associated with disseminated galena. The Fe-Mg altered rocks typically comprise garnet-staurolite-chlorite-biotite-anthophyllite-cordierite ± kyanite/sillimanite hosting disseminated-stringer pyrite and sphalerite; in this environment, Au is primarily associated with the occurrence of chalcopyrite.

Petrographic studies, including detailed scanning electron microscope (SEM) work, were employed to determine the nature of Au mineralization with respect to metals and mineral assemblages. Typical minerals found associated with Au mineralization include sulfosalts (hessite Ag_2Te, altaite PbTe) and sulfides (chalcopyrite $CuFeS_2$, galena PbS). Gold commonly occurs with Ag as electrum and occasionally in sulfosalts such as aurostibite ($AuSb_2$). Proposed stages of Au mineralization are pre-peak metamorphic introduction (including primary VMS mineralization) and a syn- to post-peak metamorphic introduction or remobilization. Evidence for pre-peak metamorphic introduction is the occurrence of auriferous inclusions in peak metamorphic minerals such as tremolite. Syn- to post-peak metamorphism introduction of Au is supported by the occurrence of auriferous phases in grain boundaries and fractures. **(*SS14, Thurs. 4:20*)**

Characterization of wear material associated with silica lubrication

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Faults in silicate rocks have been observed to have a seemingly lower frictional strength than predicted. Past friction experiments on silica-rich rocks have shown that a large drop in frictional strength occurs at high slip rates, thought to be due to the formation of a thin layer of silica gel which lubricates the shearing surfaces. Silica lubrication is proposed to be a cause of weakening during seismic slip on natural silicate faults, though little has been done to study this mechanism. Here we characterize the wear material from friction experiments that have shown dynamic weakening that is considered to be analogous to silica lubrication on faults. The friction experiments were performed on α-quartz chert cores at a normal stress of 2.5 MPa, with displacements of 3 or 30 m, and at slip rates ranging from 10^{-1} to 10^{-6} m/s. Raman and FT-IR spectroscopy were used to investigate the slip surface and the properties of the wear material, of which the quantity increases with increasing rate and distance of slip. The Raman spectra of the wear material are polarization dependent and do not show evidence of α-quartz or any other known phase of silica. There is a broad, rounded background peak interpreted to be amorphous silica, with several smaller, wide peaks that may represent an unidentified crystalline phase of silica. FT-IR analyses reveal the presence of silanol in the wear material. Annealing experiments are in progress to determine if the unidentified phase is metastable and may convert to a recognized phase of silica at higher temperatures. **(*SY2, Poster*)**

Geological and structural controls on hydrothermal alteration and W-Mo mineralization in the Sisson deposit, New Brunswick

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The Sisson deposit is a Late Devonian, structurally-controlled, intrusion-related W-Mo deposit located in west-central New Brunswick. Resources are estimated at 383 Mt grading 0.067% WO_3 and 0.021% Mo (measured/indicated) and 178 Mt grading 0.051% WO_3 and 0.021% Mo (inferred). Host rocks to Sisson include quartz diorite and gabbro phases (432 Ma; U-Pb on titanite) of the Howard Peak intrusion on the west, which are in fault contact across the vertical, north-trending Sisson shear zone with north-northwest-striking, steeply east-dipping metavolcanic and metasedimentary rocks of the Cambrian to Ordovician Tetagouche and Miramichi Groups on the east. Re-Os dates of ~378 Ma on molybdenite overlap U-Pb dates on zircon from narrow granite dykes within the deposit, which are likely related to the Late Devonian Nashwaak Granite batholith located immediately northwest of the deposit. The deposit is cut by narrow, undeformed, barren granite porphyry dykes dated at ~364 Ma (U-Pb on zircon).

The Sisson deposit obliquely straddles the Sisson shear zone. Hydrothermal activity comprises: (1) early, weakly to unmineralized amphibole veinlets with albite alteration envelopes and small, erratically-distributed zones of biotite±pyrite alteration; (2) quartz-scheelite veinlets with biotite envelopes; (3) quartz-molybdenite±scheelite veinlets with sericite envelopes; (4) mostly late but possibly long-lived, larger and more continuous, polymetallic quartz-shear veins with broad sericite envelopes and associated sulphide-rich veinlets, which also introduced minor Cu, Bi, Sb, As, Pb and Zn to the deposit; and (5) rare endoskarn with scheelite mineralization of uncertain timing in narrow granite dykes intersected only at depths of >400 metres. Alteration is mostly restricted to the envelopes which enclose veinlets. Scheelite mineralization occurs primarily in quartz veinlets and their alteration envelopes, molybdenite is restricted to quartz veinlets, and minor ferberitic wolframite, mostly replaced by scheelite, occurs in some quartz-scheelite veinlets and in most quartz-shear veins.

Veins throughout the deposit form a sheeted array with consistent northwest strike and steep to moderate southwest dips. The nature and geometry of the vein sets are most compatible with formation during crustal extension, which was synchronous with sinistral, syn-hydrothermal displacement across the north-trending Sisson shear zone. The structural plumbing system focused ascent of W-mineralizing fluids from intrusions at depth, the presence of which is indicated by syn-hydrothermal granite dykes within the deposit. Precipitation of W and Mo mineralization resulted from chemical interactions between hydrothermal fluids and wall rock at a low fluid to rock ratio, and from changes in sulphur and oxygen fugacity. **(*SS3, Wed. 9:20*)**

Mineralogical study of the auriferous shear zone along the Augmitto-Astoria segment in the Cadillac break south of Rouyn-Noranda, Abitibi, Quebec

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The Cadillac-Larder Lake fault zone is a well-known structure holding important gold deposits. Different kinds of mineralization are observed in relation with many hydrothermal events. This study focused along the Augmitto-Astoria segment, Rouyn-Noranda, Quebec, where greenschist facies is the common regional metamorphism. Mineralogical and geological studies made possible comparisons between four sectors: Augmitto, Cinderella, Lac Gamble and Astoria. Two styles of mineralization have been observed: 1) in the sericitized footwall and hanging wall sediments, in the Temiskaming group, with quartz-carbonate-tourmaline veins mineralized with arsenopyrite and visible gold, 2) in the carbonatized komatiites, in the Piche group, with quartz-carbonate-tourmaline veins mineralized with gold and arsenopyrite.

Temiskaming rocks are composed of quartz, carbonates, plagioclases, tourmaline, chlorite, muscovite and sericite. Piche rocks are composed of carbonates, epidote, chlorite, sericite, plagioclase, tourmaline and fuchsite. Among the sulphides are arsenopyrite, pyrrhotite, pyrite, chalcopyrite and sphalerite. Few oxydes, such as magnetite, ilmenite, hematite, monazite and rutile, are either present in the matrix or form veins. Areas located inside the ore deposit are characterized by quartz, sericite, muscovite, fuchsite, carbonates, tourmaline, visible gold and arsenopyrite. Areas away from the ore deposit are defined by sericite and traces of tourmaline. At least three auriferous stages are observed: i) invisible gold within arsenopyrite, ii) visible gold inclusion and filling the cracks within arsenopyrite and iii) gold nuggets in quartz veins. Gold shows a strong association with arsenopyrite which is the main sulphide. Wherever gold and arsenopyrite appear together, a strong link exists between highest gold rates and xenomorphic clusters of fractured arsenopyrite: the more the arsenopyrite crystallized, the less the gold is visible.

Hanging wall sediments show a rather strong association between antimony and nickel with minerals such as ullmannite and famatinite. These minerals are located within the matrix or along sulphides such as pyrite or pyrrhotite.

In the vicinity of major Proterozoic dykes (1141 Ma) in Astoria, surrounding rocks reach the amphibolite metamorphic facies with particular minerals including epidote, zoisite, amphibole and loellingite. This area has three characteristics: i) gold is located at the interface of loellingite and arsenopyrite, ii) the size of gold particles does not exceed 20 microns, and iii) the average gold / silver ratio reaches 10:1, which is higher than any other places along the Augmitto-Astoria segment. The gold concentration in the Cadillac break south of Rouyn-Noranda results therefore from the combination of late Archean and Proterozoic events. **(*SY5, Wed. 9:40*)**

A comparison of supervised classifiers applied to RADARSAT-2 polarimetric SAR and Landsat-7 ETM+ images for mapping surficial materials in Nunavut

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In our study, surficial materials (bedrock, boulders, organic material, sand and gravel, thick till, and thin till) of a region of Nunavut have been mapped from RADARSAT-2 polarimetric SAR and LANDSAT-7 ETM+ images. The maps were producing using four supervised classifiers, namely a standard maximum likelihood classifier, a maximum likelihood classifier where the input features were selected using a genetic algorithm, a multi-layer perceptron-based classifier where the input features were selected using a genetic algorithm, and the *Random Forest* classifier. The classifier input features include the six optical bands of LANDSAT-7 ETM+, and for the RADARSAT-2 SAR image, four polarization intensity images (HH, HV, VH, and VV) and several polarimetric variables. These variables included the covariance matrix elements, the Freeman-Durden decomposition parameters, the fractional polarization, and the extrema of several polarimetric variables (degree of polarisation, completely polarised component element, completely unpolarised component, received power, and scattered intensity). A comparison between classification accuracies shows that adding the polarimetric variables did not improve the classification, and that the highest overall accuracy (92.5%) was obtained with *Random Forest* applied to the six LANDSAT-7 ETM+ optical and the four RADARSAT-2 polarized intensity images (HH, HV, VH, and VV). The study was funded by a *Canadian Space Agency* and *GEOIDE* grant. It is a contribution to the *Northeast Thelon Compilation* under the *Northern Uranium for Canada* and *Remote Predictive Mapping (RPM)* projects of the *GSC Geomapping for Energy and Minerals (GEM)* program. The *Canadian Space Agency* provided the RADARSAT-2 image. **(*SS11, Fri. 9:20*)**

Keynote (40 min): Strain localisation in magmas

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During ascent to the Earth surface magma undergoes a series of physico-chemical changes, which modify its rheology. Recent interdisciplinary studies have significantly changed our view of magma transport mechanics in the last decades and a picture is emerging in which strain localisation regulates magma ascent and eruption dynamics. Here, field examples will be integrated to experimental and monitored data to present a description of the deformation mechanisms taking place in magma during transport, with emphasis on the dynamics of fracturing, healing and slip processes and their implications for eruption monitoring.

Examination of proximal lava dome structures reveals a range of shear zone thicknesses across volcanic conduits and even across a given section of a volcanic conduit. We note an increase in crystal alignment, crystal breakdown, and fracture density (and permeability) towards the margin of the conduits, which, in the case of exogenic spine growth, is bordered by narrow fault zones hosting gouge, cataclasite and occasionally pseudotachylyte. Magma deformation experiments support our observations in which an increase in strain rate, as envisaged near conduit margins, induces crystal alignment as well as seismogenic failure and development of the permeable porous network. Rotary-shear experiments on volcanic ash gouge have demonstrated the importance of rate weakening in dictating gouge frictional mechanics, whereas volcanic rocks have shown a propensity for melting with a complex rheological outcome. Shear experiments at variable slip rates have enhanced our description of stick-slip dynamics during magma ascent, which is often accompanied by drumbeat seismicity. We finally combine our observation to theoretical analysis to constrain the dynamics of fault healing in volcanic conduits. **(*SY2, Thurs. 8:20*)**

Keynote (40 min): Baseline near-surface bedrock and groundwater geochemical data prior to shale gas development - Preliminary data from southern Quebec

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In southern Quebec, from 2006 to 2010, drilling and fracking results have shown that the Upper Ordovician Utica Shale is a potential shale gas producer. In 2010, exploration came to a halt pending an environmental review of all issues related to shale gas exploration and development. The Geological Survey of Canada has initiated a detailed evaluation of shallow and deep sub-surface conditions (geology, hydrogeology, geochemistry, geophysics and geomechanic) at a specific site southwest of Quebec City where one shale gas well targeting the Utica Shale has been drilled and fracked. During the summer and fall of 2013, twenty-five private water wells were sampled and 4 shallow (50 m) wells were drilled, cored and sampled for water chemistry and rock organic geochemistry. In addition, 250 sites were sampled for pore-space radon and hydrocarbons in soils.

The shallow bedrock geology is dominated by Upper Ordovician shales and sandstones of the Lorraine Group, the cap rock of the Utica Shale present at roughly 2 km deep in the subsurface. Rock-Eval and organic matter reflectance results from the organic matter rich Lorraine shales suggest that thermal maturity increases southerly from oil to condensate windows. GC and GC-MS analyses of core extracts document the presence of low but detectable concentrations of C1 to C20 hydrocarbons.

Most water samples have significant concentrations of dissolved hydrocarbons including mostly methane, as well as ethane and propane in a few wells. The presence of dissolved hydrocarbons in groundwater is fairly well established in southern Quebec, although their source (biogenic versus thermogenic) remains ambiguous. The presence of dissolved propane indicates that some of the hydrocarbons are thermogenic in origin. Gas wetness and isotopic ratios ($\delta^{13}C$, $\delta^{2}H$) of methane suggest mixed thermogenic and biogenic origin. Areas with elevated radon, methane, ethane and butane in soils are located close of the Appalachians – St. Lawrence Platform contact, a sector with high concentrations of hydrocarbons dissolved in groundwater. **(*SS12, Fri. 10:20*)**

Keynote (40 min): Temporal and spatial change in grain size and erodibility on a meso-tidal channel-flat complex in Willapa Bay, Washington, USA, *versus* a macro-tidal channel-flat complex in Kingsport, N.S., Canada

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Understanding of sediment texture and erodibility on muddy tidal flats and channels on temporal and spatial scales is required to resolve formative processes and the subsequent transport of sediment in these areas. Recognition of the importance of flocculation to the formation and maintenance of cohesive intertidal deposits has spurred investigations on textural studies of bed sediments, field studies of suspended flocs, and modelling studies.

Regional grain size surveys were carried out in September 2008, July 2009, and February 2010, on the muddy meso-tidal flats and channels in the southern end of Willapa Bay, Washington State. Results indicated that floc fraction, the amount of bed sediment deposited as flocs, showed a strong inverse correlation with seabed elevation. No correlation between sediment grain size and distance to the nearest channel could be delineated. Erodibility studies, using a Gust chamber, showed that bottom sediments became more erodible in the tidal channel during winter when suspended sediment concentrations were high in comparison to summer values.

In April 2012, a study was initiated to examine the seasonal change in grain size and erodibility on a muddy macro-tidal flat and channel complex in Kingsport, N.S. Samples were collected for bottom sediment grain size analysis every month for a full year from a tidal flat and from a tidal channel and its banks. Results suggest that a mud threshold may exist as a mechanism for seasonal deposition. Erodibility measurements were made monthly with a Gust erosion chamber on duplicate samples from the tidal flat, left and right tidal channel bank, and the channel thalweg. These measurements show an annual order of magnitude difference in cumulative mass eroded and may be responsible for the order of magnitude change in suspended sediment concentration in the Upper Bay of Fundy between winter and summer. **(*SS1, Fri. 8:00*)**

Contrasting fault localization processes as the consequence of asynchronous variation in porosity, permeability and fluid chemistry – examples from Kiggavik, Nunavut

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Faults routinely act as primary conduits and barriers to fluid flow, both during their active dynamic stage, and as passive structures in post-tectonic periods. During the dynamic stage, fluid transport, mineral precipitation and material evolution of faults are intimately linked to transient seismicity and displacement that create variations in material properties that affect strength and localization. Such phenomena are commonly associated with mineral deposits for which it is important to establish whether the mineral-fault association is genetic or fortuitous; in this presentation we discuss examples from one such area. Kiggavik is an emerging uranium deposit bordering the intracratonic Thelon Basin straddling Northwest Territories and Nunavut, Canada. Uranium deposits are hosted by feldspathic metagreywacke (Pipedream assemblage) within the Woodburn Lake group of supracrustal Neoarchean metasedimentary and metavolcanic rocks. The Neoarchean assemblages are unconformably overlain by and structurally intercalated with Paleoproterozoic metasedimentary strata of the Ketyet River group and affected by major igneous events (1.84-1.81 Ga Hudson Intrusive Suite and ~1.76 Ga

Kivalliq Igneous Suite). The structural intercalations comprise east-northeast-vergent nappes and thrusts, and exhibit a subhorizontal regional fabric resulting from thrusting, ductile deformation, and transposition that was refolded regionally prior to 1.76 Ga. Of specific interest to this presentation are two distinctive fault sets in the area. The first comprises crustal-scale dextral transcurrent faults with associated and subsequent dip-slip offset (*e.g.* Thelon and Judge Sissons) that accommodated deposition of siliciclastics of the Thelon Basin and were periodically reactivated from at least ~1.75 to 1.54 Ga, and most likely during mineralization. Intense silicification and an absence of uraninite within large movement regions (*e.g.* Thelon Fault) argue that these large faults had a pre-ore role of establishing low permeability zones. In contrast to the latter faults, subsequent NW-SE trending, cross-cutting quartz veins and smaller fault arrays are characterized by phyllosilicate films and/or gouge generated by cataclasis and alteration that appears to correlate with intense, sequential, hydrothermal alteration that envelops the uranium deposits. The concentration of uraninite within the heavily altered volumes of intersecting reactivated fault zones points to heterogeneous fluid flow and precipitation. Fault behaviour and the associated contrasting attributes are interpreted to reflect variations in porosity and permeability consistent with progressive hardening of the large faults by the initial silicification. The later cross-faults then formed within the compartmentalized architecture provided by the silicified faults in what was then relatively weaker material and provided conduits for fluid flow. **(*SY2, Poster*)**

Pre or interglacial regolith persistence under non-erosive ice during Last Glacial Maximum in central Hall Peninsula, Baffin Island, Nunavut, Canada

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The central part of the Hall peninsula is locally covered by a 1 to 3 meters deep, red, weathered superficial material defined as a regolith, over Precambrian meta-sedimentary and granitic bedrock. This region is surrounded by a transition zone where surficial materials are composed of a mixture of regolith and glacial till. The presence of the regolith zone, as well as felsenmeers and weakly eroded bedrock outcrops, suggest that a cold-based glacier was covering the region of central Hall Peninsula, protecting it from glacial erosion during the Last Glacial Maximum. Field evidences and laboratory analyses such as geochemical Fe and Al forms extractions, silt-clay mineralogy, and ESM imaging on surficial deposits samples and on the regolith indicate that it is a regional residue that could have effectively been protected from erosion. The regolith would be a pre-glacial or interglacial *in situ* material originating from the weathering of the bedrock under a warm climate. During summer 2012, continuous frozen cores were extracted from the regolith down to depth of 2.3 m below surface in what seems to be a transition zone where the bedrock gradually becomes less weathered with depth showing a gradation in alteration. The presence of illite as well as crystalline kaolinite showed by the X-ray analyses on the silt-clay fraction of regolith samples supports this hypothesis. Heavy mineral analyses on the regolith and till samples showed that sulfides are rarely found in the region. No gossans or economic ore minerals have been identified in the regolith area.

This project will result in an improved higher resolution 1:20 000 surficial geology map and a better understanding of the Pleistocene ice dynamics on Hall Peninsula and will facilitate drift prospection. This glacial geology study supports the search for economic minerals in the region and permafrost characterization will be useful for land management related to future infrastructure development by mining companies. **(*SY4, Wed. 9:20*)**

Use of RADARSAT-2 and ALOS-PALSAR Images for Wetland Mapping in New Brunswick

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RADARSAT-2 C-band and ALOS-PALSAR L-band SAR images were used for mapping wetland areas in New Brunswick. The study also used LANDSAT-5 TM and DEM data. The resulting maps were compared to GPS field data as well as to two wetland maps currently in use by the Province of New Brunswick, namely the *Department of Natural Resources (DNR) wetland* and *forested wetland* maps. Overall, the best classification accuracy was achieved with the combination of LANDSAT-5 TM, DEM and RADARSAT-2 images (93.7%). With the RADARSAT-2 (ALOS-PALSAR) images, all the classes were classified with an accuracy superior to 85% (80%), except the *mixed forest* class that only has a classification accuracy of 78.4% (69.8%). This class is primarily confused with the *forested wetland*, *hardwood forest* and the *softwood forest* classes. The comparison with the 146 wetland-classified GPS sites shows that the number of correctly identified wetland GPS sites on the classified images is higher when the image acquired during the flooding is considered, the difference being higher with the ALOS-PALSAR images than with the RADARSAT-2 images. The number of correctly identified sites is higher for the ALOS-PALSAR images (91.1%) than for the RADARSAT-2 images (88.7%). Both percentages are well above those computed using the DNR maps (44.5 %). For both SAR images, the majority of misidentifications are due to wetlands not being classified in the right wetland class and very few are wetland sites being classified as a non-wetland class. For the DNR maps, about half of them are associated to wetland sites that not being mapped on the DNR maps, the remaining half being wetland sites that are not classified in the right wetland class. The study was funded by an *NB Environmental Trust Fund* grant and supported by a *NASA Interdisciplinary Science Program (NASA-IDS)* grant. The RADARSAT-2 images were provided under a SOAR grant awarded to the Province of New Brunswick. **(*SS11, Fri. 9:00*)**

Combining ZTEM and magnetotelluric data for a three-dimensional conductivity model of the Morrison porphyry-Cu deposit, British Columbia

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The airborne Z-Axis Tipper Electromagnetic (ZTEM) method uses natural low frequency electromagnetic signals in the range 30-720 Hz to determine electrical conductivity from the surface to a depth of 2 km. However, this penetration depth may be limited by attenuation of electromagnetic signals within conductive media. ZTEM measures vertical and horizontal magnetic fields and is effective at determining lateral changes in conductivity, but does not provide the same vertical resolution as the ground-based magnetotelluric (MT) method. Broadband MT stations collect signals in the range 0.001-1000 Hz and can resolve features at greater depth than ZTEM. However, MT surveys require ground contact to measure electric fields and as a consequence are slower and more expensive to deploy. The spatially dense and higher frequency ZTEM data and the lower frequency MT data complement each other to reduce the non-uniqueness of the three-dimensional inversion. Since both methods derive the tipper from measurements of the vertical and horizontal magnetic fields, both datasets can be inverted simultaneously to create electrical conductivity models. We show with a synthetic model that a limited MT survey can be sufficient to improve the inversion of larger-scale ZTEM surveys.

ZTEM is used to resolve metallic sulfide-bearing ore bodies because of their resistivity contrasts relative to the surrounding host rock. We present a case study from the Morrison

deposit, a copper-gold porphyry system located in the Babine Lake region of British Columbia. The deposit is genetically and spatially related to an Eocene biotite feldspar porphyry stock (BFP), which intruded into Middle-Late Jurassic sediments. Alteration and mineralization zoning at Morrison are apparent, which are centered on the BFP stock. Proximal potassic alteration is associated with disseminated chalcopyrite and minor bornite. Outward, distal chlorite-carbonate alteration is mainly accompanied with pyrite. The original annular shape of the deposit has been changed by post-mineralization faults. This complicated but small scale structure requires densely sampled ZTEM data and lower frequency MT data in order to constrain the inversion model. Our research shows that inverting a combination of MT and ZTEM data brings out the advantages of each technique and creates a more comprehensive three-dimensional conductivity model. **(*SS3, Wed. 3:20*)**

Magma mingling in the Avalonian Holyrood Granite

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Detailed mapping and sample analysis have been carried out on an outcrop of the 620 Ma Holyrood Granite where spectacular magma mingling features are displayed. The ~50×10 m^2 outcrop is located on the coast of the Avalon Peninsula, Newfoundland. The outcrop corresponds to the upper levels of a granitic magma chamber – as evidenced by sporadic columns of pegmatite – and the main features of interest to this study relate to the intrusion of a tonalitic magma into the chamber. Most occurrences of the more mafic rock type are in the form of metre-scale, rounded blobs, many of which have been preferentially eroded, but there are also occasional dykes. No chilled margins were observed and we interpret both magmas as crystal-bearing slurries at the time of the intrusion. A changing rheology is observed across the outcrop. At its northern end, contacts between host and blobs are smooth and unbroken, whereas at the southern end blobs have arcuate spalled rims, where the surrounding granite cracked and the more mafic magma intruded into the cracks. Modelling of the magma mingling has been carried out based on physical properties inferred from chemical analyses, and this emphasizes the difference in rheological behaviour can result from small changes in temperature and crystallinity. **(*SS6, Thurs. 2:20*)**

Petrogenesis of the Early Devonian Lake George auriferous polymetallic system, southwestern New Brunswick: Evidence from LA ICP-MS analyses and *in situ* sulphur isotopes

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The Late Silurian - Early Devonian Lake George granodiorite stock is located approximately 40 km southwest of Fredericton, New Brunswick. The contact metasomatic aureole is known to contain tungsten, molybdenum, antimony, and gold mineralization. The shallowly north-dipping antimony vein system cuts the stock and host Silurian metasedimentary sequence and was for much of the 20th century the largest antimony-producing deposit in North America. Several publications have systematically described the earlier W-Mo and later Sb mineralization. However, no systematic ore mineral studies have been conducted in an effort to better understand the physio-chemical controls on gold mineralization in this magmatic-hydrothermal system. Recognized only in the late 1980's, the gold is hosted within arsenopyrite and arsenic-rich pyrite in the hydrothermally altered selvages surrounding quartz and quartz-carbonate veins. These auriferous veins cross-cut the W-Mo-bearing stockwork and pre-date the Sb vein mineralization. All hydrothermal activity in the area post-dates peak contact metamorphic conditions, which is evident from overprinting relationships. It appears that the vein system which hosts the gold mineralization is not directly associated with the granodiorite cupola.

Results from this study and previous research indicate that the grades of the auriferous veins locally exceed 7 g/t.

Laser ablation ICP-MS spot analyses and elemental mapping, supported by SEM-BSE imaging, were used to characterize the elemental associations between gold and other trace elements in the main sulfide phases. This revealed a positive correlation between gold concentrations and As, Cu, Bi, and Sb that all occur in solid solution within the cores of arsenic-rich pyrite. Concentrations of gold within the cores of arsenic-rich pyrite reach up to 225 ppm. This trace metal zonation records dynamic changes in the physio-chemical conditions during gold mineralization. *In situ* sulphur isotope analyses were conducted using SHRIMP II on different generations of pyrite in this system. The S isotopic signatures of the arsenian pyrite associated with gold suggests that they are genetically related to the Sb mineralization, supporting a hypothesis that the sulphur is predominantly derived from the Silurian Kingsclear sedimentary sequence, with values consistent with those of the Sb vein system. These are dissimilar to those analysed from the cupola of the Lake George Granodiorite stock.

It is hypothesized that replacement-style sulfidation reactions are responsible for the precipitation of gold-bearing sulfides. Sulfidation of biotite by auriferous hydrothermal fluids resulted in the precipitation of phengitic muscovite, rutile, arsenopyrite, and auriferous arsenic-rich pyrite. Characterizing the associated alteration style and mineral-scale distribution of trace-metals is a crucial component in understanding the physiochemical conditions present during gold mineralization. **(*SS20, Wed. 3:00*)**

Reexamination of the exhalitive and subvolcanic replacement origins for various phosphatic iron oxide deposits with Cu and Au (IOCG): The role of volcanic and subvolcanic processes, geothermal evolution, and brine-igneous rock reactions

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There are many very different types of magnetite-rich deposits that have variable phosphate contents, as well as syngenetic to epigenetic Cu (& base-metals), Au (& Ag), with quite anomalous light REE contents, typically in apatite. Of note, the genesis of traditional banded iron formations (BIFs), mainly of the Algoma type, which are petrogenetically related most closely to submarive exhalative activity associated with volcanism. There are Algoma-type BIFs with quite variable P contents, although none quite as high as in most IOCG deposits, *i.e.*, a magnitude less. One of the most notable differences between BIFs and other non-magmatic iron ore deposits is the lack of silica interlaying, *i.e.*, no “B” in BIFs (so what? so IFs). It is known that silica solubility is higher in acidic or very alkaline environments. Also, saturation of components in open versus closed basin conditions, within a density stratified ocean system is quite different, *i.e.*, Red Sea, Salton sea, *etc.* An important consideration in looking at the range of exhalites are the nature of the footwall sequence, in particular felsic alkalic rocks, *i.e.*, with high $Mg(OH)_2$ fixation potential that lowers pH, plus high primary Fe/Mg, Fe-P interrelations in glasses and their close association in related minerals, and low to no quartz, *i.e.*, at certian temperatures maybe silica undersaturated at points in the subsurface to exhalative fluid flow system. As well, during glass devitrification, there are silica-consuming reactions in alkaline volcanic rocks that are not common in other reacting glass-rich systems. The very high salinities that have been inferred for some types of IOCG-forming systems definitely lead to density stratified water, with redox boundaries that limit oxidation in the exhalative environment. In the subsurface environment, redox of the fluids is controlled to by the low ferric/ferrous of the volcanic and subvolcanic rocks, thus responsible for magnetite-dominant vein, limestone replacement, and derivative exhalative systems. Sulfate saturation and (or) reduction in the subsurface, with high primary Fe and Ca, with Mg, typically limits $f(S_2)$. So the high salinity fluids associated with low to high T devitrification results in very high Fe solubilities (& high P_2O_5 if Ca activity is low), at low pH and $f(O_2)$, with minimal silica. Stockwork vein systems and related exhalites associated with volcanic and subvolcanic alkalic igneous rocks typically are magnetite dominated with higher apatite contents, with variable sulfide and minimal silica. Like VMS-forming environments, the fluid temperature controls the Cu, precious metals, and LREE content, such that very special mineralized IFs would form rather than typical BIFs. **(*SS6, Thurs. 9:00*)**

Extreme fractionation processes in the formation of felsic magmatic ore deposits: Examination of the role of thermal-chemical aspects

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Extreme fractionation is evident in many magmatic systems including highly evolved felsic magmatic systems. Although considerable focus in the literature has been on volatile complexing (alone) in explaining metal enrichment in magmatic systems, only a few experimental studies and selected field studies present primary magmatic processes as responsible for generation ore-forming systems in various granitoid magmas. The behavior of incompatible elements during partial melting and (or) fractional crystallization is well know, although the effects of the duration of a magmatic system directly related to the thermal structure of the area is very rarely considered. There are several key considerations that are of consideration, including efficiency of crystal-melt partitioning and crystal-melt separation two of which are very much a function of the duration of a cooling system. Using thermal modeling techniques, various magma injection scenerios were examined, in particular mafic magmas cogenetically emplaced with felsic magmas, to illustrate the range in cooling times for fractionating magmatic systems. It is easily shown that the duration of crystallization of felsic magmatic bodies can be easily extended by >> 10 times, such that crystallization from a typical granitoid solidus temperature of 700°C to << 600°C could be extended to over 1 million years; it is probable that could overcome the viscosity issues with crystal fractionation (crystal-melt separation) at very low temperatures. As well, an approach to equilibrium partioning of incompatible elements. If correct, any system can now be geochronologically be constrained by dating each phase of a magmatic system, and associated ores formed, *i.e.*, the importance of thermal models can then be tested in ore systems. Furthermore, if correct, then prediction of economic potential of a particular felsic magmatic system is possible, if the regional thermal structure and advective magmatism within an area are also considered in evaluating exploration potential.

For calculating the thermal energy aspects of this study, a freeware computer program called HEAT by Ken Wohletz was used. The program is enables input of variable thermal gradients, and emplacement of different timing of intrusions into any package of rocks. The methods used were designed to simulate thermal regimes into which various magmatic systems were emplaced, so as to determine the duration of either partial melting and (or) fractional crystallization. The time between cooling from liquidi through to their lower-most solidus affects degree of fractionation to extremely low T's consistent with each of their solidi, *i.e.*, well below 600°C. **(*SS24, Thurs. 4:40*)**

Geochemistry and petrogenesis of the Main Mass of the Sudbury Igneous Complex

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The Main Mass of the 1850 Ma Sudbury Structure comprises a lower unit of Norite, a middle unit of Quartz Gabbro, and an Upper unit of Granophyre, and has been interpreted to have crystallized from i) a single melt layer, ii) a density-stratified melt comprising lower mafic and upper felsic "emulsions", or iii) density-stratified layers of melt + mafic clasts and melt + felsic clasts. Geochemical and petrographic data for a very well-exposed section across the South Range provides important constraints on the mechanisms of crystallization: 1) The lower part of the norite (including inclusion-bearing norite) is composed of Opx-Plag cumulate rocks derived from a quartz dioritic melt with 4% MgO and 61-62% SiO_2, ~0.9% TiO_2, ~16% Al_2O_3, ~8% FeO_t,

~6% CaO, ~3% Na_2O, ~2.5% K_2O, ~100 ppm Cr, and ~60 ppm Ni. 2) The middle (including a particularly fresh obliquely-laminated melanorite) and upper parts of the norite are composed of Opx-Plag cumulate rocks derived from a more aluminous-calcic less potassic quartz dioritic melt with 4% MgO and ~57% SiO_2, ~0.8% TiO_2, ~19% Al_2O_3, ~8% FeO_t, ~9% CaO, ~3% Na_2O, ~1% K_2O, ~60 ppm Cr, and ~20 ppm Ni. 3) The quartz gabbro and lower part of the granophyre (perthitic mircopegmatite) exhibit complimentary enrichments/depletions in Fe-Ti-Mn-P and highly incompatible lithophile elements, indicating that they crystallized as part of the same system. These geochemical variations and the requirement for at least two melt compositions in the norite are mirrored in the behavior of all trace elements. The liquid that formed the lower norite may represent the original impact melt modified by incorporation of quartzofeldpathic sedimentary, mafic-felsic volcanic, and felsic plutonic footwall rocks (which would vary across the melt sheet) and the liquid that formed the middle and upper norite may represent a contribution of a more aluminous mafic magma derived by melting of footwall basalts and East Bull Lake Suite intrusions. Superimposed on these vertical variations are lateral variations in chalcophile element enrichment/depletion trends and Pb isotopic contents of norites overlying and away from ore-localizing embayments, and S-Os-Pb isotopic compositions and As contents of different ore zones that appear to reflect preservation of these signatures from the original Ni-Cu-PGE sources (Nipissing and EBLI) within relatively small (~15 km^3) convection cells in the melt sheet. **(*GS5, Fri. 3:00*)**

A genetic model and the age of the Macusani uranium deposits, Puno, southeastern Perú

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The focus of the present study is uranium deposits of the Meseta de Quenamari, Cordillera Oriental (Latitude 13° 57' S; Longitude 70°37' W). Sillimanite-andalusite-muscovite-biotite rhyolites of the 6.8 – 12.3 Ma Macusani Formation host uranium mineralization in fractures. The Macusani rhyolites are extremely-fractionated, strongly-peraluminous (aluminum saturation index ≥ 1.2) and are enriched in U (average U content of 28 ppm). Mineralogical studies reveal that meta-autunite $Ca[(UO_2)(PO_4)]_2(H_2O)_{2-10}$ is the main uranium mineral, deposited in several stages in association with hydrous Mn (-Si, Al, K) mineraloids and subordinate weeksite $K_2(UO_2)_2Si_6O_{15}(H_2O)_4$. Meta-autunite forms extended mineralized beds and fills pores and fractures in the rhyolites. The absence of uraninite and the dominance of meta-autunite suggest that meta-autunite is not a product of *in situ* weathering of U^{4+} minerals, but the primary uranium mineral precipitated directly from the fluid. U-Th ages for meta-autunites from the Macusani district range from 188 ka to 20 ka and are considerably younger than the final eruptive events in the area, which took place at 6.8 Ma. The deposition of meta-autunite occurred in several stages and the most significant deposition event occurred 80-100 ka ago during the interglacial period in the Central Andes. Stable isotope studies indicate that the autunite formed at low-temperature from fluids with δ^2H values from -126.7‰ to -68‰ and $\delta^{18}O$ values from -17.8‰ to -9.9‰. The low temperatures and isotopic composition indicate that the Quelccaya Ice Cap, covering the western area of the Meseta de Quenamari, is the most likely source of the fluid.

The data are most consistent with model wherein uranium was derived through the leaching of the Macusani rhyolites, transported by meteoric waters in the form of uranyl phosphate complexes and precipitated as autunite due to evaporation and change of the CO_2 pressure when uranium-bearing ground waters reached the surface. The location of the majority of known deposits on the upper walls of the active fluvial canyons suggests that the geomorphological environment that is focusing both groundwater flow and its evaporation is the most favourable for the precipitation of meta-autunite ore. **(*SS7, Wed. 4:20*)**

Topographic features of the sub-Athabasca Group unconformity surface in southeastern Athabasca Basin and its relationship to uranium ore deposits

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Topographic features of the sub-Athabasca Group unconformity surface, such as paleovalleys, topographic highs and fault scarps, have been documented in some previous studies, and have been linked to localization of unconformity-related uranium deposits in the basin. However, it remains poorly understood why these features may have been related to mineralization, and how they are distributed on a regional scale.

A 100 by 60 square kilometres area of the southeastern Athabasca Basin encompassing the McArthur River, Phoenix, and Key Lake deposits was selected to study the relationship between these topographic features and U mineralization. Using Paradigm's • 6¾4 GOCAD • 0…3 software, a fairly detailed 3D model of the basin has been constructed using data from more than 1200 drill holes. The elevation of the unconformity surface in the study area generally decreases from circa +500 m (datum, mean sea level) at southeastern margin to about -250 m at the northwestern edge, for a total relief ~750 m. The McArthur River deposit is situated beside a NE-trending topographic ridge about 20 km long and 2.5 km wide, with the elevations ranging from a high of +150 m to a low of -100 m. Another, similarly trending 5-km-wide ridge extends from the Wheeler River area northeastward for approximately 40 km, with a high and low of +350 m and -100m, respectively. To the west, an approximately 12 km long, 1.5 km wide, nearly N–S-trending topographic ridge occurs adjacent to the Millennium deposit.

Structural interpretation and cross-sections illustrate that these topographic features may be controlled by variably oriented reverse faults, some of which were long-lived, having been active both pre- and syn-basin development, and subsequently reactivated. Regional clay anomalies in the Athabasca Group broadly coincide with the topographic highs of the Phoenix–McArthur River deposits trend. Projection of the major U deposits, prospects and occurrences onto the unconformity surface indicates that the majority of them are located on or adjacent to these topographic features. In addition, 'quartzite' ridges, whose origin is controversial (*i.e.*, part of Wollaston Group stratigraphy or hydrothermal in origin?), are associated with some of them. These topographic features may have been enhanced by differential erosion due to the differences in resistance of basement lithologies, especially where they involve such quartzite, and/or by subsequent reactivation, which in turn may have served to focus fluid flow and controlled alteration and mineralization. **(*SS7, Wed. 9:00*)**

Formation of mantle plumes and superplumes: Driven by subduction?

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Mantle plumes and superplumes (broad lower mantle seismic low velocity zones, or mantle superswells, that can drive "secondary" mantle plumes above them) are widely believed to be features caused by thermal anomalies or thermal instabilities around the core-mantle boundary that are independent of the plate tectonic system, and are relatively stable with respect to the Earth's core and the rotation axis. It is also believe by some that the antipodal superplumes in the present-day lower mantle could have been a stable feature since Earth's early history. However, geodynamic modelling suggests that slab subducting to the lower mantle could promote the formation of plumes. Here we argue for a case that the formation of both antipodal superplumes (along with secondary plumes above them) and some isolated plumes in the lower mantle are linked to slab subduction. It is widely accepted that the positions of the present-day antipodal Pacific and African superplumes align with the position of the supercontinent Pangea before it broke up. Current global large igneous province (LIP) record also indicates that global plume intensity intensified soon after Pangea assembly and peaked during its breakup, thus permitting spatial and temporal linkages between Pangea supercontinent and the antipodal superplumes. A similar supercontinent-supercontinent coupling has been documented for the time of the Late Precambrian supercontinent Rodinia, and the sub-Rodinia superplume appears to have travelled together with the supercontinent from higher latitude to the paleoequator through a true polar wander event. Supercontinent history before 1 Ga is yet unclear, but the global plume intensity appears to show a cyclic nature similar to that during the post-1 Ga time. It has thus been proposed that circum-supercontinent subduction of cold slabs to the lower mantle may have caused the formation of antipodal domes of hot and dense lower mantle, or superplumes, that were aligned with the positions of the respective supercontinents. Preliminary geodynamic modelling has demonstrated the feasibility of such a mechanism. A similar mechanism could also cause the formation of lone plumes away from the superplumes, such as the late Cenozoic Hainan plume. Both primitive Pb-Nd-Os isotopic and seismic tomographic data indicate that the Hainan plume originated from the lower mantle, and seismic tomography also shows the presence of subducted cold slabs surrounding it. We thus suggest that circular descending cold slabs might be the main mechanism that drives the formation of both superplumes and lone plumes in the lower mantle. **(*SY7, Thurs. 4:20*)**

Keynote (40 min): Near surface manifestations of the structural controls on Ni-Cu-PGE sulfide mineralization in the roots of large igneous provinces

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The history of discovery of large magmatic Ni-Cu-PGE sulphide deposits has often been underpinned by discovery of a gossan or surface outcrop of mineralization either through careful science or more often serendipity. Once the discovery is made, the creation of value through exploration is typically rooted in very careful geoscience investigations. Notwithstanding, the holy grail of discovery remains attractive, and geologists continue to search remote areas for the surface manifestations of ore deposits. It often helps to know the characteristics of the target.

The distribution of magmatic Ni-Cu-platinum group element (PGE) sulfide deposits and mineralization in mafic intrusions is controlled by the geometry and structural setting of the magma chamber. The recognition that the Ovoid Deposit and the Eastern Deeps Deposit at Voisey's Bay are localized where a dyke-like conduit connects to a larger intrusive body has been a key observation that has underpinned much of the exploration activity. Likewise the geological relationships in the Noril'sk Type intrusions indicate a localization of mineralization within the thicker axial parts of magma conduits that follow and are modified by major structures like the Noril'sk Kharaelakh Fault. These relationships are not unique. Some of the best examples of mineralization within intrusions adjacent to feeder conduits are found in China; the Hong Qi Ling deposits in Jilin Province shows the juxtaposition of small mineralized mafic intrusions within structural corridors. These relationships are repeated at Huangshan, Huangshandong and Jingbulake in Xinjiang Province, where disseminated sulphides are localized at the base of differentiated intrusions above comagmatic dykes, and at Jinchuan in Gansu Province; where the configuration of the intrusion is controlled by regional structures that create space for the emplacement of a small intrusion. Many other small differentiated intrusions have dyke-like keels, including the Limahe and Qingquanshan deposits in Sichuan Province. Other cases of mineralization controlled by magma conduits include the Kalatungke deposit in Xinjiang province, the Babel-Nebo deposit in Western Australia and the Eagle and Tamarac mineralisation in the Mid-Continent Rift. All of these examples share common features including the space created within and adjacent to fault zones by the local structures that link into mantle-penetrating fractures that localize magmatism in the roots of large igneous provinces. **(*SY4, Wed. 2:20*)**

Diapirism and sagduction as a mechanism for deposition and burial of the Borden Lake conglomerate (a "Timiskaming-type" sedimentary rock) in the Kapuskasing uplift, Superior craton

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In Archean granite-greenstone terranes in the Superior craton, a dome and keel map pattern is evident on the regional scale, with greenstone belts occurring in narrow synclinal keels between open granitoid domes. These dome and keel structures have been interpreted as a result of diapirism and sagduction (vertical tectionism). Also occurring in the Superior craton are regional scale shear zones. They are interpreted as a result of regional-scale horizontal shearing during final amalgamation of the Superior craton (horizontal tectonism). Diapirism/sagduction and regional-scale horizontal shearing, and thus vertical and horizontal tectonism, were synchronous in the Neoarchean. This contribution is mainly concerned with diapirism and sagduction.

"Timiskaming-type" sedimentary sequences are the youngest supracrustal rocks in many Archean greenstone belts. They show features of structurally controlled basins and recent results show that they were deposited in synclinal keels between granitoid domes during diapirism and sagduction.

The Borden Lake conglomerate in the Kapuskasing uplift was deposited after 2667 Ma and most workers correlate it with the Timiskaming Group in the Swayze and Abitibi greenstone belts to the east. It was metamorphosed to upper amphibolite and granulite grade and deformed between 2660 and 2585 Ma, indicating that it was buried to mid-crustal levels shortly after its deposition. Although evidence for post-Timiskaming thrusting is present in the Abitibi-Wawa supbrovince, there is no evidence for any such thrusting to have led to major crustal thickening before the Kapuskasing uplift event, as greenstone belts in the subprovince, including the Timiskaming Group, are generally of low grade. Therefore, such thrusting cannot explain the burial of the conglomerate. In the diapirism and sagduction model, supracrustal rocks can be brought down ("sagducted") to deep crustal levels, and for the Timiskaming-type sedimentary sequences, this can happen shortly after their formation. This model can thus readily explain the burial of the Borden Lake conglomerate. Assuming what is observed in the Kapuskasing uplift is representative of the middle to lower crust of the Abitibi-Wawa subprovince, our interpretation implies that many lower grade greenstone belts and the associated Timiskaming-type sedimentary rocks in the subprovince, and potentially elsewhere, have deep and much higher grade "roots", as indicated by the steep contacts between the greenstone belts and the surrounding granitoid domes and the steep bedding observed in many Timiskaming-type sequences. **(*SY3, Thurs. 8:40*)**

Neoarchean gold mineralization in the Superior Province: A result of synchronous vertical and horizontal tectonism at the late stages of Archean cratonization

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In the Superior craton, there is evidence that vertical and horizontal tectonism occurred synchronously at the late stages of Archean cratonization, and horizontal shearing (a result of horizontal tectonism) is concentrated in synclinal keels (a result of vertical tectonism). The Timiskaming-type sedimentary rocks are interpreted to have been deposited in the keels during the process. The synclinal keel-shear zone association provided a link between the upper crust and the lower crust or mantle, and might have served as a conduit for mineralizing fluids and magma that were generated in the crust and/or mantle during the process. Such a process at the late stages of Archean cratonization can readily explain the common association of gold deposits with greenstone belts in synclinal keels, shear zones, late felsic to intermediate intrusions and Timiskaming-type sedimentary rocks, as exemplified by the geology of the Hemlo gold deposit (containing >650 tons of gold). It is suggested that synchronous vertical and horizontal tectonism was a common process in the Neoarchean and represents a transition from dominant vertical tectonism in the Mesoarchean (and Paleoarchean?) to dominant horizontal tectonism in the Proterozoic and Phanerozoic. It is further suggested that the process and the associated gold mineralization were both related to a range of tectonometamorphic and magmatic processes that arise in response to slab break-off or roll back and associated extensional orogenic collapse following terrane accretion. A main feature of our model is the overall synchronicity and interplay of compressional and extensional, vertical and horizontal, and magmatic and structural/tectonic processes. **(*SY5, Wed. 8:40*)**

The Cadomian Orogen: Neoproterozoic to Early Cambrian crustal growth and orogenic zoning along the northwestern periphery of the West African Craton

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The Cadomian Orogen in the NE Bohemian and the northern Armorican Massifs shows a distinct orogenic zoning from recent NW to SE consisting of (i) an outboard sitting continental crustal unit comprising Neoproterozoic rocks associated with *c.* 2.0 Ga old Icartian Basement, (ii) a magmatic arc and a back-arc basin, (iii) a foreland or retro-arc basin, respectively, and (iv) the passive margin of the back-arc basin. New U-Pb zircon ages of detrital zircon of Neoproterozoic to Fortunian siliciclastics from the Schwarzburg Antiform in the Saxo-Thuringian Zone (NE Bohemian Massif) identify the West African Craton as the hinterland for the Cadomian Orogen demonstrated by zircon populations in the range of 1.8-2.2, 2.5-2.7, 3.0-3.1, and 3.4-3.5 Ga. Dominant zircon population (*c.* 50-70% in each sample) is derived from Cadomian magmatic arc activity in a time slice of *c.* 570-750 Ma. The magmatic activity of the Cadomian arc became extinct at *c.* 570 Ma. Closure of the back-arc basin by arc-continent collision occurred between *c.* 570 and 542 Ma under the formation of a foreland (retro-arc) basin. A short-living remnant basin existed between *c.* 542 and 540 Ma. Granitoid plutonism at 539 to 540 Ma document the final pulse of the Cadomian Orogeny. Hf isotopes, calculated εHf_i values and TDM model ages from detrital and magmatic zircon show, that during the *c.* 180 Ma long Cadomian magmatic arc activity juvenile arc magmas became contaminated by the recycling of Eburnian and Archaean crust. Mixture with continental crust is always present. The required geotectonic setting is a continental magmatic arc during the Neoproterozoic developed on stretched Archaean and Palaeoproterozoic (Eburnian) crust. In the West African crustal evolution it can be demonstrated, that during Eburnian orogenic processes (*c.* 1.8-2.2 Ga) in most cases a 2.5 to 3.4 Ga old basement became recycled. Archaean 2.5-2.9 Ga old magmas recycled a 3.0 to 3.4. Ga old crust. Zircons with an age of 3.0-3.1 and 3.4 Ga are derived from juvenile magmas. Two zircons aged at 2779±22 and 3542±28 Ma imply a recycling of pre-existing Eo-Archean to Hadean crust and show TDM model ages of 3.98 and 4.29 Ga, respectively. **(*SY1, Wed. 10:40*)**

Canadian Malartic geological footprint: New insight from portable XRF data

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The Canadian Malartic gold mine is hosted mainly by metasedimentary rocks of the Pontiac Group, located on the south of the Cadillac – Larder Lake fault system, and by Piché Group mafic and ultramafic rocks. This world-class deposit contains over 14 Moz of gold (past production and current resources) and thus it is of interest to establish the size and characteristics of the footprint of the deposit. This is the aim of the CMIC-NSERC Exploration Footprint project, where multiple dataset (geological, mineralogical, geochemical, petrophysical and geophysical) will be integrated. Part of this study utilizes portable XRF (pXRF) to both evaluate the extent and character of the halo and to determine whether pXRF has sufficient precision and accuracy to be applied to characterizing the footprint. Over 1000 drill core sample pulps from plan and section views of the Malartic area were analyzed. Preliminary interpretation suggests some decreasing trends in Hg, Mo, Pb and K_2O contents, which correlate with Au previously analyzed by Osisko, from the mine toward south in the Pontiac meta-sediments. Some of the analyzed elements (*e.g.* SiO_2, TiO_2, Co, Cu) show distribution trends on a map view that may represent lithological variation within the Pontiac Group, rather than a hydrothermal overprint. By contrast, other elements such as K_2O are enriched in mineralized Pontiac metasediments, and values decrease away from the mineralization. K_2O values from pXRF also correlate well with gamma-ray data. Three kilometers south-west of the main deposit, the Bravo zone is a gold occurrence that was believed to be similar to the main deposit. However, pXRF data show that the Bravo zone mineralization contains significantly more arsenic, which suggests that the origin may be different. These examples show how pXRF can be very efficient and rapid technique to establish the geochemical composition and to recognize geochemical variation in the footprint of a deposit. *CMIC-NSERC Exploration Footprints Network Contribution 009.* **(*SY5, Wed. 2:40*)**

Geochronology, geochemistry, and fluid inclusion study of the Newton epithermal gold deposit, British Columbia

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Newton is an epithermal gold deposit located 105 km southwest of Williams Lake, British Colombia. Disseminated Au mineralization is mainly associated with quartz-sericite alteration, in which gold is mostly present as electrum and gold-silver telluride inclusions in sulfides. The mineralization can be divided into 3 stages: (1) quartz-sericite-pyrite-gold; (2) quartz-sericite-marcasite-gold-base metal-sulfide; and (3) polymetallic veins (pyrite-chalcopyrite-sphalerite-galena-arsenopyrite). Re-Os dating of molybdenite from stage 1 yielded an age of 72.1 ± 0.3 Ma (McClenaghan, 2013). The mineralization is mainly hosted by Late Cretaceous felsic volcanic rocks, granodiorite porphyry, and quartz-feldspar porphyry, which yielded U-Pb ages of 72.1 ± 0.6 Ma, 72.1 ± 0.48 Ma (new data), 70.9 ± 0.5 Ma, respectively. These mineralized rocks are intruded by a barren diorite, which yielded a U-Pb age of 69.07 ± 0.52 Ma.

The narrow age range for all the volcanic and intrusive rocks (~3 m.y.) and their major and trace element compositions suggest that they constitute a comagmatic volcanoplutonic complex. All the rocks are enriched in incompatible large-ion lithophile elements, and depleted in Nb, Ta, Ti, and P. These igneous rocks are interpreted to be part of a major Late Cretaceous suite of continental-arc magmatism in central British Columbia.

A series of magmatic events in central British Columbia records the tectonic evolution from an island arc during the Late Triassic–Early Jurassic to an Andean-type continental margin magmatic arc which started in the Middle Jurassic and continued to the Eocene. A major phase of arc volcanism and plutonism occurred during the Late Cretaceous, and is associated with several large porphyry deposits in British Columbia, such as Prosperity (79 Ma; Cooke and Hollings, 2005).

Fluid inclusions were found in mineralized quartz veins hosted by quartz-sericite-altered felsic volcanic rocks and quartz-feldspar porphyry. The fluid inclusion data indicate that a relatively hot and saline fluid (average Th = 294 ± 2°C, 5.16 ± 0.2 % NaCl equiv., n = 18) of probable magmatic origin was dominantly responsible for the first stage of mineralization. Cooler and less saline fluids were also present in the veins, which may represent groundwaters that locally mixed with the magmatic fluids. Some evidence for boiling was also observed in the veins, although the veins do not host significant amounts of gold. It is thought that fluid-wall rock reactions and cooling were the main controls on gold precipitation in the quartz-sericite altered wallrocks. **(*SS3, Poster*)**

pH measurement in high ionic strength brine solutions

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pH is a fundamental parameter for understanding the geochemical behaviour (speciation and sorption), and therefore transport, of many solutes in groundwater. Reliable pH measurements are important to support studies of solute transport related to radioactive waste isolation and establishment of a deep geological repository (DGR). In Canada, Ordovician rocks in the Michigan Basin are being considered as possible host rocks for a DGR for low- and intermediate-level waste. The porewater in these formations is highly saline (up to 28 wt% salinity), with ionic strengths up to 8 mol/kg or higher.

pH is commonly measured potentiometrically using pH electrodes. The measurement is based on a calibration using standardized, low ionic strength pH buffers. Because of differences in the liquid junction potentials between the buffers and test solutions, inaccuracies in pH measurement occur when the test solution ionic strength is >0.1 mol/kg. Standardized, high ionic strength buffers are not available. To achieve greater confidence in pH measurements in brine solutions, buffers were formulated and their pH values were determined by geochemical modelling using the Pitzer ion-interaction approach that is implemented in the geochemical program PHREEQC. These buffers were used to test the electrode response in solutions of varying ionic strength and composition. As an alternative approach, the buffers were also used to determine the ionic-strength dependence of the association constant (pK'a) of phenol red, a colorimetric pH indicator, spectrophotometrically.

The pH electrode response is linear over a range from 1.4 to 9.0 and for ionic strengths up to 8.2 mol/kg. However, there is a systematic offset with increasing ionic strength such that an electrode calibrated with low ionic strength buffers will underestimate pH of a high ionic strength solution (8.2 mol/kg) by approximately 0.7 pH units. For any given ionic strength, the potentiometric measurement is also sensitive to the ionic composition of the solution. Despite these effects on the potentiometric measurements, accurate potentiometric measurements are possible if the composition of the calibration buffers is similar to the test solution. The results of spectrophotometric measurements indicate that the pK'a of the phenol red indicator is virtually insensitive to the ionic composition of the solution. A maximum error of 0.2 units was observed for pH measured spectrophotometrically. However the measurement range of phenol red is limited to pH ≈7-9; additional indicators can be used to increase the effective range for the spectrophotometric approach. **(*SS8, Thurs. 2:20*)**

Identification and origin of anomalous osmium enrichments in organic-rich mudrocks

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Compilations of redox-sensitive metal concentrations (notably Mo, U, Zn) from organic-rich mudrocks (ORM), including black shales, have been used to infer temporal trends in oceanic metal inventories, which in turn provides information about atmosphere and ocean redox conditions. Such compilations also reveal instances of anomalously high metal enrichments that could be of economic value. The platinum-group element Os is another redox-sensitive element that occurs in high concentration in ORM, and has the additional advantage of a radiogenic isotope tracer that fingerprints the dominant source of Os to seawater. Specifically, the initial $^{187}Os/^{188}Os$ from ORM can distinguish between radiogenic crustal and unradiogenic magmatic/hydrothermal/extraterrestrial sources. Here, we present a compilation of total Os and ^{192}Os (non-radiogenic Os isotope) abundances in ORM through time, and compare with temporal trends in seawater $^{187}Os/^{188}Os$. Notably, there are a few instances where the total Os concentration exceeds 4 ppb and in extreme cases 10 ppb, which is similar to the lower end of the range of Os concentrations observed in chromites, molybdenite and iron meteorites. These instances of anomalously high Os concentration can be divided into two groups based on initial $^{187}Os/^{188}Os$. The first group constitutes ORM with unradiogenic initial $^{187}Os/^{188}Os$ and were deposited during Oceanic Anoxic Events (OAE), such as OAE1a (*ca.* 120 Ma) and OAE2 (*ca.* 93.5 Ma). They are related to large igneous provinces (LIP) (magmatic events), with no conclusive evidence (*e.g.*, Ir anomalies) for a bolide impact. The second group is ORM with radiogenic initial $^{187}Os/^{188}Os$ (>0.80). Examples include Member IV of the Ediacaran Doushantuo Formation (*ca.* 590-550 Ma) and the Cambrian Nuititang Formation (*ca.* 535 Ma). The radiogenic seawater ^{187}Os/sup>188Os indicates that the high Os concentrations probably do not have a magmatic/hydrothermal origin. Controlling factors for these anomalous Os enrichments are poorly constrained. Possible explanations include ultraslow sedimentation rates in an unrestricted basin with access to the open ocean Os reservoir, and/or operation of a particulate Fe-Mn oxyhydroxide shuttle that efficiently delivered Os to sediments. More generally, our study highlights that Os abundances and $^{187}Os/^{188}Os$ together are potentially useful for inferring the source of redox-sensitive metals to ORM. **(*SS2, Wed. 9:00*)**

Geochronological and geochemical constraints on the formation of the Erlingyao granite-hosted uranium deposit, Zhuguangshan uranium ore field, Guangdong, China

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The Guangdong province, South China is host to numerous granite-related hydrothermal uranium deposits. The geology and geochemistry of these deposits have been extensively studied. However, accurate and precise ages for the uranium minerals are rare because the uranium minerals in these deposits are fine grained, and bulk dating techniques previously employed were unable to discriminate between different generations of uranium minerals. Consequently the genetic models for these deposits are controversial. The focus of this research is to determine the timing of ore formation and the source of uranium.

The Erlingyao uranium deposit is one of the highest-grade uranium deposits in the Zhuguang granite complex, Guangdong province, China. Uranium mineralization in this deposit is associated with Na-metasomatism. These metasomatic zones are brecciated and discontinuous, and are spatially associated with mantle-derived mafic dykes, which crosscut the granitic pluton. The main types of hydrothermal alteration associated with veins that host uraninite are albitization, chloritization and silicification. High-calcium (8-9 wt% CaO), colliform and vein uraninite is associated with microcrystalline to fine-grained quartz and pyrite with minor galena, sphalerite and chalcopyrite. Altered uraninite has higher SiO_2 (>4 wt% SiO_2) and lower CaO (<8 wt% CaO) contents relative to unaltered uraninite. Silica-rich and calcium-poor uranium alteration minerals occur along fractures that cross cut uraninite.

