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COMPARATIVE STUDY OF GARNETS FROM STREAM SEDIMENT AND SKARN OUTCROP ON THE CLY PROPERTY, SOUTHEASTERN BRITISH COLUMBIA

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The CLY property is a polymetallic Au+W prospect located in the Nelson mining division of B.C., 16 km southwest of the town of Salmo and 6 km north of the international border. The historic Bunker Hill mine is located in central CLY, and minor production of silver and gold (0.30 oz/ton Au and 0.87 oz/ton Ag) occurred from 1933 to 1942 in an intrusive-related gold system. The Lefevre skarn is found within 500 m of the Bunker Hill mine, and formed at the contact between mid-Paleozoic limestone units and the Cretaceous Wallack Creek stock. The current study shows that the skarn is composed mainly of garnet, amphibole, epidote, and calcite, with a variably brecciated texture. The garnets are anhedral, partially replaced by silicate minerals, and appear to have formed as aggregates of small grains. The skarn garnets are characterized by a pale pink colour and are not isotropic in cross-polarized light, a feature that has also been observed in garnets from other skarns. Accessory minerals such as pyrite, sphalerite, fluorite and zinc were also identified in the skarn. Electron microprobe analyses identified the skarn garnets as grossular, the Ca-Al end-member of the garnet solid solution series. Heavy mineral surveys of small creeks on CLY prospect in 2015 found anomalously high grain counts of garnets, which include grossular, andradite (Ca-Fe end-member), and spessartine (Mn-Al end-member). New SEM imaging of the creek spessartine garnets reveals that some are euhedral, with distinct crystal faces, while others display a highly rounded shape. The creek spessartine garnets show a zoning trend of increasing Fe towards the rims and increasing Ca and Mn towards the core, whereas there is no zoning visible in the brecciated skarn garnets. Geochemical analysis indicates that the grossular garnets in the streams may be sourced from the skarn deposit, but the source of the spessartine garnets remains unknown. The variable degree of rounding of the creek spessartine grains suggests that there could be multiple sources, one of which may be quite local in order to explain the euhedral crystals. Trace element analysis of both the creek and skarn garnets will be conducted in order to further investigate chemical differences, and to gain insight on a possible source for the creek garnets.

APPLICATIONS OF "FOUR BILLION YEARS AND COUNTING" AT THE SECONDARY LEVEL: STUDENT ENGAGEMENT, STUDENT UNDERSTANDING, AND USE OF THIS TEXT AS A TEACHING RESOURCE

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My interest following the publication of Four Billion Years and Counting surrounds the question of its application in a high school setting. In collusion with a master teacher working in Victoria, I intend to use this book as a resource within a science classroom. My intention is to do both pre and post assessment of student interest in earth science, and their engagement and understanding in topics covered during my time in the class. These assessments would help instructors to gauge whether the book is a good resource for these students and how it can best be applied in a high school setting. This provides an important opportunity to evaluate this Canadian-focused resource in a high school setting and to determine what aspects of the text and online component are effective for teachers and students.

MINERAL RESOURCE POTENTIAL NORTH –EASTERN SEAS OF RUSSIA

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Geological prospecting works on the shelf, islands and deep-water areas of the Eastern Arctic and Far Eastern seas of Russia have made it possible to establish mineral resource potential of the

onshore and offshore deposits of both placer and vein types. The relationship of metallogeny of the shelf areas and islands with the adjacent continental regions is traced clear.

Most commonly three types occur - placers of gold, tin, ferrous metals with Zr and V; locally - placers of platinum, and precious stones on the shelf of all these water areas.

The tin bearing potential of the Russian Arctic Shelf can be compared to the world largest tin provinces. The majority of these sites are concentrated in the Laptev and East Siberian seas of the Arctic ocean.

The unique Ryveem deposit of the Chukchi Sea shoreline is characterized by a combination of two types of gold placers (alluvial and littoral). There are also parallels between these gold placers and equivalent bench placers at Nome in Alaska.

One of the main tasks lying ahead of us is the development of Arctic gold placers. In order to succeed, it is necessary to carry out indepth reseach of the Arctic ocean shoreline and islands on the Arctic shelf.

We are considering the shelf and deep-water areas of the Far Eastern seas: the south-western part of the Bering Sea, the Bering Sea and the Pacific coastal sea area of Kamchatka and the Kuril Islands.

The active coastal erosion is observed around the Bering Sea and in the eastern part of Kamchatka and the Kuril Islands. The major placer minerals near shore are ferrous metals with Zr.

The South Koryak platinum - bearing ophiolite zone continues to the area of the Karaginskiy Bay of the Bering Sea. There are placers of which gold and platinum in the area of Karaginskiy Bay can be economically important.

In the back-arc Bering Sea area, north of the Commander Islands, an ore-bearing hydrothermal activity associated with the Pyep volcano was recorded; the pellets of native copper were found in the littoral zone of the Bering Island.