In-situ SIMS U-Pb analysis of unaltered uraninite gives an age of 73 ± 4 Ma, which is consistent with the age of the mafic dykes. Trace element geochemical analysis of uraninite from Erlingyao uranium deposit by *in situ* LA-ICP-MS shows that the uraninite has low Th concentrations (≤0.05%) and chondrite-normalised REE patterns exhibit a negative Eu anomaly and are LREE-enriched. The negative Eu anomaly suggests that the REEs are from a fractionated magmatic source. Not surprisingly, these REE patterns are similar to the patterns of the host-granite. Our new data from Erlingyao uranium deposit suggest that source of the uranium is the host granite and uranium minerals precipitated from a single hydrothermal fluid event that is associated with regionally emplacement of mafic dykes. **(*SS7, Poster*)**

The adsorption of U_{60} uranyl-peroxo cage nanoclusters to clay mineral surfaces

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In the presence of hydrogen peroxide and base cations (*e.g.*, Li, Na, K, Ca, *etc.*), uranyl ions (UO_2^{2+}) in aqueous solution may readily combine and form a variety of topologically complex polyoxometalate species. Referred to uranyl-peroxo nanoclusters, these highly soluble species exist on the scale of several nanometers and are known to persist in a fully dissolved state for years at a time. In a geological nuclear waste repository, the eventual failure of engineered barriers may expose groundwater to spent fuel, and the subsequent production of hydrogen peroxide through alpha-radiolysis may result both in the creation of such clusters and their introduction into the natural environment. Given their relative novelty to Science, little is known about how the presence of these uranyl-peroxo nanoclusters may influence uranium mobility in the subsurface. Here, we focus on assessing how the U_{60} cluster, topologically identical to the C60 buckminsterfullerene with each carbon replaced by a UO_2^{2+} ion, might interact with the surfaces of common phyllosilicate minerals [particularly muscovite - $KAl_2(AlSi_3O_{10})(OH)_2$ and kaolinite - $Al_2Si_2O_5(OH)_4$]. In an aqueous environment, the U_{60} cluster shows a complex chemical behaviour, making them non-trivial to study: for instance, they may: exist as isolated clusters (or fragments thereof), adsorb cations to their exterior surface, and form large aggregates, referred to as 'blackberries', measuring 10's of nm in diameter that can remain suspended in solution. The system is extremely labile, and each of these species can potentially interact differently with the charged phyllosilicate surface. Here we use a multi-analytical approach to investigate this complex problem and constrain the fundamental mechanisms governing the cluster-surface interactions. Electrospray-ionization mass spectrometry (ESI-MS) and dynamic light scattering (DLS) assist in determining the state of clusters and aggregates in aqueous solution, and *in situ* atomic force microscopy (AFM) and synchrotron-based X-ray reflectivity techniques (crystal truncation rods/resonant anomalous X-ray reflectivity – CTR/RAXR) show details of the physical arrangement of clusters on the mineral surface and the near-surface distribution of elements. **(*SS8, Thurs. 3:00*)**

The importance of mudstone-layer characteristics in environmental interpretation of tidal deposits: A case study of the Bluesky Formation (Cretaceous), Alberta

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The Bluesky Formation (Cretaceous) in the Peace River area of north-central Alberta is a strongly heterolithic succession that formed in a series of tide-dominated deltaic and estuarine environments that were broadly contemporaneous with the better-known McMurray Formation. The environmental interpretation of such heterolithic tidal successions has proven to be difficult because of the complex interlayering of mudstone and sandstone at various scales. The complexity of the deposits has lead workers to devise cumbersome facies schemes with numerous subtly different facies. The interpretation of such successions is made more complex because environmental conditions vary in three dimensions: both in a proximal-distal manner through the fluvial-tidal transition, but also vertically because of the complex channel-bar morphology that characterizes tidal systems. Most previous facies classifications for tidal deposits focus almost exclusively on the sedimentary structures and grain size of the sandstone layers, but this only provides information about the strongest currents present. We believe, however, that equal importance must be given to the characteristics of the mudstone layers (*i.e.*, the thickness of individual depositional events and the sedimentary structures present within them), because they provide information about the depositional conditions, and especially the suspended-sediment concentration (SSC) at or close to slack water. Thus, using the characteristics of both the sandstone and mudstone layers allows a more holistic reconstruction of depositional conditions than is possible using only one type of layer. Within the Bluesky Formation, we recognize three main types of sandstone layers: ripple-laminated, cross-bedded and planar/low-angle inclined lamination. We also distinguish three mudstone-layer facies assemblages that reflect low, medium and high SSC conditions. Low-SSC assemblages consist of sand-dominated deposits with few and/or thin (< 2 mm thick) mudstone laminae; thicker mudstone layers are rare. Intermediate-SSC assemblages consist of heterolithic deposits with 2-10 mm thick mudstone layers in which horizontal stratification is common; thick homogeneous mudstone layers are also present but are not abundant. High-SSC assemblages consist of heterolithic deposits that contain thick mudstone layers (> 10 mm) that are either homogeneous or horizontally stratified. Low-SSC assemblages are most abundant at high topographic elevations within channels or on the fringing tidal flats, and in areas landward or seaward of the turbidity maximum. High-SSC assemblages occur mainly in channel-bottom locations directly beneath the turbidity maximum. We then combine the 3 sandstone and 3 mudstone facies into a 3x3 facies matrix that is capable of describing all of the deposits in the Bluesky Formation. **(*SS1, Fri. 9:00*)**

The perils of *Protichnites*: Revisiting the earliest-named arthropod trackways

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The ichnotaxonomy of arthropod trackways is confusing and needs significant revision. *Protichnites* was the first such ichnogenus to be named and also is notable as an early representative of animal activity dry land. *Protichnites* was documented by William Logan from the Cambrian Potsdam Group (Cairnside Formation) at Beauharnois, Québec, and described by Richard Owen in 1852. Owen named six ichnospecies, illustrating each with a lithographic plate. Ichnospecies were delineated on the basis of the arrangement of appendage impressions within trackways. Most of the material consisted of trackways with two parallel rows of appendage imprints and a medial groove. In the century-and-a-half since then, several misconceptions have arisen concerning diagnostic attributes of the ichnogenus. Some early workers used *Protichnites* as a "catch-all" term for any arthropod-produced trackway, including those without a medial groove. Some recent workers suggest that *Protichnites* be restricted to trackways with an intermittent, bilobate medial groove and bifid or trifid appendage impressions. In this, they apparently follow the *Treatise of Invertebrate Paleontology*, which was influenced by ichnotaxonomic decisions made by C.D. Walcott in the early twentieth century. Plaster casts of *Protichnites* donated by William Logan to the Hitchcock Ichnology Collection at Amherst College, Amherst, Massachusetts, included copies of all type specimens, save one ichnospecies. These plastotypes confirm the accuracy of Owen's illustrations and falsify the misconceptions mentioned above. Each specimen has a unilobate medial groove; this groove is continuous in several specimens, including the type ichnospecies, *Protichnites septemnotatus*. Although appendage impressions may have been made by bifid or trifid appendages, this feature cannot be recognised confidently or consistently. Proposals to exclude trackways lacking these features from *Protichnites* cannot be justified with reference to the surviving type material for the ichnogenus. Redescription and photographic illustration of these plastotypes should help clarify the relationship between *Protichnites* and other ichnogenera. **(*SS18, Thurs. 8:40*)**

History of Mackenzie Arch and its influence on Cambrian sedimentation in the eastern Mackenzie Mountains and adjacent Mackenzie Plain, Northwest Territories

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Mackenzie Arch was an elongate, northwest-trending, positive tectonic element in the eastern Mackenzie Mountains. Studies carried out during the GSC's Geo-mapping for Energy and Minerals (GEM) Program permit the history of the Arch and its influence on sedimentation to be reconstructed in more detail than previously was possible. Mackenzie Arch is cored by strata of the early Neoproterozoic Mackenzie Mountains Supergroup. The Arch may have formed during the late Cryogenian to Ediacaran and its present-day southwest flank essentially marks the eastern limit of the Windermere Supergroup. By the Cambrian, uplift of the Arch had led to local erosional removal of more than a kilometre of the upper Mackenzie Mountains Supergroup. Facies belts were well-developed west of the Arch during the Terreneuvian (earliest Cambrian). East of the Arch, the age of the oldest Cambrian deposits is not well constrained. The oldest trilobite faunas east of the Arch, from shale of the basal Mount Cap Formation, belong to Cambrian Stage 2 (traditional Bonnia-Olenellus Biozone). However, the underlying Mount Clark Formation is dominated by intensely burrowed quartz sandstone that records earlier Cambrian deposition of uncertain duration. On the east flank of Mackenzie Arch, Mount Clark Formation formed a sand-dominated, nearshore facies belt that passed eastward into shalier facies of the lower Mount Cap Formation. These facies belts persisted until early in Cambrian Stage 5 (traditional early Middle Cambrian), when transgression led to deposition of shale-dominated upper Mount Cap Formation across a wide region, persisting until late in Stage 5. Uplift of Mackenzie Arch, recorded by westward erosional bevelling of Mount Cap Formation, was followed by deposition of red beds across the crest of Mackenzie Arch. The distribution of red beds delineates local depocentres and highs along the crest of the Arch. To the east, deposition of the correlative, evaporite-bearing Saline River Formation reflects the impact of the uplifted Arch on basin circulation during a poorly constrained period of time that may have encompassed part of the Drumian and Guzhangian (traditional mid- to late Middle Cambrian). By late Guzhangian (traditional latest Middle Cambrian) time, a restricted carbonate platform had developed across the study region, leading to deposition of Franklin Mountain Formation. The basal carbonates of that unit contain quartz sand and silt in proportions that reflect proximity to Mackenzie Arch, but the influence of the Arch was minor by the end of the Cambrian. **(*SS13, Thurs. 3:00*)**

Can widespread euxinic conditions still be considered a prerequisite for sedimentary exhalative mineralization in the Selwyn Basin

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Euxinic conditions have previously been considered a fundamental component of the genetic model for sedimentary-exhalative (SEDEX) mineralization in the Selwyn Basin. Precipitation of base metal sulphides and barite in a stratified water column has long been the proposed mechanism to explain Pb-Zn-Ba enrichment during episodes of mudstone deposition in the Cambrian, Silurian and Late Devonian.

This study provides initial results from a geochemical study of the Late Devonian mudstones that host the SEDEX deposits (Tom, Jason) at Macmillan Pass (YT). Samples (n = 38) from two drill-holes provide a comparison of the mudstones deposited in both a proximal and a distal location from the hydrothermal vent. Primary barium enrichments that are preserved within radiolarians suggest there may be an important productivity-derived input to the system. Iron speciation data from the distal hole, which have Fe_{py}/Fe_{HR} ratios mostly <0.8, indicate background conditions in the basin were dominantly anoxic and ferruginous rather than euxinic. Furthermore, ferruginous conditions would suggest low concentrations of water column sulfate (<5mM). A dynamic interplay between fluxes of sulfate (riverine), organic carbon (productivity) and reactive iron (hydrothermal, detrital) were the main factors governing redox conditions in the basin.

We suggest a model whereby the hydrothermal activity occurs in an oxygen minimum zone on a productive continental margin, as opposed to a restricted euxinic basin. This has important implications for exploration strategies on this sub-class of sediment-hosted base metal deposits; we would argue that future exploration should focus on detailed regional mapping, and target continental margin sediments in highly productive regions. **(*SS14, Fri. 3:00*)**

In-situ **Raman spectroscopy of uranyl peroxide cage clusters during hydrothermal reactions**

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The study of the crystal structure and behavior of inorganic uranyl compounds is important to understand the performance of geological repositories for nuclear waste. Corrosion of uranium oxide fuel in an oxidizing environment, coupled with the production of peroxide by the radiation-induced breakdown of water, creates conditions under which nanoscale uranyl peroxide clusters may form. Such clusters could significantly increase the reaction rates and solubility of solid state uranium materials. Although it has been demonstrated that such clusters are stable at room temperature, no study has examined their persistence under elevated temperatures.

Raman spectra provide insight into the presence and persistence of uranyl peroxide cage clusters in aqueous solution (U24, U28 and U60). These display a correlation between the position of the Raman band of the symmetric stretching mode of the peroxo ligand and the uranyl-peroxo-uranyl dihedral bond angles that is indicative of the cage cluster. In this study we examine the stability and structural variations of aqueous uranyl peroxide cage clusters under increasing pressure and temperature conditions by observing changes in their Raman spectra.

We have developed an apparatus for the collection of *in-situ* Raman spectra using a hydrothermal reaction vessel. This method has the benefit of a relatively simple experimental setup and reduced sample volume. Hydrothermal reactions are conducted in a steel vessel in which a borosilicate glass vial is held by a plexiglass holder in front of a sapphire window used for spectra acquisitions. The vessel is maintained at an internal pressure to avoid sample water loss while the temperature is progressively increased up to 150°C (ramp up, hold, ramp down).

We are currently collecting Raman spectra for aqueous solutions containing uranyl peroxide clusters at elevated temperatures. Pure uranyl clusters are synthesized as previously described (combination of an aqueous solution of uranyl nitrate hexahydrate, hydrogen peroxide, potassium chloride, and lithium hydroxide). Crystals are harvested, rinsed and redissolved to obtain monodisperse solutions. Purity is evaluated by inductively coupled plasma – optical emission spectroscopy (ICP-OES) and electrospray ionization – mass spectrometry (ESI-MS). **(*SS8, Thurs. 3:20*)**

Evidence for Li supersaturation in pegmatite-forming melts - Experimental results

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Pegmatites currently account for 38% of the known global lithium resources. The mining of Li-bearing pegmatites is predicted to dominate the future markets, since these rocks provide the highest grade ore and enough supplies to cover the increasing demand of lithium. The Moblan spodumene-pegmatite in Quebec consists of simple aplite and albite-rich wall zones that enclose a central quartz-spodumene-rich core. The core contains approximately 35% modal spodumene, which corresponds to a concentration of approximately 15000 ppm Li in the rock. This extreme Li enrichment coupled with the relatively simple mineralogy does not appear consistent with equilibrium crystallization of a granitic melt. In this study we investigate possible disequilibrium mechanisms that could create such ore resources. Experimental results at 500 MPa and 625 °C demonstrate that the minimum degree of undercooling of a Li-bearing melt at the onset of formation of pegmatitic textures is ~85 °C. Furthermore, Li-aluminosilicate saturation experiments at 650 °C constrain the Li concentration of a hydrous granitic melt at petalite saturation to be ~8000 ppm, consistent with previous values in the literature. However, the nucleation of Li-aluminosilicates is inhibited in Li-bearing crystallization experiments that contain a melt with ~12000 ppm Li at 600 °C. Crystallization of a Li-aluminosilicate phase in experimentally produced pegmatites was delayed until the melt reached 500 °C and yielded a saturation concentration of ~6000 ppm Li in the coexisting melt. The evidence for Li supersaturation of a pegmatite-forming melt before the crystallization of Li-aluminosilicates leads to a plausible mechanism for the genesis of simply zoned Li-pegmatites, such as the Moblan spodumene-pegmatite: a highly evolved and mobile Li-supersaturated melt is generated through fractional crystallization - this melt escapes through faults and fissures and eventually crystallizes in narrow dikes where Li-aluminosilicates are developed following the formation of narrow bands with quartz-feldspar intergrowths and albite-rich wall zones. **(*SS25, Thurs. 2:40*)**

Dealing with impacts of dust from geological sources: An overview

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As much as 2 billion tonnes of dust is entrained in the atmosphere per annum, much of which is mineral dust. Some arises from natural wind erosion, volcanic eruptions and wildfires. Other emissions arise from industry, farming, transport, accidents, war and terrorism. Effects can be local, regional or global. The physical, chemical and biological compositions and properties of dust are diverse thus impacts when deposited, ingested or inhaled are varied ranging from nuisance to serious harm. Dust affects the health and well-being of people, livestock and ecosystems. It can also cause disruption to industry and transport, or affect water quality, weather and climate. There is a growing awareness that dust, including that carried long distances, carries viable pathogenic organisms. However dust can also add nutrients to soils and, in some cases, promote rainfall. Exposure to dust in the workplace is well recognised, can be readily minimised and is widely regulated. Less attention is often paid to dust arising in the open environment, even though this also has a wide range of impacts. Such emissions are usually accepted as a fact of life unless extreme adverse events occur. While problems associated with soil erosion can be managed, responses to large volcanic events can only be dealt with as part of disaster management responses. Impacts of dust are increasingly important because of climate changes are altering the scale and the nature of dust emissions and growing urbanisation is increasing exposure to effects. There is a need to promulgate present knowledge more widely and to identify matters that need more research in order to address the impacts. It is important to: reliably monitor dust emissions and improve modelling and prediction of impacts; manage the land and processes to reduce emissions; develop responses to reduce exposure for large scale emissions; and better quantify costs and benefits. The necessary research will require collaboration between geologists, geomorphologists, economists, atmospheric scientists, microbiologists, medical practitioners, soil and agricultural scientists and ecologists. Clear information is also required by administrators and the public. A Dust Working Group has been convened by the IUGS Commission on Geoscience for Environmental Management to help to improve awareness of dust issues. **(*SS10, Wed. 3:40*)**

Keynote (40 min): André Lalonde's M.Sc. on the Baie-des-Moutons syenite complex, Québec: Unfinished business about a new mineral species and a late femic liquid in a fractionating A-type magma

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I acted as thesis advisor for André Lalonde's two graduate theses. Both theses led to publications, but André and I both realized that more needed to be done to better document important discoveries made in his M.Sc. thesis. For one thing, both of us were very surprised to learn that André had inadvertently documented a new mineral species, ferro-edenite, in his work on the Baie-des-Moutons syenite complex (1981). It is L szl¢ Horv th, author of Minerals first Discovered in Canada (The Canadian Mineralogist, Special Publication 6, 2003) who broke the news to us. We resolved to go through the proper motions to get ferro-edenite formally legitimized by the IMA once he recovered from being Dean of Science at the University of Ottawa. In some units, the amphibole poikilitically encloses euhedral to subhedral laths of perthite. The striking oikocrystic texture led us to ponder in the field about its significance. We noticed areas where there were vein-like segregations of dark material in the syenite, and areas where the growth-induced texture was wildly disturbed into swirls and streaks as a result of deformation while the assemblage was partially molten. It now seems clear that the massive hypersolvus crystallization of a (K,Na) feldspar, locally with quartz, caused the interstitial magma to become increasingly femic *in situ*, and to crystallize ferro-edenite ñ annite after the feldspar had already crystallized. In such A-type syenitic to granitic magmas, such a phenomenon now is better understood, although it still is difficult to accept by some that a felsic melt can differentiate to a femic composition by fractional crystallization. Locally, there is even evidence that the femic melt has unmixed to an iron-oxide-rich melt, which also poikilitically encloses perthite laths. The system was of course by then H_2O-saturated, and contained fluorine. André was a meticulous observer, and carefully catalogued his thesis collection. It will be my responsibility to carry out the unfinished business. **(*SS24, Fri. 10:20*)**

Fascinating mud geological events in Colombia: Far from rhetoric, closer to reality

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Along the Colombian Caribbean coastal area, numerous mud geological phenomena are present as current events such as Clay Diapir and Mud Volcano; while folds on the Mud Tertiary rocks have occurred thousands of years ago. In a general origin, these mud phenomena are produced by tectonic efforts from the Caribbean Plate on the South American Plate during Quaternary representing simultaneously both benefits and risk for the population.

Current mud phenomena represents social benefits if they are fully identified, analyzed in its physical, chemical, biological and paleontological characteristics, recognized as geological heritage, classified in cultural behaviors, and registered in a scientific catalogue. These geological mud phenomena are potential targets for national and international tourism and scientific purposes. There are administrative opportunities for public and private agencies through public policy and enough budget appropriations.

On the contrary, mud phenomena represents negative impacts such as natural hazards and environmental issues. As natural hazards along the seashore and further areas, such as beach changes, geomorphological changes, potential collapse of some volcanoes, island emerging and disappearing periodically, recent examples of these last phenomena are in the San Juan de Uraba region, Antioquia, or the island emerging in Pakistan in September 2013. Another real examples of hazard is in Turbaco, Bolivar, the town suffered damages in its constructed system in 2010, and a similar situation happened in Indonesia in the same year. Those regions of the Colombian Caribbean threats by mud movement caused by tectonic forces need international support for scientific and business development, such as technical investigations, geophysics, sedimentology and tectonic evaluation through drilling and installation of equipment to measure mud movement.

In an administrative area, mud geological events in Colombia need to be instituted seriously in government enforcement such as Act 99 of 1993, Act 165 / 94, and Act 1523, 2012. Also, in National Development Plans hydrocarbons, mines and Energy. Also, in Public policies of tourism and private businesses. **(*SS9, Thurs. 9:00*)**

The International Appalachian Trail: The ancient Appalachians as ambassador of the geosciences to modern societies

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Throughout human history, the geological foundation of our landscape has determined the location of settlements, trade routes, and human migratory paths, inextricably linking our culture to geology. The International Appalachian Trail (IAT) addresses our common geoheritage by establishing a long-distance walking trail that extends beyond borders to all geographic regions once connected by the “Appalachian Mountain” range, formed more than 300 million years ago on the super-continent Pangaea. In addition to connecting people and places, the goal of the IAT is to promote natural and cultural heritage, health and fitness, environmental stewardship, fellowship and understanding, cross-border cooperation, and rural economic development through eco-recreation.

The IAT was founded on “Earth Day” in Maine, USA, in 1994 and currently includes 21 Chapters representing an estimated 12,000 miles of trail along the ancient Appalachian terranes rimming the North Atlantic. A work in progress, the development of the IAT continues as individual Chapters: (1) construct a long-distance walking trail; (2) locate the IAT within areas that have been identified by geologists as having been part of the ancient Appalachian/Caledonian landscape; (3) locate the IAT so that it connects to bordering Chapters; (4) make available to the public map and trail descriptions of the IAT within its jurisdiction via the IAT web site; and (5) produce educational web site trail guides. In Europe, the IAT has been a natural fit, both in terms of mission and geography, with Geoparks. The IAT provides an excellent opportunity for earth scientists to participate in this unique recreational/educational project and to engage the public in a discussion of the geological foundations of modern society. **(*SS15, Fri. 2:40*)**

Alteration and mineralization of the copper skarn system in McKenzie Gulch area, northern New Brunswick

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The McKenzie Gulch copper skarn system in northern New Brunswick formed during the terminal stages of the Acadian Orogeny. The copper-skarn system is localized between two northeast-trending, dextral strike-slip fault systems, the McKenzie Gulch Fault to the southwest and the Rocky Gulch Fault to the northeast. The skarns are genetically associated with the carbonate-bearing sedimentary rocks of the Upper Ordovician through Lower Silurian Matapédia Group and Middle to Late Devonian (~381 Ma) felsic porphyritic dyke swarms, constituting three Cu-mineralized zones: the Legacy deposit (490,000 tonnes of 1.6% Cu, central), the Woden Rock Brook occurrence (0.5% Cu over 6.0 m, northeast), and the Burntland Brook occurrence (0.40% Cu over 10.2 m, southwest). The exploration work in the McKenzie Gulch area indicate that the mineralized zones consist of a horizon of limestone interbedded with a sequence of more or less calcareous argillite.

Like most skarn deposits, various styles and stages of alteration are evident in the McKenzie Gulch copper skarn system: an early contact metamorphic event forming argillaceous hornfels and marble; an early prograde alteration stage with anhydrous minerals such as garnet and pyroxene, possibly formed from relatively high-temperature, hypersaline liquid; a late retrograde alteration related to the transition of anhydrous skarn to hydrous skarn; a late phyllic alteration in intrusive felsic rocks mainly composed of amphibole, epidote, and chlorite, possibly formed from lower temperature, lower salinity fluids. This alteration of felsic rocks is probably coincident with the retrograde alteration in skarns; a late veinlet alteration of silicification and calcitization characterized by the development of different quartz, quartz-calcite, and calcite veinlets of at least four generations in skarns, hornfels, marbles and felsic dykes.

Different styles and stages of mineralization occurs in the McKenzie Gulch copper skarn and is interpreted to be contemporaneous with various styles and stages of alteration described above: an early weak, fine-grained, disseminated sulphide (pyrrhotite + chalcopyrite, 1-2%) mineralization, possibly formed during early prograde alteration; a late mineralization associated with 3 to 10% disseminated and patchy sulphides such as pyrite, chalcopyrite, sphalerite, galena, and 1% ilmenite + magnetite formed from lower temperature, lower salinity fluids during retrograde alteration; a later deposition of minor disseminated pyrite (2-3%) and chalcopyrite (1%) in the altered felsic rocks associated with silicification and calcitization; and a late fine-grained pyrite, sphalerite, and galena (3 to 5 %) associated with quartz and quartz-calcite veinlets marking the last episode related to copper mineralization. **(*GS5, Poster*)**

Characteristics of diagenetic fluids affecting two major carbonate units on Victoria Island, Northwest Territories

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The Neoproterozoic Wynniatt Formation and the Paleozoic "Victoria Island formation", two thick and widespread dolostone units on Victoria Island (NWT and NU), were studied using micro-analytical techniques such as fluid inclusion microthermometry, evaporate mound SEM-EDS, SIMS (O and S), and LA ICP-MS, to characterise their diagenetic history.

Field and petrographic relationships indicate that the Wynniatt Formation contains four Paleozoic cements: saddle dolomite (SD), brown dolomite (BD), replacive calcite (RC), and late calcite (LC). High homogenisation temperatures (>100°C), systematic change in evaporate mound compositions (K-dominant to Na-dominant), and shale-normalised rare-earth element (REE) signatures (positive Ce anomalies and middle REE-enrichment) suggest that mixing of reduced hydrothermal fluids that had interacted with shale units at depth recrystallised the dolostone ($\delta^{18}O_{Dolostone}$ = ~24‰) and precipitated the SD ($\delta^{18}O_{SD}$ = 24.7‰) and BD ($\delta^{18}O_{BD}$ = 24.7‰) cements. Negative Ce anomalies, low fluid salinities (1.7 to 0.4 wt. % equiv. NaCl), and light $\delta^{18}O_{calcite}$ values (~7‰) for the calcite cement suggest that a meteoric fluid infiltrated the system, initially in low fluid:rock ratios (preserved REE patterns from BD), and dedolomitised the BD to RC. An ensuing change to a high fluid:rock system is recorded by the LC cement, which has a different REE pattern.

"Victoria Island formation" dolostone contains three diagenetic cements: quartz ($\delta^{18}O_{Quartz}$ = 0‰) and dolomites 1 and 2 (D_1 and D_2; $\delta^{18}O_D$ = 18.6‰). High-temperature (>100°C) and high-salinity (~21 wt. % equiv. NaCl) fluids with marine isotopic values ($\delta^{18}O_{fluid}$ = 0‰) are recorded by quartz cement, and the association of framboidal pyrite ($\delta^{34}S$ = ~-7‰) with quartz precipitation indicates that reduced hydrothermal fluids mixed with bacterially reduced sulphur at the site of quartz precipitation. Dolostone REE patterns (light and middle REE-enrichment with positive Eu anomalies) and isotope values ($\delta^{18}O_{Dolostone}$ = 31.7‰) indicate subsurface fluid interaction with a shale reservoir. Despite similar homogenisation temperatures (~115°C) and fluid compositions (Na+K-dominant), different REE patterns for D_1 (similar to dolostone patterns) and D_2 (middle REE-enrichment) indicate a change from a low fluid:rock system (D_1) to a high fluid:rock system (D_2) with a seawater-sourced fluid that had interacted with shale based on fluid isotope values ($\delta^{18}O_{fluid}$ = ~0‰) and REE patterns (middle REE-enrichment). The two dolostone formations have diagenetic histories and settings that resemble those of base-metal deposits, such as the Polaris Zn-Pb deposit. This similarity suggests that Victoria Island may have the potential to host base-metal mineralisation. **(*GS5, Fri. 8:00*)**

Timing of high-grade Grenvillian metamorphism in southeastern Ontario from *in-situ* monazite trace element geochemistry and U-Pb geochronology

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The Flinton Group in southeastern Ontario is a package of monocylic amphibolite-grade metasediments that were metamorphosed during the Grenville Orogeny between 1090 and 980 Ma. Relatively few prograde metamorphic ages are currently available for Grenvillian metamorphism in southeastern Ontario leaving much of the history between deposition and cooling (*ca.* 1150-940 Ma) unknown. The investigated metapelitic samples contain the peak metamorphic mineral assemblage plagioclase + ilmenite + garnet + biotite + sillimanite ± kyanite ± staurolite ± white mica. Numerical modeling with the THERIAK-DOMINO software indicates peak conditions of metamorphism over the P-T interval 4.5-6.5 kbar and 600-690°C. The presence of highly resorbed staurolite crystals and absence of foliated white mica suggest consumption along a clockwise P-T path. Reconnaissance of one sample shows that matrix monazite typically displays two distinct growth zones characterized by a yttrium-poor core and a yttrium-rich rim. Monazite inclusions in garnet are not zoned with respect to yttrium and are typically yttrium-poor. Preliminary LA-ICP-MS U-Pb geochronology results indicate that the yttrium-poor core crystallized at 1026 ± 8 Ma while the yttrium-rich rim crystallized at 976 ± 9 Ma. Chondrite normalized rare earth element patterns indicate that the yttrium-poor cores are depleted in heavy rare earth elements (HREE) relative to the yttrium-rich rim. The core depletion in HREE suggests that monazite initially co-crystallized with garnet while the HREE enriched rim suggests growth during dissolution of garnet. Garnet is predicted to be consumed via the reaction garnet + white mica + plagioclase = sillimanite + biotite + H_2O over the temperature interval *ca.* 640-690°C. Coupling the results of preliminary monazite geochronology and numerical modeling, slow rates of prograde heating on the order of 1-3°C/Ma are obtained. These results agree well with recent estimates of prograde heating rates from diffusion modeling in garnet from lower grade samples, reinforcing that the Grenville Orogeny was a long-lived orogenic event. **(*SS19, Poster*)**

Quantifying timescales and rates of Grenvillian metamorphism: Coupling garnet growth modeling and *in situ* monazite geochronology

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Although the cooling history of the Grenville Orogen has been well characterized, key details regarding the conditions and timing of prograde metamorphism remain scarce. The Flinton Group in southeastern Ontario is a greenschist to upper amphibolite grade package of metasediments deposited late in Grenvillian history (<1150 Ma) and metamorphosed during the Grenville Orogeny (*ca.* 1090-980 Ma). The monocyclical nature and relatively low metamorphic grade of the Flinton Group in comparison to the Grenvillian basement on which it unconformably lies make it an ideal unit for pressure-temperature-time (P-T-t) reconstructions. Growth zoning in a population of garnet porphyroblasts has been successfully used to infer the prograde metamorphic evolution of garnet-biotite-staurolite schist of the Flinton Group. Characterization of the garnet population with high-resolution X-ray micro-computed tomography reveals a unimodal, slightly positively skewed crystal size distribution (CSD). Garnet porphyroblasts ranging from 4000 to 200 µm in diameter from the different size classes of the CSD were centrally sectioned. Electron probe micro-analyses of the centrally sectioned porphyroblasts exhibit decreasing Xsps and Xgrs and increasing Xalm and Xpyp from core to rim consistent with a prograde growth zoning. Moreover, a strong correlation between Xsps and diameter of garnet was documented. Garnet growth simulations with the THERIA_G software were used to reproduce the observed growth zoning along a specific P-T-t path. Large porphyroblasts of the population were used to determine a clockwise P-T path over the interval 3.7 to 5.9 kbar and 512 to 615°C while modification of growth zoning via intracrystalline diffusion in relatively small porphyroblasts was used to infer an average heating rate of 2°C/Ma. *In situ* laser ablation – inductively coupled plasma – mass spectrometry U-Pb monazite geochronology was used to calibrate the P-T-t path and provide absolute time constraints on the relative timescales predicted through THERIA_G modeling. Monazite occurs in the rock matrix and as inclusions in the outer 250 µm of garnet. Based on the distribution of accessory phases and trace elements in garnet, a single monazite age population at 977 ± 4 Ma is interpreted to represent monazite growth at the expense of allanite and apatite late in garnet's growth history. By coupling the relative timescale of garnet growth with the absolute time anchor, initial garnet growth is predicted at approximately 1030 Ma providing a minimum duration of 50 Ma for Grenvillian metamorphism in southeastern Ontario. **(*SS19, Wed. 4:40*)**

Crawford Lake- a geological, ecological and archeological gem

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Crawford Lake Conservation Area is situated ~50 km west of Toronto on the edge of the Niagara Escarpment and is thus part of the Niagara Escarpment World Biosphere Reserve. It has also been designated as an Area of Natural and Scientific Interest (ANSI) by the Government of Ontario. The small (~2.4ha) but very deep (zmax >24 m) lake that occupies a sinkhole in the Silurian Lockport Dolostone is meromictic, and resulting bottom water anoxia allowed undisturbed calcite-organic annual couplets to accumulate over the last millennium. The exceptional fossil record provides insights into the lake ecosystem as it responded to two distinct phases of human settlement: prehistoric Iroquois (~AD 1286 – 1486) and historic Euro-Canadians (since the mid 19th C), with varve counting providing a precise chronology. In addition to commonly preserved microfossils like pollen and diatoms, the sediments deposited in anoxic bottom waters of this meromictic lake contain the fossilized remains of otherwise rare microfossils, such as rotifer lorica and cellulosic dinoflagellate thecae, as well as cysts of dinoflagellates with viable cell contents. Reports of fossilized cellulosic dinoflagellate thecae are extremely rare and always associated with exceptional conditions, and their presence, together with the germination of cysts from sediments deposited ~200 years ago, allowed the affinities of previously unidentified dinoflagellates cysts to be determined.

Although a wide range of educational programs and tours for schools and organizations are available, these tend to focus on the Iroquoian village reconstructed on its original site following an archeological survey instigated in the early 1970s by the discovery of cultivar pollen by Maria Boyko and her supervisor Jock McAndrews. The potential for illustrating the response of the lacustrine ecosystem to cultural eutrophication has yet to be fully realised at the site. **(*SS15, Fri. 2:20*)**

New temporal constraints on late Caledonian magmatism from the Galway Granite Complex; insights into late-post Caledonian tectonics and granite petrogenesis

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The Galway Granite Complex (~420-380Ma) in western Ireland straddles the northern margin of the Iapetus Suture Zone and represents the southwestern extremity of the Caledonian Orogenic front in NW Europe. Published chronological data illustrate the synchronous nature of these intrusions with the final closure of the Iapetus Ocean and subsequent orogenic collapse. Despite the critical temporal-tectonic position of this complex, little is known about the precise chronological order of intrusion and regional scale kinematics which dictated the siting and evolution of this heterogeneous suite of granitoids. Attempts to synthesize a unifying petrogenic model for the origin of the British and Irish Caledonian granitoids highlight the significance of the Galway Granite Complex as no current hypotheses account for the anomalous temporal or spatial position these intrusions.

We present four new U-Pb zircon dates from key constituent plutons in the Galway Granite Complex. Our results show that the earliest magmatism initiated at 423.8±3.2Ma and that this was followed by a punctuated second phase between 412.8±2.4Ma and 409.6±3.6Ma. These data, compiled with those already published, reveal that the Galway Granite Complex was constructed as a consequence of four distinct phases of magmatism each separated by ~10Ma. Along with earlier structural work describing the internal architecture of these intrusions, our data show a concomitant relationship between the age of these intrusions and the reactivation of different fault conduits as the regional stress field evolved during and after the closure of the Iapetus ocean.

It is proposed here that the Galway Granite Complex was constructed over a prolonged time period between ~423Ma and ~380Ma during four discrete magmatic episodes at ~420Ma, ~410Ma, ~400Ma and ~380Ma. The siting of plutons during each of these phases was controlled by distinct sets of pre-existing structures, that were reactivated and preferentially exploited by ascending magma, at different times during the continued evolution of the Caledonian and post-Caledonian regional stress field. Current hypotheses which suggest that the latest Caledonian granitoids were generated primarily due to post Caledonian extensional exhumation are thus called into question as the current data clearly indicate magmatism continued 20Ma after orogenic collapse. We postulate that the latest "Caledonian Granites" may reflect distal crustal thickening associated with the subduction of the Rheic Sea during the convergence of the Armorican terrane with Avalonia; an event totally disassociated from the Caledonian Orogeny. **(*SS5, Wed. 4:40*)**

Keynote (40 min): Raman spectroscopy: identification and characterization of minerals and application to the solution of geosciences-related issues.

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Raman spectroscopy, a technique that employs scattered radiation to investigate interatomic bonding, has been widely applied to the study of organic and inorganic compounds. It has also been used to study geological materials (minerals, fluid-inclusions), but in a very broad manner, principally in differentiating between polymorphs. Furthermore, Raman is typically applied in the geosciences in an indirect manner, *i.e.*, spectra are not generally predicted in an a priori manner, based on crystal-chemical knowledge but rather, are compared and information extracted, on the basis of comparisons made with similar minerals. This presentation will focus on the application of Raman spectroscopy to the documentation of chemical solid solution in

HFSE-bearing minerals (alkaline Ti-, Zr-, Nb-silicates), identification of platinum-group minerals (both as micro-inclusions in chromite and as liberated grains) and differentiation between like-minerals in alteration environments associated with mineral deposits. It will highlight the strengths of Raman spectroscopy in solving geosciences-type problems, its limitations, the type of and extent to which information can be extracted, along with an overview of methodology involved in the calculation of Raman spectra and how such spectra can be obtained from crystal-structure data. The over-riding goal of the presentation will be to demonstrate how Raman spectroscopic studies of minerals can be directed at addressing and solving geosciences-related questions that range from detailed crystal-chemical issues to ore-deposit research. **(*SS24, Thurs. 2:20*)**

Hydrothermal resetting of U-Pb ages in zircon, monazite, titanite, and allanite at *ca.* 1000 Ma in the Belt-Purcell Supergroup in southeast British Columbia

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A new geochronological framework for sedimentary deposition, felsic magmatism, and high-grade metamorphism in the Lower Belt-Purcell (Lower Aldridge) strata in southeast BC has been assembled. High-precision *in-situ* U-Pb data collected by LA-ICP-MS has been obtained on the Hellroaring Creek and Matthew Creek stocks and lustrous sillimanite-grade schists and foliated metasbasalts from the Matthew Creek Metamorphic Zone (MCMZ). *In-situ* geochronology was guided by careful optical, BSE, and compositional X-ray mapping to characterize the morphological, textural, and chemical zoning within the target grains.

Each of the datasets contains well-constrained concordant populations that have helped to define mesoproterozoic magmatism and metamorphism that affected the lower Belt-Purcell strata at *ca.* 1411 Ma and 1365 Ma. However, zircon in magmatic samples, monazite in micaceous schists, and titanite and allanite in foliated metasbasalts record variable ancient Pb-loss. This is manifested as a continuous array of discordant data points lying along a discordia with a lower intercept at *ca.* 1000 Ma. In mica schists, textural evidence suggests that this ancient Pb-loss event is developed in the outer margins of accessory minerals, locally where the grain is intersected by fractures in neighbouring minerals. Accessory mineral domains that have succumbed to Pb-loss appear to have undergone recrystallization along inward-propagating reaction fronts which has obliterated pre-existing compositional zoning. EPMA major and LA-ICP-MS trace-element maps reveal recrystallized domains as having generally higher Th. The main post-peak metamorphic hydration event in micaceous schists involved the replacement of andalusite and sillimanite by spangly margaritic white mica and chloritoid. This reaction has been modeled as a result of andalusite, muscovite, plagioclase and a Fe-Mg phase reacting with H_2O to form margarite, chloritoid, chlorite, paragonite and quartz during retrogression below 450°C at 1-2 kbar. Evolution of locally alkali fluids during hydration and breakdown of plagioclase and paragonite are the mostly likely mechanisms for monazite recrystallization and Pb-loss. Similar fluids and metasomatic temperatures as also implicated in hydrothermal alteration and recrystallization of titanite.

Whereas the manifestation of this *ca.* 1000 Ma recrystallization event is cryptic at best, similar U-Pb ages for monazite, zircon, and titanite and Lu-Hf ages in garnet have been reported regionally in the lower and middle Belt-Purcell sequences. This suggests that the western margin of North America was tectonically active at this time and the occurrence of similar cryptic U-Pb ages in potential western cratonic margins may help constrain competing paleogeographic reconstructions. **(*SS20, Wed. 9:20*)**

Unusual features of the Early Mesozoic Grand Manan Basin, New Brunswick and Maine

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The island of Grand Manan in the southwestern Bay of Fundy exposes strata and basalt of the Grand Manan Basin, an Early Mesozoic rift basin about 30 km wide by 70 km long that is mostly submerged along the border of New Brunswick and Maine. On the eastern side of Grand Manan and its archipelago, the fault-bounded White Head Horst exposes Ediacaran to Cambrian basement rocks between the small basin and the much larger Fundy Basin, which has a similar Triassic stratigraphy. End-Triassic (201.3 Ma) Dark Harbour Basalt covers western Grand Manan with a thickness around 240 m, but it is probably missing from erosion in most of the submerged basin. Up to 12 m of sub-horizontal lacustrine grey mudstone and red sandstone of the Late Triassic Dwellys Cove Formation are exposed along the western shoreline beneath the basalt, and the sediment probably forms most of the seafloor bedrock of the basin. These uppermost formation strata and overlying basalt represent the top of tectono-stratigraphic unit TS-III and lower part of TS-IV. A few metres of conglomeratic fluvial red sandstone (Late Permian? TS-I) at Miller Pond Road rest on a basement of Cambrian argillite immediately east of the basin.

Several unusual features of the Grand Manan Basin set it apart from most Early Mesozoic rift basins in eastern North America. The basin is bounded on opposite sides by normal faults with similar vertical displacements, so strata at Grand Manan are not tilted as in a half-graben. The Miller Pond Road arkose is probably a remnant of the base of basin strata now perched on the horst, and juxtaposed by the border fault to nearly the same level as the top of Dwellys Cove mudstone to the west. Thus by amazing coincidence, the vertical offset of the border fault must nearly match the thickness of Permian/Triassic sub-basalt basin formations, estimated at 3 km.

Extending from beneath the Miller Pond Road sandstone, a level surface of low relief covers much of the eastern island and archipelago at the top of the White Head Horst, which may be interpreted as a relict Permian/Triassic peneplain that was beneath the Mesozoic strata. Finally, structures and dikes of basalt indicate a unique syngenetic origin for the middle and upper members of the flood basalt that filled the Grand Manan and Fundy basins, before separation by border faulting along the White Head Horst. **(*GS3, Poster*)**

Structural setting of Pb-Zn sulphide veins hosted by Silurian sedimentary rocks of the Nicholas-Denys property, Bathurst mining camp – genetic implications

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The Nicholas-Denys property of Puma Exploration Inc. offers a large variety of potential mineral exploration targets, from synvolcanic massive sulfides within the Ordovician formations lying south of the Rocky-Brook Millstream Fault (RBMF) to skarn mineralization located on the edge of the Nicholas-Denys intrusion, a Middle Devonian (*ca.* 381 Ma) granodioritic pluton known to contain Mo, Cu and Au mineralization. Pb-Zn-Ag hydrothermal-skarn deposit containing also Au occur in the Nicholas-Denys property, which is located between the RBMF and the Main Fault, two major EW-striking strike-slip faults of the Bathurst Mining Camp in northern New Brunswick. The Nicholas-Denys intrusion lies just a few hundred meters to the north of the RBMF. Regional geological structures belong to the Nigadoo River synclinorium, which is part of the Chaleur Bay synclinorium. The polymetallic veins are essentially transverse tension structures, they crosscut limestone and siliciclastic rocks of the La Vieille and Simpsons Field formation, a sedimentary rock sequence that was deformed during the Middle Devonian Acadian orogeny.

This study presents maps of scoured outcrops along with the analysis of drillcore logs, the description of polished thin section accompanied with Scanning Electron Microscopy analysis as well as the results of sulfur isotope ($\delta^{34}S$) analysis. A summary of regional geological events and a regional-scale compilation and analysis of Pb-Zn occurrences is also shown.

The determination of relationships between faults, contact metamorphism, metasomatism and structures related to hydrothermal activity have been used to constraint the timing of the Pb-Zn mineralization. Genetic hypothesis such as regional deformation-related hydrothermalism mineralization is still to be evaluated. Mineralized hydraulic breccias, commonly occurring next to major regional faults affect the limestone/skarn and gabbro transversally, and along sedimentary contacts. However sulfur isotopes signatures of galena and sphalerite suggests that they are genetically related to the Nicholas-Denys granodioritic intrusion and the deposit is therefore considered to be a Pb-Zn hydrothermal intrusion-related deposit, most specifically, a distal Pb-Zn skarn.

The source-transport-trap concept is also important to understand on a regional scale, as it would permit to identify and localize low-pressure zones where the mineralizing fluids are most likely to have focused. Such low-pressure zones can be either some lithologies with high permeability and porosity, but also areas where faults intersect. The location of low-pressure zones can be predicted by the analysis of magnetic and gravimetric geophysical maps. **(*SS25, Thurs. 3:40*)**

Columbite and tantalite: Measuring disequilibrium in pegmatites

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In nature, columbite and tantalite, (Fe, Mn)Nb_2O_6 and (Fe, Mn)Ta_2O_6 resp., can exist in two different structural states; ordered and disordered. Both structures are part of the orthorhombic crystal system. The ordered structure has one layer of (Fe-Mn)-O octahedra, alternating with two layers of (Nb, Ta)-O octahedra in the b direction, whereas the disordered structure does not. This causes the unit cell edges to have different lengths between the two structures. The a and c unit cell values are used to determine whether the structure is ordered or disordered. In previous studies, fully ordered samples have been synthesized, but disordered samples have not. These minerals are most commonly disordered in nature, but when heated, become ordered. This is contrary to what would be predicted from entropy, and suggests disequilibrium in the system.

The two main hypotheses on the cause of disorder investigated are the degree of undercooling during crystallization, and the effect of trace elements incorporated in the crystal structure. The trace elements selected for use in this study are Ti, Sc, W, Zr, and Hf, based on their presence in natural columbite and tantalite. These experiments are completed by crystallizing the Mn end-members; $MnNb_2O_6$ and $MnTa_2O_6$, from a supersaturated silicate melt at 600° and 700°C, and 200 MPa for 5 days. The temperatures were selected to reflect different degrees of supersaturation, and experiments were quenched to an assemblage of glass + crystals, preserving the compositions and structures of the phases at high pressures and temperatures. Crystals were then analyzed by µXRD.

The results of the undercooling experiments indicate that the $MnNb_2O_6$ and $MnTa_2O_6$ crystals have a completely ordered structure. An example unit cell for a 700°C columbite experiment is a = 14.449 Å b = 5.755 Å c = 5.0886 Å (errors a = 0.004 Å b = 0.0026 Å c = 0.0024 Å). This suggests that undercooling is not the cause of disorder in natural crystals. Preliminary experiments on the effect of trace elements in columbite at 700°C indicate that they are disordered with unit cell values of a = 14.3458 Å b = 5.709 Å c = 5.150 Å (errors a = 0.0016 Å b = 0.001 Å and c = 0.002 Å). This suggests that trace elements are a cause of disorder in natural crystals. Tantalite experiments are currently being conducted. **(*SS24, Fri. 8:20*)**

Stream sediment and water geochemical study, South Fiord area, Axel Heiberg Island, Nunavut, Canada

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Stream sediment and water sampling programs such as the Geological Survey of Canada's (GSC) National Geochemical Reconnaissance (NGR) program have long been used to efficiently obtain systematic geochemical information, which is key in establishing the mineral potential of an area.

As part of an environmental geoscience study on gossans in Canada's High Arctic, a complementary stream sediment and water study was conducted to better understand the relevant geochemical and mineralogical signatures of gossans found within permafrost in the down-drainage environment. The objectives were to characterize bedrock lithologies in the study area and to evaluate the economic mineral potential. The sampling strategy undertaken targeted drainages with known gossans and were within a day foot traverse from base camp in the South Fiord area of Axel Heiberg Island, Nunavut.

Stream silt and water samples were collected from 32 sites with bulk sediment samples taken for the heavy mineral concentrate (HMC) component from the <2 mm fraction, at 10 of these sites. Silt and water samples were analyzed by ICP-MS and ICP-ES as well as for carbon content. Water samples also have alkalinity data, anions by DIONEX and *in-situ* physico-chemical measurements. Bulk sediment samples were processed and the resulting HMC samples were picked for indicator minerals of various deposit types. Sampling and analytical techniques followed established NGR methodologies, ensuring data compatibility with the NGR database.

This poster will summarize and highlight preliminary results. **(*SY4, Wed. 3:20*)**

The character and distribution of Cu-PGE mineralization at the Geordie Lake Deposit within the Coldwell Complex, Ontario

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Cu-PGE mineralization at the Geordie Lake Deposit (GLD) is spatially associated with weak to intense actinolite alteration within a heterogeneous-textured gabbro, and a troctolite that is characterized by abundant skeletal olivine. These mineralized lithologies are overlain by barren gabbros that display varying degrees of plagioclase alignment. The heterogeneous-textured gabbro is unusual in that it contains pink albite alteration that is variable in intensity, but widely distributed, particularly through mineralized horizons. The most significant Cu-PGE occurrence in the GLD is dominantly stratiform, and in contact with a basal syenite (this is termed the "main zone" mineralization). Chalcopyrite and bornite mineralization is preferentially hosted by actinolite, and not albite alteration. Pyrrhotite is notably absent within the "main zone" of mineralization. Scanning electron microscopy has shown that the platinum-group and precious metal minerals including kotulskite, merenskyite, sopcheite, and altaite are hosted by blebby to disseminated chalcopyrite and bornite. Similar patterns of REE with progressive enrichment from the skeletal troctolite, to the heterogeneous gabbro, and basal syenite indicate that these lithologies are genetically linked. Pearce element ratios suggest that magma evolution was controlled by olivine and plagioclase crystallization. However, major element geochemistry of 92 samples representative of the various Geordie Lake gabbro and troctolite show slight, but continuous variations in SiO_2, MgO, CaO, and Na_2O, with the exception of a skeletal-olivine rich troctolite. The skeletal troctolite contains: 1) a high abundance of olivine and magnetite, 2) consistently high Cu-PGE grade, and 3) sulfides and PGM that are hosted at the margins of skeletal olivine and spatially associated with magnetite. These observations imply that the skeletal troctolite is a cumulate phase. Whole rock $\delta^{18}O$ analyses were also conducted in equal intervals down the stratigraphy of the GLD. The results reveal a steady depletion in $\delta^{18}O$ from 5.1‰ at the surface of the deposit, to 1.3 ‰ at the basal contact with cross-cutting syenite. The most mineralized samples (over 2000 ppm Cu) occur within a tight range of $\delta^{18}O$ values of 1.3 ‰ and 3.2 ‰. This implies that mineralization at the GLD has potentially been influenced by the basal syenite, or another $\delta^{18}O$ depleted source. **(*GS5, Fri. 2:40*)**

Stratigraphy of the Black Label chromitite horizon, Black Thor Intrusive Complex, McFaulds Lake greenstone belt, Ontario

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The Black Thor Intrusive Complex is a semi-conformable sill-shaped intrusion that can be subdivided into: 1) a lower ultramafic series of basal olivine websterites and lherzolites, interlayered dunites and lherzolites with minor interstitial chromite, and overlying websterites, 2) a middle ultramafic series characterized by a basal chromitite horizon (Black Label), olivine websterites, lherzolites and dunites, and an upper chromitite horizon (Black Thor), and 3) an upper ultramafic to mafic series of websterites, mela/meso/leucogabbros and lesser anorthosites. A late websterite intruded the lower and middle ultramafic series and locally brecciated the Black Label chromitite horizon. Black Label and Black Thor are similar in many respects, but Black Thor is more continuous and contains more chromite in individual layers. The late websterite disrupts the central portion of Black Label producing a marginal heterolithic breccia zone, comprising clasts of dunite-chromitite-lherzolite within a matrix of hybridized olivine websterite-lherzolite. Clast geometries and contact sharpness vary from amoeboidal to subangular, and sharp to embayed, depending on clast lithology and proximity to the pyroxenite core. Six representative boreholes from the least-disrupted NNE and SSW parts of Black Label have been selected for initial studies of chromitite textures and layering. Chromitite-bearing rocks have been subdivided on the basis of texture and abundance of chromite, and are dominated by 6 main facies: 1) massive chromitite, 2) semi-massive chromitite and 3) matrix-textured chromitite, both containing pseudomorphed olivine patches, 4) net-textured chromite in altered lherzolite, 5) heavily-disseminated chromite in lherzolite, and 6) lightly-disseminated chromite in lherzolite. Many of the zones are dominated by net-textured, semi-massive, and massive chromitites, but of the textures heavily disseminated and lightly disseminated are most abundant. The contacts between chromitite layers and interbeds have been classified as sharp, graded, diffuse, flame and load, and irregular. Although many of the chromitite seams exhibit more than one type of contact, sharp lower contacts with graded upper contacts are most common. It is not yet clear, however, whether individual beds or groups of interbeds within the non-brecciated parts of the Black Label horizon can be correlated along strike or with depth. **(*GS5, Poster*)**

VMS ore lens imaging and modeling using vertical seismic profiles from Flin Flon, MB

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One of the main drivers of recent geophysical research in mineral exploration is to explore and define targets at greater depths. Seismic methods, including Vertical Seismic Profiling (VSP), currently provide the most powerful potential means to do so. In October 2006, three-component VSP data using dynamite and vibroseis sources were acquired from three deviated wells in the Flin Flon mining camp as part of a larger 3D seismic survey. These VSP data potentially contain a reflection signature of the 85.5 Mt Flin Flon-Callinan-777 VMS ore system. From the many drill records, surficial maps and seismic data, a 3D voxel model of the local geology and known ore lenses has been built, which can be used in 3D finite difference-modeled simulations of the VSP surveys. The number of geological units partitioning the 3D voxel model is increased incrementally to study the effects on seismic response of massive sulfide ore and major rock units. The simulations are jointly visualized with the VSP data to aid interpretation. (***SS14, Thurs. 4:40***)

The Navan Zn-Pb orebody, Ireland: A case study of the potential of Zn and Fe isotopes for determining metallogenesis and in mineral exploration

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The Navan Zn-Pb orebody is the largest Irish-type orebody, with reserves and mined ore amounting to 107 million tonnes at average grades of ~8% Zn and ~2% Pb. Navan mineralization, hosted primarily in Lower Carboniferous carbonate sedimentary rocks, comprises mainly replacive and lesser exhalative sphalerite and galena, with Fe sulfide, barite and carbonate gangue. The orebody is surrounded by halos of mineralogically similar sub-economic mineralization. Structural, fluid inclusion and S, Pb and Nd isotope evidence has previously provided strong support to a model in which mineralization occurred due to fluid mixing during Lower Carboniferous crustal extension and normal faulting. A warm moderate salinity fluid bearing metals, but relatively little sulfide, leached from Lower Palaeozoic basement was brought into contact with a cooler, surface-derived hypersaline brine containing abundant dissolved sulfide reduced from seawater sulfate by bacterial action.

In orebody sphalerite, negative δ^{56}Fe (-1.0 to -2.2‰) and δ^{66}Zn (0.0 to -0.3‰) values correlate with positive δ^{34}S, indicating kinetic fractionation of light Fe and Zn isotopes into sphalerite in situations where the deep metal-bearing hydrothermal fluid dominated mixing. This sphalerite typically displays colloform and other styles of millimeter-scale banding indicative of rapid precipitation in open space of probable hydrothermal karstic origin. Sphalerite with negative δ^{34}S, indicating dominance of bacteriogenic sulfide, exhibits less negative δ^{56}Fe (mostly ~0.0 to -1.0‰) and δ^{66}Zn ranging to positive values up 0.3‰. Low sphalerite δ^{56}Fe is enhanced by the incomplete leaching of Fe from source rocks. This effect dominates the negative δ^{56}Fe values in hydrothermal Fe sulfides in the orebody (δ^{56}Fe -1.0 to -2.2‰), also allowing their discrimination from sedimentary and diagenetic Fe sulfides (δ^{56}Fe -0.2 to -0.7‰). Sphalerite in part of the Navan halo displays similar δ^{66}Zn to the main orebody, but higher Fe isotope ratios (δ^{56}Fe -0.8 to 0.0‰), for reasons not yet understood.

Understanding of sulfide weathering reactions in soils suggests that they will retain the Zn isotope compositions of weathered sulfides. Fe isotope fractionation is expected to occur during weathering of Fe sulfides, with δ^{56}Fe of dissolved Fe^{3+} up to 3‰ higher than Fe^{2+}. However in practice almost all Fe will be oxidized into ferrihydrite, mass balance therefore implying little scope for Fe isotope fractionation. The negative and highly variable δ^{56}Fe, and highly variable δ^{66}Zn, generated by Irish-type ore-forming processes should be retained by soil, allowing their use in mineral exploration. (***SS14, Fri. 3:20***)

Mg-metasomatism caused by the circulations of evaporated seawater at the origin of the alteration halo in the unconformity-related U deposits

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The unconformity-related uranium deposits from the Athabasca Basin are specifically located at the vicinity of an unconformity between the sedimentary formations and the underlying basement rocks. The U mineralization are systematically related to massive fluid/rock interaction marked by the development of alteration haloes formed by Mg-bearing minerals: Mg-illite, Mg-chlorite (sudoite) and Mg-tourmalines (dravite/magnesio-foitite). Here a systematic study describing the development of this Mg-alteration from a fresh basement lithology (granitic pegmatite) to its fully altered counterparts was undertaken to better understand the conditions of formation.

This study reveals that this Mg-alteration can be considered as Mg-metasomatism formed during four successive steps. The two first steps correspond to the successive destabilization and replacement of the initial silicate minerals, except quartz, to a Mg-rich alteration matrix and a first generation of hydrothermal quartz. The third step corresponds to the dissolution of the magmatic and hydrothermal quartz. The last step is the crystallization of a secondary generation of hydrothermal quartz and magnesio-foitite in the cavities created during the former step.

During the Mg-metasomatism, the chemical composition of the granitic pegmatite strongly changes with major enrichment in Mg, concomitant with B, Li and H_2O input. Conversely, Na, Ca and K are leached during the alteration. Si concentration is constant during the two first steps, strongly decreases during step 3 and increases during step 4. Stable isotope and fluid inclusion analyses indicate that the Mg-metasomatism is related to the interaction between the granitic pegmatites and a unique type of fluid, *i.e.* basinal brines deriving from the evaporation of seawater, at 150 ± 30°C and pressure below 100 MPa. The B isotopic values of the Mg-tourmalines, the O and H whole-rock isotopic values and the simultaneous enrichment of Mg, B, H_2O (and potentially Li) indicate that all these elements were only brought to the alteration by the brines. This peculiar Mg- and B-rich alteration is directly related to the specific primary chemical composition of the brines, which had originally the highest concentrations for Mg and B compared to all known crustal fluids due to the elevated degree of evaporation reached by the seawater. These fluids were also previously proposed to be the mineralizing fluids. Consequently, we propose that the formation of the Mg-rich alteration halo and U mineralization in unconformity-related uranium deposits are related to the specific implication of a unique type of fluid, *i.e.* brines deriving from the evaporation of seawater, at the basin/basement interface. **(*SS7, Poster*)**

Gold mineralizations of the Wasamac shear zone, Abitibi greenstone belt, Rouyn-Noranda, Quebec

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The Wasamac Property is located 9 miles southeast of Rouyn-Noranda. It is situated along the Francoeur-Wasa shear zone which is a second order kilometric-scale fault of the Cadillac – Larder Lake fault. The Cadillac – Larder Lake shear zone hosts more than 72 gold deposits in Quebec, some of which contain more than 100 tons of gold. These orogenic deposits mostly present two hydrothermal gold traps: brittle systems (lode gold deposits) and/or brittle-ductile metasomatized shear-zones.

The Wasamac fault is a brittle-ductile shear zone, generally oriented along an east-west trend (260°) and with an average dip of 55° towards the north. This deformation is hosted by two major lithologies: rhyolite on the hanging wall and andesites in the footwall, in which the deformation is most likely penetrative. These rocks are part of the meta-volcanic units from the Archean Black River Group. The sheared zone can be up to 100m width, and is characterized by a highly metasomatized mylonite. The Wasamac shear zone is marked by an intense foliation (S_1) locally affected by a crenulation clivage (S_2) containing Z-type folds and micro-folds slightly overturned.

Gold mineralization is associated with an albite-sericite-carbonate-microcline-chlorite-hematite alteration. Regional greenshist grade metamorphism is surimposed by a pervasive millimetric to centimetric alteration layers in the mylonite. Two types of hydrothermal minerals assemblage display a particular zoning in a longitudinal section at the scale of the property, each one linked with a particular gold mineralization. A potassic alteration affects the sheared volcanic units in the center of the property, where half of the gold is mineralised as tellurides, and as native gold on the other half. Major albitic alteration is common on both sides of the first described, related with a native gold mineralisation only. The potassic alteration appears to be younger than the albitic alteration.

The spatial organization of this zonation and the sequence of alterations suggest that the Wasamac mineralization is the result of two hydrothermal events. The first one, with an alcaline affinity would have been of magmatic origin and appears similar to the Kirkland Lake deposits. The second one, more usual on greenstone belts, would be the result of cooler processes. This preliminary study focuses on the particular zoning of both mineralisations and alterations at the scale of the property; which brings interrogations about the nature of hydrothermal fluids and precipitation conditions. **(*SS25, Thurs. 3:20*)**

The environmental management of unconventional resources: Lessons learned from the oil sands

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The exploitation of unconventional resources, including the oil sands, shale gas, tight oil and coal-bed methane, involves significant environmental issues. In the case of the oil sands, publicity surrounding these issues caused a climax in public concerns in the summer of 2011, and this led to the appointment of several expert panels by the federal and Alberta governments. Following site visits, and consultations with stakeholders, the major recommendations to emerge from the panel reports were 1) for a substantial increase in basic scientific monitoring of the oil–sands environment, and 2) for the creation of an independent monitoring agency, to be funded largely by industry, to examine and report on environmental issues as a basis for informed public judgement and for the implementation of appropriate remedial action. Implementation of these recommendations is in progress, but there remain concerns, particularly with regard to the effects on First Nations treaty rights and the long-term cumulative effects of multiple development projects.

Although the scientific concerns are different in the case of shale gas and tight oil, there is much that can be learned from the oil-sands experience about the management of the environmental issues. Legitimate public concerns, such as the extensive use of surface waters, the potential for groundwater pollution, and the dangers of induced seismicity, are all amenable to scientific study and technical solutions, but for the public to be satisfied with these solutions there must be confidence in the bodies tasked with environmental responsibilities. In the case of shale gas, there is much that can be learned from experiences in the United States (particularly Texas and Pennsylvania) where this resource has been under development for more than a decade. **(Plenary Address*, Fri. 11:05*)**

Fe-rich domains in the Archean mantle: Constraints from Neoarchean ferropicrites

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The iron content (FeO^{TOT} > 14 wt. %) of ferropicritic magmas is too high to reflect melting of "pyrolitic" (Mg/(Mg+Fe) = 0.88-0.92) sources that are believed to make up the majority of the Earth's mantle. Although the composition and mineralogy of ferropicrite sources are poorly constrained, it is widely accepted that their Mg/(Mg+Fe) ratios are low (<0.85), possibly approaching those of the Martian mantle or ordinary chondrites (> 0.75). The observation that olivine and garnet do not coexist on the ferropicrite liquidus under any pressure has fuelled a debate as to whether the mantle sources of ferropicrite are garnet-free peridotite or olivine-free garnet-pyroxenite.

Two main types of Neoarchean (~2.7 Ga) ferropicrites can be recognized on six cratons (Superior, Slave, W. Churchill, Yilgarn, Kaapvaal, Baltic) on the basis of trace element profiles, Ni contents, and Sc/Fe ratios. Alkaline ferropicrites have fractionated trace element profiles (Nb/Y_{MORB} ? 3) that resemble modern ocean island basalts (OIB), and have relatively low Sc/Fe ratios ($< 3 \times 10^{-4}$). The Ni contents of the alkaline ferropicrites are higher than those of the comparably magnesian primary melts of pyrolitic terrestrial mantle and are similar to the Ni-rich tholeiitic basalts from Hawaii. In contrast, the subalkaline ferropicrites have relatively unfractionated trace element profiles characterized by low Nb/Y_{MORB} ratios (<3), and have relatively high Sc/Fe ratios ($> 3 \times 10^{-4}$). The Ni contents of the subalkaline ferropicrites are depleted relative to the melts of the normal terrestrial mantle at equivalent MgO concentrations.

The partitioning of Scandium into melt is strongly controlled by the residual mineralogy of the source (ΔS_{cga}~1-6; $\Delta S_{col} < 0.5$), and Sc/Fe ratio may be an effective discriminant between olivine and garnet-dominated sources. The low Sc/Fe ratios and Ni contents of the alkaline ferropicrites overlap those of the Hawaiian tholeiitic basalts, and are consistent with derivation from incompatible element-enriched garnet-pyroxenite sources. In contrast, the high Sc/Fe ratios and low Ni contents of the subalkaline ferropicrites are more consistent with the melting of an olivine-dominated peridotitic mantle, in the absence of garnet. Widespread occurrence of minor ferropicrites with more ubiquitous Fe-poor komatiites, tholeiites and calc-alkaline basalts indicates a global contribution of unusually Fe-rich peridotite and garnet-pyroxenite during Neoarchean mantle melting. **(*SY3, Wed. 8:40*)**

Petrology and geochemistry of the Otish gabbros and comparison to *ca.* 2.17 Ga mafic dyke swarms of the Superior Province

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The Superior Province of North America experienced multiple episodes of mafic magmatism during the Paleoproterozoic, each providing information on the temporal and spatial variations in the composition of the mantle underlying the Earth's largest craton. Gabbroic dykes and sills of the Otish suite were emplaced into the conglomerate and sandstone-dominated Otish Basin, central Québec, *ca.* 2.17 Ga. The mineralogy of the Otish gabbros is relatively fresh and dominated by clinopyroxene and plagioclase. Variable amounts of olivine, orthopyroxene, apatite, oxides, sulphides, and secondary amphibole are subordinate. The gabbros display a wide range of Mg-numbers ($Mg/(Mg+0.9Fe^{TOT}) = 0.34\text{-}0.66$) and MgO (4-11 wt. %) and FeO^{TOT} (8-16 wt. %) contents. All gabbros have fractionated rare earth element (REE) profiles ($Ce/Yb_{MORB} = 3.5\text{-}6.5$), and show depletions in Nb-Ta relative to light REE ($Nb/La_{MORB} = 0.3\text{-}0.8$). The Otish gabbros may be subdivided into two groups, based on major and trace element geochemistry. Group 1 gabbros have relatively high MgO concentrations (6-11 wt. %) and Mg-numbers (>0.50), and relatively low absolute abundances of REE ($Yb_{MORB} = 0.47$ +0.13/-0.15). Furthermore, Group 1 gabbros display positive Sr and Eu anomalies relative to REE of similar compatibility. In contrast, Group 2 gabbros have lower MgO contents (4-7 wt. %) and Mg-numbers (<0.5), higher absolute abundances of REE ($Yb_{MORB} = 0.82$ +0.45/-0.10), and lack marked relative enrichments in Sr and Eu. Geochemical modelling suggests that Group 1 gabbros are likely crystal cumulates formed by physical addition of plagioclase and clinopyroxene to Group 2 gabbros, which may approximate liquid compositions.

At least two other mafic dyke swarms were emplaced into the Superior Province *ca.* 2.17 Ga. The Biscotasing and Payne River dyke swarms are both coeval with the Otish gabbros and, together, may offer new insight into the spatial variability in the mantle-melting conditions beneath the Superior Province during this time. The quartz-tholeiitic Biscotasing dyke swarm of eastern Ontario has MgO (3.5-8 wt. %) and FeO^{TOT} (9.5-16 wt. %) contents, and Mg-numbers (0.35-0.60) that are comparable to those of the Otish gabbros. Dykes of the Biscotasing suite also show similar trace element systematics to Otish gabbros, including comparably-fractionated REE profiles (Ce/Yb_{MORB} =2-8) and depletions in Nb-Ta (Nb/La_{MORB} = 0.4-1.0). In contrast to Otish gabbros, the Payne River dykes of northern Québec are characterized by flatter REE profiles (Ce/Yb_{MORB} = 2-3) and lack systematic Nb-Ta anomalies (Nb/La_{MORB} = 0.7-1.3). **(*SY3, Poster*)**

Developing a geoheritage site list for New Brunswick, Canada

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In 2010 the Province of New Brunswick passed the Heritage Conservation Act, the first version of heritage legislation in the province to include palaeontology and regard fossils as heritage objects. Concerning palaeontology three items are included in the legislation; a permit requirement for professionals and amateurs to collect fossils; a requirement for a permit to alter a fossil site; and designation of a heritage inspector responsible for palaeontology. But what is a fossil site and how should we define it? At a very basic level a fossil site could be any place a fossil is found. From a management viewpoint, that broad scope may not be a practical way of defining sites to issue a permit required to alter a site. In addition there is an obligation to identify the boundaries of a fossil site, to define the area requiring permitting. The provincial [property] Assessment Act states that land ownership does not include minerals or fossils. However for a permitting process a surveyed, legal boundary might be necessary so property owners know the location of fossil sites. Our current approach is to better define the criteria for a fossil site – or perhaps ‘significant’ fossil site, to create a manageable list of places important to New Brunswick’s heritage and geoscience interests. Among the criteria considered, significant fossil sites should be: unique with an important assemblage or rare fossils; the best examples of their kind; from a stratotype defined in part on palaeontology; representative of the province’s geological diversity; of historic significance to geological exploration or a broader cultural context. Examples on the list include the place where the world’s first Precambrian stromatolite was described; the outcrops where Canada’s first Cambrian trilobites were discovered; the province’s only Silurian vertebrate locality; the Early Devonian formation that contains primitive land plants, early land animals, and fish; the historic Upper Carboniferous ‘Fern Ledges’; and Quaternary coastal outcrops that have yielded late-glacial marine and terrestrial faunas. An advantage to this approach is that palaeontological and geological sites become an integral part of the overall heritage of New Brunswick, and thought of in the context of both their scientific and broader cultural heritage. **(*SS15, Fri. 10:20*)**

Geochronology and geochemistry via SIMS and LA-ICPMS depth-profiling: Results from the Trans-Hudson orogen, Baffin Island, Nunavut

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The Hall Peninsula of southeastern Baffin Island, Nunavut, Canada, represents an exposed section of orogenic middle crust in which the lower Superior plate converged with the upper Churchill domain during the Paleoproterozoic, forming the Himalayan-scale Trans-Hudson Orogen. Our study is part of the Canada-Nunavut Geoscience Office project to map the peninsula. The area is dominated by Archean orthogneisses and Paleoproterozoic metasedimentary rocks exhibiting prograde upper-amphibolite to granulite facies assemblages that are overprinted by amphibolite facies mineral assemblages. Analysis of monazite and zircon were used to help decipher the age of tectonothermal events. Monazite are yellow, prismatic crystals with sharp terminations, ranging in size from 20-80 µm. *In-situ* LA-ICPMS U-Pb analyses on monazite within metasedimentary rocks yielded ages of *ca.* 1.85-1.83 Ga. LA-ICPMS trace element depth-profiling analyses on unpolished monazite generally exhibit homogenous trace element distribution throughout the crystal, consistent with a single dominant age population. Zircon morphologies include well-rounded anhedral grains, euhedral to subhedral prisms with small (2:1) aspect ratios, and acicular zircons between 20 and 80 µm in length. Distinct from the monazite results, trace element depth-profiles of unpolished zircon indicate the presence of thin (<5 µm) rims that are enriched in LREEs relative to zircon interiors by 1-2 orders of magnitude. Zircon U-Pb geochronology using SIMS depth-profiling approach on unpolished grains from Archaean gneissic tonalite reveal the presence of distinct rim ages ranging from *ca.* 1.85-1.83 Ga, and less common, ultrathin (<2 µm) 1.78-1.76 Ga rims. Archean ages are preserved within the zircon cores. The striking similarity of zircon rim and monazite ages at *ca.* 1.85-1.83 Ga, coupled with mineral geochemistry, suggests regional metamorphism attributed to crustal thickening during the Trans-Hudson Orogen. The younger, less common 1.78-1.76 Ga ages may indicate a second, regional thermal event that was late-to-post-orogenic. The growth of chemically distinct zircon rims during both thermal episodes indicates protracted circulation of LREE-rich fluids. Enrichment of LREE in metamorphic fluids may be attributed to the breakdown of accessory minerals during prograde metamorphism and anatexis, or potentially to concomitant felsic magmatism such as the nearby *ca.* 1.86 Ga Cumberland Batholith or younger pegmatitic dykes. The coupled use of trace element and geochronology depth-profiling methods allowed us to resolve the nature and age of ultrathin zircon rims, and provided an increased understanding of Paleoproterozoic tectonism in this understudied region of Himalayan-type middle crust. **(*SS17, Poster*)**

Verification of the textural and chemical effects of crystal fractionation determined from the Thingmúli volcano magmatic series, eastern Iceland

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The importance of crystal fractionation in the creation of the chemical and mineralogical diversity observed in volcanic rocks is a major problem in igneous petrology. Crystal fractionation is a physical process with chemical effects. Therefore, it is interesting to study the textures of rocks, such as crystal size distribution, to verify and clarify the effect of crystal fractionation. For this study samples were collected from the Tertiary Thingmúli volcano in eastern Iceland, where erosion has revealed a section through a central volcano. The lava flows of the Thingmúli volcano are dominated by basalts, together with andesites and a few dacites and rhyolites. Most lavas have 0-5% macrocrysts, except for a few ultraphyric basalts. The majority of macrocrysts are plagioclase but it is also possible to observe pyroxene, magnetite and rare olivine. The groundmass of these rocks is often glassy or aphanitic with mineralogy similar to the macrocrysts.

We have started to quantify the textures and chemical compositions of macrocrysts of 14 samples. This data will be used to address the following questions: 1) Can the physical crystal separation in the silicate liquid explain the compositional variations which are observed in a volcanic sequence? 2) What is the origin of macrocrysts which are observed in the lava flows? Mass balance calculations will be used to answer the first question. To answer the second question, Rayleigh fractionation will be modelled to determine if the macrocrysts are in equilibrium with the magma and hence phenocrysts. Moreover, the phenocrysts can also be distinguished by their normal zonation. Once this distinction is made, the CSD will be studied to distinguish the antecrysts from the xenocrysts. By grouping the shape of the CSD curves, the Rayleigh fractionation and the zonation type, it will be possible to determine the macrocryst's origin and the history of magmas from the Thingmúli volcano. **(*GS3, Poster*)**

Cathodoluminescent quartz microstructures in granulites and amphibolites of the Central Gneiss Belt, Ontario, Canada

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Cathodoluminescent (CL) quartz microstructures are ubiquitous in the Parry Sound Domain of the Central Gneiss Belt in Ontario. We have documented four major microstructures that are dark within otherwise brightly luminescing quartz grains: (1) mantles on grain boundaries, 50-200 µm, varying in width within single grains; (2) thin lines, ~2 ìm wide that tend to be sinuous; (3) thick lines, ~20 µm wide that tend to be straight; and (4) grains that are entirely CL-dark.

Samples come from both granulite facies protolith and sheared amphibolite facies samples. The first three microstructures have the same morphology, width and density in both sheared and protolith grains; thus we interpret that they formed after shearing-induced grain shape change. We also interpret that at least the beginning of the retrograde reactions took place under CL-bright conditions because quartz grown with hornblende after pyroxene has CL-bright cores.

The mantles do not correlate with any optical features. CL intensity typically correlates to the concentration of chemical and structural defects (CL-activators) in quartz. We have not yet verified the activator responsible for the mantles, but we hypothesize that water was involved in forming them. We infer that mantles formed at lower amphibolite facies because lower temperature assemblages are not present. Thin lines correlate to subgrain boundaries, some with chessboard or similar patterns; formation at lower amphibolite conditions is consistent with the lowest reported formation conditions for chessboard patterns. Thick lines correlate with fluid inclusion trails, which form as healed fractures; inclusion trails are typically reported to form at greenschist or lower conditions. Grains that are entirely CL-dark include grains from the cores of km-scale shear zones. Some ‘granulite’ protolith/amphibolite shear pairs also have quartz that is mostly dark; it is not clear whether there is a correlation between volume of dark quartz and the amount of shearing. In some dark grains, the other microstructures are present; we interpret that the grain darkening occurred before the other three microstructures, likely more intimately tied with the shearing and retrogression process.

In summary, quartz grains were CL-bright under granulite and initial amphibolite conditions. Some local regions experienced events, likely hydration, that darkened quartz. After shearing was complete, but while still in amphibolite conditions, quartz experienced enough strain to form subgrains (thin lines) and water on grain boundaries diffused in to form mantles. Fracturing and healing to form fluid inclusion trails (thick lines) occurred during exhumation. **(*SS19, Poster*)**

Constant compositions, evolving techniques over the lifespan of an analytical lab

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The McGill Department of Earth and Planetary Sciences ran an analytical services lab for decades, before closing it in 2012. Initially offering X-ray fluorescence, atomic absorption spectroscopy, and some wet chemical techniques, the lab expanded into ICP-MS during the last decade. Over these decades, tens of thousands of samples were analyzed from researchers located across Canada and the world. Operation of these labs were made possible by support from NSERC, CFI, McGill University, and instrument partnerships with PANalytical and PerkinElmer Canada. As the research interests of the Department changed and infrastructure and technical support became more difficult, continued operation of the service lab became untenable.

As a routine procedure, in-house and certified reference materials were run as part of each analysis set. These analyses form a unique dataset that chronicles the evolution of technique and instrumentation from the early 1990s to 2012. The precision and accuracy of these repeatedly analyzed materials allow the estimation of the uncertainty associated with combining older compositional datasets from the literature with currently generated ones. Specific results from XRF major element (using fused beads), XRF trace element (using pressed pellets), and ferric/ferrous ratio (wet chemistry) determinations will be presented.

Analyses of samples from greenstone belts and other mafic assemblages from northern Quebec will be used to illustrate the application of this dataset. Samples of the two in-house standards are available for inter-laboratory comparison. These are LSB2 (a HFSE-enriched phonolite) and LSE (a syenite). **(*SY3, Thurs. 3:00*)**

What happened during the metamorphism of Ni-Cu-PGE deposit: The example of the Delta deposit (Raglan area, Northern Quebec)

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The formation of Ni-Cu-PGE (platinum-group element) sulphide deposits from mafic-ultramafic magmas is now quite well understood, however the behavior of these sulphide bodies during regional metamorphism remains a matter of debate. The Cape Smith Belt, located in the Ungava peninsula (northern Quebec), holds multiple Ni-Cu-PGE deposits associated with komatiitic basalts during the early Proterozoic (*ca.* 1.9 Ga). We have studied 20 samples from two massive sulphide lenses of the Delta deposit which is located 50 km E-SE to the main Raglan mine. These lenses are located in a fault zone and have undergone a regional metamorphism that reached upper greenschist to lower amphibolite facies. The petrographic study shows that the massive sulphides have recrystallized and been slightly deformed but still have magmatic mineral assemblages (pyrrhotite, pentlandite and chalcopyrite). The lenses have not been altered by fluids and represent an ideal material to determine the effects of the regional metamorphism on the metal contents of the komatiitic sulphide minerals. The whole rock geochemistry shows that the massive sulphides kept their magmatic signatures and have not been affected appreciably by the regional metamorphism and deformation. However the two lenses can be differentiated by their PGE content. Whereas the first lens has cumulus monosulphide solid solution (MSS) characteristics; the second lens formed from a more evolved sulphide liquid (chalcopyrite-rich samples). LA-ICP-MS analyses have been performed in order to characterize the trace element (PGE and other chalcophile elements) content of the metamorphosed massive sulphides. Our results show that Os, Ir, Ru in the sulphides represent respectively 41-64%, 21-27% and 75% of the elements. These elements are commonly thought to be held by the MSS phases suggesting that they could have been exsolved from the sulphides during metamorphism. Iridium is less present in the MSS minerals in the more evolved lens and could be associated with the Pt-PGM. Rhodium is present at 9-12% in the MSS minerals suggesting that the rest is present in PGM and sulf-arsenide minerals observed with SEM. Palladium is present at 35% in pentlandite, the other 65% in the form of testibiopalladinite (Pd[Sb,Bi]Te). Less than 3% of the platinum is present in the sulphide minerals, the rest forming sperrylite ($PtAs_2$).

Our study shows that regional metamorphism in the greenschist facies conditions can slightly increase the exsolution rate of PGE from the sulphides but did not modify greatly the PGE content of the sulphide minerals. **(*SY6, Fri. 2:20*)**

Linked histories of allochthon emplacement, pulsed subsidence and faunal evolution in the Taconic foreland basin

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Previous interpretations of Taconic foreland basin evolution in New England have emphasized a gradual westward migration of facies in which the Utica Shale and related flysch deposits prograded over the drowned Trenton shelf in response to a gradual subduction of the Laurentian plate and subsequent basin filling. Recent work on the tectonic setting suggests instead that the Utica Shale formed in a retro-arc basin with two episodes of accelerated foreland subsidence and facies response. The first occurred within the latest C. bicornis Zone, between 452.8-452.3 Ma (bracketed by the Millbrig and Sherman Falls K-bentonites) and lead to deposition of the Utica Shale above an abrupt drowning surface that is essentially synchronous from Ballston Spa to Little Falls NY.

The second event took place at ~451.65 Ma, bracketed by the Manheim and Ostquago K-bentonites. That event emplaced O. ruedemanni Zone age, shelly greywackes onto the Vischer Ferry-Cohoes mélange belt, and produced soft sediment and thrust deformation in lower D. spiniferus Zone rocks west of the Vischer Ferry mélange zone (on the up-thrown side of the Saratoga-McGregor Fault), as well as extensional fault-block rotation and sediment slides (Thruway Disconformity) in the central Mohawk Valley. The "Thruway event" terminated deposition of the Dolgeville Formation and abruptly spread Utica Shale yet farther west.

These events affected basin hydrography and faunal evolution as well. The initial Utica onlap event was accompanied by the immigration of a modest graptolite fauna and a unique set of geochemical conditions. The graptolite fauna became more species poor and more endemic as the basin became restricted during local base level fall in O. ruedemanni Zone time. The Thruway event was accompanied by abrupt shifts in $\delta^{13}C$ and $\delta^{18}O$ values, and by immigration of a new tropical oceanic graptolite fauna. Simultaneously, the endemic trilobite Triarthrus beckii underwent a basin-wide shift in morphology. These faunal responses suggest that thrust emplacement in the retroarc foreland and the ensuing basin-wide subsidence lead to rapid changes in local basinal conditions, probably including changes in current circulation, water temperature and productivity. **(*SS13, Thurs. 3:40*)**

Keynote (40 min): Risks to groundwater from shale gas development: The Canadian context

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Shale gas development has sparked global controversy for the risks it poses to the environment, especially in relation to valuable groundwater resources which must be protected. Not all risks are the same, they can vary from one region to another, and many are difficult to evaluate because of the lack of independent data and peer-reviewed literature. Leakage of gas or fluids into shallow aquifers along improperly sealed boreholes, or via legacy wells, has emerged as one of the greatest risks. In some cases following development, contamination may take decades or longer to develop thus complicating attempts at mitigation and reinforcing the need for better understanding system behaviour through site characterization and monitoring. Monitoring poses a particular challenge because of the significant depths and long time scales involved, and there is a critical need for monitoring baseline (pre-development) water quality to allow identifying natural *vs.* anthropogenic sources of contamination. Contaminant pathways through natural faults can also pose a risk. This talk will present an overview of the risks and challenges to shale gas development in Canada with regard to possible impacts on water resources, particularly groundwater. Current initiatives for reducing risk and protecting groundwater resources will be reviewed, such as characterizing aquifer vulnerability. Perspectives from two recently-completed studies on these issues (reports from the Council of Canadian Academies and the Quebec Shale Gas Review Committee) will be provided. **(*SS16, Wed. 8:00*)**

Long-term mineralogical and biogeochemical evolution of sulfide-rich tailings under a shallow water cover

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The oxidation of sulfide-minerals in sub-aerial tailings deposits generates acid and releases SO_4 and metals to pore waters. Sub-aqueous disposal below shallow water covers is commonly employed to reduce the rate of sulfide mineral oxidation reactions and thereby reduce the environmental impacts of mining operations. Several short-term studies have demonstrated that shallow water covers can effectively limit oxidation reactions; however, long-term studies on the mineralogical and geochemical evolution of submerged tailings are lacking. The former Sherritt-Gordon Zn-Cu mine (Sherridon, MB) deposited sulfide-rich tailings into Fox Lake in 1951. The tailings formed a number of small exposed islands with the majority of submerged tailings extending outward into the lake. Surface water, pore water and core samples were collected in 2001 and 2009 to examine the mineralogy and biogeochemistry of sub-aerial tailings and corresponding tailings submerged under a 1 m water cover. Characterization of sub-aerial tailings revealed a zone of extensive sulfide-mineral alteration extending to a depth of 40 cm below the tailings surface. Moderate alteration was observed from 40–60 cm, but was limited at depths > 60 cm. In contrast, sulfide-mineral alteration within the submerged tailings was confined to a zone < 6 cm thick immediately below the tailings-water interface with only minimal sulfide-mineral alteration observed compared to the sub-aerial tailings. Sulfur K-edge X-ray absorption near edge structure (XANES) spectra confirm that sulfide-mineral oxidation within the submerged tailings is limited compared to sub-aerial tailings. Pore water within the upper 40 cm of the sub aerial-based tailings was characterized by low pH, depleted alkalinity, and elevated SO_4 and metal concentrations. Acidophilic sulfur-oxidizing bacteria dominated the microbial community within these tailings. Conversely, pore-water in the submerged tailings was characterized by strong reducing conditions, near-neutral pH, and low concentrations of dissolved SO_4 and metals. These tailings also hosted elevated populations of sulfate reducing bacteria, exhibited H_2S production and strong $\delta^{34}S$-SO_4 and $\delta^{13}C$-DIC fractionation, both of which are indicators of bacterial (dissimilatory) sulfate reduction. Additionally, mineralogical investigation revealed the presence of secondary marcasite as coatings on primary sulfide minerals. This observation suggests that oxidized coatings subsequently converted to marcasite in the presence of H_2S. The formation of secondary sulfide phases within the submerged tailings also may serve as a control on metal mobility. Results from this study provide critical long-term information on the viability of sub-aqueous tailings disposal as a long-term approach for managing sulfide-mineral oxidation. **(*SY6, Fri. 9:20*)**

Efflorescent sulfate salts from the former Sherritt-Gordon Zn-Cu mine

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The former Sherritt-Gordon volcanogenic massive sulfide ore deposit in Sherridon, Manitoba, was mined for zinc, copper, silver and gold between 1930 and 1951. Since mine closure, two high-sulfide tailings impoundments have undergone extensive oxidation resulting in the release of extremely elevated concentrations of dissolved sulfate and metals to the tailings pore water.

During precipitation events and spring freshet, surface seeps developed along the flanks of the impoundments discharging groundwater with a measured pH as low as 0.39 and dissolved concentrations of sulfate and iron up to 203 g/L and 68 g/L, respectively, along with other elevated metals. A number of efflorescent minerals were observed within the seepage areas. Using a combination of powder X-ray diffraction and scanning electron microscopy, secondary efflorescent minerals at seepage zones were identified, including melanterite, rozenite, halotrichite, chalcanthite, alpersite, copiapite, hexahydrite, jurbanite, pickeringite and gypsum. Geochemical modeling of seepage waters using a modified WATEQ4F database for ferric-sulfate minerals and a modified version of PHRQPITZ for ferrous sulfate minerals predicted most of the observed sulfate salts. The geochemical modelling used data available for seepage waters that are representative of discharging water after mineral precipitation has already occurred. Discrepancies between some of the observed and modeled results are likely due to data used in the modelling being for seepage water that are more dilute then the original porewater due to mineral precipitation. The formation of secondary efflorescent minerals temporarily removed sulfate and metals from solution, however the subsequent dissolution of these minerals resulted in increased loading to receiving surface waters. **(*SY6, Fri. 9:00*)**

The potential for *in-situ* monazite age dating in polymetamorphic granulite-faceies rocks and associated plutonic intrusives in the Larsemann Hills, E Antartica

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The Larsemann Hills is a geologically distinctive exposure in Prydz Bay on the coast of the East Antartic shield. Polymetamorphic granulite-facies rocks comprise basement orthogneisses and cover paragneisses affected by two major tectonothermal events at about 900 Ma and the Pan-African orogeny at about 500Ma based on isotopic dating of zircon. Plutonic intrusives include *ca.* 1000Ma orthogneisses and *ca.* 530-500Ma granite and pegmatites. Using *in-situ* monazite electron microprobe age-dating, my goal is to refine the established zircon-based ages of the metamorphic and plutonic history of the Lasemann Hills, with special attention given to determining the ages of the tectonothermal events and how they affected the rock formations. Analyzing minerals *in-situ* for dating has the advantage over using separates, as is the case in most zircon-based geochronology, in that the microstructural context of the dated mineral is preserved.

The relatively high concentration of rare earth elements in rocks exposed in the Larsemann Hills area allows for monazite to be a relatively widespread accessory mineral in the orthogneisses, paragneisses, granites and pegmatites. Twenty samples of representative rock types were selected for detailed study. Sample 121401D from the Stornes Gniess in the cover metasediments has numerous unusually large rounded monazite grains ~500µm across (grains in other samples average ~100 µm in size), encased in abundant and unusually fresh cordierite. Samples 123105 and 123104 (Blundell Orthogneiss) have a number of rounded average sized monazite grains with concentric zoning: relatively sharp 5-10µm thick rims that are lighter than the core of the grain under back-scattered electron (BSE) imaging. Energy-dispersive spectra reveal the inner zone to have significantly lower counts of thorium; a difference in Th content could reflect a drastic difference in age. In contrast sample 011603A1 (pegmatite) has monazite grains of similar shape and size, but these grains show little zoning under BSE imaging; instead they are extensively cracked. Xenotime is also present in most samples, usually in very small grains (~5µm) clustered around the edges of monazite grains. Sample 121401C (Stornes Gneiss) is an exception with large round xenotime grains (~200µm), dwarfing nearby monazite grains. In addition to relating periods of monazite growth to zircon growth, quantitative compositional and geochronological analyses of monazite will be used to determine whether the compositional zoning could reflect differences in the conditions under which monazite grains grew during one event rather than monazite growth at different times. **(*SS19, Poster*)**

Nature's diabolic transition from magmatic-hydrothermal iron oxide copper-gold to porphyry Cu ± Au ± Mo deposits: Secular evolution of atmosphere, ocean and lithosphere chemistry and geothermal gradient

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Fundamental secular changes to the chemistry of the Earth's atmosphere, oceans and lithosphere are reflected in a continuum of mineralization styles that provide a link between ancient magmatic-hydrothermal iron oxide copper-gold (IOCG) and modern day porphyry Cu ± Au ± Mo (porphyry copper) deposits. A temporal, spatial and genetic relationship between these seemingly disparate deposit types becomes evident when broad geotectonic setting, thermal environment and chemical constraints are considered.

Magmatic-hydrothermal deposits form from arc magmas generated during subduction processes. They form also from magmas that originated due to melting of subduction-modified lithosphere during orogenic extensional relapse and from post-subduction magmas in distal intra-plate extension settings. Oxidized magmas with high-sulfur content may generate porphyry copper deposits with wide-spread late-stage acid (phyllic) alteration superimposed on early potassic alteration with abundant sulfides. Oxidized magmas with low sulfur content preclude porphyry copper formation, but favour IOCGs with abundant hydrothermal magnetite and/or hematite, minor but still important sulfide mineral content, and absent to moderate late-stage or distal acid alteration.

Both IOCG and porphyry copper deposits depend on the generation of hydrous, oxidized magmas by either subduction or post-subduction processes. However, the distinction between these two broad deposit classes reflects a change from sulfate-poor to sulfate-rich arc magmas at the end of the Precambrian. This transition in magma chemistry is the result of global oxygenation of deep ocean waters in the late Proterozoic, a resultant increase in deep seawater sulfate, and concomitant voluminous fixation of sulfate into seafloor-altered oceanic crust. At the end of the Proterozoic, for the first time in Earth history, subduction and slab devolatilization could provide abundant sulfate to form S-rich magmas with potential to form porphyry copper deposits in upper crustal settings. The paucity of sulfur in earlier Proterozoic and Archean oceans precluded formation of porphyry copper deposits except under rare anomalous conditions. However, the Precambrian environment was favourable for IOCG deposit formation, while their persistence into the Phanerozoic appears to correlate with episodic return to deep ocean anaerobic conditions, or to post-subduction magmatic processes. Other differences such as the apparent greater extent of high-temperature alteration and the occurrence of lithophile element enrichments (*e.g.* U and REEs) in IOCG deposits can be explained by their temporal and/or spatial deposition within geotectonic environments that had relatively high geothermal gradients, coupled with a greater degree of crustal metal ± fluid fluxing. **(*SS3, Poster*)**

Overview of appinites: The leprechauns of petrology

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Like leprechauns, appinite complexes are small and where they exist provide a treasure trove of petrological insights including visible evidence of the effect of water on the generation, emplacement and crystallization history of magma. Appinite complexes typically consist of coeval plutonic and/or hypabyssal rocks, ranging from ultramafic to felsic in composition. Hornblende is the dominant mafic mineral, occurring both as large prismatic phenocrysts and in the matrix. The complexes also preserve abundant evidence for mixing and mingling between diverse magma types and variable degrees of contamination by host rock. Textures are consistent with rapid growth and with experimental evidence for the reduced viscosity of depolymerized melts allowing efficient migration of ions to the sites of mineral growth.

Appinite complexes range in age from Neo-Archean to Recent, occur at all crustal levels, and share some similar geochemical features with shoshonites, high-Mg andesites, sanukitoids and adakites. Melting may be triggered by asthenospheric upwelling caused either by slab breakoff (*e.g.* after terrane or continental collision) or by the generation of a slab window (*e.g.* where a ridge collides with a subduction zone). Some common traits include intrusion soon after the cessation of subduction, and the important role of deep crustal faults as conduits for magmas of diverse compositions to rise towards the surface. These conduits provide the setting for magmas to mix and mingle. Neo-Archean appinites, and relationship with coeval sanukitoids, have been interpreted as evidence for the existence of some form of plate tectonics at that time.

The *ca.* 607 Ma Greendale Complex (GC), Nova Scotia is an 5 km wide appinite complex and a local representative of regional arc-related magmatism. The complex is located between two major faults which were active during its emplacement. Steeply dipping, intrusive sheets of ultramafic, mafic and felsic composition were emplaced during dextral shear on the bounding faults. GC is heterogeneous on all scales with abundant evidence for mixing and mingling. The ultramafic sheets are commonly discontinuous, occurring as boudins derived from early-formed layers. Felsic rocks occur in conjugate veins or networks that typically terminate in pegmatitic lenses. Mafic rocks dominate the complex and are composed of amphibole-rich porphyritic gabbros. Each type of intrusive sheet has a geochemical equivalent in the Georgeville Group host rock, implying that active movement along the bounding faults tapped arc-related magmas of diverse compositions thereby facilitating the mixing and mingling of these magmas. **(*SY3, Wed. 9:00*)**

The geology, petrology and geochemistry of the Montviel alkaline-carbonatite hosted lanthanide-Nb ore deposit, Abitibi, Canada

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The 1.9 Ga Montviel alkaline-carbonatite intrusive system, Abitibi, Canada, comprises peridotites and clinopyroxenites which evolved towards Si-deficient rocks of the melteigite-ijolite-urtite series, high K rocks of the melano- to leucosyenite series, and towards silica-saturated, riebeckite granites. Based on $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ data performed on bulk rocks, ferromagnesian and carbonate minerals, the most primitive rocks originated from the depleted mantle and gradually assimilated an enriched crustal component. Also based on Sr and Nd isotopic data, a second mantle pulse produced a series of silicocarbonatites and calciocarbonatites, which also assimilated a crustal component and evolved into ferrocarbonatites. The alkaline-carbonatite system terminated its evolution with an explosive eruption creating a polygenic breccia. These carbonatites appeared to have been accompanied by a magmatic volatile phase which metasomatized all pre-existing silicate rocks as well as the carbonatites themselves. Stable isotopes ($\delta^{13}C$ and $\delta^{18}O$) suggest that CO_3^{2-} anionic groups in carbonate minerals underwent down temperature re-equilibration but very little low temperature alteration. At Montviel, biotite shows magmatic and hydrothermal textures and is present in most lithologies. Crystallization temperatures range between 800°C and 300°C based Ti (up to 3.5 wt.%) contents. These temperatures show that biotite resulted from metasomatism in primitive silicate rocks, but that it could be both magmatic and hydrothermal in carbonatites. Sodic fenitization recrystallized augite in pyroxenites into aegyrine-augite and in aegyrine. Metasomatism in the melteigite-ijolite-urtite series crystallized cancrinite $[Na_6Ca_2Al_6Si_6O_{24}(CO_3)_2]$, sodalite $[Na_8Al_6Si_6O_{24}Cl_2]$ and analcime $[NaAlSi_2O_6 \bullet H_2O]$. Whether nepheline $[Na_3KAl_4Si_4O_{16}]$ and microcline in ijolite-type rocks and in melanosyenites are magmatic or the result of potassic fenitization remains unknown. Although pyrochlore $[(Na,Ca,Ln)_2(Nb,Ti)_2O_6(OH,F)]$ and burbankite $[(Ca,Na,Ba,Sr,Ln)_6(CO_3)_5]$ were present in primitive lithologies as liquidus phases, most of the lanthanide (Ln) mineralization at Montviel is hydrothermal. The Ln-bearing minerals consist of qaqarssukite [(Ba,Ca,Sr)(Ce,REE)$(CO_3)_2$F], with subordinate amount of parisite-synchysite [Ca-Ln fluorocarbonates], cebaite-huangoite-zhonghuarcerite-kukharenkoite [Ba-Ln fluorocarbonates], ewaldite [(Ba,Sr)(Ca,Na,Ln)(CO_3)2•10-12H_2O], monazite [$LnPO_4$], and xenotime [YPO_4]. Coupled to known Ln carbonate/carbonatite partition coefficients, laser ablation ICP-MS (LAICPMS) data on magmatic carbonates allowed modelling of the evolution of the Ln content of carbonatites and the timing of Ln-bearing fluid exsolution. With the aid of rare carbonatite and Ba-F-Cl-bearing melt inclusions, these results are used to derive a petrogenetic and metallogenetic model. **(*SS23, Fri. 2:00*)**

Does Megumia extend into SW England?

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The Meguma terrane of southern Nova Scotia is the only major lithotectonic element of the northern Appalachian orogen that has no clear correlatives elsewhere in the Appalachians and lacks firm linkages to the Caledonide and Variscan orogens of western and southern Europe. This characteristic is in contrast with its immediate peri-Gondwanan neighbour, Avalonia, which shows similarities to portions of Carolinia in the southern Appalachians and has been traced from the Rhenohercynian Zone of southern Britain eastward around the Bohemian Massif to the South Carpathians and western Pontides. At issue is the tendency to assign all peri-Gondwanan terranes (like Megumia) lying north of the Rheic suture in Europe to Avalonia, characterized by relatively juvenile basement and detrital zircon ages that include Mesoproterozoic populations, and those to the south of the Rheic suture to Cadomia, characterized by a more evolved basement and detrital zircons with ages that match Paleoproterozoic and older sources in the West African craton.

Although the unexposed basements of Avalonia and Megumia are thought to be isotopically similar, Megumia's sedimentary cover contains scarce Mesoproterozoic zircons and is dominated instead by Neoproterozoic and Paleoproterozoic populations. Hence, felsic magmas produced by crustal melting in the Meguma terrane (*e.g.* the *ca.* 370 Ma South Mountain Batholith) are isotopically more juvenile (εNd = -5 to -1, TDM = 1.3 Ga) than the rocks they intrude (εNd -12 to -7, TDM = 1.7 Ga). This distinctive relationship has also been recognized in the South Portuguese Zone of southern Spain where the Sierra Norte Batholith (*ca.* 330 Ma; εNd = +1 to -3, TDM = 0.9-1.2 Ga) is on average more juvenile than the Late Devonian host rocks (εNd = -5 to -11) it intrudes, suggesting the possible presence of Megumia basement in Europe. Available data for the Cornubian Batholith in SW England (*ca.* 275-295 Ma; εNd = -4 to -7, TDM = 1.3-1.8 Ga) and the Devonian metasediments it intrudes (εNd = -8 to -11) suggests this may also be true of that part of the southern Britain (Rhenohercynian Zone) with which the South Portuguese Zone is traditionally correlated. **(*SY3, Wed. 9:20*)**

Could barite play an important role in the formation of REE deposits in carbonatite?

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Rare earth elements (REE) are critical elements that are important for green technologies that could help reduce greenhouse gas production. Hence, access to economic REE deposits could be an important condition to reduce the risk of global warming. Carbonatites are an important host for REE deposits with examples of economic deposits such as Mountain Pass. So, understanding the REE concentration processes in carbonatites could be critical to find and exploit successfully such deposits. Among the models to explain economic enrichment of REE in carbonatites, the breakdown of REE- and/or Sr-rich primary carbonates and apatite during post-magmatic processes is commonly proposed. As such, REE are hydrothermally leached from magmatic enriched minerals and precipitated above as bastnaesite and monazite. However, a compilation of Ba in Fe-carbonatites shows a strong correlation of Ba concentration with REE grade suggesting a REE-rich magmatic source. Moreover, it also suggests that barite might play an important role in REE enrichment. Barites from St-Honoré Fe-carbonatite deposit were analyzed for REEs with LA-ICP-MS. The mineralization occurs mainly as clusters of bastnaesite within brecciated Fe-carbonatite. Calibration for REE has been done using CMP-1 (USGS) reference material (Mountain Pass carbonatite with 12 % Ba and 2.5 % La). Three textural occurrences of barite have been recognized: euhedral, triple-junction anhedral and as veinlets. Euhedral barites are interpreted as formed by early crystallisation and of magmatic origin. Triple-junction anhedral barites are interpreted as brecciated and/or recrystallized. Barites in small veinlets are interpreted as late stage hydrothermal. Magmatic barites are 500-1000 times richer in LREE than brecciated-recrystallized barite whereas late-vein barites are 5-10 times poorer in REE than brecciated-recrystallized barites. These data suggest that barites could have been a significant mineral that concentrated REE through magmatic processes. Subsequently, the leaching by post-magmatic processes liberated REE for remobilisation. Hydrothermal fluids, then rich in REE, could have further concentrated REE as bastnaesite and monazite. Halite associated with mineralisation suggests that REE were remobilized in a chlorine-rich fluid. **(*SS23, Fri. 2:40*)**

Biomonitoring evidence that nutrient loading speeds up reclamation of oil sands process-affected materials

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Constructed wetlands and end-pit lakes will play an important role in reclamation options for fluid tailings at surface oil sands operations. Natural bioremediation will allow viable aquatic habitats to develop through time. Biomonitors capable of rapidly recording changes in ecological heath in response to various strategies are required to properly assess the effectiveness of strategies capable of speeding up the natural reclamation process. The fossil remains of organisms at or near the base of the food chain are ideally suited to this aim.

Testate protozoans are benthic primary consumers that have been proven to be sensitive indicators of both wetland and lacustrine ecosystem health, responding quickly to environmental changes. Arcellacean (testate lobose amoeba/ thecamoebian) assemblages in samples collected in 2008 from Suncor Energy Inc. Constructed Wetlands Test Facility, Fort McMurray, Alberta recorded changes in levels of oil sands process-affected water/materials (OSPW/OSPM) relative to samples collected in 2007. The beneficial effects of nutrient loading on the ecology of a highly contaminated site are evident in the comparison between Sustainable Lake North Test Pond (Site 14) and Sustainable Lake South Test Pond (Site 15). Higher species diversity and greater relative abundance of difflugiid arcellaceans found in the samples from Sustainable Lake South relative to the parallel Site 14 (Sustainable Lake North) illustrate that the practice of nutrient loading accelerates the reclamation process. This is consistent with the observation of abundant desmids and cysts of dinoflagellates in palynological samples from Sustainable Lake South, whereas there is little evidence of algae at Sustainable Lake North where the only common non-pollen palynomorphs seen were fungal spores. **(*SS16, Wed. 9:20*)**

Mechanisms of strain localization in the lower crustal root of a collapsing orogen, central Fiordland, New Zealand

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Central Fiordland records a transition from convergence, subduction, and arc magmatism along the Gondwana margin to the extensional collapse of over-thickened arc crust beginning in the Early Cretaceous. The spatial distribution and evolution of structures that accommodated this transition allowed us to evaluate the processes that localized strain during orogenic collapse.

A 45 km long cross section through two mafic-intermediate igneous units, the Breaksea (BO) and Malaspina (MO) orthogneisses, shows superposed fabrics illustrating a progression from magmatic flow to distributed high-T (>750°C) deformation, to focused lower-T (~650°C) deformation during extension. Igneous foliations are widespread throughout the BO and MO (~560 km^2), and defined by tabular plagioclase and hornblende-pyroxene aggregates showing no evidence of subsolidus recrystallization. Superimposed on the igneous flow fabric are foliations defined by eclogite and granulite facies mineral assemblages with lenticular garnet, pyroxene, and hornblende aggregates set in a plagioclase matrix. In these zones, which are spread over >200 km^2, high-T (>750°C) subsolidus recrystallization leading to plagioclase grain size reduction is common. The concentration of leucosome in dilational sites also records deformation in the presence of partial melt. Crosscutting the high-T fabrics are the Doubtful Sound (DSSZ) and Resolution Island (RISZ) shear zones. These shear zone systems exhibit upper amphibolite facies foliations defined by aligned and flattened hornblende and biotite aggregates and recrystallized plagioclase. They record hydration, retrogression of granulites, and deformation in narrow (~80 km^2) zones. Where it is best expressed in the northern MO, the DSSZ is 3 km thick and occurs at or near the MO-host gneiss contact. Elsewhere, it splits into a diffuse network of ~20-30, <0.5 km shear zones distributed across ~15 km of the MO interior. Strands of the RISZ (<0.5 km thick) occur both along the margin and interior of the BO. These patterns suggest that the dominant strain localization mechanisms during orogenic collapse included cooling, hydration, focused fluid flow, and grain size reduction affecting both pluton margins and interiors.

The sequence of lower crustal deformation from widespread igneous flow to high-T granulite facies deformation, to cooler, upper amphibolite facies deformation records changing strain localization mechanisms during extensional collapse. These mechanisms include the crystallization of magma, the removal of partial melts from the lower crust, cooling, hydration, plagioclase grain size reduction, and lithological contrasts. Our observations suggest that this evolution occurred over a ~10 Ma timespan, and highlight a changing lower crustal rheology during extensional collapse. **(*SY2, Poster*)**

High temperature volatile activity within the Caribou Lake mafic-ultramafic intrusion, NWT and its impact on ore tenor

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The Caribou Lake Intrusion (CLI) comprises the western intrusive suite of the Early Proterozoic Blachford Lake Intrusive Complex, which intrudes the sedimentary rocks of the Archean Yellowknife supergroup and the Morose granite. The CLI is located approximately 90 km southeast of Yellowknife, NWT, has a strike length of approximately 12 km north-south, and is up to 1 km wide. A 2006 drilling program identified several intersections of massive to heavily disseminated pyrrhotite ± chalcopyrite ± pentlandite. The focus of this study is to use the mineralogy of the cumulate rocks, sulfur isotopes, and fluid inclusion analyses to develop a fluid-evolution model for the CLI. These data will be compared to mineralized and barren tholeiitic layered and multi-phase mafic-ultramafic intrusions from other locales, which have experienced substantial late magmatic to post-cumulus volatile modification of primary metal tenors (*e.g.*, Duluth, Muskox, Lac Des Iles).

Apatite generally occurs within moderate-highly altered gabbro to gabbronorites. Primary H_2O-CO_2-NaCl inclusions in apatite are elongated parallel to the c-axis. Secondary inclusions include: 1) immiscible brine – CO_2, 2) solid halite, 3) solid opaque, 4) polyphase brines, and, 5) vapor-rich (>90 vol% vapour) inclusions. The majority of the fluid inclusions in quartz are secondary and vapour-rich. H_2O-CO_2-NaCl and vapour-poor (<15vol% vapour) inclusions are minor and primary fluid inclusions have yet to be identified in quartz. Bulk $\delta^{34}S$ values in pyrrhotite, pyrite, and chalcopyrite range from -0.4 to 2.5 ‰. *In situ* $\delta^{34}S$ values range from -0.6 to 1.4‰ and 0.6 to 1.1‰ for primary and secondary pyrrhotite, respectively. These values are consistent with a mantle source for sulfur and suggest the sulfur was internally derived. Sulfur isotopes on the sedimentary country rocks are to be completed and should they differ, it would suggest fluids were autolytically derived (*i.e.* cooled) and not related to contamination from surrounding host rocks. The secondary fluid inclusions hosted by fluorine-rich apatite (2.9 to 3.9 wt %) and quartz represent high-temperature fluids that migrated through the cumulate pile during its cooling history. Based on this preliminary fluid inclusion study, the fluid history of the CLI is complex. Similarities exist between fluid inclusion types in the CLI and in other large mafic-ultramafic intrusions (*e.g.* Stillwater, Duluth) in which high temperature, late magmatic volatiles have interacted with mineralized cumulates and modified ore tenors. **(*SS20, Wed. 10:40*)**

The differences between geohazards on liquefaction fluidization and ground wave "Jinami" in each fill-land type

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Urayasu City facing Tokyo Bay and Foster City facing San Francisco Bay are the fill-lands on each delta and estuary.

Urayasu city is where the channel in the delta, the estuary and the sea bed was partitioned in rectangle for the reclaimed land. Sand and mud and sand dredged from the offshore sea bottom was fed by sand pumps to settle in such rectoangular areas for reclamation facing Tokyo Bay. The delta and estuary of the geo-environments are not remained in the city.

Foster city is where the geo-environments of the delta system, channel and estuary are kept in the reclaimed land. It's shape is not rectoangular but like a fan of the delta.

The differences between geohazards on liquefaction, fluidization and ground wave "Jinami" are shown respectively in tow cities. Urayasu City, Japan, was suffered from the serious geohazards at the 2011 off Northeast Pacific Earthquack. But Foster City was not so damaged at the 1989 Loma Prieta Earthquack. However, the distance from the city to the epicenter of the 1989 Loma Prieta Eearthquack is more near than it from Urayasu City to epicenter of the 2011 off Northeast Pacific Earthquack. It is concluded that the differences between geohazards on tow cities are coursed by how to deform the land as reclaimed land. **(*SS10, Wed. 3:20*)**

The 2011 Earthquake off the Pacific Coast of Tohoku and The Katori-Narita-Itako International Declaration

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We, International Union of Geological Science (IUGS) Commission on Geoscience for Environmental Management (GEM), had organized the symposium on International Workshop on Man-Made Strata and Geo-pollution, June 18, 2011, Katori-Narita, Chiba, Japan.

The International Workshop led to the declaration including three points for mitigation of Geological hazard due to the 2011 big Earthquake. One in the declaration is mentioned below. This presentation is how to have used the International Declaration in Japan.

Katori-Narita-Itako International Declaration

International Declaration for Deterring the Geological Hazards occurring in the 2011 Earthquake off the Pacific Coast of Tohoku. We, international researchers of man-made strata and geo-pollution, extend our sincere prayers for the rest in peace of the souls lost in the 2011 Earthquake off the Pacific Coast of Tohoku and heartfelt wish to those hit by the disaster for the quickest possible recovery. We also extend our deepest sympathy to those who are suffering from radiation pollution following the nuclear power plant disaster.

At the closing of the International Workshop, we are making the following proposals.

1. The 2011 Earthquake off the Pacific Coast of Tohoku caused serious geological hazards, including large-scale liquefaction and fluidization in man-made strata formed by reclaiming land from the sea or valleys, and the calamitous tsunami along the coastline. Man-made strata are abundantly seen not only in Japan but also in the entire world. To prevent further occurrence of these large-scale geological disasters we need to conduct detailed investigation of the Jinji unconformity, *i.e.* the boundary discontinuity between man-made strata and natural strata in Japan, and the physical units in the man-made strata. **(*SS10, Wed. 2:40*)**

Inorganic geochemical analysis of fine-grained rocks from the Carboniferous of New Brunswick: Preliminary data analysis

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The Carboniferous of New Brunswick is host to the only known commercially producing onshore petroleum system in Atlantic Canada. Here, strata are divided into six lithostratigraphic groups: Horton, Sussex, Windsor, Mabou, Cumberland, and Pictou. However, it is often difficult to distinguish particular units, including some of economic importance, from each other because of complications including: restricted outcrop exposures, lithologically similar fine-grained strata in many units, a near complete absence of radiometrically datable materials, and reworking of rare microfossils throughout the succession. Recently, in other stratigraphic successions with similar complications, chemostratigraphic methods have been used to differentiate units (*e.g.* comparison of bulk inorganic elemental geochemistry determined using ICP-MS or XRF). Little such geochemical data currently exists for the Carboniferous of New Brunswick. Accordingly, samples are being collected from fine-grained strata in outcrop and borehole from each of the Carboniferous groups throughout the province for ICP-MS analysis of 55 elements. The data is being statistically analyzed to determine if unique major, minor, or trace elemental composition can characterize any or each of the stratigraphic units.

To date, 51 samples from the Horton Group; exclusively in the Albert Formation, have been assessed to determine the elemental variability present within this one unit. Preliminary analyses of the geochemical data indicate noticeable spatial- and sample-type distributions of certain elements, for example: chromium records higher concentrations in surface samples and in the western area of sample collection, whereas copper concentrations are higher in core samples and to the east. When Al_2O_3:Ga and K_2O:Rb ratios are calculated, strongly positive correlation and goodness of fit to the regression line can be seen, indicating that Ga and Rb are strongly tied to the presence of kaolinite and illite respectively. When compared against existing ICP-MS data from a borehole containing rocks assigned to the Mabou Group, similar goodness of fit values for Al_2O_3: Ga and K_2O: Rb are calculated, but values indicate a distinctly higher proportion of clays in comparison to the Horton Group samples.

Future work will extend collection of samples to the entire lithostratigraphic column, possibly resulting in a chemostratigraphic characterization of all the fine-grained sedimentary units in New Brunswick. **(*SS12, Poster*)**

Keynote (40 min): Formation of iron-sulfate minerals by oxidation of pyrite and aqueous ferrous iron and evaporation of acid mine water

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The paragenetic sequence of iron-sulfate minerals that occur in association with oxidizing pyrite is dictated by (1) pyrite stoichiometry, (2) the amount of pyrite oxidized (3) the amount and geochemistry of neutralizing minerals present, (4) redox conditions, which depend on microbial rates of Fe(II) oxidation, (5) the degree of evaporation (relative humidity or moisture content), and (6) temperature. Acid mine water composition is often enriched by evaporation. The hydrated iron-sulfate minerals formed include low-solubility minerals (schwertmannite, jarosite group minerals, butlerite), and the more soluble ferrous sulfate hydrates (melanterite, ferrohexahydrite, rozenite, szolmonokite), mixed ferrous-ferric sulfate hydrates (copiapite, bilinite, and römerite), and ferric sulfate hydrates (ferricopiapite, lausenite, kornelite, coquimbite, quenstedtite, mikasaite, and rhomboclase). Schwertmannite (molar Fe/S of 5 to 8) precipitates from oxidized, relatively dilute waters of pH 2–5, typically mixed with microcrystalline goethite. In a pH range of 1–3, jarosite (or jarosite K-Na-H_3O solid solution; Fe/S of 1.2 to 1.5) commonly forms but can be mixed with schwertmannite at pH's near 3. To achieve a pH below 1.0, more than 200 mmol FeS_2 per liter must oxidize, without any neutralizing minerals. For water still in contact with pyrite, dissolved iron stays reduced and the relatively insoluble ferric oxyhydroxysulfates do not form. Instead, the solution becomes more acidic as more pyrite oxidizes until pH near 0.0 is reached when saturation with respect to melanterite is achieved. For every mole of pyrite oxidized, 1 mole of melanterite and 1 mole of sulfuric acid form. If melanterite forms, the residual fluid has a lower Fe/S than either pyrite (0.5) or melanterite (1.0). A fluid depleted in Fe/S leads to a stoichiometry consistent with the formation of copiapite group minerals (Fe/S = 0.67 to 0.78) and römerite (Fe/S = 0.75). Furthermore, copiapite group minerals form by oxidation of melanterite only in the presence of residual sulfuric acid. Copiapite group minerals typically form from fluids in the pH range 0.0 to –1.0. With increasing oxidation and evaporation, rhomboclase (Fe/S = 0.5) forms which incorporates hydronium ions. Rhomboclase has been observed forming from the most acidic fluids at Iron Mountain, California (pH of -2.5 to –3.6), equivalent to an 8 molar sulfuric acid solution. Combining field, lab, and theoretical results provides a paragenetic framework for iron sulfate mineral formation relative to solution chemistry and evaporation. **(*SY6, Thurs. 2:40*)**

Numerical investigation of methane and formation fluid leakage along abandoned wells: Application to the St-Lawrence lowland basin

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Natural gas is currently the third-largest global energy source and its consumption is expected to increase substantially in the coming decades. Investment in natural gas continues to grow due to its availability and versatility, and because it is a cleaner energy source compared to coal and crude oil.

The proportion of unconventional gas in total global gas production is projected to rise in the coming years. However, these projections are subject to significant uncertainty, particularly in regions where unconventional gas production is yet to occur or is in its infancy. Environmental concerns might also limit unconventional gas output. Under these conditions, future production is heavily dependent on response to environmental challenges and public acceptance.

Shale gas represents almost half of the unconventional gas potential. One of the key technologies applied in shale gas exploration is known as hydraulic fracturing which involves pumping a mixture of water, sand and chemical additives at very high pressure into the target shale formation, creating small fractures through which gas can flow. To protect and isolate potable groundwater from hydraulic fracturing fluids in the wellbore, wells are generally lined with steel casing and cemented between the casing and formation, from the bottom of the wellbore to the surface. Abandoned wells are also sealed internally with cement.

Despite these precautions, important risks of groundwater contamination have been identified from leakage of methane, brine and hydraulic fracturing fluids, if wells are not properly cased and cemented. Moreover, it is generally admitted that the presence of cross-connections between nearby abandoned wells or boreholes and preferential pathways through the bulk media (either natural or fracking-induced) can also stimulate the transport of gas and contaminants from the fractured shale to shallow aquifers.

To understand the role of these issues on the migration of gas and contaminants, a conceptual model of a shale gas extraction well has been developed based on the predicted extraction scenarios for the St-Lawrence Lowlands, and using local geological and fluid properties. A parametric study was then conducted with a numerical model for each of these scenarios, assuming isothermal two-phase two-component flow. The model is not calibrated, but the simulations are used to identify the possible range of leakage rates and the time and space scales for gas and contaminant migration along the casing of an abandoned well using a range of realistic geological and hydrogeological data from the St-Lawrence Lowlands. **(*SS16, Wed. 8:40*)**

Using *in situ* isotope and trace element compositions to investigate the origin of rapakivi feldspar from the Deer Isle granite complex, coastal Maine

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Rapakivi feldspar is characterized by the mantling of alkali feldspar cores by plagioclase rims. The two most accepted hypotheses for the formation of rapakivi feldspar are 1) magma mixing of two different compositions, and 2) decompression of a magma with little change in temperature. The 371 Ma Deer Isle granite complex, coastal Maine, contains rapakivi feldspars that are generally tabular and up to 2 cm in size. They are typified by cores of perthitic alkali feldspar with local plagioclase inclusions; or boxy-cellular plagioclase reentrants, occasional Ba-rich oscillatory zones that precede plagioclase mantles, and a few show evidence of resorption of the alkali feldspar prior to mantling by plagioclase. The plagioclase mantles are as much as 4 mm thick and have minor alteration to sericite. *In situ* Pb and Sr isotopic analysis by LA-MC-ICPMS was performed on both alkali feldspar cores and plagioclase rims, and trace element analysis by LA-ICP-MS was performed on plagioclase inclusions within the alkali feldspar cores, and plagioclase mantles. Two distinct populations of both $^{207}Pb/^{206}Pb$ and $^{208}Pb/^{206}Pb$ correspond to the plagioclase mantles and the alkali feldspar cores. Ranges of $^{207}Pb/^{206}Pb$ for plagioclase mantles and alkali feldspar cores were from 0.842-0.853 and 0.849-0.855 respectively. Ranges for $^{208}Pb/^{206}Pb$ for plagioclase mantles and alkali feldspar cores were from 2.057-2.093 and 2.069-2.101 respectively. No Sr isotopic difference is apparent between the cores and mantles, with both ranging from 0.704-0.706. Trace element data also shows two growth events during mantling of alkali feldspar cores. Early grown plagioclase mantles have lower Sr and Ba concentrations whereas the outer parts of the mantles have higher Sr and Ba. These inner zones are also depleted in Eu and enriched in Pb, compared to the outer mantle zones. Our data are consistent with the hypothesis that plagioclase mantles on alkali feldspar crystallized following a magma mixing event. **(*SS5, Wed. 4:00*)**

Profile of the Manicouagan Impact Melt Sheet, Quebec – Geochemical, mineralogical and isotope analysis

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The 214 Ma impact crater site at Manicouagan, Quebec (51° 23° N, 68° 42° W) is a complex impact structure (D=90 km), formed within predominantly crystalline metamorphic and igneous rocks of the Grenville Province of the Canadian Shield. Impact melt occurs in sub horizontal sheets covering much of the crater floor, and as dikes in the central region, associated with the anorthositic central peak. Recent work has shown that the melt sheet is both thicker and more complex than previously suspected, confirming a (local) depth of c.1400 metres (including basal, clast-rich impact melt) and evidence for differentiation.

On the basis of whole-rock geochemistry (major, trace and rare earth element) and mineralogy, the melt sheet is divided into undifferentiated Impact Melt Sheet (U-IMS) and differentiated Impact Melt Sheet (D-IMS). The homogeneous U-IMS (average ~300 m thick) has a composition of quartz monzodiorite, shows little compositional variation with respect to depth, and comprises the largest volume of the melt sheet. The heterogeneous D-IMS (~1100 clast-free to clast-poor melt) is subdivided into three units on the basis of its chemistry and mineralogy:

1. Upper layer (UZ) – quartz monzodiorite (*c.* 250 metres c).
2. Middle layer (MZ) – quartz monzonite (*c.* 250 metres).
3. Lower layer (LZ) – quartz monzodiorite to monzodiorite (*c.* 600 metres).

Nd-Sm and Rb-Sr analysis of the impact melt and target rocks reveal that the impact melt, though locally differentiated via fractional crystallization, was isotopically homogenized during its formation following its derivation primarily from mafic and intermediate gneisses of the Paleoproterozoic Manicouagan Imbricate Zone. Pb-Pb analysis indicates Pb mobilization, confirming the presence of a hydrothermal alteration system. Limited assimilation of the footwall in the U-IMS is attributed to the relatively rapid cooling of the thinner melt body (typically <300 m), primarily through contact with cooler footwall and clasts. The thicker D-IMS impact melt (up to 1.4 km thick, near the centre of the structure) retained sufficient residual heat to consume clasts and footwall of centrally uplifted anorthosite, which locally modified the Rb- Sr isotopic signature.

It is suggested that the thicker sections of melted material within the D-IMS facilitated differentiation, not seen in the shallower parts of the melt sheet (U-IMS). Manicouagan is only the second impact crater known to exhibit unequivocal differentiation (after Sudbury). Significantly, its smaller size relative to Sudbury indicates that differentiation can occur at much smaller diameters than previously recognized. **(*SS21, Thurs. 2:20*)**

Regulatory geosciences in an ever-changing world

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The oil and gas industry in the Newfoundland and Labrador offshore area has been growing and expanding in deeper and challenging environments over the last few years. An example of this is the 2013 Statoil announcement of a discovery at Bay du Nord in the Flemish Cap area of the Grand Banks.

Each phase of oil and gas development has its own demands and challenges and tests the regulatory regime legislated by governments and administered by the Canada Newfoundland and Labrador Offshore Petroleum Board (C-NLOPB).

As a regulator, the C-NLOPB represents the public interest in the stewardship of petroleum resources and strives to provide a stable, efficient and impartial regulatory regime for operators who invest in the development of these resources. The Resource Management department of the C-NLOPB is tasked with those objectives while the industry continues to grow and expand.

Geosciences are an integral part of the Resource Management department, especially its staff. Because of the nature of the department activities, generally, staff must be familiar with several technical areas in the geosciences and engineering fields. This involves very extensive and continued training. In addition, staff must understand the legislation and its implementation.

This has been a challenge for the department over the years with changing demographics, technologies and budgets. New frontiers such as deepwater drilling, new plays such as unconventional resources and new technologies such as 4D seismic provide geoscientists at the C-NLOPB with new opportunities.

The changing environment has required the C-NLOPB to change its human resources strategy, workplace environment and thinking when it comes to training and information technology for geoscientists. More focus has been on the individual geologist and what their technical and career needs. Integration of resources between departments at the C-NLOPB has been a key element in ensuring talents and opportunities are maximized. Also, the use of consultants for mentoring has been a factor in a lower turnover rate in the past few years, as compared to other government or regulatory agencies.

The Reservoir Management department's vision is to be a leader in resource management issues in Canada's offshore area and to be recognized by other regulatory agencies, governments, industry and the public for its technical competence, efficiency, fairness and leadership. This is a challenge for us but one that is expected by all involved. **(*SS4, Thurs. 2:20*)**

Volcanogenic massive sulphide deposits in the Archean Slave craton: Where, when, why, and are there more?