Mineral resources of the Far East seas, along with the adjoining land, are waiting for their development. They can fully ensure a successful self-sufficient economic development of the Far Eastern border regions of Russia.

STENIAN-CAMBRIAN TECTONIC EVOLUTION OF CENTRAL MADAGASCAR: INSIGHTS FROM GEOCHEMICAL AND ISOTOPIC DATA FROM MAGMATIC ROCKS

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Madagascar occupies an important location within the East African Orogen. This extensive orogen involves a collage of Proterozoic microcontinents and arc terranes wedged between older cratonic units during Gondwana assembly. Oceanic crust is an important component of palaeogeographic reconstructions that is often overlooked since exposures of in situ oceanic crust older than ~200 Myr are rare. Therefore, studies of ancient oceanic crust require proxies such as analysing the products of magmatic arcs. The Malagasy basement preserves three magmatic suites emplaced consecutively from ~1100-500 Ma. During this time, the Rodinia supercontinent amalgamated then dispersed and the Gondwana supercontinent formed. The magmatic episodes are ~1080-960 Ma (Dabolava Suite), ~850-750 Ma (Imorona-Itsindro Suite) and ~650-520 Ma (Kiangara and Ambalavao Suites). Mainly gabbroic and granitoid rocks of the Stenian-Tonian Dabolava suite combined with the probably coeval Ikalamavony Group represent a magmatic arc and marginal volcano-sedimentary sequence deposited in an arc tectonic setting based on geochemical characteristics. The Tonian Imorona-Itsindro suite represents contemporaneous emplacement of an assortment of magmas with their collective genesis most

reliably explained by plate margin processes. Tonian arc magma generation coincided with oceanic plate subduction during closure of the Mozambique Ocean along the Betsimisaraka Suture in eastern Madagascar. Recently, some authors have questioned the presence of an active continental margin and consequent suture zone in favour of intraplate magma generation based on limited geochemical characteristics. The Ediacaran to Cambrian Kiangara-Ambalavao suite is a post-collisional, mainly granitoid suite emplaced during the final assembly of Gondwana. In this whole-rock geochemical and zircon isotopic study, we attempt to: (1) resolve the conundrum of the presence or absence of Neoproterozoic suture zones in east central Madagascar and (2) reconstruct the tectonic geography of central Madagascar from the Stenian to Cambrian. Preliminary inferences question published palaeogeographic reconstructions. Interpretations also imply the possibility of a previously unrecognized and long-lived (~500 Ma) active subduction margin similar to the present-day western Pacific Ocean. This large isotopic dataset is critical for understanding Madagascar's tectonic evolution during the amalgamation and breakup of Rodinia, the closure of the Mozambique Ocean, and the final assembly of Gondwana.

PETROGENESIS OF THE TONIAN IMORONA-ITSINDRO SUITE, MADAGASCAR

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The East African Orogen (EAO) is one of the largest orogens that formed during the Ediacaran to Cambrian amalgamation of Gondwana. In the Mozambique Belt, the EAO represents the amalgamation of Neoproterozoic India with the Congo-Tanzania-Bangweulu Block. In the Arabian-Nubian Shield, the EAO consists of a pre-Neoproterozoic continental terrane surrounded by Neoproterozoic juvenile oceanic-arc like terranes. A large ocean, the Mozambique Ocean divided these Neoproterozoic landmasses. Many oceanic sutures tie together the various terranes in the northern EAO but the location of potential sutures become less obvious moving south. Authors have suggested a band of pelitic gneisses in eastern Madagascar with Neoproterozoic depositional ages and pod-like peridotite bodies, gabbro and emerald mineralisation represented a Mozambique Ocean suture and named it Betsimisaraka Suture. This suture separated central Madagascar (in the microcontinent Azania) from India. The ~100 Ma subduction of the Mozambique Ocean resulted in voluminous continental-arc magmatism (Imorona-Itsindro Suite) associated with stitching of Azania with the Dharwar Craton along the Betsimisaraka Suture. Recently, the existence of Azania has been challenged, and an alternative 'Greater Dharwar' continent has been proposed that incorporates most of central Madagascar on the margin of Neoproterozoic India reverting to a single suture hypothesis for the Mozambique Ocean. The assortment of Tonian lithologies emplaced contemporaneously has their collective genesis most reliably explained by plate margin processes. However, some authors have also questioned the presence of an active continental margin and consequent suture zone in favour of intraplate magma generation based on limited geochemical features. Although the age of the Imorona-Itsindro Suite is well documented, the geochemistry of the suite overall is poorly understood. We present petrographic and mineralogical results with complimentary whole-rock geochemical and Sm-Nd-Sr isotopic data to better constrain the components involved during genesis of the Imorona-Itsindro Suite. We advocate that a plate margin genesis is more appropriate rather than an intracratonic tectonic setting. In addition, we discuss the broader implications for the plutonic suite's relevance during the consumption of the Mozambique Ocean.

CHEMICAL COMPOSITION OF THE KITILÄ OROGENIC GOLD MINE (FINLAND) INDICATOR MINERALS

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The Kittilä deposit, a world-class orogenic gold mine, is located along the 25 km-long north-south striking Kiistala Shear Zone. It is hosted within the Kittilä Group of the Paleoproterozoic Central Lapland greenstone belt. The rocks are mostly volcanic and metamorphosed to the greenschist facies.

Mineralization is contained in arsenopyrite and pyrite, mostly as invisible gold. Ore zones are strongly albitized and carbonate alteration is common. Sampling of 38 drill core, selected from 10 cross-sections along the 4.5 km long deposit, provides a good spatial representation of the deposit geology. Rutile and tourmaline, were identified in polished thin sections and analyzed by microprobe for their chemical composition. In the deposit, rutile has a grain-size between 10 and 50 microns, and its chemical composition changes proportionally to its distance from the mineralized zones. Higher concentrations of tungsten and vanadium are associated with rutile near the ore zones. There is a positive correlation between iron and silica contents and the distance. This indicates that rutile has the potential to be a mineral vectoring toward mineralization in Kittilä and maybe to a greater extent for gold deposits. One sample contained tourmaline of schorl composition. Use of the electric pulse disaggregation (EPD) on the samples has confirmed the absence of magnetite in the deposit.

Four till samples were taken, on top of the Etelä pit. The first sample was taken up-ice of the main shear zones and the three others with 20 m spacing between each following the ice flow direction (toward East). The number of gold grains in till samples located on top of the main shear zones is three to four times higher than in the sample up-ice. Several grains from samples down-ice from the main shear zones have pristine or modified shapes suggesting more local derivation than the reshaped grains found in the sample up-ice from the shear zone.

Till samples above to the deposit enabled the comparison of indicator minerals that are found in each respectively. Magnetite is abundant in the till samples which indicates that part of till above the deposit has a remote origin. Rutile was not found in the >0.25 mm till fraction, likely a consequence of the small grain size of rutile in the deposit (<0.2 mm). Kittilä mine indicator minerals characterization gives more details on the rutile geochemistry and seems to indicate that it could be used as a mineral vector for gold deposit.

EVIDENCE FROM ECLOGITE XENOLITHS FOR A REDUCING AND WARM (NOT HOT) ARCHAEOAN AMBIENT MANTLE

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There is considerable uncertainty regarding the oxygen partial pressure (fO_2) and potential temperature (TP) of the ambient convecting mantle throughout Earth's history. Eclogite xenolith suites have elemental and isotopic compositions indicative of formation of crustal protoliths in oceanic spreading ridges. Their compositions therefore retain a memory of the thermal and redox state of the Archaean convecting mantle sources that gave rise to their low-pressure protoliths, provided the effects of kimberlite contamination, metasomatic overprint and accumulation or advanced fractional crystallisation during protolith formation are recognised and filtered.

Carefully screened eclogite suites up to 3 Ga in age have TiO_2 -REE relationships consistent with fractionation of olivine±plagioclase during formation of picritic protoliths from a melt that separated from a garnet-free peridotite source, implying intersection of the solidus at ≤ 2.5 to 3.0 GPa. Low melt fractions ($F < 0.25$) inferred from

samples with the least fractionated (lowest TiO₂) protoliths further argue against deep intersection of the mantle solidus. This suggests a moderately elevated TP ~ 1420-1470°C, significantly lower than some estimates for the ambient convecting mantle at that time. As a consequence, the unusual degree of melt depletion experienced by cratonic mantle lithosphere (F=0.3-0.5) may require formation at excess TP, which sustains longer melting columns, either during plume-ridge interactions or plume subcretion. A moderate Mesoarchaean TP also argues for early plate strengthening that would support plate tectonics and topography.

Samples in the filtered database also have V/Sc - which reflects the redox state of the ambient mantle during protolith formation - corresponding to ΔFMQ as low as -1.7 at 3 Ga. Such low oxygen fugacities imply that the depth of redox melting, during which CO₂-bearing melts are formed through reduction of ferric iron in silicate minerals and oxidation of carbon hosted in graphite or diamond, was shallower than today, making it more difficult to kimberlite to form beneath thick lithospheric roots that extended into the diamond field soon after craton formation, thus explaining their sparseness in deep time. Finally, subduction of reducing oceanic crust, combined with a lack of oxidative weathering prior to the Great Oxidation Event, may imply that there was little opportunity for diamond formation by redox reactions during metamorphic dehydration and partial melting. Thus, eclogite material emplaced in the Archaean could only become a prominent diamond source during later interaction with oxidising metasomatic fluids, or if changes in metamorphic fluid volume, temperature or pH played a role.