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There are over 20 volcanic belts in the Slave craton and many host, or have hallmark indicators suggesting that they could host volcanogenic massive sulphide (VMS) base-metal deposits and prospects. Active exploration and assessment is currently focused on only four deposits: High Lake, Hackett River, Hood, and IZOK Lake. These are all in Nunavut and a comparison of known deposits indicates that the Nunavut side of the craton contains 6.5× more tonnes of VMS than the Northwest Territories side. However, detailed geological compilations support the conclusion that VMS prospectivity disregards political boundaries and that the tonnage discrepancy is likely a result of historical exploration targeting. This single observation indicates that the volcanic belts in the NWT require further evaluation for their VMS deposit potential. To facilitate this and to compare known deposits with prospective environments, we have undertaken CA-ID-TIMS U-Pb zircon dating on VMS hosting, prospective, and barren rhyolites across the southern part of the craton. The new ages allow more precise belt-to-belt stratigraphic correlations and provide a refined temporal evolution of VMS mineralization. For example, we can now clearly and confidently resolve multi-VMS formation times at >2740 Ma, 2700 Ma, 2680 Ma, and 2667 Ma. While the oldest is rare, the latter three VMS time frames occur simultaneously in various locations across the Slave craton.

Whole rock geochemistry and radiogenic isotopes ($Nd_{whole\text{-}rock}$, Hf_{zircon}) from these same deposits and prospective volcanic belts test the geodynamic environment of volcanism and mineralization, and reveal the role that Mesoarchean and older crust may have played in these processes. Rhyolites that host Slave VMS deposits have elevated LREE and flat HREE profiles and Zr-Y systematics consistent with an FII signature, using Superior craton nomenclature. While the Superior VMS deposits are predominantly hosted by FIII rhyolites, the FII signature of Slave VMS deposits is in line with many other continental crust-associated VMS environments, globally and through time, that occur in rifted environments. Significantly, within the Slave craton, the FII rhyolites are consistent from deposit to deposit, regardless of age. This signature has also been picked up in prospective VMS environments that remain underexplored. The host-rock geochemical attributes point to the right geodynamic setting and ore-associated petrological processes, suggesting potentially prospective environments for VMS mineralization, and are a key to future mineral exploration for VMS in the Slave craton. **(*SS14, Fri. 10:40*)**

Impact metamorphism of carbonates at the Haughton impact structure, Canadian High Arctic

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Limestone and dolomite is present in the target sequence of ~30 % of the world's known impact structures. Despite the significance of such carbonate rock types within terrestrial impact structures, the response of such lithologies to hypervelocity impact remains debated. Indeed, despite the recognition of carbonate melt phases in several impact craters (Chicxulub, Haughton, Meteor Crater, Ries, Steinheim, Tenoumer), a recent review on the Ries impact structure, Germany, chose to dismiss this large body of previous peer-reviewed literature and, based on no provided data, suggest that the volume of carbonate melt "is subordinate and cannot be derived from shock-molten Malmian limestone".

This work revisits the fate of carbonates at the 23 km diameter, ~23 Myr. old Haughton impact structure located on Devon Island in the Canadian High Arctic. The target rocks at Haughton impact structure are mainly shelf-type carbonates of Lower Paleozoic age. This impact structure possesses a series of impactites (impact-produced rocks) that are well preserved and well exposed in the present-day polar desert environment of Devon Island. Previous work at Haughton has focused on carbonates within the groundmass of these impactites. Here, variably shocked clasts of carbonate lithologies from the crater-fill impact melt rocks have been studied using optical and analytical scanning electron microscopy (SEM). These clasts have been split into 6 classes based on increasing shock state. Quartz and feldspar in the samples are used to provide a qualitative guide to shock level with the recognition that without shock experiments on similar lithologies, exact quantification of shock will not be possible. However, the results are clear in that a calcite melts at lower shock pressures than feldspar and quartz. The most surprising outcome of this study is that dolomite is more stable than feldspar and quartz. For example, in some samples (class 4 in this study) feldspar and quartz are completely transformed into diaplectic glass; whereas dolomite shows only minor evidence for shock. Overall, this work lends support to the previous observations that the dominant response of limestone and dolomite to impact is melting and not decomposition. **(*SS21, Thurs. 3:40*)**

New insights on the geological setting of the world-class Musselwhite gold deposit, Superior Province, northwestern Ontario

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The Musselwhite mine is a world-class syn-deformation gold deposit hosted by amphibolite facies Algoma-type banded iron formation (BIF) and comprised in the Mesoarchean North Caribou Lake greenstone belt, Superior Province. The deposit is located 2km west of a major fault zone that defines the tectonic boundary with the *ca.* 2857 Ma Schade Lake gneissic complex of the Island Lake Domain.

Detailed surface mapping provides new data on D_1 and D_2 structures and their influences on the regional and deposit scales setting of the gold mineralisation. Multiple occurrences of decimeter to meter scale refolded F_1 folds, along with S_0 and S_1 geometries, indicate the presence of megascopic F_1 folds. Reappraisal of stratigraphic relationships supported by ongoing U-Pb geochronological results indicates that the mine stratigraphy is overturned. These datasets suggest the mine is located along the overturned limb of an early map-scale F_1 syncline, which axis lies to the South of Opapimiskan Lake. F_1 folds, evidence of which are strongly overprinted by D_2 in the immediate mine area, influence the distribution and geometry of the BIF units hosting the bulk of gold mineralisation and could generate new regional exploration target areas.

The bulk of the ore is hosted by the Northern BIF and occurs as stratabound pyrrhotite-rich replacements and associated silica flooding of the silicate BIF with local discordant syntectonic grey quartz±pyrrhotite veins. The ore zones are associated with D_2-related to high strain zones concentrated along hinges (T Antiform and PQ Deeps) and strongly attenuated fold limbs (*e.g.* Lynx Zone) of shallow northwest-plunging F_2 folds. The layered anisotropy induced by competent BIF horizons embedded in strongly deformed and less competent mafic and ultramafic volcanic rocks strongly influenced rheological response to deformation, both at macro and microscopic scales, and hence played an important role in gold-bearing fluids flow and ore formation and distribution.

Volcanic rocks proximal to the ore zones display a strong biotite alteration. Preliminary petrographic observations of the ore, such as iron carbonate content, Ca-bearing amphiboles and locally hedenbergite suggest calcium-rich alteration. Initial geochemistry results indicate traces elements such as Cu, Se, Te, Zn ±As are associated with gold. Typically, the high-grade ore zones display metasomatic/metamorphic layering with ~50% coarse red almandine garnet porphyroblasts, intergrown with fine to medium grained, bladed grunerite-cummingtonite (5-10%) and red brown biotite (&le10%) aligned sub-parallel to the S_2 foliation. Such mineral assemblages can be found regionally as well as closely associated with gold mineralisation so that its characterization is most probably instrumental in uncovering the hydrothermal footprint of the deposit. **(*SY5, Thurs. 8:40*)**

Model testing for mapping permafrost using Landsat-5 TM and RADARSAT-2 images

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Soil temperature (T_s) regime is an important factor influencing northern ecosystem carbon and water cycles. Permafrost, ground that remain frozen for greater than two years, is also regulated by T_s and is currently subject to increased deterioration and accelerated thaw due to global warming. The paper presents a study that uses a process-based model, the *CCRS Northern Ecosystem Soil Temperature (NEST)* model, to model soil temperature regimes and related active layer (depth to permafrost) thicknesses from climate, soil and vegetation data. The model has been applied to data acquired over a wetland area surrounding Victor Mine in northern Ontario having discontinuous organic permafrost. Daily climate data for the 1979 to 2010 period were extracted from the grid climate data sets of the Canadian Forest Service and of the *National Center for Environmental Prediction (NCEP)*. The surficial material and land cover maps were derived by applying the *Random Forest* supervised classifier to a combination of RADARSAT-2 and LANDSAT images. The surficial material map was used to derive surficial material-related NEST variables, *e.g.*, mineral soil texture, fraction of organic material, and fraction of gravel. Leaf area index (LAI) was derived from LANDSAT imagery for each land cover type. We found good correlations between estimated and observed soil temperatures. The study is funded by a *Canadian Space Agency* grant. The *Canadian Space Agency* provided the RADARSAT-2 images, whereas the Ontario Ministry of Natural Resources and Ministry of Environment provided field observations. **(*SS11, Fri. 9:40*)**

A hydrothermal system within the central uplift of the Manicouagan impact structure

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Impact events on water-bearing planets, such as Earth and early Mars, can produce hydrothermal circulation systems due to the imposition of various thermal gradients. The 90 km-diameter, 214±1 Manicougan impact structure, provides excellent examples of impact-induced hydrothermal alteration arising from three heat sources: (1) residual heat from exhuming previously buried central uplift material; (2) waste shock heat, and (2) superheated impact melt. Manicouagan is one of the best preserved complex impact structures on Earth, located in Quebec, within the Grenville province of the Canadian Shield. Field-based observations, drill core, and laboratory studies reveal evidence of hydrothermal alteration present at different regions within the structure. In the central uplift, heat due to exhumation of previously buried anorthositic rocks, as well as waste shock heat, has combined to generate hydrothermal alteration effects. Within the anorthosites, albite-epidote facies assemblages are developed as the higher temperature alteration products of plagioclase and amphibole. Thomsonite and natrolite are predominant. Thomsonite overprints albite and labradorite grains within pervasive vein systems, and replaces material within anatomising shock veins and associated fractures. Natrolite occurs as vug and fracture fillings, commonly in close proximity to thomsonite veins. The formation of thomsonite and natrolite suggest that large volumes of water were introduced to central uplift lithologies toward the end of the hydrothermal alteration phase, and that Na^+ and Ca^{2+} were dominant cations in solution, rather than K^+. This probably reflects the breakdown of anorthosite and a plagioclase–dominated protolith. Retrogressive alteration within the central uplift can be classified as: (1) relatively high-T labradorite-hornblende alteration resulting in albite-epidote mineralization, and (2) relatively low-T labradorite-albite alteration forming thomsonite-natrolite. In addition, this study reveals that shock veins generated within the central uplift have been susceptible to water infiltration and associated hydrothermal retrogression, largely as a result of shock-induced fracturing facilitating enhanced permeability. As such, the mineral parageneses of shock veins need to be carefully characterized in terms of distinguishing prograde and retrograde effects. **(*SS21, Thurs. 9:40*)**

Organic-walled microfossils from the Ediacaran-Cambrian Global Boundary Stratotype Section, Chapel Island and Random formations, Newfoundland, Canada

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Data for organic-walled microfossils from coastal sections of the Chapel Island and Random formations on the Burin Peninsula, southeastern Newfoundland, add substantial detail to the limited previous information in this region concerning the distribution of these biostratigraphically important fossils for the Ediacaran-Cambrian transition and the early Cambrian. Filamentous sheaths and leoisphaerids occur throughout the examined interval of the Chapel Island and Random formations, as do the polyhedral *Octoedryxium*. This assemblage dominates the Ediacaran-Cambrian transition interval of upper member 1 to lower member 2A of the Chapel Island Formation. Also present are probable *Cochleatina* and several problematic forms of uncertain identification, including a single specimen of an acritarch with rigid processes. The first specimens of *Granomarginata prima* approximate the base of the *Rusophycus avalonensis*

Zone in member 2A. The first abundant and diverse process-bearing acritarchs were encountered in the mid-portion of the Random Formation, with *Asteridium tornatum*, *A. lanatum*, and *Comasphaeridium agglutinatum*. A more diverse assemblage of acritarchs appears near the top of the Random Formation, with *Fimbriaglomerella membranacea*, *Skiagia ornata*, *S. orbicularis*, *Comasphaeridium mollicum*, and *C. brachyspinosum*.

The association from near the top of the Random Formation indicates the *Skiagia-Fimbriaglomerella* Zone of Baltica, which has been taken to approximate, or somewhat precede, the first global appearance of trilobites. Acritarchs from the mid-portion of the Random Formation indicate the *Asteridium-Comasphaeridium* Zone, which on Baltica has been suggested to have a first appearance that approximates the base of the Cambrian. In the present study *Granomarginata*, which has generally been considered elsewhere to first appear in the Cambrian, have a first appearance much closer to the base Cambrian GSSP than do *Asteridium* or *Comasphaeridium*. One solution would be to include *Granomarginata* as a taxon indicative of the *Asteridium-Comasphaeridium* Zone, as has been previously suggested. Alternatively, the early appearance of *Granomarginata* may suggest either a new basal-most Cambrian zone, or a new sub-zone of the *Asteridium-Comasphaeridium* Zone. Support for this interpretation comes from northern Norway where basal-most Cambrian rocks yield *Granomarginata* but no *Asteridium* or *Comasphaeridium*. This study shows that, in Newfoundland, the first appearance of *Watsonella crosbyi*, a candidate fossil for the base of Cambrian Stage 2, is within the range of *Granomarginata*, but below the first appearances of *Asteridium* and *Comasphaeridium*.

Comparison with acritarch stratigraphy in southern New Brunswick suggests that the generally accepted age correlation between the prominently quartz-arenitic Random and Glen Falls formations may be inaccurate. **(*SY1, Poster*)**

Gold mineralization in the Cantung W-skarn deposit, Northwest Territories: An examination of distribution, mineralogy, and petrogenesis

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The Cantung mine is a world-class W-skarn deposit; it is located just east of the Yukon border in the Selwyn Mountain Range of the Northwest Territories. The deposit area is within the southern extent of the polymetallic Tintina Gold Belt, which has many notable intrusion-related Au deposits. The extensive W skarns at Cantung were developed by hydrothermal fluids that, based on earlier research, were determined to be predominately supercritical magmatic brines with homogenization temperatures ranging from 270-500°C. Mineralization is composed of calcic exoskarn replacement of a clean limestone and lower grade replacements in a calc-silicate/chert unit; these occur in both the operating open pit and underground mine (the E Zone). The main sulphide identified petrographically is pyrrhotite, which is abundant in all skarn facies. Scheelite and chalcopyrite are dominant and there is locally abundant sphalerite. Native Bi exhibits textures indicative of forming later than the silicate assemblage in the paragenetic sequence, and it is decorated by bismuthinite, Bi tellurides, Ag tellurides, and Bi selenides. Tungsten and Cu are the main mine products, but the Au potential of the deposit merits further investigation.

This study characterized the distribution, mineralogy, and petrogenesis of Au mineralization by examining five skarn samples with bulk rock Au assay values >0.5 ppm taken from the E Zone. No free gold or electrum were identified petrographically or by SEM and FEG-SEM analyses. A positive correlation (Spearman's Rank, r') of Au with Bi (0.76), Ag (0.70), Fe (0.64), Cu (0.64), and Mo (0.60) was identified using the bulk rock geochemical data (n = 48). The strong correlation between Bi and Au is suggestive of a liquid bismuth collector mechanism for Au enrichment. However, LA ICP-MS analysis of native Bi and Bi alloys failed to reveal significant Au predicted by the liquid bismuth collector model. In contrast, the highest Au concentration was encountered in hessite (Ag_2Te) and other tellurides. Nano-inclusions within chalcopyrite and silicate minerals were also investigated using FEG-SEM for their Au content, but their composition consisted of native Bi. The decoration of native Bi by bismuthinite, Bi tellurides, Ag tellurides, and Bi selenides provides evidence for a late stage S-, Ag-, and Te-rich fluid. This fluid is thought to have remobilized the Au and deposited it as lattice bound invisible Au within the tellurides. This new data constrains Au exploration targets at Cantung to areas of altered skarn or where there is a presence of telluride minerals. **(*SS3, Wed. 3:40*)**

Kinematic links between the Rocky Mountains fold-and-thrust belt and the Omineca belt; insight from structural data and $^{40}Ar/^{39}Ar$ dating along the northern segment of the Southern Rocky Mountain Trench

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A new set of muscovite, biotite, feldspar, and whole rock $^{40}Ar/^{39}Ar$ ages have been obtained from the western margin of the Rocky Mountains fold-and-thrust belt (RM-FTB). Samples from phyllite and phyllonite with conspicuous subhorizontal stretching lineation and steeply dipping foliation were collected along the northern 200 km segment of the southern Rocky Mountain Trench, from the Walker Creek fault zone, and from the Valemount strain zone. Nine $^{40}Ar/^{39}Ar$ ages from the Trench indicate two Early Cretaceous (*ca.* 135 and 125 Ma), one mid-Cretaceous (111-96 Ma), and two Late Cretaceous (85 Ma and 74-72 Ma) peaks of transpressional tectonism. Four samples from the Walker Creek fault zone revealed the same pulses of strike-slip displacement, with the exception of the Campanian pulse. In contrast, four samples from the Valemount strain zone yielded exclusively late Campanian-earliest Maastrichtian ages (*ca.* 73-71 Ma). The Monarch and Moose Pass thrusts in the adjacent RM-FTB yielded less well constrained $^{40}Ar/^{39}Ar$ ages of 131 Ma (whole rock) and 135 Ma (muscovite), respectively.

The new structural and geochronological data from the three merging strike- and oblique-slip shear/fault zones indicate protracted, apparently distinct, orogen-parallel Cretaceous tectonic pulses along an anastomosing network of heterochronous strain concentration lineaments at the western margin of the RM-FTB. The *ca.* 135 Ma Early Cretaceous tectonism recognized in the southern Rocky Mountain Trench and the Walker Creek fault zone is recorded, albeit insufficiently constrained yet, by the Monarch and Moose Pass thrusts in the RM-FTB. The mid-Cretaceous strike-slip displacement along the same shear/fault zones is contemporaneous with the Greenock and Broadview thrusts identified at the same latitude in the RM-FTB. The late Campanian-early Maastrichtian oblique compression (75-71 Ma) recorded by phyllonite, both in the southern Rocky Mountain Trench and in the Valemount strain zone, is contemporaneous with the emplacement of major thrusts (*e.g.*, Rocky Pass, Sulphur Mountain, Rundle, Lewis) in the RM-FTB. The Cretaceous ages of phyllite and phyllonite documented in this study are also consistent with previously reported ages of tectonic and/or metamorphic and igneous events in a zone, tens of kilometres wide, along the eastern margin of the Omineca belt, bound by the southern Rocky Mountain Trench. This wide linear zone of Cretaceous strain and metamorphism, which includes the network of dextral orogen-parallel shear/fault zones in the examined portion of the southern Rocky Mountain Trench forms the complex kinematic link between Cretaceous oblique compression in the hinterland and major thrusting in the foreland. **(*SY3, Fri. 9:00*)**

Age constraints on the Hoidas Lake REE mineralization, northern Saskatchewan, Canada, using U-Pb laser ablation ICP-MS geochronology

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The mineralized veins of the Hoidas Lake REE deposit (Saskatchewan, Canada) are localized along the Hoidas-Nisikkatch Fault, a splay off the regional Black Bay Fault System. The mineralized veins cross-cut the highly deformed rocks of the southern Rae Province that reached peak metamorphic conditions at *ca.* 1.9 Ga. The mineralization consists of diopside-allanite-(Ce)-hyalophane veins that also contain titanite, biotite, hornblende, apatite and zircon, and later fluorapatite breccia veins, which include, from oldest to youngest, a red apatite phase, green apatite and a coarse red apatite phase. Hydrothermal alteration of the mineralized veins resulted in chlorite and hematite alteration, and precipitation of REE-carbonates and monazite. Late quartz-carbonate veins cross-cut the mineralization, and some of these contain euhedral oscillatory zoned allanite crystals.

Petrographic and electron microprobe analyses were followed by laser-ablation ICP-MS U-Pb geochronology of zircon and titanite crystals from the diopside-allanite veins, and green apatite crystals and monazite of the apatite breicca veins, in order to constrain the age of REE-enriched phases and the duration of the mineralizing system.

The titanite crystals of the diopside-allanite veins show evidence for recent Pb loss, but a subset of the data yield concordant ^{204}Pb-corrected U-Pb ages from 1920 to 1830 Ma. Apatite crystals from the green apatite breccia yield ^{204}Pb-corrected U-Pb values that define a discordant trend intersecting with concordia at *ca.* 1.82 Ga. The concordant monazite analyses from the red apatite breccia cluster at 1909 ± 11 Ma and 1841 ± 5 Ma. Zircon crystals from the early mineralized veins yield two dominant clusters of concordant ages at 2348 ± 19 Ma and 1906 ± 34 Ma. The older ages suggest that the zircons are inherited and probably crystallized during the Arrowsmith Orogeny, which is known to have affected the rocks in this area. The younger ages are interpreted to indicate recrystallization of the zircons during peak metamorphism and/or the emplacement of the REE mineralization.

The Hoidas Lake REE veins, that formed from a pegmatitic melt related to a carbonatitic magma source and then interacted with carbonic and aqueous hydrothermal fluids, yield ages ranging from *ca.* 1.92, broadly the age of peak metamorphism in the area, to as young as 1.82 Ga, the age of alkali basalts in the Uranium City area to the south. The deeply-rooted Black Bay Fault and splays are the long-lived conduits which allowed transportation of the mantle-derived melts/fluids responsible for REE mineralization. **(*SS23, Fri. 3:20*)**

Glacial stratigraphic, till geochemical, and indicator mineral studies at the Sisson W-Mo and Mount Pleasant Sn-W-Mo-Bi-In polymetallic deposits, southwestern New Brunswick

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During the Geological Survey of Canada's (GSC) Targeted Geoscience Initiative (TGI-4; 2010-2015), GSC and the New Brunswick Department of Energy and Mines (NBDEM) conducted indicator mineral case studies around the Sisson W-Mo and the Mount Pleasant Sn-W-Mo-Bi-In polymetallic deposits in New Brunswick. The objective is to document glacial dispersal patterns of W, Mo, Sn, and In-bearing indicator minerals and matrix geochemical signatures in till at varying distances down-ice of the deposits, in support of exploration in New Brunswick and other glaciated terrains. This is the first study to document glacial dispersal of W-bearing minerals around a significant W deposit.

At Sisson, 3 tills are present: Illinoian Northumberland till, Early-Middle Wisconsinan Caledonia till, and the geochemically barren, Younger Dryas, Collins Pond till. This presented sampling challenges as the tills are deposited by ice flows from different source areas and are geochemically distinct but not easy to distinguish. At Sisson, 79 bulk till samples were collected up-ice, overlying, and up to 14 km down-ice (SE) of the deposit. The distribution of sample sites was guided by previous sampling by Kidd Creek Mines and the NBDEM. Stream water, silt, and bulk samples were collected at 16 sites at Sisson to characterize scheelite abundance, size, and shape for comparison with grains in the till. At the Adex-owned Mount Pleasant deposit, 22 bulk till samples were collected. Here, sampling was guided by previous work conducted by N. Szabo (University of New Brunswick) and the NBDEM.

Till sampling was optimized by first collecting 200 g till samples (61 at Sisson and 50 at Mount Pleasant) and determination of W, Mo, Sn, Bi, Sn, and Cu concentrations, using a portable XRF (pXRF) spectrometer. At Sisson, anomalous pXRF concentrations match previously known NBDEM anomalies in the glacial dispersal train extending 14 km to the SE, and correlate well with subsequent borate fusion and aqua regia/ICP-MS analyses of the <0.063 mm fraction of till (up to 815 ppm W, 65 ppm Mo, and 978 ppm Cu). Till, stream, and a suite of bedrock samples have been processed to produce heavy mineral concentrates for assessment of indicator minerals and to characterize the indicator mineral signature of each deposit. Scheelite is abundant in both deposits, and a significant indicator mineral in till down-ice. Other indicator minerals of the Sisson deposit include molybdenite, chalcopyrite, wolframite, Bi minerals, sphalerite, and galena. Cassiterite, topaz, beudantite, anglesite, and wolframite are indicators of the Mount Pleasant deposit. **(*SS3, Wed. 8:40*)**

Revised age and correlation of the Paleoproterozoic Penrhyn and Piling groups of Arctic Canada

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Paleoproterozoic metasedimentary successions on the Western Churchill Province are useful archives of the history of regional tectonic events during the Trans-Hudson orogen. The Penrhyn and Piling groups of Melville Peninsula and Baffin Island, respectively, record deposition on the Rae craton in the northeastern part of the Trans-Hudson orogen. The age, regional correlation, and basin histories of the Penrhyn and Piling groups have been poorly resolved in the past due to a lack of appropriate geochronological and stratigraphic data. New U-Pb age and stratigraphic data demonstrate that the Penrhyn and Piling groups are not correlative based on traditional lithostratigraphy. Instead, the data suggest that the Penrhyn basin was initiated much later than the Piling basin, and that deposition in the <1.9 Ga Penrhyn basin is temporally related to only the uppermost Piling Group. The new U-Pb age data from detrital zircon, combined with existing metamorphic monazite age data, demonstrate that the Penrhyn Group was deposited in a short time interval between ~1897 Ma and ~1877 Ga.

The Piling foreland basin was closed via collision of the Rae craton with the Meta Incognita microcontinent by ~1.88 Ga, but there continues to be debate about whether the Rae craton was the upper or lower plate in this continent-continent collision. Basin analysis of the Piling Group can provide an additional constraint on the polarity of collision, by considering the Piling Group as either a pro-foreland (lower plate) or retro-foreland (upper plate) basin. The stratigraphy and inferred subsidence history of the Piling basin shows characteristics most consistent with a pro-foreland basin, implying that the Rae craton was the lower plate in the collision with the Meta Incognita microcontinent. **(*SY7, Fri. 9:40*)**

Outcropedia.org – An open access online database of geological outcrops of the world

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Outcropedia is a public online database of geologic outcrops of the world. The project is hosted under the domain outcropedia.org and includes an integrated global map that allows users to upload outcrops either directly on the map or by using the outcrop's coordinates. Along with the outcrop photo the user can add a short description and references (if necessary) relating to the submitted geologic site. Outcrops appear on the global map by location although the database is also searchable by the use of keywords (*e.g.*, types of structure). The Outcropedia project started as the initiative of a small group of structural field geologists lead by Dr. C. W. Passchier and is sponsored by the Commission on Tectonics and Structural Geology (TecTask) of the International Union of Geological Sciences (IUGS).

Ultimately, Outcropedia is aiming to be a central database of diverse geologic outcrops from around the world. The two core objectives of a central outcrop database are to make outcrops in unfamiliar places known and raise awareness on the protection of global geoheritage sites. Outcropedia's ready and easy access serves both geologist and non-geologists as a teaching, research and outreach resource (*e.g.*, virtual fieldtrips, field work planning). In addition, scientifically unique, geo-historically important or just beautiful outcrops are regularly threatened by building activity, irresponsible geo-tourism, overzealous sampling, and other activities. Raising awareness within the geosciences community, as well as the general public will prevent the destruction of important geologic heritage monuments around the world.

Currently Outcropedia counts over 350 users and several hundreds of outcrops from all over the world. We would like to invite Canadian geoscientists to contribute and use this unlimited resource in order to document, protect as well as share the exceptionally rich geological heritage within Canada and globally. **(*SS15, Poster*)**

Modern petrological perspectives on a famous debate over the tectonic evolution of the Southwest Highlands of Scotland

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The Ballachulish area of the southwest Highlands of Scotland was the focal point of a famous debate in the 1920s between two of the giants of British geology: Sir Edward Battersby Bailey, a field geologist with of the Geological Survey of Great Britain, and Professor Cecil Edgar Tilley, a petrologist at the University of Cambridge. At issue were contrasting interpretations of the identity, geometry and timing of regional metamorphic zones in the southwest Highlands, and the fundamentally different interpretations of the tectonic evolution of the region that flowed from these. The point of contention in the Ballachulish area was the cause of the abrupt disappearance of garnet, in the direction of increasing metamorphic grade, across a major fault, the Ballachulish Slide. Bailey attributed the abrupt disappearance of garnet to differing bulk composition of rocks of the same metamorphic grade on either side of the slide, interpreting the slide to be pre-metamorphic, whereas Tilley and later his Cambridge colleague Gertrude Elles and he attributed the abrupt disappearance of garnet to mechanical juxtaposition of rocks of different metamorphic grade, implying that the slide was post-metamorphic. The kernel of the debate – grade versus bulk composition as the cause of differences in metamorphic mineral assemblages – is one of the timeless concerns of metamorphic petrology. New mineral assemblage data, microstructural observations and rock and mineral compositional data are combined with isochemical phase diagram modeling (Theriak-Domino) to re-assess the regional metamorphism in Ballachulish area, leading to a resolution of the debate. **(*SS19, Thurs. 8:20*)**

Carbon isotope stratigraphy of the Borden Basin (Nunavut): Implications for depositional age and correlation of carbonate strata in the Nanisivik District

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The Mesoproterozoic Borden Basin (Nunavut) contains four distinct carbonate formations deposited in contrasting but temporally equivalent depositional environments in a tectonically active basin at ~1.1 Ga. The Iqqittuq Formation (distally steepened carbonate ramp) was deposited at the same time as the Ikpiarjuk Formation (isolated deep-water carbonate mounds). The overlying Angmaat Formation (rimmed platform) was deposited at the same time as the Nanisivik Formation (deep-water dololaminite). Stable isotope ($\delta^{13}C$ and $\delta^{18}O$) profiles were prepared for each of these distinct units in order to compare this basin to other contemporaneous basins. The base of the Nanisivik and Iqqittuq Formation sections is characterised by light $\delta^{13}C$ values (~0‰), which are overlain by a rapid up-section increase in $\delta^{13}C$ to ~2.5‰. These basal values are interpreted to result from burial of organic carbon derived from deep anoxic water inherited from the underlying shale basin (Arctic Bay Formation) during transition to regional carbonate-dominated regional depositional systems. Above this basal interval, $\delta^{13}C$ values are relatively constant (Iqqittuq and Angmaat Formations), with slight deviations in $\delta^{13}C$ (±0.5‰) expressed coevally in different but coeval paleoenvironments; no significant geographic fractionation is evident. Iqqittuq and Angmaat Formation $\delta^{13}C$ values (~3.5‰) are in the expected range relative to global data at ~1.1 Ga, and probably precipitated from a near-surface marine water mass that was in isotopic equilibrium with the global ocean. Ikpiarjuk Formation (isolated carbonate mounds) $\delta^{13}C$ values are consistent through each mound (~1.9 ‰ to ~3.0 ‰), varying geographically by ~1.0‰; these rocks formed in bottom water of anoxic subaqueous fault basins that experienced limited mixing with surface waters, but have $\delta^{13}C$ values close to those of the time-equivalent Iqqittuq Formation. Deep water dololaminite of the Nanisivik Formation has $\delta^{13}C$ values that are consistently ~0.5 ‰ lower than equivalent strata of the temporally equivalent shallow-water Angmaat Formation, suggesting depth-related carbon isotopic zones in pelagic carbonate that formed in an anoxic lower water column. Carbon isotope values and excursions in the ranges reported from the shallow-water environments of the Borden Basin are known from other late Mesoproterozoic carbonate successions, but the lack of a reliable global compilation curve constrained by good geochronological data remains a hindrance to using $\delta^{13}C$ data for correlation or dating of the few known successions of this age. **(*SS13, Poster*)**

Long-lived, tight fit of Siberia and Laurentia in Proterozoic time

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Long-lived connections among Proterozoic cratons, if they can be demonstrated, form important keys to pre-Pangean supercontinent reconstructions. As an example, increasing paleomagnetic support of a connection between Laurentia and Baltica, between 1.8 and 1.2 Ga, allows those two cratons to be juxtaposed confidently within the Nuna supercontinent. Here we address various hypothesized Proterozoic connections between Laurentia and Siberia, which range from various tight geometric fits of differing relative orientations, mainly based on aligning tectonic provinces or sedimentary basins, to a more distal arrangement that was based primarily on 1.1-1.0 Ga paleomagnetic data from the Aldan region in southeast Siberia. We present three new paleomagnetic poles from 1.7-1.5 Ga unmetamorphosed clastic sedimentary rocks and mafic intrusions surrounding the Anabar Shield in northern Siberia, and compare those results to the Proterozoic apparent polar wander path (APWP) from Laurentia. We find that a tight connection between the southern margin of Siberia and the northern margin of Laurentia, which is favored by several Proterozoic tectonostratigraphic datasets, is compatible with our new results, as well as other paleomagnetic data from the interval 1.9-0.7 Ga. The earlier 1.1-1.0 Ga paleomagnetic poles are brought into line with the Laurentian APWP largely through restoration of Devonian rotations between the Anabar and Aldan regions, across the Vilyuy graben. We propose that Laurentia+Baltica+Siberia formed a large, internally stable component of the Nuna supercontinent, and that the Laurentia+Siberia connection persisted until mid-Neoproterozoic breakup of Rodinia. **(*SY7, Fri. 2:20*)**

Indium in cassiterite and ores of tin deposits

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Indium-rich VMS and tin deposits are recently the most investment attractive. Geochemical composition of In-rich mineral system may be represented as Fe-Sn-Cu-In-Zn-S±REEs. Tin deposits at Russian Far East, Northern Vietnam and Erzgebirge in Germany are characterized by different indium contents in the ores:

1) Sn deposits represented by cassiterite-quartz veins with accompanying greisen and linked with granites are characterized by In contents in the ore <10 ppm, up to 0.1 wt% In in sulfides and in cassiterite from 10-80 ppm by data of new analytical method using LA-ICP-MS for the less abundant ^{113}In isotope up to 200-700 ppm (XRF, etc.).
2) Sn-In deposits composed by cassiterite-sulfide veins (quartz-cassiterite-chalcopyrite-pyrrhotite-stannite-sphalerite-arsenopyrite with In minerals) and superimposed on earlier Mo-W mineralization (Tigrinoe, Pravourmiisky/Russian Far East; Mount Pleasant/Canada) are located at recent and former continental margins and linked with subalkaline to alkaline mafic magmatism coeval with granitoid chamber cooling in the crust. Indium contents in the ores vary from 20 to 500 ppm with an average of 50-70 ppm (Tigrinoe, Pravourmiisky deposits), in sulfides 0.1 to >6 wt% and 40-400 ppm in cassiterite (LA-ICP-MS data for ^{113}In isotope).

Indium content in sedimentary rocks is about 0.05 ppm, 0.02-0.07 ppm in granites, 0.05-0.15 ppm in gabbro, and the highest contents are found in alkaline mafic/basaltic rocks 0.05-0.3 ppm. Later low temperature (<200°C) Ag-Sb mineralization in the Sn-Ag ore districts contains only trace indium, main part of which had been deposited during the Sn-In cassiterite-sulfide polymetallic stage at the higher temperature (350-300°C).

Some VMS deposits are characterized by vein and massive cassiterite ore (“tin corridor”), “copper zone” (chalcopyrite, bornite, roquesite, fahlore, Ag-sulfosalts) and sphalerite ore, for example: Neves Corvo, Lagoa Salgala in Portugal, Kidd Creek, Brunswick 12 in Canada. Indium contents in these ores are about 50-300 ppm. Sn-In sulfide-rich and some VMS deposits may be considered as derivatives of the Sn-In-Ag ore-magmatic systems which were implemented at different geological environments and conditions. Kuroko type Miocene deposits in Japan with indium content up to 20 ppm are likely to be attributed to this group.

Geodynamic environments of the Sn-In sulfide-rich polymetallic mineralization forming:

1) bimodal magmatism (granitoid and alkaline mafic) in the back-arc sector (Malku Khota in Bolivia) and volcano-plutonic belts (Sikhote-Alin, Primorye/Russia) of active continental margins; bimodal magmatism (basalt-rhyolite) of ensialic arcs (Kudryavyi volcano, Kuriles);
2) bimodal postorogenic magmatism (granitoid and alkaline mafic) in the continental collision zones (Deputatsky, Kester/Yakutia, Russia; Freiberg/Erzgebirge, Germany). ***(GS5, Poster)***

Categorization of unconventional tight light oil play types of the Western Canada Sedimentary Basin

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North America has the last years witnessed a boom in light oil production, similar to the shale gas revolution, with multistage hydraulic fractured horizontal well technology unlocking hydrocarbons from low-permeability (tight) reservoirs. The low-permeability oil plays exhibit a wide variety of reservoir and flow characteristics, requiring different drilling and completion strategies to exploit them. The unconventional light oil reservoirs can be categorized into different play types based on reservoir/fluid properties and completion/stimulation styles analogous to that used for unconventional gas reservoirs:

1. "**Halo Oil**" – light oil plays where the matrix permeability is relatively high (> 0.1 md) compared to the other play type categories. The oil is commonly migrated from a source rock separated from the reservoir. Halo Oil plays represent portions of conventional light oil pools that do not meet traditional petrophysical cutoffs and pay criteria, and may be clastics or carbonates. E.g. Cardium, Viking, Dunvegan, Montney, etc.
2. "**Tight Oil**" – light oil plays where matrix permeability is low (< 0.1 md). Oil might be sourced from migrated oil or from source rock proximal to the reservoir. These plays are analogous to tight gas plays and may be clastics or carbonates. E.g. Bakken (Viewfield), Montney, Wilrich, etc.
3. "**Shale Oil**" – light oil plays where matrix permeability is very low, and organic matter content may be high with source rock being the same unit as the reservoir. These plays are analogous to shale gas plays. E.g. 2nd White Speckled Shale, Duvernay, Muskwa, etc.

Examples for all three light oil play categories will be presented from the Western Canada Sedimentary Basin focusing on geological, reservoir and production characteristics based on core, well logs and production data to infer the primary controls on production performance in each of the play types. The listed examples of tight oil reservoirs span a wide range of geological ages and depositional settings and thereby very different reservoir geometries and lateral extent. Note that the same stratigraphic unit might in different part of a basin fall into different play categories depending on depositional setting, burial, fluids and pressure, *etc.* The Unconventional Light Oil play classification scheme distinguishes light oil plays with very different properties and facilitates proper use of these as analogs for new light oil plays. **(*SS12, Fri. 2:20*)**

Keynote (40 min): Why was Rodinia underendowed?: Comparing the effects of paleogeography versus lithosphere thickness on secular ore deposit preservation

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An empirical observation from the geologic record of assembly of the supercontinent Rodinia, is that this period, spanning the Mesoproterozoic and early Neoproterozoic, is one of the least well endowed in mineral deposits. In conjunction, despite a general consensus that the supercontinent existed, unlike other well known entitites such as Pangea and Gondwana there is no associated peak in preserved juvenile magmatic rocks. At face value this underendowment is at odds with models that suggest peaks in contraction-related deposit formation, such as volcanic-hosted massive sulphides, Lode gold, Ni-Cu-PGE and Mississippi-valley type Pb-Zn.

One model suggests that the secular change in lithospheric thickness, towards thinner, more negatively buoyant, sub-continental lithosphere with time would result in a lack of preservation of many deposit types, due to enhanced uplift and rapid erosion. Superficially this concept is supported by the tendency of Rodinia welding orogens to be high grade. Examination of global deposit databases for volcanic- and sediment-hosted massive sulphide deposits reveals that fully 30% of the deposits are hosted in amphibolite to granulite terrains, irrespective of age and interpreted subjacent lithospheric thickness. Against this global average, Rodinia's high grade belts still are underendowed, hence an alternative explanation must be sought.

New models for the transition from assembly and breakup of the Paleoproterozoic supercontinent Nuna to Rodinia show a significant difference in their pattern and paleogeography of assembly. Nuna was an introverted supercontinent, assembling on recently rifted interior margins, whereas Rodinia extroverted, assembling on older exterior margins that predated Nuna's breakup. This has profoundly influenced the character of the bounding orogens and their metallogeny due to the age of oceanic lithosphere involved in collision. Introversion with its younger oceanic lithosphere, abundant pericratonic arcs and minimal subduction erosion allowed rapid obduction, trapping newly formed submarine VMS deposits before they could be consumed. Extroversion with its subduction of older oceanic lithosphere and often strong subduction erosion doomed Rodinia's VMS endowment. In addition, Nuna formed by sequential closure of a series of dominantly north-south oriented small ocean basins, littered with pericratonic arcs. In this environment the dual benefits of quick accretion and more restricted ocean circulation improved VMS preservation. A significant portion of Rodinia by contrast formed in a long-lived, more latitudinally disposed, peripheral orogen setting, wherein the open ocean circulation, antiquity of accreted arcs and strong subduction erosion inhibited VMS obduction and preservation. A similar difference in endowment of Lode gold deposits in interior versus peripheral orogenic settings is observed, suggesting that ultimately the paleogeography and style amalgamation plays a significant role in mineral deposit preservation. Experimentally running geologic history forward in time suggests that the future supercontinent Amasia is destined to be another Rodinia. **(*SY7, Fri. 10:20*)**

Geologic and structural controls on ore style and distribution in the Archean Rainy River Gold deposit, Wabigoon Subprovince, Ontario: Preliminary results

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The Rainy River gold project (measured and indicated resources of 177 Mt @ 1.09 g/t Au: 6.2 Moz) is located in the Archean Rainy River greenstone belt, part of the Wabigoon Subprovince in northwestern Ontario. Hosted mainly within felsic volcanic units, the deposit is set in a succession of variably altered basaltic to dacitic flows and associated volcaniclastic rocks. These volcanic products suggest a flow-dome-style volcanic center, with massive facies including aphanitic to strongly quartz±plagioclase-phyric flow-banded lobes, amygdular flows and flow-breccias, and volcaniclastic rocks consisting of fine-grained to lapilli-sized, largely monolithic fragmental units. Mineralization is correlated with well-developed sericite alteration best developed within felsic rocks. Local zones of chlorite-bearing alteration are preferentially developed within intermediate to mafic rocks. Additional alteration minerals noted locally include carbonates, epidote, garnet and biotite. The mineralized zones occur as a series of E-W orientated elongate bodies, moderately south dipping, and subparallel to the main foliation (109°/46°S). High-grade ore shoots are elongated parallel to a SW-plunging stretching lineation (47°/233°). The ore (Au-Ag) is directly associated with disseminated sulphides (pyrite, sphalerite, chalcopyrite±galena, arsenopyrite and pyrrhotite) and sulphide-rich veinlets. Gold correlates with copper and zinc at the deposit scale. Rare visible gold and electrum occur with disseminated sulphides and are also present in folded, transposed and boudinaged sulphide±quartz-calcite-tourmaline veinlets. An envelope of intense sericite alteration is preferentially developed in the felsic volcaniclastic rocks coincident with gold-silver mineralization and a prominent zinc anomaly. Silver and lead form a slightly enriched halo around the Au-Zn-Cu zones. Pyrite analyses (LA-ICP-MS) indicate an early (pre-deformation) enrichment in Au with subsequent remobilization during metamorphism (pyrite recrystallization). The presence of deformed, foliated, and neither altered nor mineralized dykes crosscutting some ore zones and their associated alteration halos, coupled with deformed gold bearing veinlets suggest a pre- deformation mineralizing event. These cross-cutting relationships plus the nature of the ore support the working hypothesis of an early, synvolcanic gold system, overprinted by regional deformation.

Detailed geological and structural mapping (drill core and surface), U-Pb zircon geochronology, lithogeochemistry, mineralogy, mineral chemistry, and isotopic mapping are the means taken to further define the deposit footprint, the effects of regional and local deformation on ore style and distribution. Although still hypothetical, the Rainy River deposit could represent a new type of economically viable Archean synvolcanic gold deposit. **(*SY5, Poster*)**

Morphology of gossans in the Canadian Arctic Islands

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Chemical and physical weathering of bedrock and surficial materials may produce secondary minerals that vector to buried ore deposits. For example, the classic gossan includes a sulphide-depleted and silica-enriched leach cap, underlain by the main gossan zone enriched in Fe-oxides, Fe-oxyhydroxides and other secondary minerals, overlying mineralized bedrock or surficial material containing primary sulphide minerals. Under certain conditions, some of these gossans react with permafrost and provide an analogue for mine wastes in the northern environment.

The Arctic Gossans Activity was supported by the Environmental Geoscience and Geo-Mapping for Energy and Minerals Programs between 2011 and 2014. Over the course of 2 field seasons on Victoria Island, NT, and Axel Heiberg Island, NU, several types of oxide-sulphide gossans were located and sampled. Remarkably, the morphology of these gossans is complex and in some cases, does not match the classic profile described above. The deposits are found within a variety of host rocks that include: volcanic successions, mafic sills, pyritic shale, evaporite diapirs and sulphide chimneys. In most cases, the gossans are associated with mafic intrusive rocks and local faulting. In other cases, there is no direct field evidence of an igneous protolith or nearby fault. In all cases, goethite, jarosite and gypsum predominate.

Remote sensing technology has enabled detection of these alteration zones and identification of their inherent mineralogy, at various scales. Ground truthing during mapping, combined with analysis of materials (surficial and at depth) using field portable instruments such as reflectance spectroradiometer, allows rapid and precise detection of key alteration minerals. Follow-up laboratory mineral analysis (XRD/SEM) enabled detailed characterization of these deposits. This presentation will explore the similarities and differences in gossan development in the two study areas. It will demonstrate the need to be systematic with respect to (1) detection (2) classification (3) sampling (4) mineralogy and geochemistry (5) and (6) integration with regional mapping. **(*SY4, Wed. 10:40*)**

Canadian Malartic geological footprint: Integration of airborne magnetic surveys, field observations, mineralogical and geochemical data of mafic intrusive rocks

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The Canadian Malartic gold mine is hosted mainly by metasedimentary rocks of the Pontiac Group, located on the south side of the Cadillac – Larder Lake fault system. On the north side, gold is also locally hosted in Piché Group mafic and ultramafic rocks. With a resource of over 14 Moz of gold (past production and current resources), this epigenetic world-class deposit should have a significant alteration halo, which is currently being investigated by the CMIC-NSERC Exploration Footprint project. Integration of multiple datasets (geological, mineralogical, geochemical, petrophysical, and geophysical) aims to characterize the footprint of the Malartic deposit and to identify exploration criteria that could be used in other areas of the Superior Province. Preliminary interpretation of new field data, including outcrop data, previous maps, and aeromagnetic surveys resulted in a revision of the MNRQ-SIGEOM map for the Pontiac metasediments in the Malartic area. The integrated data reveal the presence of multiple intrusions around Lac Fournière, which have distinct compositions, orientations, intensities of deformation, metamorphism, and alteration. In the Canadian Malartic mine area, highest gold grades (>1ppm) are associated with the nearby presence of intrusive rocks (monzodiorites) and major structures (the Sladen fault and the "Zone NW" fold hinge). Various generations of mafic dykes cross-cut the Pontiac meta-sediments and the monzodioritic rocks in the Malartic region. Some of them are cut by the felsic intrusions and they have been affected by multiple deformation and alteration events. Preliminary petrographic and geochemical investigations suggest that the mafic dykes, because of their more homogeneous (and mafic) composition than the Pontiac metasediments, may allow for a better discrimination of the various hydrothermal alteration events that affected the Malartic property. They appear to be a fundamental element in determining the relationships between mafic magmatism, deformation, hydrothermal alteration, and gold mineralization. *CMIC-NSERC Exploration Footprints Network Contribution 008.* **(*SY5, Wed. 3:00*)**

An overview of selected research on the genesis of, and exploration methodologies for volcanogenic massive sulfide deposits under the Targeted Geoscience Initiative 4 (TGI-4) Program

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TGI-4 is a federal program focused on providing new innovative geoscience knowledge and techniques for more effective targeting of deeply buried mineral deposits. Volcanogenic massive sulphides (VMS) are 1 of the 7 ore systems being studied, with research activities focused on 2 main themes: 1) Innovative, new and unconventional detection and vectoring methodologies for VMS exploration (activities: spectral geology/geochemistry and oxygen isotope mapping/vectoring, portable x-ray fluorescence (PXRF) spectrometry for till surveying, integration of rock properties with geophysics, volatile element vectoring); 2) Controls on precious metal endowment and enrichment in VMS deposits (activities: geological, geochemical, and mineralogical characterization of several Au-bearing deposits).

The Izok Lake area, NU was used to test the efficacy of airborne and ground spectrometry, together with oxygen isotope mapping to delineate hydrothermally altered felsic volcanic rocks associated with mineralization. Within both the airborne dataset and the ground outcrop and drillcore data, there are systematic shifts in the wavelength of the 2200nm absorption feature of white mica and the 2250nm absorption feature of chlorite that, together with variations in the bulk oxygen isotope composition reflect paleohydrothermal fluid pathways that may serve as exploration vectors. In the Halfmile Lake deposit area (Bathurst camp, NB), a comparison of standard laboratory till geochemical analyses with PXRF data for processed samples show comparable results. PXRF data for unprocessed tills give slightly lower abundances of some elements due to the matrix effects of moisture. Thus, PXRF can be used to guide and optimize a till sampling program using conventional methods.

Although the VMS model is well established, precious metal enrichment processes are less well understood. Several deposits were studied (Lalor-Snow Lake camp, MB; Ming-Rambler camp, NL; Lemarchant-Tally Pond belt, NL; Lemoine-Abitibi belt, QC). At Lalor, Au is associated with several ore mineral assemblages, each with distinct metamorphosed alteration assemblages. The Au-bearing zones are all within footwall hydrothermally altered rocks, indicated that Au introduction is primary. At Lemoine and Ming Au is also thought to be syngenetic. Introduction of Au at Lemoine was multiphase and is associated with Bi in sulfosalts; at Ming, Au is overgrown by Cu-rich mineralization. At Lemarchant, Au and Ag are enriched with a high-sulfidation epithermal suite in mineralization comprised in part of sulfosalts and low-Fe sphalerite. Mineralization formed in the subsurface via replacement in relatively shallow water. Characteristic trace element enrichments (Sn, In, Sb, Au) and light sulfur isotopic value suggest a contribution from magmatic fluid. **(*SS14, Thurs. 3:40*)**

Preliminary experimental anisotropy of magnetic susceptibility data on ice: A proxy for fabric development within glacial ice

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Anisotropy of magnetic susceptibility (AMS) has been shown to provide useful information regarding the kinematics of deformation within subglacially deformed sediments. The most commonly used method to examine fabrics within glacier ice is the analysis of c-axis crystallographic orientations of ice crystals in thin section. However, glacier ice has been shown to recrystallize over quite short timescales, so the final measured fabric may not represent the finite strain but rather the last recrystallization event. Here we present results from ice deformed under controlled laboratory conditions in an attempt to model finite simple shear fabric development within glacial ice. Preliminary experiments involved mixing ferromagnetic oxide phases (titanomagnetite) and paramagnetic mineral phases (biotite) into solutions of both pure water and viscous gelatin and placing the solution in an apprentice that exerted radial compression on the material during freezing to -5°C. In addition, we conducted rock magnetic experiments on the ferromagnetic and paramagnetic materials to fully characterize their magnetic parameters. The magnetic fabrics from the materials doped with ferromagnetic material show a strong prolate magnetic susceptibility ellipsoid that parallels the uniaxial extension direction generated by the applied radial compressive stress. We interpret these data to indicate the rotation of ferromagnetic grains in the ice to bring their easy axis of magnetization (maximum susceptibility axes) parallel to the extension direction during viscous flow as a consequence of the continually applied shear stress. Rock magnetic data indicate that the magnetic grains size of the titanomagnetite grains falls within the multidomain grain size, thus the AMS fabric is considered normal. In contrast, materials doped with pure paramagnetic materials did not yield interpretable results. It is probable that the concentration per unit volume of the paramagnetic material within the ice was not sufficient to achieve a stable AMS fabric.

These experiments are being rerun to test this hypothesis. We conclude that the measured magnetic anisotropy reflects the preferred alignment of titanomagnetite and hypothesize that the observed fabric is a product of grain rotation that occurred during deformation associated with ice flow and surge propagation. These results suggest that AMS can be used as a petrofabric indicator within ice and subsequently could be a useful new tool for investigations of glacier deformation and interactions with the bed. **(*SS22, Poster*)**

How phyllosilicate-rich fault zones creep: The argument for pressure solution-accommodated creep over frictional sliding

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Two case studies from creeping phyllosilicate rich fault zones are presented: the first from five sections of core from the active San Andreas Fault Observatory at Depth (SAFOD) located at 3km depth with a local temperature of 120°C, and a second from an extinct, exhumed segment of the Minas Fault Zone, near Port Greville, Nova Scotia, which was uplifted from conditions of ~10km and 300°C based on mineralogy and chlorite geothermometry. Using a combination of XRD of clay mineral separates, optical microscopy, and electron microscopy we examine the distribution of clay minerals and associated microstructures to elucidate the deformation mechanisms controlling creep. Within samples from the SAFOD site a broad range of low temperature clays (*e.g.*: corrensite, interstratified illite-vermiculite, interstratified illite-chlorite) exist as foliated seams through four of the five samples. It has been argued that the low frictional strength of these clays (μ = 0.2-0.3) is the controlling factor of creep along active sections of the SAFOD site, yet we see these clays as foliated seams throughout most of the drill hole. Microstructural evidence of pressure-solution accommodated creep is ubiquitous and it is demonstrated how creep is primarily dependent on the thickness of the gouge seams and not the frictional characteristics of weak phases. Within the Greville Bay region of the transpressive Minas Fault Zone a distinctive shear band domain is hosted within a black, chlorite rich phyllite, bounded on one side by a discrete fault followed by a folded variant of the same unit, and on the other side by a brecciated rhyolite containing seams of foliated cataclasite. Microstructural study shows that the shear band domain is deforming primarily through pressure solution accommodated creep. One of the unresolved questions at the SAFOD site has been that smectitic clays decay at ~120°C, thereby requiring a different deformation mechanism at greater depths if frictional sliding controls slip at shallower crustal levels. The clear display of pressure solution-accommodated creep within samples from the Minas Fault Zone could provide this needed mechanism, as studies of old exhumed fault zones present a horizontal cross section of processes occurring in active fault zones. **(*SY2, Thurs. 2:20*)**

Repeating obduction in the process of forming the Canadian Appalachians

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Northwestward obduction of the Pre-Atlantic ocean plate, its continental margin detaching and being displaced by 300-500 km onto the Archean craton, forming Grenville Province, was the beginning for the Canadian Appalachians. This obduction started ~1250-1190 Ma and ended forming the Grenville Front Fault at ~1030–980 Ma. It was slowed by emerging decollements (Central Metasedimentary Belt border tectonic, Elzevir-Frontenac boundary, other zones) and associated ophiolites (Queensborough, Ontario and Shawinigan, Adirondacks), causing northwestward younging of metamorphic belts in Grenville Province. The edge of the obducting ocean plate (Dunnage zone) took position above the remnant of the Mid-Proterozoic margin of Laurentia (Appalachians' basement). Humber zone is composed of fragments and debris of Mid-Proterozoic margin (Grenvillian inliers including anorthosites) and the obducting plate. On the East flank, the plate stopped at Newfoundland before reaching Labrador and St. Lawrence

Bay. The plate created perfect conditions for sediment transport to Avalon and Meguma zones. During the ensuing submersion of the obducted plate, sedimentary collection (immersing below sea level) began in the Neoproterozoic for Avalon and in Cambrian for Humber and Dunnage zones. The submerging plate reached a depth conducive of the serpentinization process in Latest Cambrian-Ordovician, beginning the Taconian Orogeny. The fact that during this period different crustal parts of Dunnage zone obducted Notre-Dame and Dashwoods subzones onto Humber, Exploits Subzone onto Gander and other obductions of subzones within Dunnage (Dashwoods onto Notre-Dame; Notre-Dame over Exploits) shows that during initial obduction, following immersion and diachronous Cambrian-Ordovician activation of ophiolites, the ocean plate was fragmented and each of its blocks was independent. Increase of volume of the plate's peridotite layer during serpentinization generated uplifting and growth of the Appalachians, since upwards is the path of least resistance for increasing rock volumes. As ophiolitic mélange cannot be obducted as a single plate, presence of mélange and ophiolites in the same place indicates serpentinization of the old plate forming mélange (Saint-Daniel and Rivière-Port-Daniel mélanges) and obduction of a new plate. From time to time (Acadian and Alleganian orogenies) the Appalachian region experienced northwestward-directed pressure from a re-activated Pre-Atlantic oceanic plate causing limited obductions. This stopped with formation of the Mid-Atlantic ridge. Grenvillian and Taconian orogenies are not directly related to Sveconorwegian/Grenvillian and Caledonian orogenies, which culminated later in Svalbard, Norway and Greenland (at ~968 Ma and ~420 Ma, respectively). Repeated obduction processes are known in regions of the Alps, California, Japan, Russian Far East, Norway, Mozambique, and others. **(*SY1, Poster*)**

The involvement of forsterite and dunite layers of the oceanic lithosphere in obduction during formation of the Appalachians

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Lithospheric formation from the bottom began during solidification of the magma-ocean, creating forsterite, dunite with some chromites, and harzburgite layers in order of their melting points. Unserpentinized forsterite and dunite layers' rocks, characterized with velocities of 8.5-8.7+ km/s, are usually present at depths of ~70-120 km in continental crust. However, such velocities were determined at shallower depths in: Southern Grenville Province (50-60 km), Central Appalachians (~52 km), St. Lawrence Gulf (~43-56 km), Gaspé Peninsula (~40-50 km), northeastern (~30-41 km) and central (~55 km) Newfoundland, and rocks from Bay of Islands Complex; within the crust of mid-Norwegian margin (Vøring Basin (~14.5-18.0 km), Møre Basin (~22-25 km)), Knipovich Ridge-Lena Trough in Norwegian-Greenland Sea (~13 km), and Barents Sea (~33-43 km); Trans-Hudson Orogen (~40-60 km), New Zealand (~28.5-30.0 km), Alaska (~31-48 km), Middle Urals (~45-60 km), etc. Remnants of a dunite+chromite/chromitite layer (serpentinized dunites, chromitic serpentinites) were found in numerous Appalachian regions (Blue Ridge province, Piedmont, Quebec and Newfoundland); Advocate, Bay of Island, Estrie-Beauce and Thetford Mines ophiolites; Nadeau Ophiolitic and Falls Lake mélanges; etc. Several ultramafic bodies up to 20×2 km are known in Outer Piedmont, and one 10×5 km Webster-Addie is known in North Carolina. Associations of dunite+chromite/chromitite and dunite+troctolite+anorthosite with platinum group elements (PGEs), known in anorthosite-bearing layered mafic intrusions, were also found in the Appalachians. The usual concentration of PGEs in rocks is fractions or single digits of ppb. However, in some Appalachian chromites and anorthosites the content of PGEs is drastically elevated: chromites/chromitites of Blue Ridge Province, Southeast Québec, Gander zone (hundreds of ppb); Middle Arm Brook, Newfoundland (PGE_{Total}=1.03 ppm); Mechanic intrusion, Avalon terrane (PGE_{Total}=2.4 ppm); Hall mine, Thetford Mines (PGE_{Total}=2 ppm with a single grab of 13.37 ppm); Newfoundland anorthosites - Steel Mountain (PGE_{Total}=2.97 ppm) and Indian Head (PGE_{Total}=1.21 ppm). While their content in CI carbonaceous chondrites is PGE_{Total}=3.29-3.39 ppm; and for low-iron ordinary chondrites PGE_{Total}=2.54-3.59 ppm (LL6-chondrites: PGE^{Total}=1.5 ppm). PGE_{Total} values higher than in the mentioned chondrites were recorded in ophiolite/serpentinite massifs of: Butirin, Northern Urals (≤61.0 ppm); Cliff, Shetland Islands (≤60 ppm); Veria, Greece (≤24.92 ppm); Al'Ays, Saudi Arabia (>15 ppm); New Caledonia (11.5 ppm); Albania (11.1 ppm); Korydallos, Greece (≤6.86 ppm); Cuba (≤3.7 ppm); etc. Since the principal minerals of CI-chondrites are olivine and serpentine, it is possible that they were formed from ophiolite/serpentinite massifs of their parent objects. All this indicates the involvement of forsterite and dunite+chromite layers in obduction in the Appalachians. **(*SY1, Poster*)**

Emplacement of multiple phases within the Foy offset dyke at the Sudbury Impact Structure, Canada

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Offset dykes are thick metre to hundred metre-scale sub-vertical intrusive bodies composed of granodiorite. They occur radially and concentrically around the Sudbury Igneous Complex (SIC), a differentiated melt sheet within the ~200 km diameter, 1.85 Byr. old Sudbury impact structure. The offset dykes formed when the impact melt was injected into large fractures in the brecciated crater basement. The SIC and offset dykes have been mined for over 100 years for their nickel-copper-platinum group element sulfide ore, and is still being actively mined today. Despite this long history of exploration, the origin of this ore and the method of emplacement of the offset dykes is uncertain.

The Foy is a radial offset dyke found in the north range hosted by Archean granites, gneisses, and greenstones of the Abitibi subprovince. It extends 37 km along strike, and ranges from 400 m across at its southern end to 50 m at its distal portions. It is composed of quartz diorite, a clast-bearing granodioritic igneous rock with multiple phases. The Foy is particularly clast-rich compared to other offset dykes, which makes it an excellent area to study the emplacement of the dykes by measuring clast variations and orientations.

The dyke is composed of three phases of quartz diorite: the inclusion-poor (IP) phase (<5% clasts), the inclusion-bearing (IB) phase (5-25% clasts), and the inclusion-rich (IR) phase (>25% clasts). The IP phase was emplaced first, is coarse grained and is found along the margins of the dyke, often with a quenched margin. The IB phase was emplaced second, and is found in the center of the dyke. The contact between the two varies from gradational to sharp. This indicates that the IP phase may have been partially ductile during emplacement of the second phase. The third phase is found in pods within the IB phase, and occasionally within thin dykes in the IP phase. This phase has sharp contacts with the other phases, and contains clasts of the first phase. This indicates that it was emplaced last once the other phases were cooled.

Inclusions close to the IP-host or IP-IB contacts are typically oriented sub-parallel to the contact, while inclusions in the centre of the dyke are randomly oriented. Rip-up clasts of the host rock are commonly found within the IP phase. These observations suggest that the dykes were emplaced via a forceful flow with more turbulence in the centre of the dyke. **(*GS5, Poster*)**

The Cambro-Ordovician Cu-Au Ming VMS deposit, Baie Verte peninsula, Newfoundland: Geological environment, ore zone architecture, and hydrothermal alteration

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The producing Cu-Au Ming volcanogenic massive sulphide (VMS) deposit is part of the Cambro-Ordovician Baie Verte Belt, host to numerous past producing Cu and Cu-Au VMS deposits. The Ming deposit (reserves of 1.50 Mt at 1.62 wt% Cu, 2.40 g/t Au, 10.90 g/t Ag, and 0.49 wt% Zn and resources estimated at 3.65 Mt at 2.26 wt% Cu, 1.13 g/t Au, 6.78 g/t Ag, and 0.32 wt% Zn) contains four elongated Cu-Au-Zn±Ag massive to semi-massive sulphide lenses, all gently plunging northeast and separated 30 to 50 metres from each other along the same stratigraphic horizon. The lenses are hosted by intermediate to felsic volcanic and volcaniclastic rocks of the Early Ordovician (*ca.* 487 Ma) Pacquet Harbour Group, which is part of a regional mafic-dominated rock assemblage of boninitic to tholeiitic affinity.

Preliminary field observations and lithogeochemical results indicate that the footwall is composed of at least three distinct intermediate to felsic calk-alkaline (*e.g.* Zr/Y>7) volcanic and volcaniclastic units. The immediate hanging wall is lithologically heterogeneous, varying from a highly silicified (SiO_2>88 wt%) volcaniclastic rock to a magnetite-rich volcanogenic siltstone. Locally, the mafic-dominated subaqueous, syn-obduction ophiolite cover sequence is in structural contact with the massive-sulphide as a result of post-mineralization deformation. Three generations of mafic to intermediate sills and dykes are present in the deposit and have distinctive lithogeochemical signatures; they are interpreted to be genetically related to the mafic rocks of the ophiolitic cover sequence.

The Ming deposit has distinct alteration mineral assemblages including sericite, chlorite, quartz, biotite, tremolite, Mn-Ca-rich garnet and calcite, green mica, epidote, magnetite, and pyrite. A Cu-rich zone consisting primarily of chalcopyrite, pyrrhotite, and pyrite with minor Bi-Te sulfosalts and sphalerite in a strongly chlorite-epidote altered felsic volcanic rock occurs 50 to 100 metres below the main sulphide lens, representing the high-temperature discharge zone of the Ming hydrothermal system. An overprint of metamorphic biotite is ubiquitous throughout the felsic footwall rocks and represents metamorphosed K-Fe-(Mg) alteration to upper greenschist facies.

The relationship between the stratigraphy, spatial distribution and styles of alteration, and the mineralization strongly favor a syngenetic origin for the ore zones. Despite local chemical and mechanical remobilization of the massive sulphide in the westernmost zone (1807 zone) due to subsequent deformation events (*i.e.* Taconic, Salinic, and Acadian orogeneses), the sulphide bulk composition for all zones, including the precious metals, has not been changed by deformation and metamorphism, suggesting intrinsically enriched VMS ore-forming fluids. (***SS14, Fri. 8:00***)

Preliminary results of coupled Fe and Mg isotopes plus Fe speciation investigations at the Bong uranium deposit, Thelon Basin Canada

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The precipitation of significant amounts of Fe- and Mg-bearing minerals (*e.g.* hydrothermal Fe-oxides/hydroxides and chlorite) is often genetically linked with formation of Proterozoic unconformity-related U deposits. The proposed mechanism is that the formation of these alteration minerals during host-rock alteration reactions released Fe^{2+} whose oxidation to Fe^{3+} facilitated reduction of U^{6+} to immobile U^{4+} through a coupled redox reaction, and the precipitation of uraninite, the dominant ore mineral. Located on the southern margin of the northeast Thelon sub-basin, U at the Bong deposit is associated with a broad alteration halo characterized by intense illitization ± chloritization of the host Woodburn Lake Group metasedimentary rocks. Uranium precipitated in two generations, in veins associated with graphite (Stage A) and in miniature roll-fronts (Stage B) around 1120 Ma and 1040 Ma.

Iron and Mg isotope compositions ($\delta^{57}Fe$ and $\delta^{26}Mg$) were determined by MC-ICP-MS for whole-rock and clay-sized fractions after a four acid digestion of powdered core samples from a mineralized drill hole. Both whole-rock and clay-size fraction data exhibit downhole zones with significant positive isotopic shifts. Whole-rock samples produced the widest range in $\delta^{57}Fe_{IRMM-14}$ values (+0.48 to +1.30‰), whereas the clay-sized fraction yielded the greatest range in $\delta^{26}Mg_{DSM-3}$ values (+0.73 to +1.02‰). A zone with elevated $\delta^{57}Fe$ and $\delta^{26}Mg$ values is associated with the alteration zone of the Bong deposit and a hematitic alteration zone, located at the top of the drill hole, that is often ascribed to 'paleoweathering' in the literature. These isotopic values correlate with relatively low molar Fe^{2+} concentrations in the altered zones (0.47 mol.% Fe^{2+}) whereas the molar concentration of Fe^{2+} in unaltered zones is 2.30 mol.%. Concentrations of Fe^{3+} remain relatively constant in both altered (0.47 mol.% Fe^{3+}) and unaltered (0.51 mol.% Fe^{3+}) zones.

Therefore, host-rock alteration processes, that formed both the U-bearing alteration and the red hematitic so-called 'paleoweathering', mobilized Fe^{2+} while enriching the fluids in the lighter isotopes of Fe and Mg. The association of similar elevated isotopic values with both the host-rock alteration and the red hematitic material suggests that this latter material is unlikely to have formed through paleoweathering processes. **(*SS7, Wed. 3:00*)**

Cathodoluminescence of scheelite: Quantifying color and chemical variations

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Scheelite ($CaWO_4$) is a common accessory mineral found in a variety of geologically diverse ore-deposit settings, including vein/stockwork, skarn, porphyry, epithermal and strata-bound. As part of the Geological Survey of Canada's (GSC) Targeted Geoscience Initiative (TGI-4) program, the project reported on here was developed to investigate the potential for discriminating scheelite originating from different ore-deposit types. The study investigated whether crystal-chemical features of scheelite, such as cathodoluminescence (CL), trace-element chemistry, and isotopic signature (O), could be used independently or together as deposit-type discriminators, thereby assessing the feasibility of using scheelite for provenance studies in regional till-sampling programs. An initial study of 121 scheelites from twenty-seven different locations, which covered a spectrum of ore-deposit systems, was undertaken and then the suite was culled to five representative grains for detailed cathodoluminescence analysis and crystal chemistry studies. Here we report the initial results for the CL work in the context of both deposit setting and how CL relates to potential activators and quenchers accessed via SEM-EDS and LA ICP-MS analysis. Our results indicate that CL response of scheelite, although variable, shows consistent trends among samples from similar ore-deposit settings. For example, scheelite from epithermal systems have complex oscillatory zoning with variations in intensity and color ranging from light to dark blue. In contrast, samples from vein and skarn settings are generally a homogenous blue and lack evidence of complex zonation. By integrating X-ray maps made with an SEM-EDS system it was possible to quickly correlate between major- and trace-element chemistry and the CL response in scheelite. With the exception of Mo, which follows crystal growth patterns, no significant elemental contributions were however noted. In addition, generation of LA ICP-MS maps indicate that CL responses cannot be correlated with the presence of any particular element among the extensive element table used. Although enrichment in the ∑REEs occurs (*i.e.*, to 3745 ppm), no correlation with the type of CL response was evident. This latter observations contrasts with the general assumption that the REE are typically known as activators with regards to CL response. The specific cause of the different CL responses noted in the samples studied remains elusive, however it is suggested that these variations may be attributed to extrinsic variables, such as Mo, Sr, and REE contents, in addition to intrinsic defects within the crystal structure. **(*SY6, Fri. 3:20*)**

Scheelite geochemical signatures and potential for fingerprinting ore deposits

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Scheelite ($CaWO_4$) is a common accessory mineral found in a variety of geologically diverse ore-deposit settings, including vein/stockwork, skarn, porphyry, epithermal and strata-bound. As part of the Geological Survey of Canada's (GSC) Targeted Geoscience Initiative (TGI-4) program, the project reported on here was developed to investigate the potential for discriminating scheelite originating from different ore-deposit types. The study investigated whether crystal-chemical features of scheelite, such as cathodoluminescence (CL), trace-element chemistry, and isotopic signature (O), could be used independently or together as deposit-type discriminators, thereby assessing the feasibility of using scheelite for provenance studies in regional till-sampling programs. Here we report on the geochemical data obtained using the LA ICP-MS method on scheelite to see if it could be used to geochemically fingerprint its environment of formation. The samples used come from the granite-related, world-class Sisson W-Mo porphyry-type deposit, NB, along with forty-one scheelite samples from a range of deposit types that constituted the suite used in the broader crystal-chemical study. The protocol used was twofold: (1) collect data using line traverses and integrate the data over intervals showing uniform chemistry; and (2) generate element maps for a select few scheelite grains which displayed complex zoning patterns revealed through CL imaging. Despite using an extensive element list (*e.g.* LILEs, alkalies, transition metals, HFSEs), only Mo, As and the REEs, which follow crystal growth patterns, showed significant levels of elemental enrichment (*i.e.*, > 1.0 ppm). The correlation of As and Mo indicate only a small intra-deposit variance, but the large inter-deposit variation offers the potential to use this element pair to discriminate deposit types. The results for the REEs indicate: (1) a lack of apparent correlation between REEs and the type of CL observed despite previous suggestions to the contrary; (2) considerable variation in the ∑REEs amongst the sample suite used; (3) most samples are dominated by a single chondrite-normalized (CN) pattern, but rarely a second pattern is present; (4) although the type of CN REE patterns vary (*e.g.*, convex MREE, LREE enrichment), there is a similarity among deposit types; and 5) both positive and negative Eu anomalies are observed. These initial results suggest that the minor and trace-element chemistry of scheelite along with CL imaging, may offer the potential to discriminate and identify deposit types based on its geochemical fingerprinting. **(*SS3, Wed. 9:00*)**

Diagenetic history and provenance of Devonian sandstones in northern Iran

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In some areas of Iran, red clastic strata of the Padeha Formation are widespread and are assigned an Early Devonian age in view of their stratigraphic position. Studies of marine palynomorphs indicate that a widespread regression exposed much of the Iran platform during the Early and Middle Devonian, and this emersion lasted until the Late Devonian. Palynological studies suggest that mudstone associated with sandstone was deposited in quiet tidal environments or in deeper water over the platform. Fluvial facies accumulated when sea level was low.

The Padeha Formation is composed of pale quartzitic sandstone with interbeds of red sandstone, red shale, and locally gypsum. In the Binalud and Bojnourd areas, lithofacies of the Padeha Formation are relatively similar and the formation at these sites is ~130 m and ~600 m thick, respectively.

About 200 thin sections were studied and ten polished thin sections were used for SEM and EDX analysis. Rock types are mainly quartz arenite, subarkose, arkose and rarely litharenite with volcanic grains supplied from erosion of local sills. Relating sandstone composition to tectonic setting, provenance for the formation is linked to craton interior, transitional continental and basement uplift settings.

Diagenetic processes include compaction and cementation by silica, carbonate (calcite-dolomite-siderite), Fe-oxides and clay minerals (mostly illite and chlorite). Pressure solution was an important process in quartz-rich samples. Authigenic feldspar is unusually prominent as overgrowths and as euhedral grains in some thin sections, and albitization of feldspars is evident. Feldspar grains, volcanic and carbonate rock fragments, and carbonate cements were dissolved in places. Authigenic chlorite, albite, and illite are widespread, with glauconite and barite in some strata, and sericite coats detrital grains. Many grains show fracturing. These diagenetic events are variously linked to eogenetic, mesogenetic and telogenetic (uplift) conditions, the latter associated with Mesozoic to Cenozoic tectonic events, but the major diagenetic events represent deep-burial diagenesis. **(*GS4, Fri. 2:40*)**

Optimising geoscience data and information for sustainable urban design and development

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Over half the world's population now live in cities. In 2011, it was estimated that global population exceeded 7 billion. An increasingly urbanised population means increasing pressure on land-use, including the use of space in the shallow subsurface beneath cities. The ground beneath cities, including the interaction between its physical, biological and chemical processes provides natural capital on which people depend. These benefits provided can be considered geoservices. Geoservices are one type of service that includes ecological, ecosystem services that deliver natural capital to enable people to live, work and travel.

The sustainable use of geoservices in the ground and their relationship to other environmental services from which people derive direct or in-direct benefits, is critical for developing sustainable cities to support societal well-being, environmental health and economic growth. Their current and past exploitation, including the space for development, waste disposal, groundwater abstraction and heat exchange has resulted in above and below ground competition for space and resources in many cities. Data, information and knowledge about the ground beneath cities are often overlooked as a component of sustainable city design. The characterisation of the ground beneath cities can deliver benefits including hazard avoidance, identification, protection and sustainable use of resources and environmental impact minimisation.

The British Geological Survey, in partnership with Glasgow City Council, UK has set up an initiative to ensure that ground data and information is used in the best way possible in sustainable city planning. The development of the Accessing Subsurface Knowledge (ASK) network enables public and private sector users, and the research community, to exchange, access and use past and current information about the ground. It's designed to provide access to data and information and to share it. It includes 3D geological models, digital geological maps and the results of ground investigation. Common data standards have been established including the development of a customised data acquisition and exchange format called Glasgow Specification for Data Capture (GSPEC).

The importance of partnership working and efficient exchange of knowledge about the ground in city planning has also been recognised with the formation of a network of mainly European partner geological survey organisations and city authorities. The SUB-URBAN network has been formed under a European COST Action (TU1206). This Action aims to maximise the benefits from use and protection of subsurface resources, reduce conflicts in their use and ensure they are complementary to above-ground planning considerations in sustainable city design. **(*SS10, Wed. 3:00*)**

Old (stratigraphy) and new (LIDAR) tools in aid of till geochemical surveys in New Brunswick – the past, present, and future

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More than 30 years of regional till geochemical surveys have resulted in the almost complete coverage of areas with mineral potential which were sampled using a 2-km grid spacing. The database that is the result of this immense undertaking has resulted in almost 13,000 sites (many of them hand dug surface/soil pits) for which there is documented data on soil/till properties such as texture, genesis, depth, landscape setting *etc.* as well as lithology, geochemistry, and often vegetation inventory. Associated stratigraphic investigations indicate that up to four different tills may be present: 1) Northumberland till, deposited by east to east-southeast ice flow during the Illinoian; 2) Caledonia till, the dominant surface till in southern and central New Brunswick, deposited by southeast to south-southeast ice flow during the Early to Middle Wisconsinan; 3) Late Wisconsinan till, primarily in northern New Brunswick, associated with drawdown into ice-streams flowing east to northeast into the Baie des Chaleurs; and, 4) locally, a Late Glacial till associated with the readvance of remnant ice caps during the Younger Dryas Stade.

The geochemical data has been used extensively in locating mineral prospects and has thus helped to extend New Brunswick's mineral wealth into the future. Several significant prospects have been targeted because of the existing geochemical database and associated mapping (*e.g.* Clarence Stream Au, Sisson Mo-W, Menneval Au). However, use of the data extends beyond the mineral industry to the transportation, environmental, and forestry industries.

With the pending completion of regional till geochemical sampling a surficial mapping program was commenced. It is apparent that the use of LIDAR will help in mineral exploration and also in expediting surficial mapping, which with the aid of LIDAR requires less ground-truthing.

Several map sheets in east central New Brunswick were sampled as part of the TGI-4 initiative. Our focus will be on the McKendrick Lake map area (NTS 21J/16). This is an area of diverse ice flow patterns that reflect the complex glacial history of New Brunswick. **(*SS22, Thurs. 9:20*)**

Multiscale simulation of quartz lattice preferred orientations from the Shangdan tectonic zone of the Central Orogenic Belt, China

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Lattice preferred orientation (LPO) fabrics in quartz-rich rocks have been widely used to study the kinematics and mechanisms of natural deformation. Previous works are based on single-scale models which do not consider deformation partitioning arising from rheological heterogeneities. We investigate the significance of deformation partitioning in the development of quartz LPOs using a multiscale approach. Field samples for the research are from a deformed conglomerate in the Shangdan Suture zone of the Central Orogenic Belt, China. The conglomerate was formed in a forearc environment and contains polymictic pebbles including quartzite and granite pebbles. We measure quartz LPOs from different pebbles, investigate their variability, and apply a multiscale model to simulate the development of such LPOs. We consider two different characteristic scales. The conglomerate as a whole is the macroscale. The bulk rheology at this scale is approximated by a homogeneous effective medium which represents the averaged rheology of all the pebbles and matrix material. Each pebble is regarded as a mesoscale rheologically distinct phase (RDF). Partitioned flow field in each RDF is calculated using micromechanics principles and is used to simulate the quartz LPOs development in the mesoscale RDF (pebble). Once the partitioned flow in a pebble is obtained, it is used together with the viscoplastic self-consistent model for LPO development. Through this multiscale approach, we relate LPOs in pebbles to the bulk scale deformation. Both Newtonian and non-Newtonian power-law viscous materials are considered. We find that LPO patterns in rheologically weak domains have similar characteristics, but in strong domains they are more variable. **(*GS2, Fri. 2:40*)**

Transposition of a layered granulite by the progressive development of amphibolite facies shear zones, Twelve Mile Bay, Ontario: Techniques and results

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The Central Gneiss Belt of the Proterozoic Grenville Orogen in Ontario exhibits the middle to lower crustal levels of a large hot orogen. A series of island exposures reveal stages of development of a shear zone system formed on the boundary of a granulite nappe (Parry Sound domain) during ductile nappe flow. The islands record over a width of *ca.* 5 km the progressive transposition of the margin of the layered granulite facies block in the north, into an amphibolite facies shear zone to the south (Twelve Mile Bay shear zone).

The complex structure of the outcrops has been digitally imaged and documented using a pole camera and open-source software packages to produce orthorectified photomosaics. The photomosaics are then georeferenced to a grid using a series of GPS marker points, allowing the photomosaics to be displayed to scale in the software of the user's choosing. A true to scale ultra-low aerial photograph allows for accurate measurement of features (length, area, angle), and has many possible applications for mapping complex structures.

The progressive deformation and softening of the layered granulite facies block is facilitated by the widening of amphibolite facies dextral shear zones at the expense of panels of untransposed granulite fabric separating the shear zones. In the south of the strain gradient, the shear zones widen to become increasingly connected in an anastomosing pattern. Relict granulite panels collapse by formation of buckle and scar folds, which evolve to isoclinal folds within the resulting (1-10 m wide) shear zones comprising the regional Twelve Mile Bay shear zone. The occurrence of sinistral shear zones at a high angle (~90o) to the dextral set complicates the narrative further, and suggests either two phases of shearing, or the development of conjugate shear zones. **(*SY2, Poster*)**

Progressive localization in the eastern Athabasca granulite terrane: A local record of far-field orogenic stresses

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Integrated *in-situ* U-Th-total Pb geochronology, structural analysis, and thermobarometry yield insight into the temporal, kinematic, and metamorphic evolution of the Athabasca granulite terrane, along with the mechanisms and processes of strain localization. The eastern margin of the Athabasca granulite terrane corresponds to a region of nested shear zones dividing disparate, and polydeformed, lithotectonic blocks. Collectively the shear zones were active for more than 50 m.y. and suggest a zone of persistent strain localization that broadly coincides with the trace of the Snowbird tectonic zone. Internal to each block, Archean gneissic to magmatic layering was folded about a shallowly plunging axis. This was accompanied by the regional development of a localized, steeply dipping, axial planar fabric. Lineations are subparallel among at least two major lithotectonic domains, plunging shallowly to the west-southwest. Rocks record dextral kinematics defined by granulite facies assemblages and a relative increase in modal hornblende. Geochronology constrains the age of folding and progressive dextral shearing to *ca.* 1.9 Ga. This phase of localized, but regionally developed, deformation is interpreted to represent regional transpression, possibly localized due to thermal weakening and fluid infiltration triggered by the syn-kinematic Chipman dike swarm. At *ca.* 1.89-1.87 Ga, immediately following peak metamorphic conditions, the Cora Lake shear zone accommodated sinistral strike-slip deformation, with a minor normal component. This event contains kinematics in stark contrast to *ca.* 1.9 Ga shear, and records the onset of regional cooling. The *ca.* 1.85 Ga Legs Lake shear zone and contemporaneous Grease River shear zone accommodated dextral/thrust sense and dextral, strike slip shear, respectively, which served to uplift and offset the Athabasca granulite terrane. The kinematic variations of the region, along similarly oriented structural fabrics, coincides remarkably well with orogenic pulses along the margins of the Churchill Province. Dextral transpression at 1.9 Ga, coincides with the latter phases of the Slave craton’s indentation into the Rae domain. Subsequent sinistral kinematics coincide with the accretion of the Lynn Lake and La Ronge arcs along the southern periphery of the Hearne at *ca.* 1.88 Ga. Renewed dextral kinematics at 1.85 Ga corresponds to rejuvenated convergence along the western margin of the contiguous Churchill/Slave craton. Therefore, the study region may represent a weak zone within the Churchill Province, perhaps destabilized by mafic magmatism reflected by the Chipman dike swarm and associated fluid infiltration, which led to *ca.* 50 m.y. of progressive strain localization during regional cooling. **(*SY2, Thurs. 9:20*)**

Low-pressure, high-temperature conditions during crustal thickening: Insights into thermal and mechanical processes from petrological-structural studies

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The Mesoproterozoic Mary Kathleen Fold Belt in the central Mount Isa Inlier, NE Australia, represents a classic low-pressure, high-temperature metamorphic terrain. A host of petrological, structural, geophysical and geochronological data compiled for this area over the years provides an ideal basis for testing various concepts proposed to explain regional-scale LP-HT metamorphism.

To briefly summarize the basic petrological facts: The main metamorphic imprint is characterised by a complete anticlockwise P-T path. The prograde path passes through the andalusite and sillimanite stability fields, with peak conditions reaching 550-650°C at about 4 kbar. Retrograde reactions produced the aluminosilicate sequence sillimanite-kyanite-andalusite (-pyrophyllite).

Neither the P-T path nor the observed structures are compatible with crustal extension, as in rift or back-arc environments. Deformation in the Mary Kathleen Fold Belt is dominated by tight, upright fold structures that are developed from map-scale to hand specimen scale. A strong vertical stretching component is indicated by subvertical mineral lineations and rotation of fold axes towards the vertical. Minimum bulk shortening is estimated at 50-60%. Microstructural relationships reveal that the sequential growth of minerals from increasingly higher-grade reactions was entirely synchronous with progressive deformation.

The prograde P-T path indicates a major transient heat input. In the absence of crustal thinning, heating by large volumes of intruding magmas is generally advocated to explain regional-style LP-HT metamorphism. It is, however, one of the remarkable and enigmatic features of the Mount Isa region that intrusives with a syn-metamorphic crystallization age are absent at the present erosion level. The possibility of high concentrations of radiogenic heat-producing elements in the crust has also been considered to account for a high geothermal gradient, but this hypothesis would still not explain the prograde heating path, nor is it supported by relatively high post-peak cooling rates of about 10°C/Ma indicated by geochronological-thermometric data.

Petrological-structural evidence points to an initial heating event originating at deep crustal, possibly Moho level that eventually triggered prograde metamorphism at higher crustal levels. As a consequence of progressive thermal weakening of the crust, its critical strength would have been exceeded at some point by the horizontal compressional stress the entire Mount Isa Inlier had been subjected to during the Isan orogeny since about 1600 Ma. Strain was then focused into mechanically weak zones such as the Mary Kathleen Fold Belt. The coupling of thermal causes and mechanical effects thus explains the seemingly unusual synchronism of LP-HT conditions and crustal shortening. **(*SS19, Thurs. 8:40*)**

Channel-bottom fluid-mud layers in the Tilje Formation (Jurassic), offshore Norway: Deciphering changing near-bed conditions over multiple tidal cycles

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The Jurassic Tilje Formation located on the Norwegian continental shelf contains many thick (>10 mm) and macroscopically homogenous mudstone layers in association with dune cross bedding. These mudstone layers are interpreted to have accumulated rapidly from high-density muddy suspensions (*i.e.*, "fluid-mud") in channel-bottom settings. Using thin sections, three facies are observed within these mudstone drapes: unstratified mudstone (UM), some of which contain "floating" coarse grains; planar-laminated mudstone (PLM); and cross-laminated mudstone (CLM). Based on published experimental work, a three-dimensional bedform phase diagram has been created for muddy suspensions, with the axes being suspended-sediment concentration, current speed and the relative proportion of cohesive and non-cohesive sediment. Unstratified mudstone (UM) is interpreted to have formed from the highest-density suspensions, the cross-stratified mudstones (CLM) were formed by the least-dense suspensions, while the planar-laminated facies (PLM) was formed by suspensions with intermediate densities. The vertical stacking of facies, without a break, within a single mudstone layer indicate that near-bed flow conditions were not static during deposition of the layer. The succession (CLM→)PLM→UM records decreasing flow speed and increasing near-bed sediment concentrations as slack water is approached. UM→PLM successions are not common but record flow acceleration and resuspension of the high-density near-bed suspension as flow begins again after slack water. The presence of several waning and waxing flow paths within a single mudstone layer indicates that one or more complete tidal cycles are recorded in some layers. The presence of such complex mudstone layers in a channel-bottom setting, where maximum current speeds were high enough to generate medium to large dunes, is unexpected because there should have been a high likelihood that freshly deposited mud would have been eroded. It is noted, however, that the mudstone layers that show such complex flow histories always occur in the bottomset and toeset area of dune-scale cross-bedding, which indicates that they accumulated in the dune troughs where they were protected from the strongest currents. It may have been that the high-density suspensions were maintained over multiple tidal cycles in the troughs as has been documented in modern environments. By contrast, the fluid-mud layers that overlie storm-generated sandstone beds do not contain such complex facies successions because they presumably formed during a single period of decreasing energy. **(*SS1, Fri. 8:40*)**

Iapetan Crossing, Québec-Maine: Appalachian tectonics linked with carbon cycle dynamics

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Patterned after Hank Williams' legendary trans-Newfoundland field trip, the Québec-Maine version also examines key evidence for the construction and subsequent destruction of the Early Paleozoic Iapetus Ocean. Both illuminate the entirety of the Wilson cycle, the "whole elephant." Proximal to large population centers in Quebec and New England, the Québec-Maine transect approximately follows the route of the Continental Army expedition that during the fall of 1775 attempted to liberate Canada from British control. Far more successful, the geologic counterpart has captured the imaginations of hundreds of university student and K-12 teacher participants since the pilot trip of October 1992, an outgrowth of the Maine Geological Survey's CREST project.

The trip, typically 2-3 days in duration, begins on the Laurentian margin of Iapetus near Québec (Great Unconformity above Montmorency Falls, thrust nappes of continental margin strata at Chute de la Chaudières). It then passes through Thetford Mines (forearc basement of the upper plate, including upper mantle) to the peri-Laurentian arc rocks present in the Boundary Mountains (older Boil Mountain complex, and superimposed Ordovician-Silurian Attean arc). Crossing the main Iapetan suture in the vicinity of Flagstaff Lake (Hurricane Mountain mélange) into the peri-Gondwanan realm, a triplet of outcrops near Rangeley illustrates, respectively, the Gondwanan provenance of the basement (Dead River-Grand Pitch Formations), mid-Iapetan position of arc volcanic rocks (Ammonoosuc-Shin Brook), and incipient docking of this terrane against Laurentia (Partridge Formation). The route to Farmington passes through the type localities of the Siluro-Devonian formations in Maine that record demise of the "Sea of Exploits" (Tetagouche-Exploits back arc basin) followed by development of the Acadian foreland basin and peak orogenesis caused by the arrival of another Gondwanan crustal block, Avalonia.

The most recent iteration of the trip during October 2013 added a focus on Earth's carbon cycle, emphasizing how the various materials have functioned as sources and sinks of CO_2 at different times through their histories, with consequences for the climate system. The trip has a relatively low carbon footprint, and notes the recommendation by the Geological Society of America that "public policy should include effective strategies for the reduction of greenhouse gas emissions." Continuing efforts by universities, surveys, professional societies, and landowners can help to ensure that this key component of North America's geological heritage is used to enlighten the public for the sake of present and future inhabitants of Earth. **(*SS15, Fri. 3:00*)**

Was collapse of the Grenville Orogen a driver for the Neoproterozoic snowball Earth?

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On the basis of recent reconstructions, the late Mesoproterozoic to earliest Neoproterozoic (~1090-980 Ma) Grenville Orogen was a >10,000 km long orogenic belt at the centre of the supercontinent Rodinia. Supercontinent break-up began at ~800 Ma, and fragments of the Grenville Orogen are presently dispersed on several continents, with the largest, in North America, being ~5000 km long and up to several hundred km wide. Recent studies in this fragment, the Grenville Province, suggest the Grenville Orogen was a large, hot, long-duration orogen (LHO) with a Tibetan-style plateau in its hinterland. Tectonic evolution of this orogenic hinterland was characterized by a >40 Ma stage of double-crustal thickening and heating leading to the formation of the orogenic plateau (from ~1090-1050 Ma), followed by a >30 Ma period of crustal thinning, cooling and collapse (from ~1050-1020 Ma). The crustal-scale of collapse of the plateau is indicated by extensional juxtaposition of exhumed granulite-facies mid-crust (T >850 °C) against remnants of the uppermost crust (orogenic lid; T <500 °C).

Published explanations for the snowball or partial snowball episodes that characterize the ensuing Cryogenian stage are based on coupled climate-geochemical models. They invoke low CO_2 levels in the Neoproterozoic atmosphere, and posit that lowering of pCO_2 was driven by the breakup of Rodinia, which changed fluvial drainage patterns resulting in enhanced silicate weathering and carbonate burial. An interpretation involving these linked processes is also supported by the normalized $^{87}Sr/^{86}Sr$ curve for seawater. However, since Rodinia break-up did not begin until after 800 Ma, it remains uncertain whether there was sufficient time for CO_2 draw-down by this mechanism before the earliest and largest Neoproterozoic glaciation (Sturtian) at ~720-660 Ma. The question raised in this presentation is whether silicate weathering and associated carbonate burial of the erosional products derived from the collapsed Grenville Orogen provided an additional first-order driver. The volume of crust in a LHO is immense, and collapse of the Grenville Orogen began >200 Ma before Rodinia break-up, thus providing a mechanism for gradual lowering of pCO_2 prior to the second boost provided by break-up itself. If such a scheme is valid, and given that the Grenville Orogen may have been the first LHO on Earth, it could provide an explanation why Paleoproterozoic supercontinents such as Nuna were not followed by snowball episodes. **(*SY7, Fri. 3:20*)**

Connecting watershed characteristics to lake behavior: Do bedrock and vegetation influence the stability of subalpine lakes in response to storm events?

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This project investigates the potential links between the thermal stability of small subalpine lakes in the western Maine mountains and watershed characteristics. Located along the Appalachian Trail at elevations greater than 600m, these headwater lakes have small watersheds hosted in granitic or metamorphic bedrock and varying vegetative cover. Beginning in 2007, high-resolution water temperature data has been collected year-round at these sites having thus revealed diverse patterns of thermal stability during the summer season. Some lakes are strongly stratified throughout the season, while others are susceptible to wind-driven mixing associated with storm events. During these mixing events, oxygen and nutrients can be re-distributed throughout the water column with potential implications for changing the ecosystem abruptly. In this project, we will try to better understand which watershed characteristics (bedrock, size, vegetation) promote lake stability and which characteristics are associated with lakes the mix more frequently.

Using available temperature data, we have characterized the response of the lakes to typical summer storms (stable, partial mixing, or full mixing) as an indicator of thermal stability. This stability is compared to a complementary suite of water chemistry measurements, local bedrock, and watershed vegetation. Of particular interest is the relationship between dissolved organic carbon (DOC) and watershed characteristics because high DOC typically corresponds to greater thermal stability. High DOC values are associated with lower secchi transparencies and are also associated with lakes with lower average pH values. The vegetation in the watersheds was classified as hardwood or softwood dominated, which was then compared to the pH level and DOC within that lake. Lower average pH values are correlated with softwood watersheds compared to lakes in hardwood-dominated watersheds. There is a weak correlation between watershed bedrock and lake DOC. Lakes situated in sandstone and shale watersheds were associated with higher DOC values compared to the lakes in granite or granodiorite watersheds. It is possible that different combinations of characteristics determine the stability of different locations. The preliminary results suggest that a better understanding of major controls on headwater lake chemistry could facilitate forecasting the future stability of these lakes in response to large events (storms) and climate warming. **(*SS22, Poster*)**

Keynote (40 min): Identifying new vectors to hidden porphyry-style mineralisation

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Intrusion related (*e.g.*, porphyry) deposits are the most important sources for Cu, Mo, W and Sn, along with Au, Ag, and PGEs. Porphyry deposits are large, low- to medium-grade deposits in which mineralisation is hosted within and immediately surrounding distinctive intrusive phases within larger intrusive complexes that commonly have prolonged emplacement histories. To develop more effective exploration criteria to identify and evaluate deeply buried and/or hidden fertile intrusive mineralizing systems, studies into Cu-Mo/Au and W-Mo-Sn systems are aimed at answering the following questions: i) Are there distinctive proximal and distal footprints for each deposit type that will allow identification of, and vectoring towards hidden economic deposits?; ii) Is there evidence of fertility within the root system of intrusions, *i.e.* what are the triggering conditions and indicators of an hydrothermal-magmatic system of size and duration sufficient to develop a large porphyry deposit? To help answer these questions studies are being undertaken at sites associated with the Triassic-Jurassic porphyry deposits of the British Columbia interior and for the array of mineralised Canadian Appalachian Siluro-Devonian intrusions, for which the fundamental geoscience knowledge is often lacking.

A common problem facing Cordilleran and Appalachian exploration is how to detect intrusion-related mineralization through the extensive glacial sediment cover. Consequently, research activities are focussing at identifying key geochemical and mineral indicators in till near known mineralization and their detrital dispersal down-ice. Indicators are being developed for the detection of mineralization, but also the alteration halos and vein systems associated with mineralization, which represent much larger exploration targets than the actual economic orebody itself. Once identified in till, these indicators can be traced to their bedrock source using reconstructed ice movement vectors.

Structural relationships indicate that Sn – W – Mo mineralised intrusive systems can form due to extension associated with far removed non-orthogonal accretion. Deposits within these bodies form along fluid pathways such as the intersection of high-angle syntectonic breaks. Mineral potential can also be resolved through trace element fingerprinting. Subtle compositional changes in commonly occurring minerals (*i.e.*, biotite) and fluid inclusions provide evidence of chemical variations related to magma fertility and vectors to mineralisation. **(*SS3, Wed. 8:00*)**

Gold Sniffing: The design of a portable device for *in situ* measurement of particulate gold and its application in exploration

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The Gold Sniffer™ is a unique reflectance-based, hand-held, portable instrument with the ability to detect micron-sized native gold grains *in situ*. In this presentation, the theoretical basis for the instrument, along with its potential application in field-based settings are discussed. The Gold Sniffer™ is comprised of three components: a Canon MP-E 65 mm macro lens, and LED illumination ring, a Foveon F13 CMOS image sensor, and a DaVinci ™ microprocessor coupled to a 15 cm × 10 cm LCD screen. For heat dissipation and to facilitate use in a typical exploration environment, these components are mounted in a dust- and moisture-resistant aluminium housing. The Foveon chip has 14.1 MegaPixels which, when combined with the Canon MP-E 65 lens with 5X magnification, is capable of analysing a region of interest (ROI) of 10 mm^2 with a spatial resolution of 1.5 µm^2. When the magnification is doubled with a Canon EF 2× III lens extender, the ROI decreases to 2.5 mm^2 but with an increased resolution to 0.75 µm. The DaVinci TM microprocessor displays the location and habit of detected gold grains coupled with a numeric quantification of the percent area gold. In order to evaluate its applications and limitations in natural settings where gold is commonly in association with minerals of similar reflectance (*i.e.* pyrite), split core from a variety of gold-mineralized settings where gold concentration ranges from below detection to >30 ppm will be analysed. The initial sites to be investigated will include paleoplacer (Pardo, Ontario), iron-formation hosted vein and disseminated Au (Musselwhite mine, Ontario), and an Archean, volcanic-hosted, orogenic-type deposits (Hemlo mine, Ontario), but sediment-hosted and intrusion-related deposits will also be part of future studies. Since Carlin-type ore is commonly characterized by gold-in-pyrite solid-solution (*i.e.* “invisible gold”), this deposit type, although important, is not suitable for this method. Initially, large (≈15 cm x 15 cm) polished thick-sections will be analysed first by the Gold Sniffer™ then carbon coated and characterized using SEM-EDS imaging. With satisfactory completion of the SEM data comparison, the Gold Sniffer™ will then be applied to the remaining unpolished core which will represent a more realistic scenario expected in a field setting. To-date, all core acquired for this project has been split, with the absent half being sent for fire-assay analysis providing a reference for both the SEM and Gold Sniffer™ data. **(*SY5, Thurs. 10:40*)**

Keynote (40 min): The volcanic setting of VMS and SMS deposits: From the modern ocean floor to Archean examples

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Volcanogenic massive sulfide (VMS) deposits and seafloor massive sulfide (SMS) deposits are "strata-bound accumulations of sulfide minerals that precipitated at or near the sea floor in spatial, temporal and genetic association with contemporaneous volcanism" (Franklin *et al.* 2005). The control exerted by the volcanic succession (*e.g.*, rock type, architecture and facies) on the nature and style of the ore and alteration (*e.g.*, subsea-floor replacement *vs.* exhalative, conformable *vs.* discordant) is major, making it primordial to better understand volcanology in developing genetic and exploration models. Three groupings which likely cover a good proportion of cases are discussed.

First, complexes of submarine felsic domes, cryptodomes and/or blocky lavas, and their reworked equivalents, are often spatially associated with VMS and SMS deposits, especially of the bimodal-mafic and bimodal-felsic types. In addition lobe-hyaloclastite flows, which are areally more extensive and associated with lesser proportions of hyaloclastite than domes, can also be associated with VMS deposits. The facies architecture of felsic domes and lavas is well known, relatively simple, and distinctive. A felsic dome is limited in size and the spatial association with an ore deposit should therefore be clear on maps and cross-sections, not only on interpretative sketches. Five series of examples are reviewed in this category, ranging in age from modern to Archean: Manus Basin; Hokuroku district; Iberian pyrite belt; Skellefte district; Abitibi greenstone belt.

Second, some SMS and VMS deposits are associated with submarine, mostly felsic, calderas. Demonstrating a caldera association in ancient successions can be difficult. There is a scale challenge: silicic calderas tend to be large, so a regional study is necessary to identify one. Good exposure is therefore essential, which is not always the case, and major structural complexities can hamper the recognition of potential caldera complexes in ancient successions. Moreover, there is no consensual facies model showing what a submarine caldera should look like, since such volcanoes are not particularly well studied, and there are several types. But without thick piles of pumiceous felsic volcaniclastic deposits of explosive origin, arguing for a large submarine caldera remains a challenge. The two convincing examples reviewed here come from the modern Isu-Bonin arc and the Ordovician of northern Maine.

Finally, it is important to stress that several VMS deposits are not associated with felsic footwalls. Canadian examples of VMS deposits associated with mafic to intermediate footwalls include the ~300 Mt Windy Craggy deposit (BC) and the Corbet deposit (QC). **(*SS6, Thurs. 8:00*)**

Keynote (40 min): Magnitude estimates from paleoseismic carbonate faults

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Earthquakes are dynamic slip pulses that propagate along fault surfaces, emanating seismic waves. The majority of energy released is expended in heating and breaking of rocks along the fault. The fracture damage is linked to transient stress conditions at the rupture tip which only exist during dynamic slip, while the frictional heating depends on high velocity slip to generate heat energy faster than it can be dissipated, causing a temperature increase. Extensive damage and alteration should result, creating an unambiguous geological record, but in fact, there are few unequivocal indicators for past seismic slip. Previously, pseudotachylyte (melt formed when frictional heating exceeds the solidus) was the only accepted evidence, and recently more indicators of “fossilized earthquakes” have been proposed.

Temperature spikes in shallow crustal carbonate rocks can cause calcining (decarbonation) before the melting point is reached. In the Naukluft Nappe Complex, Namibia, the basal thrust fault emplaced Neoproterozoic Damara Sequence carbonates and clastics over the Cambrian Nama Group foreland basin carbonates and shales. The fault displays a regionally-extensive, characteristic dolomitized fault core and alteration zone overprinting wall rock carbonates and shales. We used differential GPS to trace the well-exposed Naukluft thrust fault over 10s km of outcrop and mapped ramping and flat regions along the fault. In regions where carbonate rocks occur in both hanging wall and footwall, the fault core is composed of a distinctive dolomite gouge, the “gritty dolomite”. This rock is characterized by spherical monocrystalline dolomite grains, euhedral magnetite, euhedral albite and sanidine, and particulate cements of calcite and mixed silicates. The gouge layer ranges from a centimeters to meters thick, and local internal banding suggests that the fault deformed granular flow. Around the fault ramps, giant injections of this dolomite gouge extend up to 70 m into the hanging wall.

We interpret this unusual fault rock to have been formed during seismic slip on the Naukluft Thrust. Carbonate thermal decomposition at >800°C left reactive calcium, magnesium and iron oxide particles and hot pressurized CO_2 gas. Breakdown of trace clays (at around

600°C) released alkalis, silica and supercritical water. The supercritical CO_2 and water facilitated fluidization of the granular gouge, and the reactive particles crystallized to magnetite, feldspars and carbonate cements. From injectite dimensions and positions we calculate the slip distance required to produce enough gases to drive injection and infer that these injections formed in an earthquake of Mw4-5 or higher. **(*SY2, Thurs. 10:20*)**

Earthquakes in mud – Insights from drilling into the Japan Trench after the Mw9.0 Tohoku-oki Earthquake

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The March 11, 2011 Tohoku-oki Earthquake displayed a different style of rupture than all other great earthquakes in the last century. The slip increased from ~25 m at the hypocenter up to >50 m at the seafloor. The extreme deformation of the seafloor contributed to the devastating tsunami. This slip distribution defies the existing paradigm that the accretionary wedge is too weak to contribute strain energy to the earthquake and frictionally strong, retarding slip. In 2012, IODP Expedition 343/343T drilled the toe of the accretionary wedge in the Japan Trench, 200 km east of the Sendai coast, to investigate the local conditions which might be responsible for the unusual slip.

The three boreholes – one for coring, one for geophysical sensing, and one for a temperature observatory – intersected the plate boundary fault at ~820 m below the seafloor in 6.9 km of water. The accretionary wedge is composed of offscraped late Miocene to Pleistocene hemiplegic sediments from the Pacific Plate, which are too tightly folded and faulted to image their structure using seismic refraction. Below the plate boundary fault, thin horizontal imbricates of the lower stratigraphic section of Pacific Plate sediments lie over chert and basalt.

The plate boundary fault runs within a sliver of basal Pacific pelagic brown clay <5 m thick, from which we recovered 97 cm of intact core. Thermal observatory measurements detected a heat signal at the approximate depth of the clay layer, although they do not have the spatial resolution to determine the thickness of the earthquake rupture surface. This clay is characterized by a unique scaly cleavage different to all other deformed mudstones in the core, and a sharp, hairline-thin fault. The fault contains a 5-µm layer of melted clay, which may be a pseudotachylyte.

Frictional tests on the recovered clays indicate bizarre properties, including extremely low shear resistance at both slow and high speeds. These properties are consistent with extreme localization during seismic slip, but very rare propagation of slip all the way to the trench. The particular properties of this clay caused the increasing slip to the trench in the Tohoku Earthquake. This clay underlies much of the sedimentary pile on the northern Pacific Plate. At any plate boundary where the tectonic evolution of the forearc leads to plate boundary faulting within this pelagic clay layer, we hypothesize that rare, exceptionally devastating tsunamis may be a fundamental part of the seismic cycle. **(*SY3, Thurs. 2:40*)**

Structural and tectonic controls on Devonian intrusion related mineralisation on the Connaigre Peninsula, NL

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The Canadian Appalachians represent an archetypal ancient, accretionary orogen the study of which has played a substantial role in developing modern geological concepts. From the initial simplistic models of a mountain belt deriving from the closure of the Iapetus Ocean, our understanding has evolved, recognising a richer, more complex geological history. Current models define multiple collisions between arcs and microcontinents due to the closures of interposed oceans and seaways. Delineating specific tectonic events provides context to the various periods and styles of mineralisation produced, which in turn can define new exploration models for the next generation of deposits.

One of the least understood deposit types in the Canadian Appalachians are the Devonian granitoid intrusion-related Sn – W – Mo mineralisation. The Connaigre Peninsula was selected to study such deposits as it contains a variety of supracrustal units plus (apparently) barren and mineralised intrusives within a relatively constrained and accessible area. The distributions of the main lithotectonic packages indicate three distinct tectonic blocks that were amalgamated by the Middle Devonian, and subsequently intruded by Upper Devonian granitoids concurrent with clastic sedimentation.

The *c.* 376 Ma Old Woman Stock contains several known Mo occurrences. Molybdenite is disseminated and associated with vugs containing dog-tooth quartz, and intense alteration zones (up to 5 cm wide) are localised along north – south to north-west – south-east trending joints. The distribution of deposits demonstrates a potential linkage between regional structures and the localisation of mineralisation. At the large scale, the Connaigre Peninsula in the Upper Devonian is interpreted to be in extension associated with far removed non-orthogonal accretion of other peri-Gondwanan elements to composite Laurentia. It is notable however that the mineralisation does not occur at a major fault, but rather at the intersection of a prominent north-east to south-west lineament and well-developed north – south to north-west – south-east jointing. The implication is that the high-angle intersection of breaks that are contemporaneous with intrusion but have relatively little motion provide ideal pathways for mineralising fluids.

In contrast to the Old Woman Stock, the adjacent, approximately coeval to slightly younger Belleoram Granite is apparently barren. It remains unclear why the Belleoram Granite contains no known Sn – W – Mo mineralisation. Possible explanations include: i) its hybrid nature makes it compositionally unsuitable; ii) it formed at too shallow a crustal depth; or iii) it was too "dry" and did not develop fluid pathways. **(*SS3, Poster*)**

Thermal modeling of clast assimilation and metamorphism within superheated impact melt

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Clasts of various lithologies that have been incorporated into the superheated (>1700°C) impact melt sheet of the Manicouagan impact structure show a complex cooling history. In some cases clasts will be almost completely assimilated into the melt sheet, showing near identical properties with the melt; while other clasts may retain indicators of shock metamorphism, including planar deformation features in their cores, with melting and early stages of assimilation around the rim. Factors affecting this transition between complete and partial melting include: (1) size, small clasts (<1m diameter) tend not to exhibit shock features, while large clasts (>1m diameter) tend to retain shock features; (2) lithology (*e.g.*, gneiss clasts tend to retain evidence of shock, while anorthosite clasts tend to be completely thermally annealed; (3) time spent in the melt (the longer clasts are exposed to the melt, the more complete the melting); and (4) location within the impact structure (clasts sourced from the centre of the crater will have been more shocked, while clasts sourced from the periphery will have experienced less shock damage). These factors are taken into consideration in creating a computer model of the rate of melting in order to determine the size evolution of clasts in time-space. This presentation will describe the processes involved in creating the model, and demonstrate the applications of the final product. The goal is to better understand clast-melt relations for superheated systems, with implications for impact melt evolution after initial formation. **(*SS21, Thurs. 2:40*)**

Metal zoning at the Greens Creek volcanogenic-hosted massive sulfide deposit: Constraints on the formation of the deposits

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The Greens Creek volcanogenic massive sulphide (VMS) deposit is located on northern Admiralty Island, southeastern Alaska, and is hosted within the Admiralty subterrane of the Alexander terrane. Significant VMS deposits in these rocks, such as Windy Craggy and Greens Creek, are linked to Late Triassic rifting of the eastern margin of the Alexander terrane. The global resource at Greens Creek is approximately 24 million tonnes at an average grade of 14% Zn, 5% Pb, 600 g/t Ag and 5 g/t Au; copper is not reported. The Greens Creek area has been metamorphosed to lower greenschist facies and complexly deformed by at least five ductile deformation events and one brittle event. The Late Triassic ore is typically underlain by Mississippian mafic volcanic rocks; in some locations a thin Late Triassic conglomerate is present. The stratigraphic position of the deposit is immediately above an approximately 100 Ma unconformity and the metal endowment is contrary to accepted VMS models, making Greens Creek an unusual VMS deposit.

Metal zoning studies of two ore bodies from the Greens Creek deposit as well as the stratigraphic footwall beneath them, were undertaken to determine their physicochemical conditions of formation and the spatial relationship between the ore bodies and their footwall alteration/stringer zones. Metal zoning in both ore bodies and their immediate footwall is coincident, demonstrating there has been no significant displacement of the ore bodies relative to the footwall alteration/stringer zones. The footwall stringer zone to the Northwest West (NWW) ore body is Cu-rich throughout with Zn, Pb and Ag enrichment on the margins. The footwall alteration zone to the East ore body is Cu-poor and Ag-rich throughout with moderate Zn and Pb content. High Cu ratios (100*Cu/Cu+Zn>20) with coincident moderate Zn ratios (100*Zn/Zn+Pb<70) within the footwall outline feeder zones that are elongated north – south, subparallel to the Maki Fault Zone. In the footwall to both ore bodies, Cu is largely associated with quartz-pyrite alteration and Zn, Pb and Ag with sericite alteration. Morphology and zone refining of the NWW ore body combined with alteration zonation and the Zn and Cu ratio within the footwall feeder zones are all consistent with the NWW ore body forming at temperatures of approximately 200°C from a relatively prolonged and focused vent source. Similar lines of evidence from the East ore body suggest it was formed at a lower temperature from a diffuse vent source of shorter duration. **(*SS14, Fri. 10:20*)**

An integrated geochronological, petrological, geochemical and paleomagnetic study of Paleoproterozoic and Mesoproterozoic mafic dyke swarms in the southern Nain craton, Labrador

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Nain craton comprises the western, Labrador segment of the larger North Atlantic craton (NAC) which exposes a significant expanse of Early through Late Archean gneisses. Owing to excellent coastal exposures and a growing amount of modern U-Pb geochronology, correlation of some individual terranes between the Labrador and south Greenland portions of the NAC are possible, aided to some extent by a limited amount of relative drift between the two blocks since the Mesozoic. Bounded on all sides by Paleoproterozoic collisional orogens that involved either considerable structural reworking (Torngat-Nagssugtoqidian-Lewisian) or the accretion of juvenile arc magmas (Ketilidian-Makkovik), the affinity of the NAC landmass to other Archean crustal blocks now dispersed globally remains an important but poorly understood issue. Compounding this problem is a lack of reliable paleomagnetic poles for NAC units that predate its assembly into supercontinent Laurentia by *ca.* 1800 Ma, which could be used to test nearest-neighbor relationships with other cratonic fragments.

In order to understand the history of the NAC as part of a possible, larger supercontinent, we are examining the record of mafic dyke swarms affecting the craton, particularly those which postdate Late Archean terrane assembly but predate Paleoproterozoic Trans-Hudson amalgamation into the Laurentian landmass. Diabase or gabbroic dyke swarms are invaluable in such studies because their geometries offer possible piercing points, they often have a punctuated emplacement and precisely datable crystallization histories, and because they have cooling histories and oxide mineralogy amenable to recovering robust paleopoles. Coastal Labrador exposes an innumerable quantity of mafic dykes, some of which are demonstrably Paleoproterozoic (*e.g.* 2235 Ma Kikkertavak dykes; 2121 Ma Tikkigatsiagak dykes), or Mesoproterozoic (*e.g.* 1280-1270 Ma Nain and Harp dykes) in age (U-Pb; baddeleyite or zircon). Despite this, the ‘magmatic barcode’ of diabase dykes in Nain craton remains very poorly defined, hindering reconstruction with other Archean blocks that might share a common record due to former proximity or breakup history. The southern half of Nain craton (Hopedale block) in particular preserves an incredibly rich array of mafic dykes ranging from pyroxenitic to olivine- and quartz-tholeiitic compositions, with thicknesses up to over 100 meters, and dominant trends which strike N-S to NE, E-W, and NW-SE. Dyke intersections are numerous and relatively well-exposed, permitting multiple opportunities for paleomagnetic field (*e.g.* baked contact) tests. We present some initial results from this program with implications not only for strengthened Labrador-Greenland correlations, but for testing possible Paleoproterozoic supercontinent reconstructions. **(*SS17, Wed. 9:20*)**

Proterozoic black shales: A source of S and semi-metals for the formation of Cu-Ni-PGE magmatic deposits

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Many black shale units close to magmatic nickel-copper-PGE (Platinum Group Elements) rich intrusions are thought to be the source of sulphur and semi-metals in the ores. Contamination of a magma by country rock is thought to be essential to form magmatic Ni-Cu-PGE deposits.

The Duluth Complex (Minnesota, USA) represent an interesting example for studying the contamination processes. Many intrusions in the Duluth Complex, such as Partridge River Intrusion, are surrounded by sedimentary rocks of the Virginia Formation. Bedded Pyrrhotite Unit (BPU) in the Virginia Formation consists of black shales with sulphide-rich beds. In contrast to PGE-rich Devonian black shales the Proterozoic BPU black shales are PGE-poor. Furthermore, BPU black shales contain less Ni and Cu than average black shales.

Black shales in the BPU outside the contact aureole contain mainly pyrite whereas inside the aureole they contain various sulphur minerals, such as pyrrhotite and chalcopyrite. Presence of chalcopyrite requires Cu, and its source is currently unknown. In the less metamorphosed zones of the contact aureole framboidal pyrite is found. In the more metamorphosed parts of the contact aureole, pyrite has been transformed to pyrrhotite. BPU black shales are enriched in semi-metals (As and Sb), have S/Se ratios greater than 20000 and an average $\delta^{34}S$ of 18‰.

Contamination processes occur in the basal part of the intrusion, close to the contact with BPU black shales units. Some fragments (xenoliths) of BPU are found inside the magma as a consequence of thermal erosion of the Virginia Formation during emplacement of the intrusion. BPU xenoliths in the magma are thought to be responsible for the sulphur and semi metals contamination of the magma. Progressive decrease in the S/Se ratios and $\delta^{34}S$ is recorded from the contacts to the interior of the intrusion. BPU xenoliths trapped in the magma contain mostly pyrrhotite, chalcopyrite and pentlandite sulphide assemblages. Gabbronorites close to xenoliths are enriched in semi-metals and an increase in the S/Se ratios and $\delta^{34}S$ values occurs in gabbronorites surrounding fragments of BPU. Contamination of the magma in sulphur and semi-metals is the result of melt transfer from xenoliths into the mafic magma as the xenoliths undergo partial melting. In conclusion, black shales of BPU are the source of contamination of the magma in semi metals and sulphur essential for the formation of Ni-Cu-PGE deposits in the Duluth Complex. **(*SS2, Wed. 8:40*)**

Geochemical composition, structure, stratigraphy, and U-Pb geochronology of the Williams Brook area, Tobique-Chaleur zone northern New Brunswick: Implications for interpreting geotectonic setting and formation of gold mineralization

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Low sulfidation epithermal-style gold mineralization occurs within Siluro-Devonian bimodal volcanic and sedimentary rocks of the Tobique-Chaleur zone in northern New Brunswick. Geotectonic discrimination diagrams show transitional (calc-alkaline/alkaline to tholeiitic) and A-type signatures. Such compositions indicate a transpressive tectonic setting and suggest that oblique convergence of Gondwana and Laurentia as driving force for basin formation and coeval magma generation. High field strength element lithogeochemical data indicate a bimodal distribution. Variations in Nb/Y *vs.* Zr/TiO_2 show that mafic volcanic samples plot in the andesite/basalt and andesite fields, whereas felsic volcanic samples plot in the rhyolite field. In the study area gold mineralization is associated with felsic units (first stage mineralization); flow-layered rhyolite, and rhyolite porphyries that are interlayered with grey laminated siltstone and cross-cut by an eruptive polymictic rhyolitic breccia. These units are cross-cut by andesitic/basaltic subvolcanic intrusions and overlain by andesite-basaltic flows. U-Pb (zircon) dating of felsic volcanic rock from the Williams Brook area yielded an age of 398.7±1.9 Ma; assigning these rocks to Early Devonian Wapske Formation (Tobique Group).

Regional strike is NE-SW; however, drill core logs and regional mapping show a possible parasitic anticline structure associated with a regional anticline, which is consistent with dextral movement along the Rocky Brook-Millstream Fault and its splays, *e.g.*, the McCormack Brook Fault (located north of the study area). Gold mineralization also occurs in quartz veins (second stage mineralization) that cross-cut the rhyolitic breccias are also consistent with a dextral movement (contraction NW-SE and extension NE-SW) as their orientation is oblique to the host rocks (NW-SE).

Molar alkali-alumina ratio analysis from the felsic volcanic rocks suggests that most of the rocks in the area have undergone limited hydrothermal alteration, consisting of weak potassic alteration (slight K_2O and Na_2O depletion), and minor albitization.

Williams Brook shares characteristics such as tectonic setting, host rocks and style of mineralization and alteration with low sulfidation epithermal deposits, *e.g.* Round Mountain in Nevada. Likewise, two main types of mineralization styles are present, including higher tonnage but lower grade disseminated gold and lower tonnage higher grade quartz veins, similar to those at Round Mountain. Stable isotopic data (oxygen and sulfur) and temperature of formation of the McLaughlin low sulfidation deposit in California, also very similar to that of the Williams Brook area.

This study suggests that similar structural settings within the Siluro-Devonian volcanic and sedimentary formations of the Tobique-Chaleur zone may be prospective for low sulfidation epithermal-style gold mineralization. **(*SY5, Poster*)**

Petrogenesis of the low sulfidation gold mineralization on the Williams Brook area, Tobique-Chaleur zone, New Brunswick: Mineral-chemical and stable isotopic evidence

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Low sulfidation epithermal style gold mineralization occurs within Siluro-Devonian bimodal volcanic and sedimentary rocks of the Tobique-Chaleur zone in northern New Brunswick. Gold mineralization is associated with felsic units; flow-layered rhyolite, rhyolite porphyries and polymictic rhyolitic breccias. Two types of mineralization have been recognized in the Williams Brook area. The first is interpreted to be early and consists of gold and galena with pyrite occurring as disseminations along muscovite/illite veinlets in weakly potassically altered rhyolite porphyries. The second is a later stage and consists of quartz veins containing minor supergene oxyhydroxides, such as jarosite, hypogene sulfides (sphalerite, galena), and native gold. Oxygen isotopes obtained from quartz and muscovite within the mineralized quartz veins yield an approximate deposition temperature of 200°C, and the calculated $\delta^{18}O$ of H_2O (+11.74‰) is consistent with magmatic fluids. Calculation of $\delta^{34}S$ from the mineralizing fluid (H_2S) for sphalerite and pyrite are +0.45‰ and +1.79‰, respectively, also consistent with a primary magmatic sulfur source. Mineral assemblages suggest a near neutral pH mineralizing fluid (muscovite and K-feldspar buffered), low $f\,(O_2)$, high $f\,(S_2)$, at a temperature of 200°C. Gold and sulfide deposition is interpreted to be a product of an increase in $f\,(O_2)$, via mixing of hydrothermal fluids with oxygenated meteoric waters.

Quartz veins are zoned in terms of $\delta^{18}O$, with values of 15.5 and 15.6‰ from the vein margins and heavier values of 16.2‰ from the vein core. Likewise, δD varies across the quartz vein with values of -66 to -88‰ on the margins to a value of -96‰ in the vein core. This variation suggests meteoric water influence during vein growth. Three generations of quartz were identified using SEM cathodoluminescence imaging. Jigsaw puzzle-like and cobweb-like textures were identified; these textures indicate brittle failure due to pressure fluctuations, *i.e.*, dilatants quartz veins. Electron microprobe analysis was performed on pyrite, sphalerite and galena. In the early-stage mineralization, Au is associated with a decrease in Cu and Se and on the rims of pyrite with values of 1218g/t. Gold in pyrite from the second mineralization style was not detected; however, visible native gold was found on hand samples. Silver is associated with the rims of sphalerite from the late stage mineralization and reaches values of 28g/t. Antimony and Se were also higher in the rims of sphalerite.

Mineral-chemical and stable isotopic evidence supports the interpretation that mineralization in the study area is part of a low sulfidation epithermal-style mineralizing system. **(*SY5, Thurs. 3:20*)**

The unique mineralogy and geochemistry of historical Roast Yards

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The historical Roast Yards in the Greater Sudbury area, Ontario, Canada are a heritage of the early ore processing in Canada. The Roast Yards operated between 1888 and 1923 and were used to reduce the sulfur concentrations in the ore through its open-air roasting for nearly seven months. Common features in the Roast yards were layered roast heaps, which ran parallel to train tracks. Remnants of the roast heaps are piles of slag and rocks which are surrounded by zoned alteration halos of different mineralogical and chemical composition. The slags and rocks are composed of a unique combination of sulfides, oxides, silicates, hydroxides and sulfates. **(*SY6, Fri. 8:40*)**

Uranium mineralogy on the nanometer scale: Precipitation of uranyl-phases within confined pore spaces

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The disposal of U-containing waste has to consider a host of issues including dissolution-precipitation processes on vitrified waste or spent fuel or the interaction of released radionuclides with Fe- and silica-rich materials such as steel canisters, the host rocks of the repository (volcanic formations or granitic bedrock) and barrier materials such as clay minerals and Fe-hydroxides. The surfaces of these materials and their solution interfaces play an important role in directing the dissolution and precipitation of uranium phases. As disequilibrium between interfacial environments and bulk solution is often the norm, not the exception [1], interfacial processes involving radionuclides and altered silica- and Fe-rich materials are difficult to model and must be thus examined in natural settings. In this regard, a Transmission Electron microscopy (TEM) study was conducted to explore the formation mechanism of U-bearing phases within confined pore spaces of surface coatings on Fe-hydroxide and silicate grains. The latter mineral grains have been collected in the surficial sediments of the U-mine tailings in the Athabasca Basin, Northern Saskatchewan (contact pH value ~ 6.5). Although almost all tailings in the basin have U-concentrations of a few hundred ug g-1 or less, a very small and limited area at the Key Lake mine site contains numerous uranyl minerals formed through interaction of mill process solutions with tailings material [2]. The TEM study shows that the formation of nanometer-size uranyl minerals within confined pore spaces is mainly controlled by the presence of oxy-anions adsorbed to surfaces of clay and Fe-hydroxide minerals and indicates that the mobility of potentially released U-species in a nuclear waste repository may be limited by oxy-anion loaded active barriers in accordance with previous experimental studies [3]. **(*SS8, Thurs. 2:40*)**

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[3] Singh, A., Catalano, J.G., Ulrich, K.U., and Giammar, D.E., 2012. Molecular-Scale Structure of Uranium(VI) Immobilized with Goethite and Phosphate. Environmental Science & Technology **46**, 6594-6603.

Reappraising the Neoproterozoic 'East Avalonian' terranes of southern Britain

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Neoproterozoic basement terranes of 'East Avalonian' southern Britain are largely predicated on the presence of first-order faults and lineaments. This premise is reviewed here in the light of a compilation of modern geochronological data from Neoproterozoic igneous rocks as well as whole-rock Nd- and O-isotopic data.

These data highlight two broad groupings. The basement to Anglesey and NW Wales, within the Menai Strait Fault System and the Fenland Terrane of Eastern England, is characterised by a dominant phase of magmatism at around 615 Ma with εNd between -7.5 and -1.3 and TDM between 1868 Ma and 1269 Ma, indicating a largely ensialic setting in which older crustal source components were important. The $\delta^{18}O$ values ranging from +7.5 to as high as +13.5 ‰ are in the range of those expected from calc-alkaline rocks with a possible contribution from sedimentary sources.

Conversely, the basement inliers exposed in Wales and the English Midlands, previously assigned to the Cymru, Wrekin and Charnwood terranes, preserve a spread of ages between about 710 Ma to 566 Ma with an apparent hiatus between 675 Ma and 643 Ma, and conspicuous absence of rocks with *ca.* 615 Ma ages. εNd between -2.0 and +3.5 and TDM between 1507 Ma and 994 Ma overlap with the other grouping but tend toward younger and less dominant crustal source components. The $\delta^{18}O$ values of +7.7 to +10.1 ‰ are within the range of calc-alkaline rocks, with little contribution from sedimentary sources.

Previous interpretations have considered the southern Britain basement equivalent to West Avalonia of the northern Appalachians orogen. However, comparison with isotopic signatures of basement rocks in the northern Appalachians shows that the British basement has more in common with ensialic Ganderia than with the oceanic-arc successions that are inferred to underlie West Avalonia. **(*SY1, Wed. 10:20*)**

Magmatism and extension in the outer trench slope and near-trench region of collisional/convergent systems

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The outer slope region of active plate convergent and continental collisional zones may develop extensional fault systems during approach to the trench or foreland basin axis, and during underthrusting beneath the overriding accretionary wedge. The more common development is of an asymmetrically-dipping system of normal faults approximately parallel to the trench or foreland basin axis. Less common is the occurrence of localized rifts at a high angle to the foreland basin axis. Alkali basalt magmatism in modest volumes in association with this extension is well known for recent examples of high-angle rifts, for instance the Rhine Graben. The trench-parallel systems have only one possible young (and very localized) example of associated magmatism identified in the present oceans, the “petitspot” volcanoes off northern Japan, although it may be argued that this is instead an example of a high-angle rift, as the faults on which the volcanics occur are significantly oblique to the nearby trench and to most of the regional outer slope fault array. In contrast, in old orogens several examples of foreland basin-parallel outer slope magmatism can be identified, the Acadian of Maine and adjacent Canada being one where large volume magmatism occurred. Others of smaller volume are the Jonestown and Starks Knob occurrences in the Laurentian Taconic foreland, and a mid-Proterozoic example, the Flaherty Formation of the Belcher Islands in the foreland basin outer slope of the northern Superior margin. The basalts of these sequences are mostly of enriched MORB parentage, but range locally from MORB to alkali basalt, and show variable evidence of continental crustal contamination. In these old examples, limited preservation and later deformation may prevent identification of which kind of extension was associated with the magmatism but, in the case of the Maine Acadian, it is clear that there were trench-parallel faults and large dikes. Such magmatism is significant in that it shows whole-lithosphere extension of the down-going plate in response to slab-pull forces, not just minor flexural extension of its upper part. The large variation in scale of magmatism between our identified examples may have resulted from differences in the rate of plate convergence and/or include mechanical differences in lithospheric strength, in Maine perhaps related to effects of Ordovician accretionary tectonics. **(*SY3, Fri. 8:00*)**

Unlocking big opportunities in small packages: Application of novel SEM imaging techniques and nano-scale HRTEM studies to enhance mineral exploration and mining efficiency

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Mineral exploration is an exceedingly expensive endeavor for mining companies. Any tool that routinely increases exploration or extraction efficiencies has the potential to create economic returns of millions of dollars. The *in situ* characterization of minerals associated with ore zones and geochemical anomalies is one such tool. The knowledge of how gold occurs within sulphide minerals (*e.g.*, in the lattice or as nano-particles) is of great importance to mineral exploration and mining companies in order to define effective exploration and extraction methods. Bulk rock and microprobe analyses alone lack the spatial resolution and sensitivity necessary to accomplish the required level of characterization. We present a suite of advanced SEM/TEM techniques and FIB technologies that can be applied in a sequence and in a short time. Two samples from the Timmins-Porcupine gold camp (Canada) and the Witwatersrand gold/uranium deposit (South Africa) were subjected to high-resolution large area SEM-BSD imaging, microprobe analyses, FIB milling, and subsequent HRTEM investigations. Samples from the Timmins camp contain free gold as well as gold inclusions in pyrite. The gold in the Witwatersrand samples is associated with pyrite and uraninite in certain conglomerate horizons that are enriched in solidified bitumen. The samples were imaged with the large area SEM imaging tool AtlasAT, which provides a comprehensive and fast means to observe images on a SEM system at very high resolutions and to acquire multi-image mosaics of large areas (entire petrographic thin sections). The obtained image mosaics were combined with microprobe elemental maps and regions for FIB foil extraction were identified. The HRTEM analyses on the Witwatersrand sample revealed that uraninite and gold crystallization occurred (at different stages) during liquid oil and water intermixing, a finding that was not known yet. The sequence of techniques used in this study enabled quick and systematic characterization of gold mineralizations from a micro to the nanometer scale in a reasonable time that is of great interest for mineral exploration companies. **(*SY5, Poster*)**

An aqueous sulphide control for hyper-enrichment of trace metals in black shales

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Hyper-enrichment of V and Zn, defined here as concentrations exceeding 1,000 ppm, is common in Late Devonian to Late Pennsylvanian black shales of the mid-continent of North America. With the exception of Zn hyper-enrichment in sediments of Framvaren Fjord, Norway, such enrichments are unknown in modern environments, raising the questions of how hyper-enrichments form and why they are characteristic of mid-continent black shales. Trace metal ratios (*e.g.*, Mo/V, V/Zn, Mo/Zn) are similar among individual basins separated by considerable distances and 10s of millions of years, arguing against local controls such as anomalously slow sedimentation rate or hydrothermal alteration as mechanisms for hyper-enrichment; normal seawater is thus implicated as the source of the metals. Hyper-enriched metals generally track organic carbon concentrations, but organic carbon-rich shales and sediments do not systematically host trace metal hyper-enrichments.

Based on the hyper-enrichment of Zn in Framvaren sediments and experimental work on V enrichment, we argue that trace metal hyper-enrichment is triggered by hyper-sulfidic conditions (>1 mM H_2S) within the depositional environment. In the case of V, hyper-sulfidic conditions are required for the reduction of V^{4+} to V^{3+}. The direct mechanism for Zn hyper-enrichment is unclear. In nearly all cases, V and Zn hyper-enrichments are coupled, meaning that either both or neither is hyper-enriched. Conversely, hyper-enrichments of Mo, Ni, and Cr occur episodically in mid-continent shales. No clear correlation exists among these metals, but their hyper-enrichments are uniformly accompanied by V and Zn hyper-enrichments, suggesting that hyper-sulfidic conditions are at least partially responsible.

Mid-continent black shales tend to be generally thin (1 to 10 m) but are widespread and based on trace metal hyper-enrichments that reflect a ~10-fold increase in burial efficiency relative to modern sediments, they represent a significant sink for trace metals in seawater. The efficient and widespread burial of metals in mid-continent shales raises the question of how to maintain such high enrichments without exhausting the seawater reservoir of dissolved metals. Considering that the Late Devonian to the Late Pennsylvanian witnessed the initial expansion of land plants and subsequent hyper-oxygenation of the atmosphere, it is possible that trace metal hyper-enrichments were triggered and maintained by increased oxidative weathering of continental crust. **(*SS2, Wed. 9:20*)**

Chemical evolution of tourmaline from a granitic pegmatite in the Náátsʼihchʼoh igneous complex, Northwest Territories, Canada

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Tourmaline-bearing granitic pegmatite dikes of the Náátsʼihchʼoh igneous complex (62°46'8.33"N, 128°56'9.07"W) located in the Sapper Ranges of the Selwyn Mountains in the Northwest Territories, Canada were investigated in order to determine the chemical composition of tourmaline as a function of its position within the pegmatite system. The chemical composition of tourmaline adjusts to a wide range of conditions therefore it can be used to interpret the crystallization history of the pegmatite. The mineralogy of all observed components of the pegmatite system was investigated by combining X-ray powder diffraction and SEM analysis. Chemical analysis of tourmaline crystals was completed using electron microprobe analysis and the tourmaline species were named using the scheme developed by Henry *et al.* in 2011. Tourmaline species occur in the parental porphyry, the aplite dikes, the pegmatite dikes, the metasomatised sedimentary host rock and the late quartz veins. By comparing the correlation coefficient of different combinations of elements, it was determined that the chemical composition of the tourmaline varies due to coupled substitution of Si + Mg ⟷Al + Fe + Ti. Different tourmaline species were distinguished as a result of the substitution Na + Ca ⟷□ at the nine-coordinated X site. Crystals of tourmaline in the pegmatite dikes vary in composition from schorl at the rim of the crystal to foitite at the core of the crystal. The sedimentary host rocks have been pervasively metasomatised to dravite and quartz. Crystals of dravite with uvite cores grow into the quartz veins. The overall mineralogy of all components of the system consists of common igneous minerals such as quartz, plagioclase, K-feldspar, biotite and actinolite. There is no evidence of rare-element mineralization. **(*SS20, Wed. 2:40*)**

Isolation of PO_4 from phosphate-bearing minerals and bio-minerals: A revised Ag_3PO_4 precipitation method

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Phosphate (PO_4) extraction methods have been developed over the past 50 years for the purpose of analyzing the oxygen isotopic composition of phosphatic materials. The most significant advancements in phosphate extraction techniques have been the transition from isolating PO_4 as bismuth phosphate ($BiPO_4$) and utilizing fluorination techniques to liberate oxygen for isotopic analysis, to simplifying the extraction process of PO_4 from phosphate-

bearing minerals and bio-minerals and precipitating the radical as silver phosphate (Ag_3PO_4). Unlike $BiPO_4$, Ag_3PO_4 is a more stable, non-hygroscopic material, which is less susceptible to chemical degradation and diagenetic alteration. Therefore, Ag_3PO_4 is the preferred analyte for oxygen isotopic analysis of phosphate-bearing minerals. As a result of decades of research, there are several published methods for the extraction of Ag_3PO_4. Some of these methods produce Ag_3PO_4 of questionable purity. Here we report a rapid and simplified technique for the precipitation of Ag_3PO_4 from inorganic phosphate-bearing minerals such as turquoise ($CuAl_6(PO_4)_4(OH)_8 \cdot 4H_2O$) and apatite ($Ca_{10}(PO_4)_6(F,Cl,OH)_2$, and the organic-rich bio-mineral hydroxyapatite ($Ca_{10}(PO_4)_6(OH)_2$) micro-drilled from tooth enamel and cementum.

Our techniques combine key attributes from the methods of O'Neil *et al.* (1994), Stephan (2000), and Wiedemann–Bidlack *et al.* (2008), and reduce the length of time required for each experiment, without sacrificing purity of the precipitated Ag_3PO_4. For phosphate-bearing minerals such as turquoise and apatite, the technique uses 30% hydrogen peroxide (H_2O_2) for the removal of any organic impurities or contamination prior to complete digestion in 2M hydrofluoric acid (HF). Organic-rich hydroxyapatite from tooth enamel and cementum require additional organic removal steps using a 2.5% sodium hypochlorite (NaOCl) solution for the oxidative removal of organics, followed by the addition of 0.125M sodium hydroxide (NaOH) for the removal of humic material prior to digestion in 2M HF. In both techniques, once the samples were completely digested, the supernatant was transferred to beakers, placed on a hotplate set at 50°C, and titrated with silver ammine solution. Maximum yields for Ag_3PO_4 from each mineral were determined through experimentation and yield calculations. Precipitated Ag_3PO_4 crystals were collected on nitrocellulose filter paper in a vacuum filtration system, and placed in an oven at 60°C overnight. Dried Ag_3PO_4 crystals were characterized using powder X-ray diffraction (XRD) and scanning electron microscopy (SEM) to determine the purity of the precipitated Ag_3PO_4 crystals and ensure organic contamination was completely removed. **(*GS1, Poster*)**

Mass bias corrections for U-Pb isotopic analysis of uraninite by SIMS; Implications for U-Pb geochronology of uranium deposits

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Important geologic information can be gleaned from zoned minerals and cemented intergranular regions using *in situ* measurements at the micron scale. An important breakthrough in this regard was the development of the Secondary Ion Mass Spectrometer (SIMS). SIMS U-Pb geochronology is a well-established technique that has been successfully applied to many minerals (*e.g.* zircon). Problems associated with mass bias, (instrumental mass fractionation (IMF) and matrix effects) are minimized with the use of standards and working calibration curves, which are used to calculate correction factors for the isotopic ratios of U and Pb. These correction factors are used to calculate the “true” U/Pb isotopic ratios in unknown samples. The first applications of this technique to uranium-rich minerals (*i.e.* uraninite) were in the late 1980's and early 1990's. Subsequent studies have tried to emulate the procedures used to correct U/Pb isotopic ratios in zircon and monazite, which often contain ppm concentrations of U and Pb. However, in uraninite, Pb and U are major elements and the techniques that work for zircon and monazite do not work for uraninite. Therefore, SIMS U-Pb geochronology of minerals such as uraninite is in its infancy.

Our preliminary results show that the mass bias for U/Pb isotopic ratios in uraninite varies as a function of Pb content. When using a Cameca 7f instrument configured to minimize interferences (combined mass resolution and voltage offset), the isotopes of Pb are preferentially ionized relative to uranium, and the mass bias correlates with lead content. Based on the observed changes in mass bias, if the Pb content of the standard and unknown are not closely matched, the calculated correction factors are incorrect. Poorly corrected U/Pb isotopic ratios can produce ages that plot above Concordia and ages that are meaningless. For example, if SIMS U/Pb isotopic ratios in uraninite from the Athabasca basin with ~12 wt% PbO, are corrected using a standard with a much lower Pb content (~5 wt%), a younger age is calculated, whereas a correction factor using a high lead (~21 wt%) standard will over estimate the age. Therefore, it is recommended that a working calibration curve that covers a range of Pb contents be used to correct for mass bias. **(*SS7, Wed. 3:20*)**

A combined ingress-egress model for the Kianna unconformity-related uranium deposit, Shea Creek Project, Athabasca Basin, Canada

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The Athabasca Basin hosts the world's highest-grade unconformity-related uranium deposits, which are primarily located in the eastern part of the basin. The Kianna deposit, Shea Creek Project, is located in the western part of the basin. It consists of disseminated to massive uraninite localized in three distinct zones: 1) perched, above the unconformity, hosted in sandstone; 2) at the unconformity, hosted by sandstone and basement rocks; and 3) below the unconformity in two separate pods, hosted by basement paragneiss. Secondary ion mass spectrometry (SIMS) was used to obtain U-Pb ages for uraninite and to measure $\delta^{34}S$, $\delta^{18}O$, and δD to characterize the mineralizing fluid.

Two generations of uraninite are preserved in the main basement-hosted pod (from 50-175 m below the unconformity), the earlier generation is associated with hematite and coarse-grained illite, and formed *ca.* 1450 Ma, whereas the later generation is associated with fine-grained illite and formed *ca.* 1000 Ma. A separate, deeper basement pod (about 230-240 m below the unconformity) is also associated with fine-grained illite and formed *ca.* 1240 Ma. Uraninite intermixed with hematite at the unconformity and perched uraninite, inter-disseminated with alumino-phosphate sulfate (APS) minerals, sulfides, and hematite, formed *ca.* 440 Ma.

Pyrite associated with basement-hosted uraninite has $\delta^{34}S$ values from 2.1 to 4.7‰, suggesting that sulfur was derived from the metamorphosed basement rocks. Sulfides associated with perched and unconformity-related mineralization have two populations of $\delta^{34}S$ values, from -1.9 to 8.1‰ and 15.0 to 25.4‰, suggesting that there were two sources of sulfur: the metamorphosed basement and the Athabasca basin (*e.g.* APS minerals).

The average $\delta^{18}O$ and δD values for coarse-grained illite are 0.7 ± 1.2‰ and -33.2 ± 11.8‰, whereas $\delta^{18}O$ and δD for fine-grained illite are 6.2 ± 2.1‰ and -145.2 ± 21.3‰. These values indicate that the fluids associated with coarse-grained illite have an isotopic composition consistent with a marine source, whereas fine-grained illite formed from fluids with an isotopic composition consistent with present day meteoric waters. The similarities between the $\delta^{18}O$ values of the fluids suggest that it was likely a rock-dominated fluid system.

Based on these data, basement hosted mineralization is a result of an ingress of fluids whereas unconformity and perched mineralization is a result of egressing fluids. **(*SS7, Wed. 10:40*)**

Genesis of the Baogutu reduced porphyry Cu deposit in Xinjiang, China

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Most porphyry copper deposits worldwide contain magnetite, hematite, and anhydrite in equilibrium with hypogene Cu-Fe sulfides (chalcopyrite, bornite) and have fluid inclusions with $CO_2 >> CH_4$. All evidence suggests a relatively high $f\,O_2$. In contrast, the Baogutu porphyry Cu deposit, located in the West Junggar Region, Xinjiang, China, lacks hematite and anhydrite, contains abundant pyrrhotite and ilmenite in equilibrium with Cu-Fe sulfides and has fluid inclusions with CH_4>>CO_2. The Baogutu is a reduced porphyry Cu deposit.

The Baogutu porphyry Cu deposit contains 0.63 M tonnes Cu, 14 tonnes Au and 0.018 M tonnes Mo. Baogutu is associated with a Late Carboniferous intrusive complex that was emplaced into Lower Carboniferous volcano-sedimentary sequences. The complex consists of a main-stage diorite stock and late-stage diorite porphyry dikes; the former hosts the most of the Cu mineralization. The main-stage stock has a wide range of composition, from minor gabbro through dominant diorite to tonalite porphyry. These are heterogeneous over a few meters, and show evidence for mingling of gabbro, diorite and tonalitic magmas, plus enclaves. The Sr–Nd compositions of the tonalite porphyry (εNd(t) = +3.2 ~ +3.8, $^{87}Sr/^{86}Sr$ = 0.7035 ~ 0.7038) have a transitional character from the gabbro and diorite (εNd(t) = +4.3 ~ +8.0, $^{87}Sr/^{86}Sr$ = 0.7035 ~ 0.7038) to the country rocks (εNd(t) = +0.7 ~ +2.9, $^{87}Sr/^{86}Sr$ = 0.70439 ~ 0.70552). These findings suggest possible country-rock assimilation and contamination.

Mineral composition data on the main-stage intrusions suggest that the parental magmas was oxidized, FMQ+1, but the assimilation and contamination of organic-carbon rich country rocks (0.41-0.62 wt% C) likely lowered the $ƒO_2$ of the hydrothermal fluid. The proposed interpretation is supported by low $\delta^{13}C_{PDB}$ of CO_2 (-11.8‰ to -20.0‰) in fluid inclusions; the $\delta^{13}C_{PDB}$ of CH_4 (-28.2‰ to -34.7‰) is also consistent with an external source of organic carbon. The country-rock assimilation and contamination resulted in the reduced mineral assemblage despite the originally oxidized magma. **(*SS3, Poster*)**

Investigating the efficacy of zero-valent iron to remove selenium from solution using X-Ray absorption spectroscopy (XAS) and stable isotope measurements

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Zero-valent iron is used in permeable reactive barriers to treat a variety of contaminants incluidng Se. Stable isotope measurements and XAS can be combined to produce a more complete picture of the mechanisms involved in removal of Se(VI) from solution. Batch experiments under anaerobic conditions have demonstrated that Se(VI) is removed from $CaCO_3$-saturated simulated groundwater. X-ray absorption near-edge structure (XANES) analyses revealed Se accumulated on the solid over time, in increasingly reduced forms, as well as the absence of Se(VI). There was no quantifiable Se(IV) in solution. Isotope ratio measurements on dissolved Se indicated enrichment in the heavier isotopes over time, with an effective fractionation factor consistent with abiotic reduction. Taken together, these results suggest the reduction of Se(VI) to Se(IV) in solution, followed by adsorption to the iron and progressive reduction on the solid phase. Knowledge of the stability of the form of Se present on the iron can aid in the planning of remedial actions. **(*SY6, Fri. 9:40*)**

Shear Zones in the Grenville Front Tectonic Zone Part 2: The role of weakening mechanisms

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The existence of shear zones in exposed mid- to lower crustal units indicates that strength heterogeneities form during mountain building events. These strength heterogeneities indicate that a change in rock properties or a stress heterogeneity (or both) played a role in shear zone formation. Data from granitoid shear zones in the Ontario segment of the Grenville Front Tectonic Zone (GFTZ), indicate that instead of one weakening mechanism resulting in shear zone development, several mechanisms worked together to sustain strain localization. For example, electron microprobe analyses of biotite, amphibole, and garnet from one of the well studied shear zones of the GFTZ show mineral compositions change with increased strain indicating that fluids played a part in shear zone development. However, we infer that fluids couldn't have been the only active weakening mechanism because they were not sufficiently abundant to substantively affect the modal mineralogy across the gradient. This shear zone also exists at a lithologic boundary, which can lead to stress heterogeneities. However, calculations suggest that the strain gradient caused by the stress heterogeneity also cannot fully explain the strain measured in the field. Lastly, all the shear zones studied exhibit grain size reduction with increased strain. Although grain size reduction can be a product of strain, it could also be a key mechanism in the strain-weakening feedback loop. An example of a feedback loop that could be applied to this shear zone is: the lithologic boundary led to a stress heterogeneity and associated strain gradient, which subsequently reduced grain size that further led to fluid pumping, which led to more strain, etc. Ongoing analysis of the strain gradients of these granitic shear zones in the GFTZ continues to produce evidence that indicates several weakening mechanisms were active during strain localization. A deeper understanding of how these mechanisms interact will lead to better shear zone parameterization and prediction of their formation in the mid- lower granitic crust. We review how each of five weakening mechanisms reduces the strength of mid crustal granite and the evidence, if any, they each leave behind. Specifically we explore the influence of fluid infiltration, textural evolution, metamorphism, stress heterogeneities, and shear heating on the studied shear zones in the GFTZ. **(*SY2, Poster*)**

Overview of Lower Jurassic source rock intervals along the Central-Northern Atlantic Margin

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Along the Central-Northern Atlantic Margin, the Lower Jurassic time interval includes several organic-rich intervals with source rock potential. These are particularly expressive in the European and African margins, where they crop out extensively in several onshore basins. In the Lusitanian Basin (Portugal), the Sinemurian–Pliensbachian is characterized by marine marl-limestone alternations deposited in a carbonate homoclinal ramp environment (Água de Madeiros and Vale das Fontes formations). Other similar organic-rich age equivalents intervals in Iberia are the Camino, Castillo Pedroso (Basque-Cantabrian Basin), and Rodiles (Asturias Basin) formations. Proven Lower Jurassic petroleum source rocks in Morocco occur in the Prerif Basin and Middle Atlas and some oils in Tarfaya and Essaouira basins are thought to be sourced from Pliensbachian to Toarcian shales.

On the other hand, Lower Jurassic source rocks are poorly known in the American margin. The Canada-Nova Scotia Offshore Petroleum Board's (CNSOPB) 2013 Call for Bids NS13-1, based in part on the Play Fairway Analysis (PFA), laid out a compelling case about the probable existence of a Lower Jurassic Source Rock "Complex" (Sinemurian/Pliensbachian/Toarcian) in the Scotian Basin, offshore Nova Scotia (Canada). This complex consists of restricted to near-normal marine series belonging to the Mohican and Iroquois formations' (Sinemurian–Bajocian) distal equivalents, that are expected to have potential for generation of hydrocarbons. It was also hypothesized the existence of local uppermost Triassic–lowermost Jurassic (Argo Formation) organic-rich intervals with potential for source rock. So far, petroleum systems models have been limited to the southwest platform, margin and slope of the Scotian Basin. It is recognised that other regions of the Scotian margin could be locations for the development of a mature source rock. Additionally, the CNSOPB and Canada-Newfoundland and Labrador Offshore Petroleum Board recent Call for Bids opened the concept of an Upper Triassic–Lower Jurassic source rock in other parts of the Canadian continental shelf, namely in the Newfoundland offshore area. Along the Labrador margin, the unbiodegraded oil encountered at North Leif I-05 suggests immaturity, but more mature source rock (most likely of Cretaceous age) and reservoired oil may exist in deeper parts of the basin. **(*SS12, Fri. 8:40*)**

Influence of freeze-thaw cycles on weathering and element release from a low sulfide waste rock pile in the Canadian Arctic

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An experimental waste rock pile (0.053 wt. % S) was constructed at the Diavik Diamond Mine, in the Northwest Territories, Canada to evaluate the generation of acid-rock drainage and the seasonal and annual release of various metals in drainage leachate. Acid-base accounting suggested that net generation of acid was possible, although the low sulfide concentration would limit the extent of acid-rock drainage over the long term. Monitoring of pore water and drainage leachate from the test pile (2007 to 2012) produced sufficient geochemical data to constrain the influence of the annual freeze-thaw cycle on sulfide oxidation and the release of oxidation products into solution. Monitoring of pore-water geochemistry within the core of the test pile indicated an evolving weathering front influenced by changes between acid-consuming mineral reactions. Initial acid neutralization occurred through carbonate mineral dissolution, but the modest carbonate concentration (0.027 wt.% C) was insufficient to maintain a neutral pH. The subsequent decline in pH was limited by acid neutralization through dissolution of Al- and Fe-bearing minerals. This lower pH environment produced increasing concentrations of SO_4, Fe, Ni and Co. Comparison of the geochemistry of migrating water that was collected in small-scale basal lysimeters within in the pile core and the overall basal drainage leachate allowed for an evaluation of the timing and retention of infiltrating water during the freeze-thaw cycle. This information was combined with thermal data collected throughout the pile to separate the test pile into discrete core and batter subsystems. Annual and cumulative element release revealed distinctly contrasting environments within the core and batter subsystems. Geochemistry of early season basal leachate was dominated by snowmelt and batter flow and late season leachate was dominated by contributions from the core of the pile. Core flow accounted for 12% of the total drainage volume, but it is estimated that about 40% of the total mass of Ni, Co and Fe and 26% of the total mass of SO_4 were derived from this zone. Results indicate that a comprehensive understanding of thermal cycling in waste rock piles is important for understanding leachate geochemistry and seasonal and annual releases of weathering products from waste rock. **(*SY6, Fri. 2:00*)**

Using UV laser $^{40}Ar/^{39}Ar$ thermochronology on muscovite to elucidate the cooling history of the orogenic middle crust of the Trans-Hudson orogen, Baffin Island, Nunavut

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The Hall Peninsula on southeastern Baffin Island, Nunavut, is part of the Paleoproterozoic Trans-Hudson orogen, which separates the upper plate Churchill collage of Archean crustal blocks and intervening Paleoproterozoic accretionary orogens from the lower plate Superior craton. Rocks now exposed across much of the peninsula represent the orogenic middle crust, where conditions during peak metamorphism range from granulite-facies conditions (>800°C and ~6 kbar) on western Hall Peninsula to amphibolite-facies conditions (~630°C and ~6 kbar) in the east. Late muscovite growth as well as replacement of peak metamorphic minerals by lower grade assemblages on eastern Hall Peninsula indicate that peak metamorphism was followed by reequilibration at lower-amphibolite-facies conditions. Zircon rim and monazite U-Pb ages suggest peak metamorphism during *ca.* 1850-1830 Ma, coeval with east-directed shortening. Regional thermochronology using step-heating $^{40}Ar/^{39}Ar$ analyses on muscovite and phlogopite indicates that temperatures upwards of about 400°C were maintained until *ca.* 1670

Ma. To further elucidate the cooling history, the UV laser $^{40}Ar/^{39}Ar$ technique was used to perform single spot rim-core-rim analysis transects across 500 μm^2 muscovite crystals from selected metapelitic rocks spanning a 5000 km^2 area of the eastern peninsula. Our results reveal systematic intragrain variation in muscovite $^{40}Ar/^{39}Ar$ cooling ages, which range from *ca.* 1670 Ma in interiors to *ca.* 1640 Ma on crystal edges. Together, the $^{40}Ar/^{39}Ar$ step-heating data and UV laser analyses indicate a protracted cooling history over 200 m.y. Following peak metamorphism, the middle crust exposed on Hall Peninsula likely resided at elevated thermal conditions (to about 400°C) until *ca.* 1670 Ma, and UV laser ages suggest cooling through the temperature window of Ar retention in muscovite during *ca.* 1670 to 1640 Ma. This implies an increase in cooling rate beginning at *ca.* 1670 Ma, and possible cooling scenarios to explain this trend are explored using thermal diffusion modeling. The cooling history of the well-exposed orogenic middle crust on Hall Peninsula can be used to predict the late stages of orogenesis in comparable modern mountain belts such as the Himalayan-Tibetan system. **(*SS19, Thurs. 9:40*)**

Deep crustal structure of the Rae Craton, mainland Nunavut

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The Rae craton is subdivided into crustal blocks separated by tectonic boundaries. The Committee Bay block contains 2.73-2.71 Ga greenstones and 2.63-2.58 Ga granitoids with 2.87-2.52 Ga neodymium (Nd) model ages. Archean sediments have Paleo- to Neoarchean zircons requiring an older source. To the east, the Repulse Bay block contains 2.97 Ga, ~2.77 Ga and <2.72 Ga greenstones and 2.77-2.69 Ga granitoids with 3.63-2.84 Ga Nd model ages. These are overlain by 2.0 Ga Penrhyn Group metasediments. The 1.81 Ga Wager Bay shear zone separates the Repulse Bay and correlative Armitt Lake blocks. The Chesterfield block contains 2.74-2.67 supracrustals and 2.6-2.68 Ga granitic plutons and is separated by shear zones from the Armitt Lake block and the Hearne craton. The Chesterfield and Armitt Lake blocks collided during the 2.56-2.50 Ga MacQuoid Orogeny. The Queen Maud block lies west of the Chantrey fault zone and comprises 2.50-2.46, Ga granitoids, 2.44-2.39 Ga metasediments, and 3.25 Ga granitoids with 3.1-3.58 Ga Nd model ages. The 2.5-2.3 Ga Arrowsmith orogeny records collision between the Queen Maud and Committee Bay blocks. Collision of the Hearne and Rae cratons across the Snowbird tectonic zone at 1.915-1.90 Ga was followed by the widespread, 1.86-1.85 Ga Trans-Hudson Orogeny and culminated in 1.82 Ga felsic magmatism.

Magnetotelluric (MT) data collected from four regional scale profiles across the Rae craton (Spratt *et al.* 2013; Spratt *et al.* 2014) reveal the deep crustal structure. Henderson (1983) described a basement–cored nappe mantled by the Penrhyn group. An MT profile across this structure (Spratt *et al.* 2013) confirms that conductive graphitic pelites of the Penrhyn Group underlie Archean basement. MT profiles across the Committee Bay and Repulse Bay blocks reveal that the upper 10-15 km of crust are resistive and underlain by less resistive mid- to lower crust. The identity of this less resistive crust is revealed: 1) in the Committee Bay block where it breaches the surface and coincides with high grade migmatite, paragneiss (<2.69 >2.58Ga deposition) and related granitic plutons, and 2) at the tectonic boundary between the Committee Bay and Repulse Bay blocks where it coincides with mixed sedimentary-derived gneisses. This less resistive metasedimentary crust was tectonically buried during Paleoproterozoic orogenesis. MT profiles reveal two south-dipping structures that transect the south-central Chesterfield block and include the Akunak Bay shear zone. The latter is truncated by the north-dipping Pike fault that defines the Hearne craton boundary. **(*SY3, Thurs. 8:00*)**

Keynote (40 min): Geochemical and Os isotope evidence for multiple metal sources in Mississippian black shales of the Lisburne Group, northern Alaska

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Metalliferous black shales of Mississippian age in the Brooks Range of northern Alaska are interbedded with phosphorites and limestones in sequences 3 to 35 m thick, and were deposited during intermittent upwelling on an outer ramp in relatively shallow (~100-200 m) waters under predominantly suboxic conditions. Deposition of the black shales at ~335 Ma was contemporaneous with sulphide mineralization in the Red Dog and Drenchwater Zn-Pb-Ag deposits, which formed in a distal marginal basin.

Maximum metal concentrations in 27 metalliferous black shales from numerous localities, including highly calcareous and phosphatic varieties, are 8770 ppm Ba, 4820 ppm Zn, 2831 ppm V, 1690 ppm Cr, 519 ppm Ni, 484 ppm Cu, 142 ppm Cd, 135 ppm Mo, 58.0 ppm Ag, 12.3 ppm Tl, 64.2 ppm U, 111 ppm Se, 10.0 ppm Ge, 3.1 ppm Os, 58.7 ppb Au, and 36.1 ppb Pd. Average authigenic (detrital-free) contents of V, Mo, and U show enrichment factors of 4.5×10^3 to 3.8×10^5 relative to modern seawater that are similar to enrichment factors in organic-rich sediments of modern upwelling zones on the Peruvian, Namibian, and Chilean shelves, suggesting wholly marine sources (seawater and biogenic material). An exclusively marine source is also likely for Ni, Cu, Cd, Pb, Tl, Ge, Re, Se, As, Sb, Au, and Pd based on comparable seawater-normalized enrichment factors. In contrast, Zn, Ag, and Os [common Os (^{192}Os)] have much larger average enrichment factors of 3.7×10^6, 1.0×10^6, and 2.5×10^8, respectively, consistent with an appreciable hydrothermal component.

Initial Os isotope ratios (^{187}Os/^{188}Os) calculated at 335 Ma show moderately unradiogenic values of 0.24 to 0.88 for four samples of metalliferous black shale. A proxy for coeval Mississippian seawater is provided by initial (^{187}Os/^{188}Os)$_{335\ Ma}$ ratios of unaltered black shales of the correlative Kuna Formation that average 1.08, nearly identical to the initial ratio of 1.06 for modern seawater. The most likely source of unradiogenic Os in the metalliferous black shales is mafic igneous rock, which in our model was leached by externally derived hydrothermal fluids that formed the coeval Red Dog and Drenchwater Zn-Pb-Ag deposits. We propose that metal-bearing hydrothermal fluids that formed these Zn-Pb-Ag deposits vented into seawater in a marginal basin, were carried by upwelling currents onto the outer ramp of a shallow-water shelf, and were then deposited in organic-rich muds, together with seawater- and biogenically derived components, by syngenetic sedimentary processes. **(*SS2, Wed. 10:20*)**

Keynote (40 min): Lithogeochemical studies of stratabound mineral deposits: Lessons and insights

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For over 50 years, lithogeochemical studies of stratabound mineral deposits have been used to characterize the major and trace element, and in some cases the REE signatures of ores, mineralized zones, and altered wall rocks, with a frequent goal of delineating geochemical haloes or vectors to mineralization. Studies have also deciphered the protoliths of altered wall rocks and evaluated mass changes associated with alteration and mineralization. This presentation will emphasize lessons learned and insights gained from personal research conducted over three decades. Studies and applications are described here for: (1) sediment-hosted Co-Cu-Bi-Au-REE deposits of the Blackbird district, Idaho; (2) Besshi-type VMS deposits of the Elizabeth Cu mine, Vermont; (3) sediment-hosted Zn-Pb-Ag deposits of the Red Dog district, Alaska; and (4) VMS-related jaspers of the Jerome Cu district, Arizona.

Whole-rock analyses of ores and altered wall rocks of the Blackbird district demonstrate the importance of complete geochemical characterization using fusion ICP-MS in order to obtain reliable data for trace elements and REE within resistate minerals. Previous geochemical studies of this district by industry, academia, and government geologists failed to discover the locally high concentrations of Be, Y, and REE in the ores (up to 1180 ppm Be, 8300 ppm Y, and 3.66 wt ‰ REE oxides), residing in accessory gadolinite, xenotime, and monazite.

Lithogeochemical studies of wall rocks at the Elizabeth deposit have revealed protoliths of clastic sediment and tholeiitic basalt. Data for relatively immobile trace elements (Zr, Cr, Ti) indicate that many rocks containing only sparse amphibole and/or biotite have basaltic protoliths, as do some samples that lack any mafic mineral (qtz+white mica+carbonate±staurolite±corundum). Such rocks record pervasive and extreme metasomatism, coupled with significant mass loss, prior to metamorphism.

Altered black shales that host sulphide ores of the Red Dog district are variably altered, mainly by the addition of silica and pyrite. Evaluating the origin and timing of the silicification event is difficult because two periods of silica addition are recognized, one coeval with Zn-Pb-Ag mineralization in the Mississippian and the other postore during the Cretaceous Brookian orogeny. Trace elements and Ge/Si ratios were useful in distinguishing these two processes.

REE data for seafloor-hydrothermal jaspers from the Jerome district show small positive or negative Ce anomalies and small positive Eu anomalies, suggesting deposition under suboxic bottom waters and hydrothermally sourced Eu and Fe. These inferred suboxic conditions establish important constraints on the redox state of the deep ocean during Paleoproterozoic time. **(*SS14, Fri. 8:40*)**

Unraveling the nature and origin of the Cortaderas polymetallic (Ag-Zn-Sn-In-Cd-Ge) deposit in the Central Andean Sn-Ag belt, northern Argentina

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The Cortaderas Ag-Zn-Sn-rich epithermal vein system is a recent (2010) discovery ~500 m north of the currently active open pit at the Pirquitas Mine in the Puna of northwestern Argentina. The Miocene-age mineralized centre at the Pirquitas Mine defines the southern limit of the prolific Central Andean Sn-Ag belt, but its details and origin remain undefined. The Cortaderas vein system contains a combined indicated and inferred resource of ~29.7 Moz of Ag and ~729 Mlbs of Zn (as of 2012) at a cut-off grade 50 g/t Ag, as well as concentrations of Sn, In, Cd, and Ge. The Cortaderas deposit area comprises ores of principally sphalerite, pyrite, arsenopyrite, Ag-Sn-As-Sb-sulfosalts, cassiterite, and galena concentrated in ESE-striking and steeply dipping vein-breccias which cut Ordovician turbiditic metasedimentary rocks of the Acoite Formation. Here mineralization is structurally controlled, occurring in dilational zones that are subparallel to regional joints and laterally bound by N-S trending faults. Mineral textures and chemistry suggest variable and often cyclical P-T-X conditions throughout the paragenesis which is exemplified by the presence of mineral replacement, and the extensive development of colloform and dendritic sulphide textures; the latter suggesting rapid deposition likely facilitated by boiling and/or fluid mixing. Ag and Sn mineralization occurs paragentically late as crusts on clasts and veinlets cross-cutting massive sulphides. Pyrite is zoned with respect to As and Ag and locally replaces bladed arsenopyrite. Sphalerite contains trace In, Cd, and Ge and is zoned with respect to Fe content. Although wall-rock alteration is generally absent, dickite ± kaolinite is locally abundant in veins and intergrown with late hypogene minerals. The Cortaderas deposit differs from the other vein systems at the Pirquitas Mine by having higher Zn/Ag ratios, less Pb and Sn, and spectacular and varied hydrothermal textures (*e.g.*, colloform, dendritic, and cockade) which provide insight into the nature of ore formation. Study of the Cortaderas vein-breccia in the context of the larger hydrothermal system at Pirquitas will provide insight into the origin of the Sn-bearing polymetallic vein deposits in the Central Andean Sn-Ag belt. **(*SY6, Fri. 2:40*)**

Petrography and geochemistry of the Schoodic dike swarm, coastal Maine

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Two major sets of mafic dikes, related to Mesozoic rifting, are distinguished in New England and adjacent Canada - the Central New England (CNE) and Eastern North America (ENA) suites, each with a distinctive geochemical signature. A major concentration of diabase and basaltic dikes is also exposed on the Schoodic peninsula, coastal Maine, but are of unknown affinity. Importantly these dikes lie midway between the major dikes of southern New England, such as the Higganum and Onway dikes, and the Grand Manan and Shelburne dikes of maritime Canada. This petrographic and geochemical study focuses on two areas of dike concentration, Grindstone Neck and NW of Winter Harbor both on the western side of the Schoodic peninsula, and aims to elucidate their field relations and geochemical signatures.

The Schoodic dike swarm intrudes the Devonian Goldsboro granite and the almost continuous coastal exposures enable cross cutting relationships to be clearly examined. The diabase dikes are 5 – 20m wide and have thin aphantic margins that grade over a few cms to coarser grained diabase. The thinner basaltic dikes (<1m – 2m wide) are aphanitic throughout and cross cut the diabase dikes. Both dike sets are clearly post-granite emplacement as evidenced by granite xenoliths and xenocrysts and the control of brittle fractures within the granite on the orientation of the dikes. A few syn-plutonic dikes are also observed and they typically show more interaction with the granite host with lobate margins and flow structures.

The CNE and ENA dike suites can be distinguished geochemically using TiO_2 wt. %, MgO wt. % and Zr levels. The CNE dikes have higher TiO_2 wt. % and Zr ppm for equivalent MgO wt. % and Mg numbers, respectively, than dikes of the ENA suite. Our preliminary data demonstrate that representatives of both the CNE and ENA suites are present in the Schoodic dike swarm although the majority have a CNE affinity. This data extends the geochemical coverage of both Mesozoic and syn-plutonic mafic magmatism along the central Maine coast. **(*SS5, Poster*)**

Progress in Canadian geomorphology during the past 25 years

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The record of progress in Canadian geomorphology over the past 25 years is reviewed under the headings of (a) distinctive emphases of Canadian geomorphological research, including their strengths and weaknesses; (b) increase in geoscientific cooperation within Canada; (c) changing balance between Quaternary geomorphology and geomorphic process studies and (d) increased emphasis on geomorphic hazards and applications. The implications of Canada's role in the international geomorphological community are more complex. Factors which contribute to this complexity include the increasing dominance of the AGU and EGU; the slow growth of national and international geomorphological groups, societies and associations and tensions that exist among different geomorphic research traditions. In general, Canadian geomorphology is far stronger, more dynamic, more mainstream North American and more productive than it was 25 years ago. **(*SS22, Thurs. 8:00*)**

Keynote (40 min): Tethyan ophiolites, emplacement models and Atlantic spreading

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This paper develops a model relating the relative motions between Africa and stable Europe during Mesozoic and Cenozoic time to the emplacement of the western Tethyan ophiolites from former Yugoslavia east to Oman. The motion between stable Africa and stable Europe defined by the plate circuit Africa-North America-(Greenland)-Europe based on Atlantic ocean-floor spreading is divisible into five phases. It is quite simple and at the same time rather puzzling.

In the first phase, from about 175 Ma (~Bajocian) to about 140 Ma (earliest Valanginian) Afro-Arabia slides approximately SSE past western Europe. During phase two from ~140 Ma to ~125 Ma, from earliest Valanginian to the Barremian/Albian boundary, the motion slows considerably. It then speeds up again in phase three, ending in the Campanian at ~75 Ma. Phase four is another slow interval from ~75 Ma to ~55 Ma, or Campanian to earliest Eocene. The final phase is faster but has slowed in the last 20 m.y.

The emplacement phase of the mid-Jurassic ophiolites of Greece and former Yugoslavia onto adjacent passive continental margins ended in latest Jurassic to early Cretaceous time. It coincided with the slow-down of phase two in the relative motion between Africa and Eurasia. The similar slow-down of phase four coincided broadly with the end of the initial emplacement of the late Cretaceous ophiolites in Cyprus, Syria, Turkey and Oman. Both sets of ophiolites have a trace element signature indicating that they are supra-subduction zone (SSZ) ophiolites.

Both slow phases and the timing of ophiolite emplacement can be understood in terms of a simple modified "roll-back" model developed by the Open University to account for the emplacement of the Oman ophiolite and its SSZ chemistry. Ophiolite emplacement onto an adjacent continent can be regarded as the attempted subduction of a continental margin at a plate boundary. Emplacement eventually ceases and a new plate boundary is established elsewhere. The phases of motion between Africa and Europe can be related to this simple model. In effect the emplacement of the SSZ ophiolites in the region seems to have influenced the spreading pattern in the Atlantic Ocean. **(*SY3, Wed. 10:20*)**

A comparative study of the deformation history of auriferous quartz veins in the Archean Côté Gold deposit and the structural evolution of the spatially-related Ridout Deformation Zone, Swayze Greenstone Belt, northern Ontario

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The Côté Gold deposit (8.3 M oz) is a low-grade high-tonnage Au (-Cu) deposit located on the southeast limb of the Swayze Greenstone Belt (SGB) in the Abitibi Subprovince. The deposit is hosted by a magmatic-hydrothermal breccia body in tonalite and diorite of the 2741 ± 1 Ma Chester Intrusive Complex (CIC). Mineralization occurs within or peripheral to the breccia as disseminations, fracture fills and stockwork, and in association with later quartz ± carbonate ± sulphide ± muscovite ± tourmaline veins with silica-sericite ± sulphide alteration haloes. These latter veins are similar in appearance to orogenic-style, quartz ± carbonate± sulphide quartz veins associated with the 600 m wide Ridout Deformation Zone (RDZ), which is located ~ 2.5 km from the deposit. In order to understand the timing relationship between the orogenic veins, the quartz veins in the Côté Gold deposit, and the RDZ, the style and kinematic significance of structures overprinting the CIC are compared to those of the RDZ. Detailed structural mapping of exposures inside the deposit envelope indicates that three deformation events affected the CIC. The first deformation event (D_1) produced sinistral, north-side up, E-W trending shear zones with a strong S_1 foliation. During the D_2 event, S_1 was crenulated during reversal of slip along the shear zones, which produced a S_2 crenulation cleavage expressed as a mylonitic foliation in other parallel E-W-trending shear zones. Subsequently, a D_3 dextral reactivation event produced a S_3 foliation oriented anticlockwise to the margins of the shear zones. The RDZ is characterized by a strong composite S_1-S_2 fabric which formed during sinistral north-side-up movement. These fabrics the S_1-S_2, are overprinted by dextral shear bands and Z-shaped F_3 folds with a S_3 cleavage, which formed during dextral reactivation of the RDZ. Because the structural histories of the RDZ and CIC are similar and the structures overprint the Côté Gold Au-bearing quartz-carbonate ± sulfide veins, this suggests, therefore, that the veins pre-date regional deformation and may have formed shortly after the emplacement of the CIC. This latter conclusion is supported by previous Re-Os dating of molybdenite from Au-bearing quartz-carbonate veins in the deposit. Future work will focus on determining how the formation of the E-W quartz veins relate to that of the breccias that host the deposit. **(*SY5, Wed. 10:20*)**

Solid state mass transfer reactions between zircon and garnet constrain an early Acadian UHP excursion in western Massachusetts

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Recently identified highly restitic garnet-kyanite schists from the Goshen Dome of western Massachusetts hold a population of <5cm purple phosphatic garnets (0.18wt% P_2O_5). Compositional and textural features identify these megacrysts as metamorphic relics within otherwise recrystallized matrix. Their oxygen isotope ($\delta^{18}O$ 2.0‰ at core), and major element profiles show prograde growth without resorption events. The garnets contain abundant precipitates of apatite, Ti-oxides and submicron zircon prisms.

The included detrital zircons exhibit partially resorbed and embayed igneous cores, with a 5-10µm thick metamorphic overgrowth of distinct composition and unusual morphology. These grains are surrounded by radial shatters and radiation darkening in the host garnet. By LASS ICP-MS, the cores are variously 455-400Ma with typical magmatic arc REE profiles; the overgrowths are uniformly 390-381Ma across the garnet, with REE profiles consistent with derivation from garnet.

FE-EPMA mapping and trace element quantitation of the boundaries between zircon cores and overgrowths find an envelope of high U, Th, P and Y against the unmodified core and a step in Hf/Zr. Micron-scale SiO_2 drops and xenotime crystals are also found near the boundary and are understood as byproducts of a prograde mass transfer reaction that partially resorbed the included detrital zircons within the garnet, in the solid state. Limited experimental data on (Zr,Hf) in slightly majoritic garnet suggest this reaction is possible >5GPa. Any solid state zircon-garnet reaction likely requires minor Si[VI] in garnet.

Quantitative atomic scale imaging by Atom Probe Tomography (APT) finds at the boundary a 10nm thick shell of Th enrichment and several at% U, Y and P, as well as 10-20nm blebs of a $(Zr,Si)O_2$ precursor to the larger SiO_2 drops. These atomic scale features capture processes and elemental distributions at the reaction front, between maximum extent of the zircon resorption and the commencement of the overgrowth.

Multiple complementary microanalytical techniques applied to zircons within phosphatic garnet from western MA describe an early Acadian P-T-t loop, affecting >400Ma arc sediments and reaching maximum P before retrograde growth of new zircon from garnet 390-381 Ma. **(*SS19, Thurs. 8:00*)**

Possible earthquake-induced soft-sediment deformation structures in the Mississippian Horton Group, Nova Scotia

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Soft-sediment deformation structures provide information on early deformation of sedimentary rocks in tectonically active environments. In the Mississippian Horton Group of the Windsor-Kennetcook sub-basin of the Maritimes Basin in Nova Scotia, soft-sediment deformation structures are well displayed. The structures include well-known features like load structures, clastic dykes and sand-supported slump-breccia, but also include previously undescribed structures here termed microbasins, balloon structures, and microboudins. Microbasins are large (3 – 20 m diameter in plan view) elliptical masses of coarser sediment that subsided into mud layers. They are exposed on modern wave-cut platforms, allowing them to be mapped in detail. Balloon structures are 1 – 5 mm diameter polygonal bodies of siltstone that protrude from the top surfaces of coarser beds into overlying mudstone. Microboudins are ribbed features exposed on the surface of bedding, spaced 5 – 25 mm apart, that are interpreted to have formed as a result of directed extension of bedding while the sediment was poorly lithified. These deformation structures formed when primary stratification was deformed while sediment was in a weakened state due to a deformation mechanism that was likely liquefaction. Proposed triggers for such deformation include: meteorite impact, permafrost thawing, tides, waves, rapid deposition, groundwater fluctuations, and seismic shaking. Some of these mechanisms can be excluded based on the likely equatorial setting of the Maritimes Basin during the Mississippian. Microbasins and clastic dykes at Horton Bluff occur in laterally continuous section and across different facies, indicating a deformation mechanism that was repeated but was not cyclical. Load structures, microboudins, sand-supported slump-breccia and clastic dykes at Cheverie show the same lateral continuity, but sporadic vertical repetition. This indicates multiple, unscheduled deformation events. Lateral continuity, vertical repetition and proximity to an active fault system indicate seismic activity as the likely trigger for deformation. **(*SS13, Thurs. 2:00*)**

Variation in sulphide mineral chemistry in massive sulphide deposits, Bathurst Mining Camp, Canada: Implication for measuring volatile trace-elements by LA-ICP-MS and its application as a vectoring tool for the exploration of VMS deposits

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Laser-Ablation ICP-MS is presently among the most efficient and precise micro-analytical techniques used for quantitative measurement of trace elements (ppm to ppb levels) in sulphide minerals. Advantages of this technique include *in situ* measurement capabilities, high-spatial resolution sampling, low detection limits, and cost efficiency. Laser-Ablation ICP-MS can be applied directly to standard polished thin sections, obviating special sample preparation. Methodologies for determining volatile trace-elements in sulphide mineral assemblages of Zn-Pb type massive sulphide deposits of the Bathurst Mining Camp (BMC) have been examined and developed. The improved analytical protocols include an evaluation of optimized ablation conditions, choice of external standards, and internal standardization and data reduction strategies.

The results show that all forms of pyrite in the BMC are arsenian in nature with As incorporating as the main substitution in pyrite, ranging from 2.2 ppm to 2.58%. Arsenic also locally occurs as a trace-element substitution in sphalerite and chalcopyrite. Cadmium occurs in sphalerite, galena, and pyrite with the former hosting the highest concentrations (845-1996 ppm Cd). Among the sulphide mineral assemblages characteristic of different mineralogical and chemical facies, sphalerite is the dominant host for Hg (1.4-174.9 ppm), followed by pyrite, and chalcopyrite. Indium is locally elevated in sphalerite, chalcopyrite, and pyrite. Antimony abundances are more variable, but commonly occur in galena, as well as pyrite, where it strongly correlates with As. Finally, Tl is variably distributed among the different phases, but is locally enriched in pyrite (0.06-338 ppm) and galena (1.13-32 ppm).

There is a strong textural control on the volatile element concentrations in massive sulphide deposits of the BMC. ‘Primary’ pyrite (*i.e.*, pre-deformational) in the Restigouche deposit has higher volatile element concentrations than ‘secondary’ (*i.e.*, syn-deformational and post-deformational) pyrite. In contrast, some deposits with primary enrichment in Au, Sb, Hg, and Tl, such as Louvicourt also, display high contents of volatile trace-elements in late recrystallized pyrite. Therefore, upgrading trends in the primary pyrite suggests that metamorphism and syn-deformational processes do not have major effect on redistribution of these elements; whereas, the signature of liberation of these elements in recrystallized pyrite offers association to the origin of the ore deposition. Hence, these primary and secondary dispersions of volatile trace elements potentially can be used as a trace-element vectoring tool in exploration for massive sulphide deposits. **(*SS14, Fri. 9:40*)**

LA-ICP-MS trace-element study of pyrite from massive sulphide deposits of the Bathurst Mining Camp, Canada: Determination of volatile trace-element contents in pyrite and its application as a vectoring tool for the exploration of VMS deposits

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Pyrite is a ubiquitous refractory sulphide mineral in massive sulphide deposits. It typically hosts minor elements, such as Cu, Ni, As, and Co, as well as many other trace elements, such as Au, Ag, Pb, Zn, Sb, Se, Te, Hg, Tl, and Bi. Pyrite can, therefore, be treated as an effective scavenger of metals from ore-forming fluids. In this study, texturally-controlled *in situ* laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS) is used to measure volatile trace-elements (As, Cd, Hg, In, Sb, Tl), in pyrite from the massive sulphide deposits of the Bathurst Mining Camp (BMC), eastern Canada.

Texturally, pyrite can be categorized as pre-deformational (primary and pseudo-primary), syn-deformational (ductile and brittle), and post-deformational (late-recrystallization and annealing textures) in nature. LA-ICP-MS results indicate that all forms of pyrite are arsenian in nature, ranging from 2.2 ppm to 2.58%. The arsenian pyrite also contains elevated concentrations of Sb, Tl, Au, and Hg, whereas In and Cd were not found in significant concentrations within pyrite forms. The LA-ICP-MS data, coupled with petrographic (textural) observations, suggests a relationship between the textural setting and grain size of pyrite and their trace-element composition. The enrichment of volatile trace-elements is typically linked to pre-deformational pyrite, which are anhedral, colloform, spongy (corroded-diseased cores), and mostly fine grained (<200 µm). This suggests that metamorphism and syn-deformational processes have not had a major effect on the redistribution of these elements. Alternatively, some deposits with primary enrichment in Au, Sb, Hg, and Tl, such as Louvicourt, also have high volatile trace element contents in late recrystallized pyrite forms. Consequently, the refractory nature of pyrite and its ability to scavenge trace elements may provide a record of both the primary style of mineralization, as well as secondary recrystallization, deciphering the metamorphic and deformational evolution of massive sulphide deposits of the BMC.

Moreover, this powerful technique can reveal whether these trace elements are accommodated in the pyrite structure by lattice substitution and (or) by nano-inclusions of other minerals. Data for single-spot LA-ICP-MS analyses of pyrite show that elevated contents of As, Sb, Tl, and Hg in pyrite occur via lattice substitution, supported by the absence of spikes in the laser-ablation time-series data. Finally, vertical metal zonation exists in the deposits studied to date and indicate that, As, Sb, Tl, and Hg are systematically enriched toward the top of the massive sulphide intervals. Hence, based on the distribution of volatile trace-elements in texturally distinct pyrite, the potential of developing sulphide mineral composition (pyrite) as an exploration vectoring tool is proposed. **(*SS14, Poster*)**

Deposit of tsunami backwash or submarine mass wasting - an example from the Pliocene La Portada Formation, northern Chile

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Sedimentary features of onshore tsunami deposits were studied in great detail for the last two decades. Many of these studies were performed in the wake of actual tsunami events. While the characteristics of the onshore deposits are well documented, the associated marine tsunami effects, such as nearshore dispersion of sediment, re-deposition, and sediment bypassing during runup and backwash continue to be poorly understood. This is partly owed to the fact that marine sediments are preferentially preserved in the pre-Quaternary geological record. The identification of characteristic features of submarine tsunami deposits is important in order to facilitate the recognition of ancient examples.

In our contribution, we present results of a field study of a Pliocene coarse clastic unit in the La Portada Formation occurring at Hornitos near Antofagasta, northern Chile, which was previously interpreted to represent tsunami backwash deposits. Some authors linked the deposits' origin to the tsunami caused by the Eltanin impact into the SE Pacific. The respective unit contains several tens of meters long rock slabs and components from both the shallow marine basin and onshore environments, such as alluvial fans, beaches, cliffs and the local basement rocks. It is intercalated into breccia layers of smaller scale representing the equally high energetic background sedimentation. The unit was most likely emplaced subaqueously by a high-density mass flow with possible hydroplaning at its base and front. This is underlined by soft-sediment deformation and sand dykes. The comparison to recent submarine tsunami sediments shows that there are hardly any similarities, most notably (i) the absence of deep basal scouring, (ii) the orientation of big rock slabs parallel to the bedding plane, (iii) the absence of any obvious grain-size or facies trends indicative en masse deposition, and (iv) the considerably grater thickness of the described mass-flow deposit.

We argue that the unit represents a debris flow deposit triggered by an earthquake in the Andean subduction zone in northern Chile. The units' deposition occurred during a phase of increased uplift during the Pliocene that caused the oversteepening of the coastal scarp. We hypothesise that a contemporaneous increase in the frequency of seismic events may have caused slope failures and cliff collapses. In this context, the megabreccia unit at Hornitos represents an extraordinary mass failure event that is intercalated into other mass wasting deposits of smaller scale. We conclude that the formation of the deposit was not connected to tsunami action of any kind. **(*SS13, Thurs. 10:20*)**

Penetration of the Manicouagan Imbricate Zone by late Triassic impact: a window into Grenvillian structure

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The 214 Ma Manicouagan impact structure of Quebec is the second largest of Canada's 30 confirmed impact structures, and within the top ten of the largest known impact craters in the world, with a rim diameter of 80–90 km. The structure was formed in rocks of the Grenville's Manicouagan Imbricate Zone (MIZ), that underlie most of the structure, except for the southwest sector of the impact melt sheet, which is underlain by the Archean Gagnon Terrane. Sm–Nd analyses indicate a mean depleted mantle model age (T_{DM}) for the MIZ of 2.01 Ga, whilst the mean T_{DM} for the Gagnon is 2.70 Ga. The MIZ is composed of two terranes and at least four imbricated units. The lowest three units comprise the Lelukuau Terrane (a 1.65 Ga AMCG (anorthosite, mangerite, charnockite, granite) suite, locally intruded by 1.3 Ga granite). This is tectonically overlain by the Tshenukutish Terrane (diorite, Fe–Ti gabbro sills, anorthosite; mafic rocks, granite, which range in U-Pb age from 1.65 to 1.02 Ga). Although there is limited Nd data for the Tshenukutish, it has the same signature as the Lelukuau, and there are indications that they are tectonically stacked equivalents. Current interpretations have the Manicouagan impact structure being underlain primarily by the LelukuauTerrane, with the overlying Tshenukutish Terrane outcropping to the northeast. However, this inference has been made, in part, on the basis that the anorthosite of the central uplift is a Seignelay massif equivalent and, thus, laterally equivalent to the Lelukuau to the northwest. If the central anorthosite has been elevated 8–10 km then it is possible that Tshenukutish formed the original basement at the time of impact (and was the main source of the impact melt), with underlying Lelukuau material forming the base of the transient crater, which subsequently rose to form the central uplift. This is consistent with deeper level anorthosite, possibly derived from the underlying Lelukuau Terrane as a component of the Seignelay anorthosite, being elevated and penetrating through the Tschenukitish Terrane (by as much as 8–10 km) during central uplift formation. The crustal excavation caused by the Manicouagan impact thus provides an important window into MIZ structure. **(*SY3, Thurs. 9:40*)**

Major element variations in the Lower Coverdale plutonic suite, New Brunswick: Constraints on the genesis of anorthosite massif-hosted Ti-oxide deposits

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The Neoproterozoic Lower Coverdale plutonic suite is comprised of anorthosite, mela-anorthosite, ferronorite, and interlayered Ti ± P-rich rocks. Located between 5 and 20 km south of Moncton, New Brunswick, it occurs beneath an unconformable, 100-200 m thick package of Carboniferous sedimentary rocks. The intrusion can only be observed in drill core, so lithogeochemical data (n = 776) collected by mineral explorationists and researchers since its discovery in 1919 has been assembled into a database that provides important information about the igneous processes responsible for the diversity of lithologies present in the intrusion.

The plutonic suite has petrologic characteristics typical of alkali anorthosite massifs that host Ti-oxide and apatite mineralization, including plagioclase of andesine composition with K-feldspar exsolution lamellae containing up to 1.5 % BaO. Anorthosite and ferronorite are the primary lithologies, and ilmenite occurs in different mineral assemblages in these different lithologies: anorthosite is interlayered with zones containing up to 60 % ilmenite, whereas ferronorite typically contains nelsonite zones with ilmenite and apatite concentrations up to 40 % and 25 %, respectively.

Lithogeochemical data has been evaluated using molar element ratio techniques to: (i) verify rock classification using lithogeochemistry, and (ii) establish the nature of compositional controls in anorthosite and ferronorite. Results have allowed identification and discrimination of end-member and mixed lithologies, and provide insights into, and constraints on, the controls of magma compositions during emplacement and cooling. A distinct compositional break exists between anorthosite and ferronorite in most major element concentrations. Additionally, strong and continuous compositional trends exist between anorthosite and ilmenite-bearing anorthosite, and between ferronorite and nelsonite, confirming petrographic observations. These features suggest that different petrologic processes may have operated to form two different types of Ti-rich mineralization in the plutonic suite. Given that other anorthosite massifs exhibit these same two varieties of Ti-oxide mineralization (*e.g.*, Havre-Saint-Pierre, Chateau-Richer, and St. Urbain, Québec), dual processes producing Ti-oxide mineralization may be common in such environments. This may explain why multiple models exist for the genesis of nelsonites and other Ti-oxide-bearing mineral deposits (*e.g.*, fractional crystallization, liquid immiscibility), and thus why there is so much controversy regarding their genesis. **(*SS24, Thurs. 4:20*)**

Mineralogy and lithogeochemistry of the weathering zone and gossan over the Bisha Zn-Cu-Au volcanic hosted massive sulphide deposit, Eritrea

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Weathering in the Bisha volcanic hosted massive sulphide (VHMS) mining camp of western Eritrea has produced a regolith profile between 20 and 60 m thick. At the Bisha deposit, a < 2 m thick layer of alluvium from an adjacent stream and a 5 to 10 m thick wedge of colluvium from nearby hill overlie weathered residuum. Un-mineralized volcanic host rocks have weathered to saprolite between 20 and 40 m thick. Over hypogene sphalerite-chalcopyrite-bearing massive sulphide mineralization, weathering has resulted in the development of: (i) an anomalously auriferous gossanous oxide zone between 20 and 30 m thick, and (ii) an underlying supergene zone of chalcocite replacement of primary sulphide minerals between 20 and 35 m thick. In addition, within 10 to 30 m laterally of supergene mineralization, white, siliceous, acid leached rocks occur. Furthermore, the upper part of the supergene Cu zone contains anomalous Pb mineralization, exhibiting a mineral assemblage of fine-grained (supergene) galena and siderite.

In order to understand the nature and genesis of the weathering profile, both from a mineralogical and geochemical perspective, lithogeochemical samples were collected from two cross-sections through the weathering zone. These were analyzed for major and trace element concentrations by fusion and aqua regia/ICP-OES and -MS methods. X-ray diffraction analysis was undertaken on representative samples to gain insight into the mineralogical changes that took place during weathering. Using the whole rock lithogeochemical compositions, ordinary least squares regression models were used to obtain 'best fit' mineral modes for these representative weathering zone samples. Results have been plotted on cross-sections to define the spatial mineralogical and geochemical patterns present in these rocks.

Results reveal an asymmetric distribution of weathering zones exists around the Bisha VHMS deposit, and acid leached rocks occur only immediately west of the deposit. These features are likely a consequence of lateral (westward) flow of groundwater through the deposit, probably due a topographic high to the east. Elements enriched in the oxide gossan include Pb, As, Mo, Sb, and Bi, all of which are relatively immobile in acid waters due to either adsorption as oxy-anions, or limited solubility. Lastly, a thermodynamic model for the supergene enrichment of Cu and Pb has been constructed that explains the occurrence of galena and siderite immediately above supergene Cu mineralization. These observations provide important physical and chemical constraints on the nature of gossan development over massive sulphide deposits. **(*SY4, Wed. 3:00*)**

A high resolution study of Greenschist-Amphibolite transition zone mineral assemblages: An example from the Flin Flon – Glennie Complex (Manitoba/Saskatchewan)

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The greenschist-amphibolite transition zone mineral assemblages of the Flin Flon-Glennie complex in Manitoba and Saskatchewan comprise metamorphosed basalts and basaltic andesites of the Hidden Formation, and represent one of the best exposed sequences of its kind in the world. The area around Flin Flon contains several mineral isograds, the most important of which are the hornblende-in and oligoclase-in isograds. The metamorphic sequence in Flin Flon can be broadly explained by two coupled continuous reactions. A lower grade reaction involves the production of amphibole with increasing edenite and tschermakite components, in place of actinolite, chlorite, epidote and albite, whilst a second reaction, producing tschermakitic amphibole and oligoclase, becomes dominant within the higher grade part of the sequence, above the oligoclase isograd.

Of particular interest was the composition and textures of the coexisting calcic amphiboles, actinolite and hornblende, due to uncertainty in the postulated existence of a miscibility gap within the actinolite-hornblende series. Detailed compositional analysis of coexisting amphiboles suggests a divergence in the compositions of actinolite and hornblende/ferro-tschermakite with increasing grade, characterised by hornblende/ferro-tschermakite displaying trends towards increasing tschermakite, edenite and ferrous iron contents with grade, in contrast to actinolite which appears to remain fixed in composition. The orientation of the vector in compositional space connecting coexisting actinolite and hornblende/ferro-tschermakite compositions is relatively consistent between samples, whilst the magnitude of the compositional gap increases with increasing grade.

It is proposed that there is no miscibility gap present within the Flin Flon amphiboles, a conclusion that contradicts previous studies in the Flin Flon area and the large majority of work on other greenschist-amphibolite transition zone sequences around the world. The continuous evolution of the hornblende/ferro-tschermakite compositions, associated with actinolite that shows no variation in composition, appears more consistent with a disequilibrium model. In addition, the complex array of different textures between the coexisting amphiboles, including ubiquitous patchy intergrowths and core-rim structures appear to provide more, albeit inconclusive, support for disequilibrium conditions. The results of this study suggest that some previous studies using textural interpretation of coexisting amphiboles as evidence for equilibrium conditions may require re-evaluation. **(*SS19, Thurs. 9:00*)**

Geochemical classification of Archean volcanic rocks in the Blake River Group, Abitibi Greenstone Belt, Québec

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The Archean Abitibi Greenstone Belt is one of the best places in the world for exploration of volcanogenic massive sulphide deposits (VMS). The Blake River Group (BRG) in the Rouyn-Noranda area includes two important mining camps: the Noranda camp and the Doyon-Bousquet-LaRonde camp, representing almost half of the total VMS tonnage in the Abitibi (374 Mt on 810 Mt).

VMS deposits are partially controlled by stratigraphy and, for the BRG, few marker horizons are known. Therefore, an improved knowledge of the volcanic stratigraphy would be valuable. Recently thousands of new geochemical analyses have become available, including trace elements analyses. Also, a large U-Pb dating effort was made, which provides a time frame for the volcanic events related with mineralization. However the geochemistry has not been used to its full potential.

The MSc project which began in 2012 is based on the compilation of lithogeochemical data in order to better constrain the BRG stratigraphy. This compilation contains previous analyses from the Québec government database SIGÉOM (including analyses from the Geological Survey of Canada), new samples, and new analyses of old samples. This compilation now contains more than 2000 complete analyses (major and trace elements).

This poster first presents a major-element classification of the volcanic rocks of the BRG, based only on the fresh samples. The BRG is known for its VMS deposits and the associated hydrothermal alteration, which modifies the major element geochemistry of the altered samples. The overall characteristics of the BRG, are the bimodality of the volcanic rocks (mafic-felsic) and a variability in their magmatic affinities. Compositions and affinities are presented individually for eight of the nine formations of the BRG. We then present a classification based on immobile trace elements, using the entire database, including the most altered samples. This second approach is essential to define the geochemical signatures of all the volcanic units and thus refine the stratigraphy of the BRG. **(*SS6, Poster*)**

Regional correlation of Carboniferous strata between the western Sackville Subbasin and the eastern Moncton Subbasin in southeastern New Brunswick

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The Sackville and Moncton subbasins are two sedimentary depocentres in southeastern New Brunswick that comprise a segment of the Late Devonian to Carboniferous Maritimes Basin in Atlantic Canada. To determine the hydrocarbon and potash potential of the two subbasins, detailed petrographic and petrophysical analyses of the sedimentary units were conducted on samples of core and/or cuttings from eight exploration wells between Dorchester in the western Sackville Subbasin and Taylor Village in the eastern Moncton Subbasin.

The petrographic and petrophysical data was used in conjunction with reinterpreted seismic profiles, spore data, and organic geochemistry to investigate the distribution and internal stratigraphy of the hydrocarbon-bearing Early Carboniferous Albert Formation (Horton Group). The Albert Formation typically contains three conformable units that, in ascending order, are the Dawson Settlement, Frederick Brook, and Hiram Brook members. All three members contain kerogenous sandstone, mudstone, and shale; and regionally, all members host economic quantities of petroleum. Historically, the Hiram Brook Member is the main exploration and development target for conventional oil and gas, whereas the Frederick Brook Member hosts unconventional gas and oil. Most of the wells examined contain Dawson Settlement and Frederick Brook facies but the Hiram Brook Member was not identified in any of the wells. Results of this investigation indicate that the Hiram Brook Member in the Dorchester to Taylor Village area may have been eroded during a basin inversion event in the Early Carboniferous. The presence of 5 to 10 metre-thick sequences of dark grey shales within the younger Boss Point Formation (Cumberland Group) have warranted detailed organic geochemical analysis.

As observed in borehole and seismic profile interpretations of the Upper Carboniferous units, thickness variations and the apparent absence of some lithological formations overlying the salt units of the Windsor Group (Pugwash Mine Formation) provide evidence of salt doming in the area. Additionally, crystalline basement intersected in two of the wells indicates that depth to basement is much shallower than previously interpreted. A combination of stratigraphic correlation and minor structural interpretations of the subbasins has been utilized to better define the subsurface boundary between the two subbasins to determine economic potential. **(*SS12, Fri. 9:20*)**

A long lived mega-hydrothermal system preserved in the granophyre unit of the 1.85 Ga Sudbury impact-generated melt sheet Ontario, Canada

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The Sudbury Igneous Complex (SIC) is a differentiated impact melt sheet and part of the mineralizing environment of one of the largest Ni-(Cu-PGE) districts globally. The upper 1.5 km of the 2.5 km thick crystallized melt sheet, referred to as the granophyre unit, consists of amphibole (north range) or biotite (south range) – bearing two-feldspar (*i.e.*, subsolvus) monzogranite characterized by variably developed granophyric texture (0-60 vol. %). We summarize below the results of a detailed textural and mineral chemical study of the granophyre supplemented with fluid inclusion microthermometry, evaporate mound chemistry, quartz CL observations and both whole-rock and mineral (quartz) $\delta^{18}O$ data. This information collectively demonstrate the pervasive re-equilibration of this unit with moderate-to low-temperature fluids during cooling of the SIC and collapse of its hydrothermal systems: (1) feldspar phases (50-70 vol. %; $Ab_{95\text{-}100}$ and $Or_{95\text{-}100}$) record equilibration to <350ºC); (2) K-feldspar is generally void of perthite due to extensive sub-solidus re-equilibration; (3) both feldspars are strongly pitted, a texture indicative of dissolution-reprecipitation reactions; (4)amphibole (mg = 0.57–0.69) is extensively replaced by secondary, locally pit-textured, Fe-rich (mg = 0.15-0.29) amphibole phases; (5) CL imaging of quartz reflects little to extensive re-equilibration with fluids; (6) Fe-Ti oxides record both unmixing (exsolution and symplectites) and replacement (titanite) textural domains; (7) primary zircon is replaced by a secondary zircon that is enriched (to wt. %) in Ca, Fe, and Al and these domains are decorated with grains of baddeleyite, uraninite, thorite, and galena; (8) two types of secondary fluid inclusions occur in quartz, one with Th values of 320ºC and 23 wt.% eq. NaCl and the other with Th = 100-140ºC and 23-28 wt.% eq. NaCl. Evaporate mound analyses indicate these fluids have a complex chemistry with variable amounts of Na-Ca-K (avg. 70:20:10) with minor amounts of Fe-Mn-F; and (9) $\delta^{18}O$ values for whole rock (6.2 to 9.0 ‰) and quartz (SIMS analysis; 6.9 to 15.9 ‰) reflect re-equilibration of the granophyre with different fluids, one magmatic/metamorphic and the second surficial, likely seawater in origin. The above data are interpreted to indicate that the granophyric unit of the SIC records a complex and protracted history of fluid:rock interaction commencing with orthomagmatic fluids through an ingress of externally derived metamorphic fluids and finally, to the incursion of low-temperature saline fluids as the hydrothermal cell collapsed. **(*SS20, Poster*)**

Granulite-hosted mineralization in the Borden gold deposit, Chapleau, Ontario

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The Borden gold deposit, with an indicated resource of 112,844,000 tonnes at 1.02 g/t Au, is located within the boundary of the Kapuskasing Structural Zone and Wawa subprovince, adjacent to the Abitibi subprovince, approximately 160 km southwest of Timmins, Ontario. Gold mineralization at Borden is situated approximately 20 km west of the Ivanhoe Lake cataclastic zone and is associated with lower-strain areas in subvertical to vertical ductile shear zones along the limbs of regional fold structures. Field mapping and whole-rock geochemical analyses show that economic gold mineralization is present in gneissic and migmatitic granulite and garnet-biotite gneiss commonly adjacent to mylonites or within boudins. Feldspar-biotite gneisses, porphyroblastic hornblende gneiss, banded iron formation, and pegmatite are host to a spectrum of gold concentrations, from high-grade to barren, and may provide constraints on relative timing due to their structures. Metamorphic mineral assemblages include Hbl + Opx + Ttn with localized areas of Grt + Cpx within the gneissic granulite. The garnet-biotite gneiss is typically composed of Grt + Bt + Sil + Kfs ± Crd. Native gold commonly occurs as inclusions or along fractures in high-grade metamorphic minerals (*i.e.*, garnet, biotite, potassium feldspar, hornblende, and orthopyroxene) and is present in quartz micro-boudins. Sulphides such as anhedral pyrrhotite and euhedral to anhedral pyrite are common and locally abundant as massive bands parallel to gneissosity in the Borden deposit. Chalcopyrite and löllingite are less common sulphides and magnetite is the most common oxide. Locally euhedral pyrite have partial to complete double coronas of gold on the inside and pyrrhotite on the outside. However, correlation between gold and sulphur is lacking on the deposit scale. Also, gold mineralization is typically absent in crosscutting cataclasite and quartz ± carbonate veins. These preliminary results suggest that the Borden gold deposit type is either syn-metamorphic orogenic or metamorphosed seafloor hydrothermal deposit. **(*SY5, Poster*)**

Synchrotron-based µXRF analysis of early gold-bearing pyrites at the Dome mine, Timmins

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Trace element associations in gold bearing sulphide minerals provide integral information regarding the nature of mineralizing fluids. The intensity and energy flux provided by synchrotron radiation allows for micron scale and ppm sensitivity to characterize trace element distributions in these minerals. By using synchrotron-based µXRF mapping, micron scale growth halos, and correlation between gold and other trace metals can be resolved. Additionally, using x-ray absorption near edge structure (XANES) analysis, the oxidation state of these elements can be elucidated, providing evidence for fluid redox states. This information provides insights into fluid evolution, mineralization conditions and depositional history as well as controls on mineralization and gold remobilization that can be applied to a myriad of deposit types. The Dome mine, located in the prolific Porcupine gold camp of the Abitibi Greenstone belt is host to a world-class greenstone hosted quartz-carbonate vein deposit. The mine has been in operation for over 100 years, and is host to a unique set of early gold bearing crustifom banded ankerite veins. These sheeted vein arrays are overprinted by main stage gold bearing quartz veins that are commonly found at flow contacts and extend sub parallel to lithological layering over 500m in strike, 900m vertically and 2m in width. Multiple veins have been sampled across their lateral extent at different levels of the mine. Thin sections were characterized using conventional methods, and pyrite grains were selected for µXRF mapping at the Canadian Light Source Synchrotron VESPERS beam line (Saskatoon), and beam line 20-ID,B,C at the Advanced Photon Source (Argonne National Lab, Chicago). Spot µXRF analysis and XANES were also performed. These techniques have provided information regarding patterns of trace element associations with gold and important new information about the mineralization history of these enigmatic early ankerite veins. **(*SY5, Thurs. 10:20*)**

Trace element analysis of placer gold: Using geochemical fingerprints of placer gold populations to track hypogene source mineralization and influence of surficial supergene processes

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There is great interest and functionality in the ability to distinguish populations of placer gold occurrences in order to characterize such factors as hypogene mineralization style, and influence of supergene mobilization. This study predominantly used trace element composition of placer gold to attain this goal while also utilizing other properties such as major element composition, placer gold grain size, morphology, and mineral inclusion assemblage. The trace element signature of the gold was able to fingerprint individual placer occurrences. More importantly, characteristics of these fingerprints can be used to determine aspects of the formation of the gold.

LA-ICP-MS analysis was conducted to determine concentrations in placer gold samples of 19 trace elements quantitatively and 3 trace elements semi-quantitatively. This provides the most extensive elemental data set for natural gold analyses to date. The sample sets analyzed for this study include placer gold from: Kilkivan Australia, Nus River Colombia, Aurizona Brazil, and four locations in British Columbia mostly from the Kelowna area.

A placer occurrence and a paleoplacer occurrence in the Kelowna area share the same hypogene source trace element signature including elevated Fe, V, Bi, and Pt abundances. This indicates that the modern placer occurrence is the product of reworked paleoplacer occurrences. Samples from a separate placer occurrence in the Kelowna area exhibited two very discrete populations. One had elevated Cu, As, Se, and Sb while the other was elevated in Sn and Pb. This indicates that two separate gold occurrences within the catchment basin contributed to the placer budget. The Sn and Pb rich population shares a similar trace element signature to a Colombian placer gold occurrence analyzed for this study that is known to come directly downstream from an intrusive hosted orogenic style deposit.

The Kilkivan, Australia samples came from the Prophet Mine placer deposit and were provided by Dr. Frank Reith. They are of particular interest due to the documented influence of supergene biological gold precipitation at this occurrence. While all other placer gold occurrences exhibit a distinct trace element signature the Prophet Mine samples only have a subset of samples that show a signature with the remaining samples showing wide scatter. All samples observed to contain primary hypogene inclusions retained a distinct signature; this suggests that some sample analyses preserved the source hypogene mineralization signature while the others had their signatures partially or completely destroyed by re-mineralization of supergene gold. **(*SY5, Poster*)**

Impact-related seismites at Manicouagan?

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A suite of intrusive sediments penetrates footwall rocks located beyond the transient cavity of the 90 km rim-diameter Manicouagan impact structure of Quebec. The intrusive sediments occur mainly as dykes ranging from <0.01 to at least 6 m in width. The sediments range from clast- to matrix-supported and predominantly consist of rounded quartz grains (0.25 – 1 mm), with many of the finer grained, <0.1 mm-size grains being angular to subangular. The sediments are lithified via an interstitial matrix of clays, carbonates or quartz, and are typically white, red or pale green. The cement appears to be a post-emplacement precipitate, indicating that the dykes were intruded as fluidized clastic systems that were subsequently lithified. This is supported by the observation of flow textures in some samples. The sedimentary dykes are relatively common, and are found penetrating gneisses, limestone, and marble, both in the field and in drill core at a 20-23 km radius from the centre of the structure. We interpret the dykes to be fluidized sediment injections that were mobilized by seismic activity associated with post-impact crustal adjustments. If so, they can be classified as seismites. Significantly, the implication is that the sediments originally resided at the surface, probably as an unconsolidated layer, and were injected down into faults and fractures. These sediments may indicate the Norian paleogeographic environment at the time of, or just after, impact. **(*SS21, Thurs. 3:20*)**

Subglacial meltwater scour zones revealed by lidar imagery of Midcoast Maine

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High-resolution (2 m) lidar imagery was recently acquired for parts of Maine including the entire coastal zone. This imagery is useful for the Maine Geological Survey's surficial geologic mapping program; it reveals vast numbers of end moraines formed in the coastal lowland during the late-glacial marine inundation, enabling better definition and correlation of recessional ice-margin positions. Lidar imagery also shows erosional and depositional features resulting from glacial shaping of till and bedrock surfaces, including fluted ground moraine, and evidence for subaerial and subglacial meltwater processes. This presentation describes a series of broad subglacial meltwater channels – referred to here as scour zones – that were discovered in lidar coverage of the Brooks area of Midcoast Maine. The scour zones are generally parallel to regional S to SE-trending esker systems. On lidar imagery they appear as linear, often sharply-bounded, areas where most of the till cover has been eroded away, resulting in distinctive ribbed topography due to the NE-trending structural grain of the underlying metamorphic bedrock. This topography is especially noticeable where subglacial streams crossed major bedrock strike ridges and incised the smooth till slopes that mantle the proximal sides of the ridges. The areas from which the till was stripped are larger than typical meltwater channels formed by subaerial streams in Maine. The scour zones may be as much as several kilometers long and 200 to at least 1400 meters wide. In places they converge on rock-floored saddles where they cross the crests of the bedrock ridges. Meltwater abrasion features occur on rock surfaces on the distal side of at least one saddle. Scour in such places is predicted by the increase in hydraulic potential gradient resulting from ice flow against adverse slopes. Eskers commonly occur down-flow from the saddles, in some cases forming anastomosing networks of low gravel ridges (esker nets) that are characteristic of parts of esker systems formed near the glacier margin in Maine. The processes and length of time involved in formation of the scour zones, and their relationship to esker deposition, are poorly understood. Perhaps most of them formed within a few years from subglacial meltwater outbursts. This may explain why much of the till was removed but fluvial erosion of the underlying bedrock appears to have been minimal. Lidar imagery of the study area also shows larger, irregular areas of contrasting smooth fluted

till surfaces and bedrock-controlled topography whose distribution and origins are unexplained. (***SS11, Poster***)

The Archean Vickers gabbroic complex, eastern Nunavut, Canada: Integrating gold mineralization to alteration processes

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The Vickers "gabbroic" intrusion (~2690 Ma), located in the Central Hearne supracrustal belt (CHSB) of eastern Nunavut, hosts a recently discovered (2012 by Northquest Ltd.) gold occurrence (*e.g.*, PB-12-09 diamond drill hole intersected 164.41 m @ 5.39 g/t Au). The host lithology, the Vickers complex, occurs in the northern portion of the Neoarchean Kaminak greenstone belt (2.72-2.65 Ga), an area that has been interpreted to lie within the Pistol Bay Corridor, a brittle/ductile deformation zone with an east-west orientation. Mapping indicates the intrusive complex is slightly elliptical with a 900 m strike length and is surrounded by a quartz arenite unit. Lower greenschist grade metamorphism dominates and quartz-carbonate veining is abundant in the map area. Exploration drilling indicates the mineralized envelope, located at the NW contact zone of the intrusion, is 150 m thick, extends to 250 m depth, and dips 70° to the south; the zone remains open to the east. Several gradational alteration assemblages occur in the ore zone and throughout the surrounding area: Chlorite Facies 1+2(CF1+CF2), Silica Facies 1+2 within the intrusive (SF1I + SF2I), and Silica Facies 1 within footwall rocks (SF1FW). The Au mineralization is most prolific in the SF alteration assemblages where pyrite ±arsenopyrite is present as disseminated sulphide and/or confined to narrow quartz-carbonate ± chlorite veins. Infusion of secondary silica, sulphide abundance (>3 %) and presence of Fe-carbonate veins are ubiquitous to the SF alteration assemblage. In contrast, CF alteration assemblages are defined as containing abundant (>35 %) disseminated and stringers of chlorite but only contain <2 % sulphides. Preliminary petrographic observations to further characterize each alteration assemblage reveals that the primary assemblage of amphibole, calcic plagioclase, and Fe-Ti oxides records progressively more alteration towards the ore zones (*i.e.*, actinolite, chlorite, carbonate), in addition to having pyrite and arsenopyrite. The proposed working model involves both chemical (Fe-rich nature of the host) and rheological contrasts (contact between units) which resulted in the precipitation of Au and sulphide in fractures due to infiltration of the mineralizing fluid. The presence of auriferous quartz-carbonate veins, the related alteration styles and pervasive lower greenschist metamorphism support affinities toward a mesothermal orogenic gold deposit model. Further characterization of the nature and origin of this alteration and the mineralizing fluid, currently in progress, will include integration of whole-rock and mineral chemistry, stable isotopes (O, C, S), fluid inclusion studies. (***SY5, Thurs. 8:20***)

The Brucejack porphyry-related epithermal Au deposit, northwestern British Columbia

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Brucejack is a precious metal porphyry-related epithermal Au deposit located in northwestern British Columbia. The deposit is one of many world-class economic deposits that formed in association with extensive volcanic arc-related magmatism in Late Triassic-Early Jurassic time in the Canadian Cordillera. Brucejack mineralization is hosted by island arc-related Early Jurassic latitic flows, and associated volcanic fragmental and subordinate volcaniclastic rocks. Variably altered and mineralized host volcanic rocks yield U-Pb zircon dates ranging between 196.4 ± 0.7 Ma and approximately 184 Ma. Age estimates for mineralization at Brucejack range between 191 ± 0.8 Ma and 188.9 ± 0.9 Ma (Re-Os molybdenite), and are within broad agreement with estimates for local porphyry-style mineralization (195-192 Ma) and for the causative intrusions. The deposit includes features typical of intermediate-sulphidation epithermal deposits, including stockwork veining and breccia-veins, along with local adularia and common acanthite, suggesting near surface ore-forming conditions. However, the general absence of colliform banding and open-space filling, along with high molybdenum content in localized zones suggest deeper levels of emplacement than is typical for epithermal deposits. Six vein stages have been recognized at Brucejack; (1) highly deformed and discontinuous pyrite stringer veins containing carbonate and quartz with common sericite-chlorite alteration; (2) electrum-bearing deformed quartz-carbonate ± sericite stockwork veins and breccias, which are spatially associated with subvertical stringer quartz veinlets, also hosting electrum; (3) Zn-Pb-(Cu) sulphide veining containing common Ag-sulfosalts and electrum; (4) highly deformed carbonate ± quartz veins containing abundant orange-coloured, Mn-bearing calcite, also containing electrum; (5) late stage quartz-carbonate shear veins with asymmetrical sericite, chlorite, and pyrite banding; and (6) subhorizontal white bull quartz-carbonate tension gash veins with appreciable chlorite alteration (these are cospatial and likely cogenetic with stage 5 shear veins). The deposit is cross-cut by late stage andesite-trachyandesite amygdaloidal dykes, which truncate all mineralized veins, and which are cross-cut by late stage (post-mineralization) veins. A U/Pb zircon age of 182.7 ± 1.0 Ma has been determined for one of these dykes, providing a minimum age for the hydrothermal system. **(*SS3, Wed. 2:40*)**

Exploring the evolution of water in the Martian crust using olivine-hosted secondary mineral veins in the Lafayette meteorite

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The Lafayette meteorite is a sample of the crust of Mars. This olivine-bearing clinopyroxenite formed in a lava flow or shallow sill at ~1300 Ma, and contains a suite of secondary minerals that crystallized from liquid water at ~670 Ma. These secondary minerals are principally clays and carbonates, and are most abundant within veins that cross-cut olivine phenocrysts. The source of the water from which the clay and carbonate formed is very poorly known. The most common suggestions are melting of permafrost in response to volcanism or impacts, although a magmatic source has also been proposed. We have sought to understand the longevity and evolution of this aqueous system by mineralogical, microstructural and isotopic analysis of the secondary mineral assemblage.

The veins are composed principally of nanocrystalline smectite that formed by incongruent dissolution of olivine focused along (001)-parallel subgrain boundaries. The vein walls were subsequently replaced by siderite, then the siderite was itself partially replaced by more coarsely crystalline clays. Our modelling of mass transfer suggests that this suite of minerals only required the addition of water and carbon dioxide from outside of the Lafayette parent rock, thus discounting a long-lived and large-scale hydrothermal system.

The provenance of water has been explored further by deuterium/hydrogen (D/H) analysis using NanoSIMS. Martian water has very different D/H ratios depending on its source; mantle-derived solutions have a δD value of ~0 per mil, whereas water derived from the Martian atmosphere should have a δD of ~5000 per mil. D/H work using the clays is problematic owing to their propensity for exchange of hydrogen with the terrestrial atmosphere. Instead the olivine walls of the secondary mineral veins were analysed, and they yield δD values of up to 4400 per mil, which is a Martian atmospheric signature. This water is inferred to have entered the olivine via arrays of shock-formed dislocations that have been identified by transmission electron microscopy. Our results suggest that aqueous alteration of Lafayette was mediated by a short-lived pulse of water derived from the planet's surface, although the source of heat that was required to stabilise this water remains to be determined. **(*SS21, Thurs. 8:40*)**

The pre-, syn- and post-impact origin of hydrated phases: A case study based on observations of the Haughton impact structure (Nunuvut, Canada)

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Ongoing detections of hydrated phases within the heavily-cratered southern highlands of Mars indicate that they are most commonly associated with impact craters (~70%). Determining whether the crater process itself played a major role in the origin of these phases is key towards for deciphering the early climate history of Mars. Hydrated phases associated with impact craters may originate as pre-, syn- or post-impact materials or any combination of the three. Determining which (or combinations thereof) of these are plausible for crater-related spectral signatures is not trivial, and may not be resolved through orbital data alone.

In this study, we use both remote sensing (*i.e.*, ASTER orbital data) and ground-truth data from the field (conducted in July 2013) of the Haughton impact structure (HIS) (Da = 23 km), Devon Island, Nunavut, Canada, utilized as a Mars analogue, to assess the origin of its hydrated phases. The hope is to place further constraints on the uses and limitations of applying remote sensing data exclusively to determine the pre-, syn- and post-impact origin of hydrated phases.

Based on previous results, we constructed a gypsum spectral parameter map exploiting the strong thermal infrared (TIR) absorption in ASTER band 11 (8.63 µm). Analysis and synthesis of this map with other remote sensing data sets were used to formulate pre-, syn- and post-impact interpretations of the data prior to ground-truthing them in the field. These include: 1) uplifted bedrock from the target, including megablocks in the crater-fill to bedrock outcrops uplifted during crater modification (pre-), and 2) hydrothermally emplaced and/or re-mobilized gypsum (syn- and post-).

Field observations of all the major concentrations of the ASTER-mapped "Gypsum" Unit during the July 2013 HIS field season indicate that the "Gypsum" spectral signature correlates with: 1) bedrock outcrops and megablocks, 2) gullies and valleys, 3) mass-wasting and depositional fans, 4) veneers/coatings and encrusted soils, and 5) hydrothermal veins and vugs of gypsum (var. selenite).

The HIS exhibits a complex history with all three modes of origin co-existing at the site. Unfortunately, hydrothermal features are too small to resolve in orbital remote sensing data, but were observed to be pervasive within the pre-impact bedrock in the field. Therefore, a syn-impact interpretation should not necessarily be dismissed based on results from orbital remote sensing studies alone. *In situ* investigations of, and sample return from these sites will be crucial towards a better understanding of the origin of hydrated phases on Mars. **(*SS21, Thurs. 9:20*)**

Sedimentary signatures of tectonic activity in the lacustrine Green River Formation (Eocene), Fossil Basin, Sevier Fold and Thrust Belt, Wyoming

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Syndepositional deformation structures preserved in lacustrine sedimentary rocks provide a little explored opportunity to interpret the paleoseismic history of the region in which they occur. The Eocene Green River Formation of the western U.S.A. is one of the best-documented ancient lake systems. Despite many studies devoted to the stratigraphy and sedimentology, deformation features have been virtually ignored. In fact, the Green River Formation displays a wide range of laterally extensive, early post-sedimentation deformation features. This study focuses on those preserved in open-lacustrine, finely laminated carbonate mudstone, which commonly has high organic content (oil shales), in Fossil Basin of southwestern Wyoming.

Deformation structures include complex folds and convolute lamination, mixed brittle–ductile structures, sedimentary dikes and sills filled with carbonate mud or sand, oil shale breccias, mass-transport debrites, synsedimentary faults, and fluid-escape structures (pipes and cusps). These features occur in a number of distinct horizons, up to 4 m thick. Many of these horizons can be correlated laterally for up to 25 km across Fossil Basin. The style of deformation was controlled by the variable rheological properties of the host sediment, especially those resulting from differences in the abundance of organic matter and the degree of cementation. Deformed layers are bounded above and below by undisturbed beds of similar facies, and this implies recurring short-lived events that affected only those sediments with a susceptible rheological state at the time. In some locations, the deformed horizons are overlain by beds showing greater bioturbation, suggesting an abrupt, tectonically-driven sudden change in lake conditions that allowed more bioturbation to occur. Mass-transport deposits indicate instability of a very gently dipping lake-floor, or brecciation of shallow lacustrine sediments *in situ* induced by seismicity. Based on their lateral extent and morphological characteristics, the tectonic history of the area and the sedimentary succession in which they occur, these deformation features are interpreted as seismites, and are attributed to elevated pore pressures from cyclic loading and to horizontal and vertical stresses induced by strong earthquakes. The tectonic activity in the study area was related to late-stage structural movements of nearby fault systems of the Sevier Fold and Thrust Belt ~52 million years ago, near the end of the Laramide Orogeny. **(*SS13, Thurs. 10:40*)**

Stratigraphic and structural setting of banded-iron-formation-hosted gold mineralisation in the Geraldton area, Ontario

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The Beardmore-Geraldton Greenstone Belt (BGB) is located along the boundary between the Wabigoon and Quetico subprovinces of the Archean Superior Province. It produced more than 4.1 million ounces of gold over the past century. This project aims to characterise the age and provenance of the sedimentary rocks and intrusions hosting mineralisation, to determine the timing and genesis of gold mineralisation with respect to the four deformation events that affected the area, to characterise the mineralogical assemblage and geochemical footprints of the mineralised system and the associated hydrothermal alteration. The BGB is composed of structurally interleaved panels of metasedimentary and metavolcanic rocks. The metavolcanic units represent back-arc basin, oceanic island arc and MORB-type oceanic crust. The metasedimentary units formed a southward-prograding clastic wedge. Sandstone and conglomerate samples were collected across the BGB and along the northern margin of the Quetico Subprovince for U-Pb detrital zircon geochronology. All BGB sandstone samples have very similar zircon age populations, with the youngest population dated at ~2700Ma. The BGB conglomerate has a youngest zircon population age of 2711Ma, similar to that of the Quetico sandstone. This is consistent with a previous interpretation of the BGB as a transitional zone between the Wabigoon and Quetico subprovinces. The sedimentary rocks of the BGB were deposited prior to the emplacement of a quartz-feldspar porphyry which has a crystallization age of 2694±1Ma. The age of the porphyry represents the maximum age for gold mineralisation in the Geraldton area as it hosts auriferous quartz-carbonate veins.

The deformation history of the belt began with D_1 thrusting followed by D_2 north-south compression and D_3 dextral shear. A previously unrecognised, sinistral transcurrent shear occurred prior to D_3 dextral shear. Gold deposits in the Geraldton area are associated with a major fault zone next to the boundary between two subprovinces. As such they share analogies with world-class gold districts such as Timmins. Gold occurs in quartz-carbonate veins and their sericite ± carbonate ± chlorite and pyrite ± arsenopyrite alteration haloes hosted within mudstone, sandstone, banded iron formation and quartz-feldspar porphyry. Most gold-bearing veins are folded by F_2 folds suggesting pre- or early-D_2 gold mineralisation. Thus, an early stage deformation most probably played a key role in the formation of gold deposits in the BGB. **(*SY5, Thurs. 9:00*)**

Copper-PGE mineralization in the Thunder mafic-ultramafic intrusion, Midcontinent Rift: A PGE and precious metal bearing early-rift conduit system

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The Thunder intrusion is a small, layered mineralized mafic to ultramafic intrusion located on the outskirts of Thunder Bay, Ontario and is interpreted to be associated with the early tectono-magmatic stages of the North American Mesoproterozoic Midcontinent Rift (MCR). This intrusion is distinct from the other known mineralized early-rift MCR intrusions as it is the only known occurrence hosted by metavolcanic and metasedimentary assemblages of the Archean Shebandowan greenstone belt. The intrusion is approximately 800 by 1000m by < 500 m thick and dips steeply south. Major textural and geochemical differences divide the intrusion into a lower mafic to ultramafic basal unit and an upper gabbroic unit, however, similar trace and rare earth element ratios of the two units suggests a single magmatic pulse that has undergone subsequent fractionation.

Significant Ni-Cu-PGE mineralization is hosted by olivine clinopyroxenite in the lower mafic-to-ultramafic unit adjacent to the basal wall rock, including 20 m of 0.22% Cu, 0.06% Ni, 0.25ppm Pt, 0.29ppm Pd. Sulphides rarely comprise up to 30% by volume but more typically 1-5% with textures ranging from medium- to fine-grained disseminated, globular and rarely net-textured. Pyrrhotite, chalcopyrite and rare pentlandite with common secondary marcasite-pyrite replacement occur along with trace kotultskite, naldrettite, merenskyite, sperrylite, electrum and native silver.

The $\delta^{34}S$ values of sulphide minerals from the Thunder intrusion are similar to the adjacent wall rock forming a tight range between +3.8 and -3.1‰. Although $\delta^{34}S$ values are broadly consistent with a mantle origin (0 ± 2‰) the involvement of crustal sulphur during the mineralization process remains a possibility. Radiogenic isotopes were measured from select samples to investigate possible contamination of the Thunder intrusion. The εNd values from the intrusion range between -0.74 and +0.99, with no trends towards wall rock compositions, whereas the $^{87}Sr/^{86}Sr$ values range from 0.703 and 0.706 and trend towards wall rock values of 0.707 and 0.709. The decoupling of the two radiogenic isotope signatures is consistent with crustal contamination at depth and local contamination during the emplacement of the Thunder intrusion. **(*GS5, Fri. 10:20*)**

Carbonates gone wild: 50 million years of invariant carbonate production and export in the lower Paleozoic of northwestern Canada

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Carbon isotope stratigraphic data for lower Paleozoic carbonate successions in northwestern Canada yield new temporal constraints on, and a new correlation scheme for, contemporaneous shallow- and deep-water environments near the newly rifted margin of Laurentia during the Sauk II-III sequence. The hitherto mysterious, extremely widespread Cambro-Ordovician Franklin Mountain Formation (max. 535 m thick; truncated by unconformity) records very slow but continuous accumulation of mildly restricted, distally steepened carbonate ramp facies over a span of ~50 m.y.; accumulation rates averaged <10 m/m.y and were maximal during the Guzhangian, (>20 m/m.y.). Distinctive carbon isotopic excursions prove that the Franklin Mountain Formation is laterally equivalent to the Hess River, Rabbitkettle, and Duo Lake (part) formations of the Misty Creek Embayment (Selwyn Basin), which together form ~2300 m of fine-grained carbonate strata that accumulated in slope and deep-basin environments from material exported from the laterally equivalent, contemporaneous Franklin Mountain Formation's shallow-water carbonate factory. Carbonate export to the deep basin vastly exceeded the volume capable of being stored and buried in the shallow-water environment, yet the shallow-water environment did not experience any depositional hiatuses of significant duration throughout its ~50 m.y.-long depositional history: sediment production and export were exceptionally well balanced by the dynamics inherent to the carbonate system. The seeming monotony of the shallow-water carbonate system is deceptive, however; episodes of enhanced accommodation in both shallow- and deep-water settings, identifiable only by using $\delta^{13}C$ data in a detailed lithostratigraphic context, point to intervals of enhanced subsidence in both environments (*e.g.*, Guzhangian), and illustrate the subtlety with which synsedimentary tectonism can be reflected in carbonate systems, which have a built-in capacity to equilibrate to changes in accommodation space. Furthermore, even though carbonate sediment production in and export from the shallow-water environment was apparently continuous, as demonstrated by the uninterrupted lower Paleozoic $\delta^{13}C$ curve in both settings, at least one conspicuous episode of sediment-starvation is recorded in the deep basin's lithostratigraphy as a black shale interval. Given the preponderance of evidence for steady sediment production and export, the black shale interval(s) must reflect the presence of sea-floor paleotopographic feature(s) that prevented sediment delivery to specific locations at specific times; such features were probably local highs produced by block-faulting in this complexly segmented extensional zone of Laurentia's northwestern passive margin. **(*SS13, Thurs. 3:20*)**

Gossans of the Cornwallis district, Canadian high Arctic

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The Cornwallis district (central Canadian high Arctic islands) contains numerous carbonate-hosted Zn-Pb sulphide showings that are assumed to be affiliated with the late Paleozoic mineralizing event that produced the Polaris zinc deposit. Although some showings are not visually obvious from a distance, many are signalled by gossans of conspicuous, rusty material that consists of unidentified fine-grained phases; this weathering characteristic was known during the district's exploration history as "Arctic weathering". The region was deglaciated at ~8 ka, and so although the Arctic islands are now characterised by low annual precipitation, thin winter snow cover, and annual average temperatures well below 0°C, the gossans are inferred to have evolved rapidly through weathering in the last few thousand years. The gossans are particularly conspicuous on Cornwallis and nearby islands, where exposed bedrock belongs to the lower Paleozoic carbonate passive-margin succession of the Franklinian basin, which is known to contain two thick Ordovician sulphate intervals in some parts of the district. The region's geomorphology is generally subdued, with extensive low plateaux covered in carbonate-rock felsenmeer, separated by broad, sparsely vegetated, poorly drained wetlands underlain by terrigenous mudrock, and ephemeral streams that feed small rivers; *in situ* bedrock is sparse, and most areas consist of frost-heaved bedrock material. Gossans are most commonly present as areally limited rusty zones in the slightly elevated areas away from larger drainages. Geological mapping has shown that most gossans, and the sulphide bodies they are inferred to overlie, are related to underlying structures (thrust, wrench, and normal faults; fold hinges) produced or reactivated during the Ellesmerian orogeny (late Devonian), where dilation and brecciation produced ephemeral void spaces and permeability networks into which metalliferous fluids migrated. The gossanous zones range from metre-scale patches over minor structural features and associated with permafrost polygons, to kilometre-scale gossan fields that overlie poorly exposed graben-like structures (*e.g.*, Bacon River gossans; north-trending graben that juxtaposes upper Ordovician – lower Silurian Allen Bay Fm. with middle Ordovician Thumb Mountain Fm.; ~74°55N, 92°27' W). No geochemical or mineralogical investigations have ever been undertaken on the gossans, and most were not drilled during the heyday of Arctic mineral exploration activity in the 1960s-1990s. The characteristics of the sparse surface waters in the vicinity of the gossans remain unknown, as does the typical depth to inferred underlying sulphide bodies. The absence of basic information about the characteristics and origin of the Cornwallis gossans leaves much to be studied. **(*SY4, Wed. 9:40*)**

Geochronology of the Mesoproterozoic Bylot basins (Nunavut) and their zinc endowment

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The Bylot Supergroup in the Mesoproterozoic Borden Basin of eastern Nunavut begins with basalt flows inferred to be related to the 1.27 Ga Ma Mackenzie LIP, yet a ~1.1 Ga U-Th-Pb whole-rock depositional age for shale just a few hundred metres higher in the lower part of the succession records deposition as much as 200 million years later. Recent work has shown that the lower and middle parts of the supergroup were deposited into a rapidly evolving, tectonically active basin; a strong tectonic influence is also implied by a switch from carbonate to siliciclastic rocks in the middle to upper part of the succession. In order to establish the maximum depositional age and sediment sources that supplied this tectonically dynamic basin, 8 samples from throughout the Bylot Supergroup were subjected to U-Pb detrital zircon analysis using LA-ICPMS and SHRIMP. Sandstones that immediately underlie and overlie the Nauyat Formation (basalt) are dominated by zircon derived from the Archean Rae craton and adjacent Trans-Hudson orogen, as are all formations up to and including Angmaat Formation (dolostone) in the middle of the succession. Siliciclastic-dominated rocks from the upper part of the succession (Strathcona Sound and Sinasiuvik formations), however, contain a distinct population of zircon grains that characterize the Grenville Orogen, and the youngest grains from the youngest strata are ~1.14 Ga (Sinasiuvik Formation). This detrital zircon age-distribution is consistent with recent interpretations of the basin's evolution, based on regional lithostratigraphy, invoking a phase of trans-tensional basin subsidence in response to stresses imposed by Rodinian amalgamation around 1.1 Ga. Detrital zircon data from basal sandstones of the correlative Aston-Hunting and Fury-Hecla basins have similar Archean and Paleoproterozoic provenance. The Hunting Formation, uppermost carbonate unit in the Aston-Hunting basin, strongly resembles the Angmaat Formation, but contains a population of zircon that are considerably younger (~1.25 Ga) than youngest zircon in the Angmaat Formation, suggesting that the Aston-Hunting basin was closer to a source of young zircon. Together, the lithostratigraphic and geochronologic data point to basin subsidence that was at least in part much younger than previously thought, and may have been contemporaneous with Rodinia's assembly. Given the ~1.1 Ga age of the Nanisivik zinc deposit, it is probable that deposition of the upper part of the Bylot Supergroup and formation of the ore-body were related to tectonism during assembly of Rodinia. **(*SY7, Fri. 9:00*)**

Petrographic observations and evaporate mound analysis of quartz-hosted fluid inclusions: Applications to assess metal fertility in granites

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The 380 Ma South Mountain Batholith (SMB), Nova Scotia, is a large (~7300 km^2), contiguous, mesozonal granitoid intrusion consisting of 13 coalesced plutons hosting a variety of mineralized zones (*e.g.*, Sn-Zn-Cu-Ag, Mn-Fe-P, U, Cu-Ag). Given the hydrothermal nature of this mineralization, it is expected that a geochemical fingerprint of the mineralizing fluids might be preserved both petrographically and as secondary fluid inclusions (FIs) in the granites on a scale equal to or larger than the mineralized zones. In this unique study, we investigate the possibility of integrating petrographic observations that reflect fluid:rock interaction and the chemistry of secondary, quartz-hosted FIs in samples from the SMB to assess granite fertility and also the scale of this potential vectoring tool. The protocol involved: (1) detailed petrographic study of >500 archived samples and focused on the extent and degree of alteration (*e.g.*, perthite textures, chlorite alteration of biotite, plagioclase alteration, percent of secondary muscovite, abundance of FI in quartz); and (2) determining fluid chemistry of quartz-hosted FIs in >100 samples collected from a 10 × 10 km grid superimposed on the SMB. The petrographic data record highly variable degrees of alteration and the results are being used to design an alteration algorithm that can be used to map the extent of fluid:rock interaction throughout the batholith. The chemistry of FIs, determined using the evaporate mound method, is being used as a proxy for both the mineralizing and altering fluids. At present, results for >600 mounds determined for 68 samples indicate the fluids are dominated by Na-K-Ca-Cl-F, with traces of Fe, Mn, and S, and that two distinct types are present, one Na-rich and the other Ca-rich. Two intriguing results to date include: (1) the pervasive occurrence of F in the mound analysis with up to 40 wt. % when normalized to 100%, even in samples distal to known mineralization; and (2) elevated Ca in many samples, including those from chemically evolved, hence Ca-depleted rocks. This latter feature may reflect extensive albitization of plagioclase, hence liberation of Ca, during fluid-mediated alteration. Thus, our preliminary findings clearly indicate that mappable variation in the degree and extent of alteration is retained in the main mineral phases of the granites and that fluid chemistry, preserved as secondary FIs in quartz, is a potential proxy for fluid:rock interaction and hence a measure of metal fertility. **(*SS3, Wed. 10:40*)**

Structural analysis of the Bellechasse-Timmins gold deposit, southern Québec Appalachians, Canada

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The Bellechasse-Timmins (BT) gold deposit is located approximately 110Km south of Québec City. It is hosted by the Ordovician sedimentary rocks of the Magog Group, a synorogenic forearc basin sequence in the Dunnage Zone of the southern Québec Appalachians.

Structurally, BT occurs within the St-Victor synclinorium, a major regional fold structure that is bounded by the Baie Verte-Brompton line to the northwest and the La Guadeloupe fault to the southeast. This gold deposit consists of Au-rich quartz veins hosted by diorite and gabbro sills/dykes crosscutting the sedimentary and volcaniclastic rocks of the Middle-to-Upper Ordovician Etchemin Formation, which has been deformed and metamorphosed during the Acadian orogeny. The regional metamorphism is of low-grade, varying from prenhite-pumpellyte to greenschist facies. The Etchemin Formation consists of interbedded dark-gray to purple mudstones, greenish siliceous mudstone, grading up-section into dark-green volcaniclastic rocks. The diorite intrusions are 100m to 300m-thick and are cutting at low-angle the bedding of the hosting rock sequence. It consists mainly of plagioclase, amphibole, biotite and/or pyroxene. The Au mineralization is hosted in quartz veins and quartz-filled breccias, essentially developed in the diorite/gabbro intrusions and mainly made up of quartz ± carbonates and minor sulphides, mostly pyrite and pyrrhotite. Quartz veins, however, occur in the sedimentary/volcaniclastic rocks but are commonly barren.

Our structural analysis of the BT deposit shows that both the intrusions and hosting sedimentary rocks are characterized by steeply-dipping NE-trending (N010-N030) schistosity (S_1). The diorite bodies are crosscutted by brittle-ductile, anastomosing, shear zone subparallel to S_1. These shear zone host steeply-plunging (down-dip) slickenlines and lineations and preserved structural evidence for reverse faulting. Subhorizontal lineations/fault striae are also locally found, suggesting late-stage strike-slip motion. Structural relationships between bedding and S_1 indicate that sedimentary strata hosting diorite are tightly folded, with fold axes plunging moderately to steeply (60°) towards both the SW and the NE, and that the contact between the Etchemin Formation and diorite intrusions is folded as well. There are 3 principal orientations of quartz veins, almost perpendicular to each other, suggesting that the overall geometry of the ore zones is mainly controlled by the regional folding and basically represents the product of filled fractures related to the formation of saddle-reef structures. Folded flat, extension veins and "en-échelon" veins that seem to be compatible with both compressive and late-stage strike-slip shearing, suggest that the Au-rich hydrothermal event related to BT mineralization occurs during the late stage of the Acadian orogeny. **(*SY5, Poster*)**

Element release from the subducting slab constrained using tourmaline: Towards a new model for element transfer in subduction zones?

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Subduction zones are the key interface between the surface, crust and mantle, and, together with their mid-ocean ridge counterparts, largely control element cycling among the Earth's interior, its solid surface and the hydrosphere and atmosphere. To quantify this element cycling, and accurately constrain element budgets for the Earth's reservoirs, requires precise knowledge of element release from the subducting plate as it descends into the mantle. The role of aqueous fluids is of particular interest in this respect, because of their high, and strongly selective, transporting capacity. Although the signature of the element flux from the subducting plate is known from suprasubduction-zone volcanic rocks, the quantitative compositions of the aqueous fluids involved, and hence the quantitative flux, are poorly constrained.

Here, we present results of a study using the trace element compositions of subduction zone minerals, in particular tourmaline, to reconstruct the compositions of the associated aqueous fluids, based on the systematic element partitioning among these phases. Together with P-T constraints obtained from tourmaline, this allows us to track the compositions of the fluids released during progressive slab devolatilization, and hence constrain the element release from the slab. Our data indicate that fluids are indeed the source of the characteristic elemental signature observed in arc volcanism (*e.g.* high B, Sr, Pb with low Nb, Ta). However, element concentrations in the fluid are low, and inconsistent with the classical model of batch transfer of material from slab to mantle to generate the arc volcanic signature. Rather, we propose a gradual transfer of this signature to a slab mélange zone by slab-parallel upward movement of fluids. Subsequent instability of this mélange zone transfers this material to the mantle, *e.g.* in diapirism, where it melts and transmits the subduction signature to arc magmas. **(*SY3, Thurs. 2:20*)**

Migration of a suprastructure-infrastructure boundary within polydeformed metamorphic rocks in the Thor-Odin – Pinnacles area of southern BC during Late Cretaceous to Eocene orogenesis

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The basement-cored Thor-Odin dome in southern BC was polydeformed in the Late Cretaceous to Eocene and exhumed in the Eocene. We focus on a 12-km thick tract of polydeformed metamorphic rocks that structurally overly the dome, contains migmatites and the South Fosthall leucogranite pluton in its lower part, and extends ~20 km southward to the Pinnacles culmination and Whatshan Batholith. The rocks are exposed in the footwall of the east- dipping,

~52 Ma Columbia River fault (CRF) ductile-brittle normal fault system. It juxtaposed upper plate with a generally Late Jurassic to Early Cretaceous cooling history against the above-mentioned tract of rocks with Late Cretaceous to Eocene cooling histories. The tract of rocks has been interpreted as a mid-crustal zone that was bounded at the top by the CRF and was exhumed and cooled during Eocene extension in a core complex setting or a mid-crustal channel. Rather, based on data compilation throughout the structural section (*i.e.* timing of metamorphism and anatexis, deformation and emplacement of anatectic leucogranites, and $^{40}Ar/^{39}Ar$ thermochronology), there are four tectonothermal domains that experienced metamorphism, deformation and cooling at different times. They exhibit a downward progression of penetrative deformation in an infrastructural setting, followed by a downward progression of deactivation and cooling throughout the section. The structurally highest domain in the Whatshan-Pinnacles area underwent penetrative deformation and polyfolding in the infrastructure in the Late Cretaceous prior to ~75 Ma. At ~73 - 64 Ma, structurally lower rocks in the infrastructure underwent progressive deformation but were deactivated by ~64 Ma, whereas deformation continued in deeper rocks. After ~58 Ma, all of these domains became deactivated and acted as suprastructure relative to the deforming rocks in the Thor-Odin dome, which were deformed in the infrastructure until ~52 Ma when they cooled through ~300°C due to exhumation during the main stage of faulting on the CRF. The CRF crosscuts the trace of these aforementioned domains in the mid-crustal tract of rocks and the fossil suprastructure-infrastructure boundaries. The fault is younger than much of the deformation in its footwall. This geologic setting is inconsistent with core complex extensional exhumation or channel flow models. The mid crustal section was progressively heated and deformed in the Late Cretaceous to Paleocene during crustal thickening as rocks were transported to the east to northeast over a basement ramp. Large scale crustal extension halted the compressional deformation and caused widespread cooling in the Eocene. **(*SY3, Fri. 8:40*)**

Geochemical modeling of mineralogies of the Bear Lodge REE deposit, northeast Wyoming, USA

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Development of deposits that were previously avoided due to complex mineralogies and resulting processing issues is becoming increasingly commonplace as material demands increase and new analytical and processing techniques develop. Many rare earth element (REE) deposits under current evaluation by exploration and development companies are the result of multiple geochemical processes that result in mineral assemblages with different REE grades, REE distributions, and/or amenabilities to economic recovery.

The Eocene Bear Lodge complex contains a series of carbonatite dykes and associated stockworks that intrude slightly older trachyte/phonolite stocks and diatremes. Post magmatic hypogene, and especially supergene alteration processes have significantly altered ore and gangue mineralogies. Fenitization, REE remobilization, oxidation, and clay alteration are all processes that contributed to an economically attractive, but heterogeneous deposit.

The use of geochemical indices, audited for accuracy with independent analytical methods, can be an extremely useful tool for quantifying information of mineralization/alteration across a deposit given complete and accurate assays. Simple geological logging of drilled core or chips cannot always provide information that can be easily used in deposit model generation. However, for geochemical indices to be effective, assumptions made during their construction must be calibrated by modal mineralogical data. Optical microscopic, XRD, and QEMSCAN/MLA data can all be used to audit the accuracy of such normative indices.

The establishment of these indices using a foundation of relatively costly mineralogical analyses on a small, representative subset of samples allows for the low-cost estimation and modeling of ore and gangue mineralogy across a deposit. Reasonably accurate estimates of mineralogical assemblages can then be resolved spatially using 3D modeling software. The resulting semi-quantitative characterization of deposit mineralogy can be of great use in resolving issues related to mineral processing, exploration, environmental characterization, and engineering.

Geochemical indices that attempt to quantify parameters including clay alteration, silicification, oxidation, and proportions of phosphate mineralization have been developed for the Bear Lodge. Given the highly variable nature of the mineralogies in a partially laterized deposit and the assumptions made, most indices have been found to be in reasonable agreement with modes observed using QEMSCAN, XRD, SEM, cathodoluminescence, and optical microscopy. **(*SY6, Fri. 8:20*)**

Use of QEMSCAN to characterize oxidized REE ore from the Bear Lodge carbonatite, Wyoming, USA

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Economically viable rare earth element (REE) deposits are mineralogically complex and typically contain approximately 4-15 REEs in sufficient concentrations to ensure profitable production. The values of these contained elements vary widely, from ~\$6/kg Ce_2O_3 to ~\$950/kg Eu_2O_3. Consequently, economic evaluations of these deposits must consider the distribution of REEs present in addition to the total REE grade. Genetic deposit models are difficult to apply, owing to the variety of natural processes that concentrate REEs into economic quantities. Detailed study of the controls on REE mineralization is required to understand the REE content and distribution, and their impact on deposit development.

The Bear Lodge REE deposit is located in northeastern Wyoming and represents the northwesterly extension of Laramide magmatism in the Black Hills province of South Dakota-Wyoming. The Eocene carbonatite dyke and stockwork system intruded trachytic-phonolitic rocks that contain multiple diatremes. The original magmatic characteristics of the REE-enriched carbonatite complex are strongly overprinted by hydrothermal and later supergene fluids. These fluids redistributed the REEs and created high variability in the REE ore mineral assemblage, and compositional variability within individual REE mineral species.

The REE ore minerals at Bear Lodge can be classified into four groups: 1. fluorocarbonates (bastnaesite, parisite, synchysite), 2. phosphates (monazite, xenotime, florencite, rhabdophane, churchite), 3. cerianite, and 4. ancylite. These minerals vary greatly in abundance, grain size, and morphology, and result in variability in REE distribution throughout the deposit.

Variations within a given REE mineral in terms of Ce depletion, Th content, degree of heavier REE enrichment, *etc.*, create difficulties in the initial definition of discrete mineral species (*i.e.*, x-ray spectra) and their resultant identification protocols (SIP) for use in automated mineralogy (QEMSCAN). Prevalent submicron-scale supergene mineralization also results in hybrid spectra from two or more phases. Iterative work in reconciling QEMSCAN data interpretation with bulk assay, XRD, SEM, CL, and optical petrography data allows for refinement of the SIP definitions for both ore and gangue minerals. The use of automated mineralogy as a tool for development of resources with complex mineralogies requires rigorous review of these data in order to achieve results that can be applied with confidence to resolve mineral processing issues.

Careful documentation of mineralogical and geochemical variations throughout the deposit allows processing issues to be identified and addressed during the pilot plant phases. Such preparation may preclude the necessity of reactionary solutions during production that can be more costly in the future. **(*SY6, Fri. 8:00*)**

Keynote (40 min): Tectonic architecture of the west-facing Popelogan Arc - Tetagouche-Exploits backarc system in New Brunswick

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Northern New Brunswick is the type area for the 475-453 Ma opening- and 447-430 Ma closing of the Tetagouche-Exploits backarc basin (TEB), evidence of which is preserved in north younging Salinic nappes developed in rocks of the Bathurst and Fournier supergroups. The Bathurst Supergroup contains Floian-Katian rocks related to rifting and isolation of slivers of the Gander margin, which was coeval with west-facing Popelogan arc volcanism. The oldest Popelogan arc phase, preserved in the 476-472 Ma Meductic Group, was deposited upon the leading edge of the Gander margin. Migration of the Popelogan arc towards the west (Balmoral Group) at *ca.* 470 Ma coincided with eruption of oceanic backarc pillow basalts in parts of the Bathurst Supergroup, linking the two systems dynamically to rollback of an east-dipping slab. Rifting culminated in oceanic spreading, evidence of which is preserved in 470-465 Ma transitional oceanic crust of the Bathurst Supergroup and the nearly complete ophiolite (gabbro, trondhjemite, sheeted dike, pillow basalt) of the 464-459 Ma Devereaux Complex (Fournier Supergroup). In the Fournier Supergroup, the Devereaux Complex is preserved in the structurally highest nappe and is linked to the underlying oceanic nappes of the Pointe Verte and Sormany groups by the composition of dikes and pillow basalts and lithology of associated sediments. In turn, the nappes of the Fournier Supergroup are tied to the Popelogan arc by the age and composition of 465-460 Ma felsic ash beds, zircon inheritance and detrital zircons in the associated sediments. Pelagic sedimentation between 462 and 450 Ma, identical in both the Bathurst and Fournier supergroups, demonstrates oceanic conditions with only minor local clastic input throughout the TEB at this stage. Closure of the TEB by west-directed subduction was instigated at *ca.* 450 Ma and led to piecemeal accretion of backarc slivers to a steadily outward growing forearc system between 447 and 433 Ma. Clastic sedimentation in syntectonic forearc slope and/or small foredeep basins between 447 and 433 Ma, unconformably and/or conformably above the various nappes developed in rocks of the Bathurst and Fournier supergoups, overlap in age with formation of blueschist and other high pressure rocks. They attest to the complex dynamic interplay between accretion, sedimentation and exhumation in a large accretionary forearc system. Accretion was finished by arrival of the Gander margin no later than 430 Ma and heralds the onset of the collisional phase of the Salinic orogeny, which lasted until the end of the Silurian. **(*SY1, Wed. 8:20*)**

Trace element analysis of native Gold by laser ablation ICP-MS: A case study in greenstone hosted quartz-carbonate vein ore deposits, Timmins, Ontario

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Native gold in nature contains trace amounts of other elements and from the relative abundance of these a geochemical signature can be obtained. The trace element composition provides a “fingerprint” that is unique to the gold deposit it comes from. This fingerprint can be used to distinguish gold sources and potentially provide insight into the geochemical processes operating in the formation of Au deposits. Native gold grains were acquired from 3 gold ore

deposits; Hollinger, McIntyre, and Aunor. These ore deposits are located near Timmins, Ontario, in the western end of the Porcupine gold camp, the south-western part of the Abitibi greenstone belt. Scanning Electron Microscope analysis (SEM/EDS) was used to determine major elements in gold grains. Ag-concentrations from the SEM/EDS analyses were used as the internal standard for the laser ablation inductively coupled plasma mass spectrometry technique (LA-ICP-MS) that yielded trace element concentrations. A new reference material (AuRM2) served as the external standard for 22 elemental analytes for the LA-ICP-MS analyses. Trace elements in native Au associating according to Goldschmidt's classification of elements demonstrates that element behavior in the native Au is not random. Such element behavior suggests that samples from each deposit formed under similar geological conditions. Chalcophile and siderophile elements provide the most compelling fingerprints of the three ore deposits and they appear to be in solid solution in Au whereas lithophile are not very advantageous for distinguishing deposits and their element compositions are mainly driven by micro inclusions such as tourmaline. The deposits show low range of Ag contents, which is consistent with mesothermal Au. Hollinger and McIntyre deposits have similar trace element abundances exhibiting high Ag, Pb, Bi, Sb and Pd and low Cu and Au; however Cu concentrations in McIntyre are higher than Hollinger. In contrast, Aunor has high Cu and Au abundances and low Ag, Bi, Sb, Pb and Pd. Gold grain signature reflects the chemical characteristics of the host rock superimposed on the chemical signature of the mineralizing fluid. Association of Pb-Bi-Cu bearing phases such as galena and chalcopyrite with gold supports hydrothermal fluids with high concentrations of these elements. **(*SY5, Poster*)**

Structural analysis of the Archean France River shear zone and its gold mineralizations, Chapais-Chibougamau, Superior Province, Québec

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The Chapais-Chibougamau mining camp, located in the northeastern part of the Archean Abitibi greenstone belt, has been the second largest mining district in Québec from 1953 to 2008 (84.26 Mt of ore which produced 1,525,962 t Cu, 176 t Au and 109 t Ag). Known for its Cu-Au vein deposits, this mining camp hosts gold-bearing veins in volcanic rocks metamorphosed to greenschist facies, and is cross-cutted by EW and NE-SW oriented shear zones, such as the France River shear zone. Existing regional studies suggest that gold is genetically related to these EW-trending shear zones without, however, providing precise chronological relationships. The main objective of this study is to evaluate the relative timing of the deformational events and the gold vein mineralization through a detailed structural analysis of a typical shear zone hosted gold deposit at the Monexco property located 30 km northeast of Chibougamau. Field work included structural measurements, small-scale mapping and sampling for petrographical and oriented thin sections descriptions.

The Monexco property is part of lode gold deposits occurring along the France River shear zone and is hosted by the volcanic and sedimentary sequences of the Bruneau and Blondeau formations. These formations are intruded by quartz and feldspar porphyric dykes and by gabbro sills that were deformed by the EW France River shear zone (150-250 metres-wide). This shear zone is parallel to the EW regional foliation (S2) and both are crosscut by D3-related NE-SW trending faults. Field observations suggest a dextral sense of shearing along the France River shear zone, based on the occurrence of S-C fabrics, synthetic shear bands and extension veins. The mineralization is mainly concentrated in these tension veins and veinlets, that are made up of quartz-ankerite-tourmaline and gold-bearing sulphides, chiefly pyrite. The veins are dominantly N-S trending. Gold mineralization also occurs as disseminated in the wallrocks of the veins. The dominant alteration minerals are chlorite, sericite and ankerite. Felsic sills and dykes are locally found and may have acted as cap rocks for the circulation of Au-rich hydrothermal fluids. D3-related dextral kink bands locally affect the auriferous extension veins, suggesting that mineralization is pre-D3.

The interpretation of data, and their regional implications, will be used to establish the structural characteristics of the France River shear zone, and its genetic links with gold mineralization in the Chapais–Chibougamau area. The results should provide regional guides for gold exploration. **(*SY5, Poster*)**

Initiation of subduction in oceans formed by supercontinent breakup: The case of the Iapetus Ocean

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The history of the modern Atlantic shows that the transition from an opening to a closing ocean is not typically initiated by subduction of old, cold ocean floor at passive margins. The central Atlantic margins formed at 200 Ma but are still passive. In contrast, the Caribbean and Scotia arcs represent eastward translation of Pacific ocean floor into the Atlantic realm, a process that has led to the subduction of Atlantic oceanic crust as young as Neogene.

In most reconstructions of the Appalachians, the continental blocks (Laurentia, Baltica, and Amazonia – West Africa) which separated to form the Iapetus Ocean during the breakup of Rodinia are the same three continents that subsequently collided during its closure, raising questions as to how and why its divergent margins of the Iapetus Ocean became convergent.

During the opening of the Iapetus Ocean, the margin of Laurentia underwent protracted rifting from ~615 Ma to at least 550 Ma, and perhaps later. The ealiest "drift" successions on the Newfoundland margin are as young as ~515 Ma. Subduction, recorded by arc volcanics preserved in the orogen, began relatively early in the history of the new ocean at ~515-505 Ma. The earliest collisional events are recorded almost simultaneously in Laurentian and peri-Gondwanan elements during the Early Ordovician, 490-480 Ma. Closure of the ocean between Avalonia and Laurentia was complete by ~425 Ma.

Subduction initiation at mature passive margins is a commonly assumed but non-actualistic part of the 'Wilson cycle'. In the case of the Iapetus Ocean it is much more likely that closure was initiated at a subduction zone migrating westward into the ocean in a manner analogous to the eastward Mesozoic-Cenozoic entry of the Caribbean and Scotia plates into the Atlantic realm. This process was probably initiated at a transform boundary between the "internal" ocean formed during the breakup of Pangea, and "external" Panthalassan lithosphere. This model may help to explain: the initiation of subduction and the early closing of the Iapetus; the timing of the earliest collisional events; the isotopic character of Iapetan ophiolites; and the distribution of peri-Gondwanan terranes in the orogen. **(*SY3, Wed. 3:00*)**

A decade of beach-dune morphodynamics research at Greenwich Dunes, PEI, Canada

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This paper summarizes a decade of collaborative research on beach-dune morphodynamics at Greenwich Dunes, PEI, Canada. Advances made via various techniques to quantify process-response relations between airflow, sand transport, surface properties, and beach-dune morphology are reviewed. Efforts to characterize micro-scale aeolian sand transport with piezoelectric sensors, laser particle counters, moisture probes, and digital photography improved our understanding of temporal and spatial variability in the transport process as controlled by natural factors including surface moisture, fetch, and vegetation). Meso-scale morphodynamics were examined by experiments with ultrasonic anemometry to explore relations between topographically forced airflow, near-surface stress, and sand transport over foredunes. This work enhanced knowledge on flow-form interactions over complex terrain that control sand transport pathways and foredune morphodynamics. Macro-scale evolution of the system was investigated by measuring seasonal to decadal sedimentation patterns and morphological changes from a network of erosion pins, volumetric change plots, cross-shore profiles, and digital photogrammetry of historical aerial photographs. This research helped improve application of event-based experimental datasets or parameterized models of sand transport to understand longer-term landscape evolution by characterizing geomorphic responses to seasonal/annual processes and broader landscape controls (*e.g.*, sea level rise, storms). Until seasonal variations in sand transport and beach-dune morphology can be parameterized, however, prediction of sand supply to foredunes will remain limited. Relatively infrequent, high magnitude storm surges also significantly influence system trajectories and the foredune tends to respond to relative sea-level rise consistent with a conceptual model developed by Davidson-Arnott. **(*SS22, Thurs. 8:20*)**

Focusing on the Central American Subduction Zone

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Central America has recently been an important focus area for investigations into the complex processes occurring in subduction zones. This talk will review some of the new findings concerning subduction input, magma production, evolution and resultant volcanic output. High precision $^{40}Ar/^{39}Ar$ age determinations have enabled valuable appraisals of extrusive and magmatic fluxes along the Central American volcanic front. In the Nicaraguan portion of the subduction zone, subduction input is unusually wet, likely caused by extensive serpentinization of the mantle portion of the incoming plate related to bending-related faulting seaward of the Middle America trench. The atypical influx of water into the Nicaraguan section of the subduction zone ultimately leads to a regional maximum in amount of mantle melting. In central Costa Rica, subduction input is also unusual in that it includes oceanic crust flavored by the Galapagos plume. Both of these exotic subduction inputs are recognizable from the compositions of magmas erupted along the volcanic front. In addition, Nicaraguan magmas bear a strong chemical imprint from subducting hemipelagic sediments. The high-field-strength element depletions of magmas from El Salvador through Costa Rica are related to local variations in the depth to the subducting Cocos plate, and therefore, to segmentation of the volcanic front. Minor phases, probably amphibole or rutile, control these variable depletions. Silicic magmas erupted along the volcanic front exhibit the same along-arc geochemical variations as their mafic brethren. This and their mantle-like radiogenic isotopic compositions suggest the production of juvenile continental crust all along the Central American subduction zone. Punctuated times of enhanced magmatic input from the mantle may aid in crustal development. **(*SY3, Wed. 3:20*)**

Understanding the heterogeneous distribution of high-pressure phases in meteorites; the role of a complex post-shock thermal history and the duration of the shock pulse

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All meteorites have been modified by shock waves, generated by hypervelocity impact events on their parent bodies. Transformational metamorphic effects in the meteorites are typically associated with shock melts, which form as local hot spots (~2500 K) that cool by conduction of heat to the surrounding host rock. Here, the mineralogy of shock melts in a shergottite (Tissint), and an L6 chondrite (Catherwood) were investigated using SEM, Raman spectroscopy and TEM. The results of a finite element model used to calculate the cooling history of shock melts will be presented.

In Tissint, thin (~20 μm) veins of shock melt contain clinopyroxene + ringwoodite ± stishovite. Host rock olivine in contact with the melt are now amorphosed silicate perovskite + magnesiowüstite or clinopyroxene + magnesiowüstite. The pressure stabilities of these mineral assemblages are 16−18 GPa and 24 GPa, respectively. The ~200-μm-wide margin of thicker mm-size shock veins contain clinopyroxene + olivine + glass, with glass + vesicles in their center. These larger melts crystallized at lower pressures compared to the thinner veins found in the same thin section. In contrast, Raman spectra extracted as a series of transects across thin and thick areas of shock melt in Catherwood show the vein matrix to be uniformly majorite + magnesiowüstite ± ringwoodite, suggesting crystallization at ~23−25 GPa.

The complex post-shock thermal history of heavily shocked meteorites determines the high-pressure mineralogy, and will be a function of the melt cooling time and the duration of the shock pulse. Calculations show that thin veins (~100 μm) cool on the order of 10−20 ms while larger pockets cool in seconds. The restriction of high pressure minerals to thin shock melts in Martian meteorites, and their widespread ocurrence in chondrites, reflects the different shock history between meteorites ejected from planets in recent impact events (0.7 to 20 Ma), and those derived from asteroids, which record impacts in the early Solar System. In chondrites, the pressure pulse is much greater than in Martian meteorites (1 s *vs.* 10 ms). This strongly affects the mineral assemblages that crystallize from shock melts; if the duration of the shock pulse is longer, then the shock melt is more likely to crystallize during shock compression. The 10 ms shock duration in Martian meteorites means that high pressure phases are only preserved in the thinnest, most rapidly cooled melts. Large veins will be hotter longer, and earlier-formed high pressure phases will transform to their lower pressure polymorphs. **(*SS21, Thurs. 9:00*)**

Characterization of mineralizing fluids and fluid-structural relationships in the Phoenix uranium deposit, southeastern Athabasca Basin, northern Saskatchewan: Preliminary core and petrographic studies

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The Phoenix deposit, a high-grade unconformity-related uranium deposit associated with a NE-trending moderately SE-dipping reverse fault (WS shear zone), is located 35 km southwest of the world-class McArthur River uranium deposit in the southeastern Athabasca Basin. Previous geological and geochemical studies have revealed features similar to other unconformity-related uranium deposits in the region, but the composition, temperature and pressure of the fluids associated with mineralization have not yet been investigated with fluid inclusion techniques. Furthermore, like other well-studied unconformity-related uranium deposits, the structural controls on mineralization, particularly the hydrodynamic relationship between structures (and related stresses) and fluid pressure, are not well understood.

Preliminary study of 6 drill cores indicates that the basement is dominated by massive quartz and spatially associated granitic pegmatite, along with garnet-cordierite-sillimanite-bearing pelitic gneiss. Petrographic study of the quartz-rich rock indicates that the quartz grains are very coarse (up to 28 mm) and contain abundant needle-like mineral inclusions. This, together with the pegmatite association, suggests that the rock may not be quartzite formed from metamorphism of quartz sandstone, but quartz generated by hydrothermal activity. CO_2-dominated inclusions are well developed in densely distributed, parallel microfractures in the quartz, suggesting relatively high fluid pressure. Near the unconformity and in the overlying

Manitou Falls Formation, angular breccias are cemented by crustiform quartz and there are abundant discordant veins containing vuggy quartz. The brittle-style deformation associated with emplacement of this secondary quartz contrasts with that in the basement rocks. Abundant vapour-only aqueous inclusions were found in the euhedral quartz crystals in these secondary veins and cements. The absence of a visible liquid phase in the inclusions, together with the low homogenization temperatures (101° to 134°C) of co-existing bi-phase aqueous inclusions, suggests low fluid pressures and boiling. However, at present it is uncertain whether or not the fluids represented by these inclusions were directly related to mineralization. Ongoing studies aim to characterize the nature and sequence of structures and related mineralizing fluids (fluid composition, temperature and pressure), as well as to evaluate the stress regime during mineralization, through the studies of the orientation of microfractures filled with fluid inclusions, or fluid inclusion planes. The results should help to resolve controversies regarding whether or not the mineralizing fluid flow was related to alternating compressional and extensional stress regime, or to fluctuating fluid pressure in a stable stress regime. **(*SS7, Poster*)**

Lithostratigraphic and paleoenvironmental analysis of the Early Silurian Woodstock Fe-Mn deposits, New Brunswick

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The Woodstock Fe-Mn deposits, located in west-central New Brunswick, are composed of six lenticular-shaped Fe-Mn deposits that collectively make up the largest Fe-Mn deposit in North America (194,000,000 tonnes; 13% Fe and 9% Mn). These Early Silurian-aged deposits form part of the Smyrna Mills Formation within the Matapedia-Aroostook Belt. Lithostratigraphic analysis of the area has revealed six Lithofacies Associations (O,I,II,III, IV, and V) that, in general, conformably to lay on top of one another. Complications from interbedding and localized folding have caused juxtaposition of the units, so the lithofacies associations are not always in stratigraphic order. The lithofacies associations consist of a turbidite-rich blue-grey calcareous sandstone (O), overlain by a finely laminated pyritic black mudstone (I), correlated Fe-Mn mineralized and nonmineralized green (II), and red siltstone (III), and laminated to massive calcareous grey to green sandstone (IV and V).

In general, the lithofacies associations mark in regional and local context: the closure of the Iapetus Ocean (O), the formation of an anoxic basin (I), precipitation and deposition of Fe-Mn oxide-carbonates and Fe-Mn carbonates during the early Salinic recession (II and III), and accretion and deposition of Ca-rich sediments during the late Salinic regression (IV and V). Na *vs.* Mg plots, chondrite-normalized REE pattern, and mineralogical indicators suggest the Fe-Mn mineralization occurred during deposition in the offshore zone of the continental shelf along a stable cratonic margin by changes in ocean redox. Al-Fe-Mn ternary and SiO_2/Al_2O_3 binary plots suggest that the Fe and Mn were sourced from hydrogenous-detrital sources and are not hydrothermal in origin. **(*SS2, Wed. 2:00*)**

Keynote (40 min): Dramatic effects of stress and fluid pressure on metamorphism

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Any chemical interaction between fluids (including melts) and solids will be governed by thermodynamics. One cornerstone of this theory is that pressure has a chemical effect (*i.e.* influences equilibrium and kinetics). However, in general the fluid pressure and the solid pressure in a porous matrix (or stressed state) are not equal.

We have run an extensive set of experiments on gypsum dehydration (to bassanite) to address key questions relating to fluid pressure evolution in systems where solid and fluid pressures are different and, in parallel, have developed a numerical model for dehydration. Experiments show that the rate of gypsum dehydration is strongly influenced by pore fluid pressure and not by solid pressure. Experiments also show the development of reaction fronts in some situations, broadly in accord with numerical simulations.

For the past 50 years assertions have been made in the geoscience literature about how chemical change should be dealt with in systems under stress but these are not always consistent with thermodynamics. We have developed a general conceptual model of chemical evolution in stressed porous materials. In our model, there is no equilibrium, reactions will occur by chemical transport along various pathways (*e.g.* pores, grain boundaries) and different pathways have different energy drops but also different kinetics. In this presentation we quantify and illustrate those energy drops for some example reactions. Our model encompasses reactions in pores, pressure solution, situations in which there is "force of crystallisation" and combinations of those phenomena. We show how experimental results fit into our conceptual model, indicating that they may be just one aspect of behaviour to be expected on longer timescales. New experiments begun in 2013 will test those ideas. Our model, when combined with kinetic information, provides a unified way of considering chemical processes in porous media. **(*SS19, Wed. 3:40*)**

Diffusion creep, mechanical anisotropy and localisation

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Diffusion creep is normally thought of as a deformation mechanism which allows localisation but only after grains size is reduced by other means. A numerical model gives insight into how grain shapes and microstructures evolve during diffusion creep. New grain-scale simulations of both pure and simple shear quite commonly show localisation in S and or C type structures formed by the alignment of grain boundaries into rather straight features on the scale of several grains. It is implicit in diffusion creep that slip occurs along grain boundaries. This has never been tested directly in geological materials but it is necessary to maintain strain compatibility. Moreover, it is implicit in the dependence of flow strength on grain size (cubic for grain boundary diffusion creep) that the shear stress along grain boundaries is small. The assumption of zero shear strength along grain boundaries is one of those incorporated in the numerical model. This background assumption allows appreciation of why boundaries become aligned. If some alignment is present, then non-aligned grains are, in a broad sense, asperities and subject to extra stress. Over time, then, they are dissolved away. This description is a simplification and is no substitute for watching the actual evolution of the numerical models; grain rotation is also an important contributor to the alignment.

Once aligned, the weak grain boundaries can take up most of the strain. The overall strength of the model rock decreases markedly during this localization and the mechanical anisotropy can be intense. Mechanical anisotropy may contribute to weakening in shear zones as much as does grain size reduction. **(*SY2, Thurs. 2:00*)**

Localization in naturally deformed systems – the normal state?

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The ubiquity of transient (cyclic), heterogeneous deformation, notably shear localization, in the rock record is such as to characterize it as the anticipated 'normal' behaviour. The corollary is that steady, homogeneous deformation is rare, and where approached must reflect some special set of conditions that are not representative of the general case. An issue central to natural deformation is then not the existance of localized strain, but rather how the extant deformation processes scale over tectonic phenomena and in turn organize to enable a coherent descripion of earth deformation. The strain energy distribution that drives thermo-mechanical responses is in the first instance established at the grain-scale where the non-linear interaction of micromechanical processes introduces fundamental, heterogeneous behaviour described by various gradient theories, and evidenced by the defect microstructures of deformed rocks. Hence, the potential for non-uniform response is embedded within even quasi-uniform, monomineralic materials, as seen in the spatially discrete evolution of dynamic recrystallization. Despite the interest in the latter purely mechanical localization, the more common type of heterogeneity promoting localization comprises mechanically contrasting materials typical of most rocks. Natural shear localization commonly demonstrates a cyclic interplay between inelastic rupture and subsequent plastic material softening resulting from the concomitant introduction of exogenous material in the form of igneous melts, deformation-induced melts and fluid precipitates (veins). Together this 2-stage process reflects localization and stabilization of the shear phenomena. The cyclicity of this behavior indicates that material hardening and non-associated flow over some characteristic time is a precursor to localized instability, with stabliization of localized shear correlated with system softening tied to redistribution of strain energy dissipation within what is effectively a reconstituted material. The resultant spectrum of mechanical responses observed at all lithospheric levels has the effect of masking brittle (seismic) records. It is suggested that variations in composition, pressure and temperature and fluid activity with crustal level produce 'windows of transience' which are particularly amenable to this behavior. **(*SY2, Thurs. 8:00*)**

Petrologic and geochemical examination of the Early Devonian, Evandale porphyry Cu-Mo-(Au) deposit, southern New Brunswick: Geothermobarometric analysis of petrogenesis

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Porphyry Cu-Mo-(Au) systems associated with the granitoid rocks in eastern North American orogenic belts have been researched using current deposit models; however, relatively few studies have examined the potential for late stage fine-grained porphyritic to aplitic intrusive phases being host to mineralization. The Evandale Granodiorite is an example of a well-preserved Mid-Devonian (U-Pb zircon age of 391.2 ± 3.2 Ma for the coarser granitoid, and 390.2 ± 1.6 Ma for the aplite) polyphase pluton intruding through deformed Silurian sedimentary and mafic volcanic rocks of the Mascarene Basin in southern New Brunswick. The two intrusive phases have been identified as I type granites with a minor sedimentary component. The pluton is separated both petrochemically and texturally into two distinct phases. The coarser phase ranges from medium- to coarse-grained seriate to porphyritic granodiorite to monzogranite and the later finer stage layered aplite ranges from a monzogranite to syeno-granite. INAA analysis of each phase found that the highest concentrations of Cu and Au (108 ppm Cu, and 33 ppb Au) are associated with pyrite, chalcopyrite, and arsenopyrite within the aplitic dykes sampled, whereas concentrations of up to 6 ppm Mo were detected within the c.g. granite. Current models suggest that the transport of metals (particularly Cu and Au) are sourced from secondary two-phase fluids at shallow depths (approximately 2 kb), and is controlled primarily by Cl fugacity of the magma. Analyses of biotite phenocrysts from both the aplite and granite contain an average of 0.21 wt% Cl, which is similar to other high grade Cu-Mo-(Au) porphyry deposits. Average zircon saturation temperatures were calculated to be 818°C for the aplite and 787°C for the granitoid. Average apatite saturation temperatures were found to be 880°C for the aplite and 934°C for the granitoid phase. Hornblende-plagioclase thermometry revealed the crystallization temperature of the granite to be 642°C and 600°C for the aplite, cooler than most deposits of the same type. Al in hornblende geobarometery indicates crystallization depths of ~2.1 kb for hornblende in the aplite and ~0.7 kb for the c.g. granite. The aplitic dykes were subject to higher crystallization pressures and lower crystallization temperatures suggesting that their formation may either be a result of pressure quenching of the melt during rapid ascent or by the sub-solidus recrystallization of the melt as pyroclastic flows. **(*SS3, Wed. 9:40*)**

Keynote (40 min): Deciphering the geology of offshore eastern Canada: A fifty year odyssey

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Today, our understanding of the subsurface geology of offshore eastern Canada provides us with a detailed knowledge of most of the sedimentary basins occurring in the vast expanse from the Scotian Basin in the south to the Baffin Basin in the far north, a distance spanning almost 5000 kilometres. This is in marked contrast to fifty years ago, when all that geologists knew was that there were *in situ* Cretaceous-Tertiary bedrock samples on Georges Bank and the possibility of similarly-aged rocks underlying the Grand Banks. What triggered this revolution in our increased knowledge of the offshore geology? The most influential factor has been the growing understanding of plate tectonics and the realization that our offshore represents the western passive margin of the still-opening North Atlantic Ocean. This has underpinned the new views of our margins and their evolution. Other key developments accompanied the search for oil and gas. Exploration has led to extensive seismic surveying and the drilling of more than 300 wells and several core holes by industry. Government and the universities have also played a crucial role in collecting and interpreting paleomagnetic, gravity, and reflection and refraction seismic data, and establishing lithostratigraphic and biostratigraphic frameworks for the offshore basins. We now know that Precambrian, Paleozoic, Mesozoic and Cenozoic rocks, including extensive salt deposits, are present offshore. Breakthroughs have included insights into the evolution not only of the North Atlantic Ocean but also of the Labrador-Baffin Seaway. Geodynamic modelling has shown how physical processes within and below the lithosphere control the evolution of our margin. Maturation studies, including visual kerogen, vitrinite reflectance, and Rock Eval have also helped in the prediction of source rock occurrences. The advances in the first twenty-five years were reflected in the 1990 Decade of North American Geology (DNAG) volume "Geology of the Continental Margin of Eastern Canada" and in comprehensive basin atlases published by the GSC. Twenty years later, with the application of 3D reflection seismic, sequence and biostratigraphic-event stratigraphy, plus the increasingly sophisticated computer software and hardware, we are heading into a new era. It would be fascinating to listen to an updated review fifty years hence. **(*SS12, Fri. 8:00*)**

Dating and characterizing metasomatic events: Recognizing and utilizing fluid moderated coupled dissolution-reprecipitation of monazite and xenotime

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Monazite has increasingly been used as a geochronometer, especially in deformed and metamorphosed rocks. Monazite is particularly useful because of its very broad compositional range, and the fact that it can be produced in a number of chemical reactions on the prograde, peak, and retrograde metamorphic path. Because diffusion is slow, monazite compositions tend to be preserved as multiple core and rim domains. Ideally, the compositional and textural domains can be linked with structural fabrics and/or metamorphic reactions and thus, provide a means of directly dating deformation events or metamorphic reactions. The use of multidomain monazite to constrain stages in a P-T history depends on the assumption that compositions and ages are essentially unmodified during subsequent events. Although closure temperatures are certainly high, recent studies suggest that under some circumstances, monazite and xenotime compositions (and dates) can be modified by fluid-moderated coupled dissolution-reprecipitation processes. This is particularly important for geochronologic studies because the replacement process may not involve the complete removal of some components, such as Pb, and thus spurious dates, either older or younger than the true age, could possibly result. Experimental results (Williams *et al.*, 2011) document the relatively rapid alteration of monazite to a new monazite composition by solid state dissolution-reprecipitation processes. In some grains, the new monazite occurs in regular domains near the grain boundaries, and might be misinterpreted as overgrowths. In other grains, new monazite occurs internally, near inclusions or microfractures or as irregular patchy domains. Altered domains are generally distinctive and distinguishable from growth domains. The new compositions are extremely uniform from grain to grain (Th: initial= 7.0 wt. %; altered = 2.0 wt%). Importantly, altered domains are free of Pb. At least in this example, the monazite date was essentially reset to zero. Thus, with the right fluids, metasomatism can change monazite compositions and reset ages at temperatures well below the diffusional "closure" temperature. This provides a means of dating hydrothermal and metasomatic fluid-rock interaction events, but it is critical to recognize the altered domains. Numerous metasomatized monazite and xenotime domains have now been recognized/interpreted in the Athabasca granulite terrane and the Proterozoic of SW North America. In all cases, dates from altered domains correspond to periods of tectonism and are interpreted to date high-T metasomatic events. **(*SS20, Wed. 9:00*)**

Environmental impact of oxide-sulphide gossans revealed by orientation surveys for base metals in the Canadian Arctic Islands

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Canada`s remote Arctic Islands represent the last frontier for regional geochemical surveys to be conducted in the search for indicator mineral signatures as vectors to ore deposits. The Geo-Mapping for Energy and Minerals Program (GEM) provided new opportunities for the Geological Survey of Canada (GSC) to carry out geochemical exploration surveys in Canada's North in areas selected for bedrock mapping. New geochemical databases acquired under the GEM program could be merged with those obtained by mineral exploration companies during previous orientation surveys in the same area. A case in point is the regional stream sediment and water geochemical survey carried out by the GSC in 2010-2011 in selected areas of the Minto Inlier on Victoria Island, Northwest Territories. The resulting databases for Lead and Zinc were combined with those acquired by Great Northern Mining and Exploration (GNME) during their exploration program for Cu-Ni-PGE and diamondiferous kimberlite between 2005 and 2008.

In this paper, we compare the results of the GNME and GEM-Victoria Island regional geochemical surveys with those obtained during an environmental study of gossans carried out near South Fiord, Axel Heiberg Island, Nunavut, in July 2013. The objectives of the 2013 orientation survey were to (1) identify the areal extent of base metal signatures and dispersion down drainage of a known gossan; and (2) determine the economic potential of local intrusive rocks by comparing the mineralogy and geochemistry of the bedrock, gossans and stream sediments. Recent studies of the lithogeochemistry of mafic igneous rocks exposed on central Victoria Island and Axel Heiberg Island suggest that both Large Igneous Provinces (LIPs) are prospective for Ni-Cu-PGE. The following questions are explored: (1) How do oxide-sulphide gossans influence the composition of the heavy metal fraction of stream sediments? (2) What is the effect on water pH and geochemistry? (3) What are the implications for Ni-Cu-PGE mineralization potential in LIPs? **(*SY4, Wed. 2:00*)**

Influence of fluid activity and deformation on ^{39}Ar-^{40}Ar, Rb-Sr, and fission track ages for very low- to low-grade metamorphic processes in the Avalonian Mira terrane, Nova Scotia, Canada

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In the Avalonian Mira terrane of southeastern Cape Breton Island, various belts of Neoproterozoic volcanic-arc rocks and in places overlying Neoproterozoic to Cambrian sedimentary rocks were metamorphosed under peak conditions of 3.5±0.4 kbar and 280±30°C. Maximum dehydration occurred in a narrow temperature range of 240-280°C. During metamorphism water was present between reactants and reaction products, which mainly precipitated in clusters. As a result, transient equilibrium conditions were present throughout the prograde P-T path.

Formation of white mica during this fluid release was dated in six samples by ^{39}Ar-^{40}Ar *in situ* UV laser ablation resulting in predominant spot age peaks within the range 366±14 Ma to 396±5 Ma. Independently, studies of small-scale Rb-Sr distribution systematics resulted in two Rb/Sr mineral isochrons at 370±10 Ma and 391±7 Ma. These data match the ^{39}Ar-^{40}Ar spot ages, but also further prove equilibrium conditions at very low grade because metamorphic assemblages were dated. All white mica studied is oriented parallel to foliations produced by prominent sinistral strike-slip or prior folding. Thus, the ages obtained can be also related to deformation. The dated Neoacadian deformation contributed to the dispersal and collisional assembly of the Avalonia microplate. ^{39}Ar-^{40}Ar spot age spectra also show relict age peaks at 420-424 Ma and 439-475 Ma. The former ages may be related to deformation and fluid access during collision of Avalonia with Laurentia and the latter to Ordovician rifting, but mixed ages or inherited Ar cannot be excluded in both cases.

In contrast, fission-track ages of zircon between 215±21 and 242±18 Ma indicate regional metamorphism of the Mira terrane below the closure temperature of 250-280°C, which occurred under dry conditions. This event is related to early Atlantic rifting. Maximum temperatures may have been maintained until the Triassic or more likely reheating occurred. **(*SY1, Poster*)**

MLA-SEM examination of sulphide mineral breakdown (and preservation) in till, Voisey's Bay Ni-Cu-Co deposit, Labrador – The distribution and quantitative mineralogy of weathered sulphide phases

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MLA-SEM analyses were used to investigate sulphide mineral breakdown in and preservation of the Voisey's Bay orthomagmatic nickel-copper-cobalt sulfide mineralization. The Ovoid ore body, a 350 m wide, 120 m deep ore body, has glacial striae and grooves on its sulfide surface below > 20 m of till, but no oxidation. The sulfide surface is covered by a thin clay in which the MLA analyses indicate a calcite cement; the clay cover is presumed to have had a lacustrine origin. Elsewhere, sulfide is heavily oxidized at the Discovery Hill gossan and in drill core through the gossan, the MLA data quantitatively and qualitatively indicated that pentlandite is must intensely replaced, whereas pyrrhotite and chalcopyrite are not. MLA examination of samples in a section from till down to weathered gossan and massive sulphide in the Mini-Ovoid open pit wall, indicates that the massive sulphide horizon is actually overlain by a paleoweathered regolith stratigraphically beneath the Pleistocene till cover. In a study of sulphide mineral distribution in surficial sediments from one sonic and five split spoon holes drilled through till surrounding the Ovoid ore body, only a minimal number of grains were detected in the material; the sulphide grains, were, however, distinct. Coarse rejects of assay pulps stored for over five years in impermeable plastic bags were also examined by MLA-SEM techniques and, in contrast with to the natural hydrated aerobic alteration of sulfides documented in drill core and outcrop, pyrrhotite was the most intensely altered phase, and in contrast chalcopyrite and pentlandite are relatively unaltered. **(*SY6, Fri. 4:00*)**

Quantitative mineralogy of indicator minerals in till – Expanding the spectrum

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Standard indicator mineral exploration techniques are based on the visual examination of a pre-defined group of minerals in Heavy Mineral Concentrates (HMCs) from tills collected in regional surveys. Typical preparation techniques involve the field collection of 25-40 kg samples, and concentration of a HMC from 0.5-2 mm size fractions through gravity settling and the use of heavy liquids. We have developed a sample preparation and MLA-SEM analytical technique that uses a HMC derived from the 125-180 µm particle size fraction of a 10 kg till sample through gravity settling on a "shaking" table. A small, 0.3 g separate from the HMC is mounted in an epoxy puck and polished, providing fresh unaltered surfaces for examination. Aside from the smaller grain size, ease of preparation, the technique allows for the quantitative evaluation of all minerals present in the till sample. Beyond the ability to detect and quantify indicator minerals, the MLA provides definition of the main lithological contributors to a till and thus allows for the confirmation of till transport directions based on bedrock geology. In some cases the distributions of unique minerals (*e.g.*, gittensite), from known point sources (*e.g.*, the Strange Lake REE deposits) can be mapped providing a definition of regional till distribution. Polishing during sample preparation also provides a fresh surface that transects the mineral grains interiors. The MLA can identify a range of minerals as inclusions in these larger till grains that would not usually survive glacial transport and deposition and as such the inclusions can essentially act as indicator minerals for mineralization up ice. Furthermore, knowing the mineralogy of both host grain and inclusion can provide key data on the relative economic significance of a potential buried site of mineralization. These inclusion indicator minerals include sulfides, uraninite (and other radioactive minerals) and REE-bearing phases. **(*SY6, Fri. 3:40*)**

Metabolics through time – learning from Andrew Hynes' approach to tectonics

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Tectonics provides a unifying framework for understanding the history of the solid Earth. Metabolics – the non-equilibrium cycling of electrons through natural microbial populations – does the same for understanding the history of life on Earth. Together tectonics and metabolics have interacted to determine Earth's environmental history, at least for Earth's first ˜4 billion years.

As exemplified by the work of Andrew Hynes, the study of tectonics through time has benefited from a reductionist approach, where first-order questions (*e.g.*, how feasible was subduction in the Archean?) are addressed through the application of basic physical and chemical principles (*e.g.*, force balances and equilibrium thermodynamics). The study of metabolics through time cannot yet apply this principle of uniformity of natural law. It relies instead on the assumption of uniformity of natural processes. Essentially this assumption is that microbes in the deep past were doing what microbes do today, though maybe to somewhat different degrees.

In this contribution I will use a model microbial metabolism – dissimilatory sulfate respiration – to show that the fundamental geological observable of a microbial metabolism – its stable isotopic phenotype – is calculable from basic physical and chemical principles. This new realization opens the door for understanding metabolics through time on a mechanistic rather than comparative level. I will also use this opportunity to settle up a bet that I made with Andrew about whether biology was amenable to his reductionist approach. I lost. **(*SY3, Thurs. 3:20*)**

The structural evolution of the auriferous Santoy shear zone, northeastern Glennie domain, Saskatchewan

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The study area lies in the northeastern corner of the Glennie domain approximately 125 km north of LaRonge, SK. This region contains three known gold deposits along a structural corridor of the Pine Lake Greenstone belt known as the Santoy shear zone (SSZ). The SSZ hosts the Santoy 8 deposit, the exhausted Santoy 7 deposit, and the recently discovered "Santoy Gap" deposit. This shear zone has long been recognized as an important gold bearing structure however its relationship between plutonism, deformation, and gold mineralization have remained enigmatic. Access to the Santoy 8 gold mine was not available to previous researchers and thus provided an opportunity to study this shear system from within.

Fieldwork indicates that the SSZ is characterized by NNW-striking, E-dipping foliation with stretching, mineral and crenulation lineations, as well as minor fold axes, all sub-parallel and plunging 45 degrees to the N. This attitude corresponds closely to the plunge of ore bodies at Santoy 8 and the orientation of regional F_3 fold axis. In addition to this, auriferous zones are cut by beriliferous pegmatite dykes which display an F_3 axial planar cleavage indicating that shear zone formation and mineralization predates or is synchronous with the early stages of D_3 deformation. Gold mineralization is closely associated with foliation-parallel quartz veins and calc-silicate altered wall rock which predominantly form along the contacts of tonalite and diorite dykes. Geomagnetic anomaly data suggest that plutons in the area acted as rigid bodies during a progressive deformational event in a thin skinned tectonic regime and greatly influenced the orientation of the SSZ and regional F_3 folds. The preliminary results and interpretations of high precision ID-TIMS geochronological analysis of these plutonic bodies, and dykes, as well as calc-silicate alteration will be discussed with an emphasis on their relationship to gold metallogenesis. This study is focused on providing new insights into the development and evolution of shear-hosted gold deposits within the SSZ and the Pine Lake Greenstone belt. **(*SY5, Wed. 10:40*)**

Influence of partial gas and brine saturation on diffusive transport in sandstone and shale

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The goal of this research is to measure the effect of partial gas saturation on the effective diffusion coefficient (D_e) of low permeability rocks such as shale that may be important for isolating radioactive waste. Partial gas saturation may result from the formation of methane by thermogenic or biogenic mechanisms, and pore-scale changes in the volume ratio of gas and porewater are expected to affect D_e for both aqueous solutes and for gases. Sedimentary rocks may contain highly saline porewater, and experimental methods for generating partial saturation must not lead to the precipitation of salts that would affect D_e. A method has been developed to generate partial gas saturation whereby a rock sample that is 100 % brine saturated is equilibrated with nitrogen (N_2) gas at high pressure (up to 6600 kPa). After equilibration has been achieved, the N_2 pressure is quickly brought down to atmospheric pressure, causing a rapid decrease in gas solubility, and exsolution of N_2 to form gas bubbles in the pore spaces. The degree of partial saturation is determined by gamma radiography as a function of the difference in the gamma-ray attenuation coefficients between the brine-saturated and partially gas-saturated condition. The D_e for iodide tracer is measured at 100 % brine saturation and compared to measurements conducted at different degrees of partial gas saturation. For convenience during method development, the initial work has been conducted on sandstone (13.0 % porosity). Results of measurements on sandstone indicate that D_e for iodide tracer in 100 % brine-saturated sandstone is 6.3×10^{-11} m^2/s, and at 86 % brine and 14 % gas the D_e for iodide tracer decreases to 2.7×10^{-11} m^2/s. First efforts to create partially saturated conditions with shale are underway and preliminary results of this work will be reported. **(*SS8, Thurs. 9:40*)**

Geochemistry of Li-bearing mica and Sn-Ti oxide minerals from the Qiguling topaz rhyolite (Qitianling district, China): The role of F in Sn mineralization

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The Sn-rich Qiguling topaz rhyolite dike intrudes the Qitianling biotite granite of the Nanling Range of southern China, which contains a very large Sn deposit. The dike is a typically peraluminous, volatile-enriched, highly evolved rock. Whole rock F and Sn concentrations attain 1.9 wt.% and 2700 ppm, respectively. Lithium-bearing micas are common in the rhyolite as phenocrysts and groundmass, and are classified as zinnwaldite, Li-annite, and secondary Li-muscovite. Topaz is typical of F-enriched minerals present in the groundmass; fluorite is present both in the groundmass and also as phenocrysts. Oxide minerals, such as cassiterite and rutile, are commonly present in the mineral assemblage; cassiterite also occurs in the quartz veinlets, which cuts through the groundmass. Tin-Ti-F aggregates (cassiterite-rutile-fluorite) and spongy cassiterite are pervasive, but rarely reported in previous studies. Electron microprobe and LA-ICP-MS compositions have been used to study the magmatic versus hydrothermal processes and the effect of F on Sn mineralization. In a previous experimental study it was suggested that Sn is transported as SnF_4, which will decompose and precipitate SnO_2 owing to changes in the physicochemical conditions. The cassiterite included in the zinnwaldite phenocryst is believed to have precipitated from the primary magma via sublimation of SnF_4 at high temperature. Meanwhile, cassiterite could begin to crystallize as the earliest mineral of the Sn-Ti-F aggregate, with euhedral rutile and fluorite developing in succession. The crystallization of abundant groundmass topaz may result in a decline in f(HF) in the melt. The presence of zinnwaldite and annite, which represent early and late mica crystallization during magma differentiation, respectively, also suggest a significant decrease of f(HF)/f(H_2O) ratio of the fluid. Spongy cassiterite containing inclusions of the groundmass minerals formed from this water-rich fluid. The cassiterite in the quartz veinlet indicates crystallization from low-temperature hydrothermal fluids, which possibly mixed with meteoric waters. As a result, cassiterite always precipitated in a locally extremely F-enriched complex and crystallized during the magmatic to hydrothermal stage, from high to low temperature. The original fluorine enrichment, f(HF)/f(OH) ratio change in the magma, and the mixing of magmatically derived fluid and meteoric waters in the later stages, are all factors responsible for the Sn mineralization in the Qiguling rhyolite. **(*SS6, Thurs. 2:40*)**

Archean tonalite-trondhjemite-granodiorite (TTG) suite in the Bird River greenstone belt, southeastern Manitoba: Lithogeochemical characteristics, geodynamic evolution, and potential for porphyry Cu-(Au) mineralization

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Granitoid rocks in the Bird River area in the western Superior Province are part of the tonalite-trondhjemite-granodiorite (TTG) suite and represent either the basement of the Neoarchean Bird River greenstone belt (BRGB) or younger plutons intruding and disrupting the supracrustal rocks of the belt, which consist of mafic volcanic and synvolcanic intrusive rocks, epiclastic and minor volcaniclastic rocks, and mafic–ultramafic intrusions. The Mesoarchean granitoid basement consists mainly of coarse-grained, equigranular to gneissic granodiorite; these rocks display differentiated REE patterns, with very small, negative (or no) Eu anomalies, and small negative Ti, and pronounced Nb anomalies in spiderdiagrams. The Maskwa Lake batholith (I) is a granodioritic basement intrusion that is geochemically indistinguishable from younger Neoarchean TTG phases (Maskwa Lake batholith II, Inconnu pluton) that are emplaced in the older granodiorite. The younger (Neoarchean) intrusive phases range from diorite to tonalite-trondhjemite-granodiorite and granite. These granitoid rocks are typically calcalkaline, Na_2O/K_2O >1.0, and metaluminous to moderately/strongly peraluminous. They are of I-type and may have been formed by partial melting of juvenile crustal materials—without direct inputs from lithospheric mantle—resulting in residual plagioclase-amphibole-bearing assemblages. These TTG rocks lack genetic evidence for either the presence of slab melts—modified by interaction with the mantle wedge—or for hydrous partial melting of mantle wedge peridotite previously metasomatized by slab melts.

The TTG suite in the Bird River area may have been formed in a magmatic-arc setting and have a notable potential for porphyry Cu-(Au) mineralization associated, for example, with granitoid phases that exhibit potassic alteration. Peraluminous granitoid rocks (with muscovite+/-garnet and biotite as the dominant ferromagnesian minerals) postdate the TTG rocks and, together with associated rare-metal–bearing pegmatites, may have been emplaced during continental collision subsequent to plate subduction. The north-northwest–trending Cat Lake–Euclid Lake dextral shear zone is confined to gneissic, peraluminous granitoid rocks, as well as strongly foliated and mylonitic granitoid rocks. The youngest granitoid intrusive phase is represented by porphyritic sanukitoid-type rocks that occur as dikes or small stocks cutting both supracrustal and granitoid rocks in the belt. These high-Mg sanukitoids display enrichment both in large-ion-lithophile and siderophile elements, and display highly fractionated REE patterns with marked heavy REE depletion; the intrusions may have been derived from partial melting of subcontinental lithospheric mantle metasomatized by subduction-related components, associated with the collapse of a thickened orogen. **(*GS5, Fri. 2:00*)**

The Manitoba Museum and its role in the preservation of provincial geoheritage

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Manitoba contains many significant geological sites, encompassing deposits and features of value to those interested in mineralogy, structural geology, geomorphology, paleontology, the history of geology, and numerous other aspects. It is home to Tyndall Stone (Canada's premier building stone), the mines of the Thompson Nickel Belt and Flin Flon, the Cretaceous marine reptiles of southwestern Manitoba, and much of the basin of glacial Lake Agassiz.

Despite this geological wealth, geoheritage preservation in Manitoba is still in its infancy. Although the province protects fossil resources through heritage legislation, and has produced educational materials such as geological highway maps, there has been only modest consideration of the formal preservation of sites of geological interest. Thus, the systematic collection and formal preservation of geological materials are of critical importance.

The Manitoba Museum has a substantial role in this aspect of geoheritage preservation. As the only institution whose mandate is to collect, study, preserve, and exhibit Manitoba's human and natural heritage, we assemble and maintain the province's only permanent broad-spectrum geological collections. Collections strengths include Precambrian rocks and minerals from Manitoba and adjacent areas, Ordovician to Devonian fossil invertebrates, and Cretaceous and Quaternary vertebrates. There are historic collections associated with particular past collectors, from the Manitoba Geological Survey and other organizations, while much of our recent collecting has targeted sites of great geoheritage significance, such as the Cat Head area of Lake Winnipeg and the fabulous Ordovician rocky shoreline near Churchill.

As a repository for lost or potentially lost geoheritage, the Museum thus serves as a resource for the recognition and documentation of localities that should be considered for future preservation, as well as sites that are disappearing because of their exposure to irreversible natural processes. We have had discussions with provincial agencies concerning the geoheritage preservation of various sites. Some protection has been achieved through measures such as classification by the Manitoba Geological Survey – for instance, the Cedar Lake amber site has been earmarked as unsuitable for claim staking. Some areas are protected within parks, while others may be protected as a result of the potential development of a national park in the Lake Winnipeg area. Still, sites continue to be lost as it does not seem possible to halt the provincial program of quarry reclamation, and some exposures such as the Churchill rocky shoreline site will eventually disappear due to natural processes. **(*SS15, Fri. 9:40*)**

Strange Lake Alkalic Complex: Mineralogy overview highlighting John L. Jambor's contributions

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The Strange Lake Alkalic Complex is one of the world's largest deposits of yttrium (Y) heavy rare earths (HREE) and zirconium (Zr). The Precambrian intrusive complex of alkalic granites in central Labrador is extensively mineralized but mineralogically complex. It is a pleasure to acknowledge John's important contributions to the understanding of the unusual and varied mineralization. He was first to identify and characterize the main economically important Y-HREE-Zr minerals in this strange complex: gerenite, a new Y-REE mineral and a new variety of gadolinite - two of the main sources of Y and HREE in the complex; and gittinsite, a common zirconosilicate in the widespread mineralized Strange Lake granites, and an unusual acid-soluble zircon – the sources of essentially all economically important zirconium at Strange Lake. John's identification and characterization of these minerals were invaluable to understanding of the complex, particularly the late-stage alteration that affected it and generated its economically important Y-REE-Zr minerals making them amenable to effective metallurgical extraction. **(*SY6, Fri. 10:40*)**

Contribution of fresh groundwater to water supply of cities

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Large and ever-increasing groundwater use as a safe source for potable water supply of the population is determined by its well-known advantages over surface water. Groundwater has better quality, better protection from contamination, more equal distribution over the area, *etc.*

The principle, saying that each city should have its own reserve source of potable water supply based on the use of environmental friendly and protected from contamination fresh groundwater is substantiated in the paper. This principle is especially important in practical issue for potable water supply in the period of emergency situations (natural and technogenic catastrophes, terrorism).

For the last decades the role of groundwater in water supply of population is growing significantly in many countries of the world. In the world scale, groundwater exploitation covers about 50% of drinking water demand.

In the paper the role of fresh groundwater in the water supply of big cities of the world is characterized. In Russia the part of groundwater in portable water supply is about 45%. The real picture of correlation between surface water and groundwater use for water supply of villages and small communities is the following: if water supply of villages and small communities by groundwater is more than 90%, then with the increase of city population the part of groundwater is going down and for some large cities it is insignificant or practically non-existent.

In some regions large groundwater withdrawal for water supply and especially its intensification, result in adverse environmental consequences such as land surface subsidence, sea water intrusion and intrusion of low quality waters, depression and dearth of vegetation, river runoff decreasing, development of karst-suffosion processes. So it is often necessary to decrease the pumping-out of groundwater. Case studies of large groundwater withdrawal and its consequences are described in the paper.

The goal of scientific investigations in this direction is to develop the strategy of groundwater resources management as a reliable source of water supply of population for the nearest and distant prospect.

The main scientific tasks are:

- development of scientific bases and practical recommendations for complex use of surfacewater and groundwater;
- assessment and mapping of natural and exploitation fresh groundwater resources accounting the perspective of its use;
- regional assessment of fresh groundwater vulnerability to anthropogenic contamination from the surface;
- development and implementation of principles of complex monitoring of surface and groundwater in studied regions. **(*SS10, Wed. 4:00*)**

The discovery of organic-rich black shale xenolith from kimberlite on the Hall Peninsula, Nunavut, and its age and implication for petroleum potential in Cumberland Sound

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Hall Peninsula, located on the southeastern part of Baffin Island, Nunavut, hosts the newly discovered Chidliak kimberlite province. Presently, this area lacks Phanerozoic sedimentary cover, except for unconsolidated glacial deposits; however, Late Ordovician and Early Silurian carbonate and black shale xenoliths have been recovered from the Late Jurassic–Early Cretaceous kimberlites. The petroleum potential and the age of the black shale xenolith are evaluated by Rock-Eval6 Pyrolysis, and Rhenium (Re)-Osmium (Os) isotope analysis, respectively. The xenolith represents an excellent oil-prone source rock, with average and maximum TOC values of 8.04% and 8.96% and a depositional age between Late Ordovician and Early Silurian. This organic-rich black shale xenolith provides reliable information that the Paleozoic source rocks may have been the candidate for the natural petroleum seeps in the Baffin Shelf area, especially in Cumberland Sound. **(*SS12, Fri. 2:00*)**

Formation hypothesis and modelling of stellate plagioclase, Central Layered Series, Isle of Rum, Scotland. A likely candidate for macroscopic pattern formation resulting from large-scale magmatic immiscibility

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We propose a model for the formation of macroscopic (~cm to m scaled) branching plagioclase textures within melagabbro of the Isle of Rum, Scotland. The interstitial plagioclase crystals are typically linked in cm channels through predominantly cumulate olivine, often as twins and form meshes of planar stellate structures (m-scale) with a large range in geometrical organization from patchy to radiating. In cases of radiating textures, the interstitial plagioclase crystals can be observed to have crystallized radially outwards as the last-crystallizing major mineral. Evidence of macroscopic crystal aggregation and alignment is attributed to interfacial free energy minimization at the microscopic scale during growth. Preferential occurrence and the inter-connected nature of interstitial plagioclase in channels through the rock can be attributed to large-scale melt immiscibility and mobility in the crystalline mush with inter-layer interactions. Accordingly, a binary immiscible Lattice Boltzmann model was developed to simulate fluid separation in the melt phase. Isothermal phase transitions modelled via first order chemical reactions are subsequently coupled with stochastic dynamics at the crystal growth front to simulate energy minimization processes including twinning during crystallization in an igneous environment. Results appear to capture several crucial observations such as the abundance and orientations of plagioclase crystals. Aspects of the natural stellates and the model will be presented. **(*SS24, Thurs. 3:40*)**

Cathodoluminescence, trace element and oxygen isotope study of quartz from the felsic intrusive rocks at the Sisson Brook W-Mo-Cu deposit, west-central New Brunswick

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The Sisson Brook W-Mo-Cu deposit, situated in west-central New Brunswick, is hosted by Cambro-Ordovician volcanic and sedimentary rocks of the Miramichi and Tetagouche groups. These rocks have been intruded by the Early Devonian Howard Peak diorite-gabbro, Nashwaak Granite, a phaneritic felsic dyke swarm, and a distinctively younger Late Devonian porphyritic felsic dyke. In order to understand the magma evolution history, the textural and geochemical characteristics of quartz phenocrysts from these felsic rocks were analyzed with the aid of SEM-cathodoluminescence (CL), laser ablation inductively coupled plasma mass spectrometry (LA ICP-MS), and secondary ion mass spectrometry (SIMS).

Four intrusive granitic units in the Sisson Brook deposit area: (1) medium-grained, equigranular two-mica granite with brown biotite that is slightly altered to chlorite; (2) biotite-granite with *ca.* 20% greenish brown biotite and accessory zircon, apatite, monazite, magnetite, titanite, sulfide and ilmenite; (3) biotite-granite dykes with similar mineralogical features to the biotite-granite; and (4) porphyry dykes with phenocrysts consisting of approximately 23% plagioclase, 10% quartz, 8% biotite, and 7% K-feldspar.

Quartz phenocyrsts in two-mica granite and biotite-granite plutonic phases is unzoned indicating that it formed at relatively stable magma chamber. Quartz dissolution textures in the dyke phases might be caused by cooling from 600 to 300 °C at pressure below 1 Kbar. Quartz phenocrysts in porphyry dyke samples are oscillatory-zoned. With the assumption that the activity of Ti in these magmas is 0.8 (based on the presence of ilmenite rather than rutile), Ti-in-quartz geothermometry indicates that the porphyry dykes formed at a temperature above 675 °C, two-mica granite and biotite-granite plutons formed at 600 to 700 °C, and the biotite-granite dykes formed at slightly below 600 °C. Higher Ge/Ti ratios reflect greater degrees of magma differentiation. This ratio increases from porpyrhy dykes, two-mica granite and biotite-granite pluton phases to biotite dykes. The highest Al content of quartz measured in two-mica granite is consistent with the highest aluminum saturation index of its whole rock. The oxygen isotope of quartz is from 8-8.5‰ for biotite-granite, 9-10‰ for biotite dykes and porphyry dykes, and 10-10.5‰ for the two-mica granites. The later mineralization quartz veins in the dykes have oxygen isotope values between 8.5‰ to 9.5‰, indicating the hydrothermal fluids related to the Sisson Brook deposit are dominantly magmatic fluids. **(*SS24, Fri. 9:00*)**

Origin and tectonic nature of the Zhangbaling metamorphic rocks in the Tan-Lu Fault Zone, China: Insights from protolith ages and deformation mechanisms

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The origin and tectonic significance of the Zhangbaling Group and the Feidong Complex along the Tan-Lu Fault Zone offsetting the Dabie and Sulu orogens have remained poorly understood. Here we report current studies on age dating of the protolith of these rocks as well as deformation mechanisms. Zircon LA-ICP-MS dating suggests that the protoliths of the greenschist facies Zhangbaling Group were emplaced at 754-753 Ma and the amphibolite Feidong Complex between 800-745 Ma. Therefore both the Zhangbaling group and the Feidong Complex must have been derived from the oldest cover rocks of the Yangtze Plate rather than its Mesoproterozoic or late Archaean basement as currently interpreted. The metamorphic grades of these rocks are lower than those of the Dabie Orogen. The structures in the Zhangbaling Group were produced by the Indosinian orogeny (245 Ma-236 Ma) and are characterized by a subhorizontal foliation and lineation with a top-to-the-SWS shear sense. In the Feidong Complex, the Indosinian structures are overprinted by many NNE-trending ductile shear zones and upright folds with axial planes trending NNE. The enveloping surfaces of these are subhorizontal. These NNE fabrics are clearly the Cretaceous Tan-Lu fabrics. We propose a model that explains the Indosinian fabrics of the Zhangbaling Group and the Feidong Complex as well as the difference in their metamorphic grades from the Dabie and Sulu orogens. In the model, the Zhangbaling Group and the Feidong complex were located in a jog or bend of the paleo-Dabie-Sulu subduction zone between the Yangtze and North China Plates. The jog/bend evolved into the final Tan-Lu shear zone. The transpressional convergence led to a shallower burial of the Zhangbaling and Feidong rocks than their Dabie/Sulu counterparts. The shallowly-North-dipping fabrics due to Indonisian subduction and subsequent exhumation were further overprinted by the Tanlu shearing in the Cretaceous. **(*GS2, Poster*)**

Structures, lithology and paragenesis of the Ogama-Rockland and Central Manitoba gold deposits, southeastern Rice Lake greenstone belt, western Uchi subprovince, Superior province

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The Archean Rice Lake greenstone belt is the most important gold district in Manitoba. The Ogama-Rockland and Central Manitoba gold deposits are located in the southeastern portion of the Rice Lake belt of the western Uchi subprovince within the western Superior province. Lithostratigraphic sequence has been established and several generations of deformation structures have been recognized through detailed geological mapping (scale 1:1000 and 1:5000) around these two deposits. The Central Manitoba gold deposit is hosted by west– to northwest–striking, steeply dipping shear carbonate-chlorite-quartz veins at the contact between basalt and feldspathic wacke or within gabbroic sills. A few feather veins occur within gabbroic intrusions as well. The ore mineralogy includes pyrite, chalpyrite, pyrrhotite and other minor sulfides. Gold is present as small irregular or angular inclusions within chalcopyrite and pyrite, or is coating adjacent to pyrite, or as small blebs filling in vein fractures. The plunge of gold mineralization within veins is good agreement with the plunge of the stretching lineation within the west– to northwest–trending, steeply dipping shear zones in the Central Manitoba gold area. The Ogama-Rockland gold deposit is situated in the chlorite-sericite-carbonate-quartz veins within northwest-striking, steeply dipping brittle-ductile shear zones in the tonalitic-granodioritic phases of the Ross River pluton. A few north–trending, steeply dipping brittle-ductile shear zones together with dominant northwest–trending ones are present as a conjugate set. The main ore mineralogy includes pyrite, chalcopyrite, and molybdenite. Visible gold is present as small irregular blebs filling in vein fractures adjacent to the vein margins. The plunge of the gold mineralization with veins appears to be structurally controlled by the intersection of the conjugate set of shear zones. Ongoing Re-Os sulfide systematics and U-Pb zircon chronometer will constrain the timing of the gold mineralization, which also helps improve the exploration model (orogenic versus intrusion-related gold deposits). **(*SY5, Wed. 9:20*)**

Mineralogy and petrology of orbicular ijolite from the Prairie Lake Carbonatite Complex, Marathon, Ontario

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Orbicular ijolite is hosted by contemporaneous ijolite rocks at the 1.1 Ga Prairie Lake Carbonatite Complex (Marathon, Ontario), and is the only known occurrence of this textural type in a rock of this composition. Orbicular textures can occur in granites and diorites, and represent rare crystallochemical reactions which occur during the later stages of emplacement(s) and crystallization of the magmas.

The Prairie Lake ijolite orbicules occur along distinct, densely packed bands in equigranular nepheline-rich ijolite and range from approximately 3 to 6 cm in diameter. Some orbicules are oblate and exhibit deformation while others show magmatic sedimentation textures within the host ijolite. From a macroscopic perspective, the orbicules show great variability in the cores, with some having an equigranular texture similar to the host matrix, whereas others exhibit quench textures. Radial modal zoning is common closer to the cores with tangential concentric zoning (up to 40 discrete zones) of distinct mineral banding towards the rims of the orbicules.

The mineralogy of the orbicules includes: nepheline, diopside, calcite and apatite, andradite-melanite garnet, titanite, biotite, titaniferous magnetite, perovskite, natrolite, secondary calcite, and cancrinite. The mineralogy of the host ijolite is similar- with less alteration and no secondary calcite present. The compositions of the diopside, garnet, nepheline and apatite are indistinguishable between the orbicules and the host ijolite. The only difference between the orbicules and the host ijolite is their unique textures. Quenched textures are identified in the orbicules, notably in the core with the presence of both fine- and coarse-grained quench textures. Earlier-forming diopside, nepheline, and perovskite are found as quenched textures in a "matrix" of garnet throughout the distinct concentric mineral zones. The rims of the orbicules form interlocking crystals with the host ijolite resulting in near-indistinguishable boundaries. The orbicules are interpreted to represent interaction of a partially crystallized quenched ijolitic melt, which was in contact with a second pulse of consanguineous ijolite magma. Immersion in the latter resulted in annealing of orbicules, in which previously formed quenched ijolite was recrystallized producing the monominerallic concentric layers sequentially from the margins towards the center of the orbicule. Some of the smaller orbicules are devoid of any quenched cores due to annealing of the entire orbicule. Liquid immiscibility was not involved in the formation of the orbicules. **(*SS23, Fri. 3:00*)**

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