MAJOR- AND TRACE-ELEMENT CHARACTERISTICS, AND CATHODOLUMINESCENCE IMAGING OF APATITES IN FELSIC INTRUSIONS OF NEW BRUNSWICK: IMPLICATIONS FOR MAGMA EVOLUTION AND MINERALIZATION

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Acadian-related felsic intrusions of New Brunswick are associated with Sn, W, Mo, Cu, Sb, Bi, and Au deposits, as well as rare Ta, Li, base-metals, and U mineralization. Whole rock lithogeochemistry and apatite trace-element classification indicated that these intrusions are mostly A- and S-type granitoids and their hybrid varieties, with a smaller presence of I-type granitoids in the region.

Magmatic apatite, a common accessory phase in these granitoids, was studied by electron microprobe (EPMA), cathodoluminescence (CL) microscopy, and LA-ICP-MS from thirty of these Devonian intrusions. The results demonstrate unique trace-element characteristics in apatite from each of the intrusions interpreted to reflect host magma evolution. However, no direct relationship was observed between concentration of Sn, W, and Mo in apatite and host granitoid lithogeochemistry.

Yellow, shades of blue, and purple are the three main colours in the CL-imaging study. Among these, the first two are believed to be magmatic in origin, whereas the last one is caused by secondary hydrothermal processes. In some cases, there is an overgrowth of purple over yellow zones with significantly different trace-element signatures. For example, in a sample from the Lake George granodiorite, Mo and W increase from 0.05 to over 0.25 ppm. Purple apatites are not zoned, whereas both blue and yellow coloured apatites show oscillatory zoning. Furthermore, blue apatites have the highest concentrations of Mo (0.1 to 2.7 ppm), W (0.4 to 1.2 ppm), and Sn (0.1 to 2.50 ppm), followed by yellow and then purple apatites.

In contrast with constant major elements from core to rim, apatite grains can show significant trace-element zoning. Results of this study showed Sr, Cs, Ba, LREE, Mo, Sn, and W zoning for blue and yellow apatites. As these elements are highly incompatible, any zoning can be a result of the magma evolution history recorded within the apatite crystalline structure. Furthermore, apatites from

two barren intrusions (Lost Lake and Hawkshaw granites) have much lower values of almost all the trace elements compared to the apatites from mineralized intrusions. It is noteworthy to add that there is an agreement between the apatite and its host biotite zoning patterns. For example both biotite and apatite from a sample of Lake George granodiorite have Mo and Sn concentric zonation.

According to the results, the use of apatite as an indicator of trace element changes within granitic systems was achieved; with the help of other types of data, the composition of apatite may be a useful tool to indicate a difference between barren and mineralized granitoids.

PALEOCLIMATE PROXIES FOR USE IN PALEOBIODIVERSITY STUDIES: A CASE STUDY FROM THE LATEST CRETACEOUS OF SASKATCHEWAN

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Coupling paleobiodiversity patterns to paleoclimatic and paleoenvironmental drivers is an important element of paleoecology. Relative paleoenvironmental data (i.e. depositional setting, faunal/floral composition, regional context) are critical for paleoclimatic reconstructions. Absolute paleotemperature estimates can additionally provide a direct comparison with modern ecological analogues. Attaining accurate paleoclimate estimates from Mesozoic sites can be challenging, especially when stable isotope analyses prove problematic. This case study examined paleobiodiversity trends immediately prior to the end-Cretaceous mass extinction in the Frenchman Formation of Saskatchewan. Paleoclimate proxies were sought that were easy-to-use, accurate, non-destructive to fossil material, and which retained a direct biological link to the paleoenvironment. One proxy was found that fit these criteria, and one new method for paleoclimate estimation was explored.

The Climate Leaf Analysis Multivariate Program (CLAMP) utilizes the physiognomy (size and shape) of fossil dicotyledonous angiosperm leaf assemblages to estimate eleven paleoclimate parameters. Two paleofloral assemblages from the Frenchman Formation were used to estimate paleoclimate at two study localities. CLAMP yielded mean annual temperature estimates of 12.1°C and 14.4°C (± 2.1), with a seasonal ranges 6.7°C – 22.5°C. As an independent assessment of these estimates, paleosol geochemistry was applied to six paleosol samples from the same localities. The paleosol data estimated mean annual temperatures of between 12.6°C and 13.7°C (± 4.4°C), falling within the ranges of estimates calculated by CLAMP. It is suggested that, where sample sizes are sufficient, fossil leaf assemblages can provide accurate paleoclimate information at a high level of precision.

Garscale Growth Ring Analysis is a new method for estimating paleoclimate fluctuations and seasonality. This technique involves examining seasonal growth increments in the scales of the garfish, *Lepisosteus*. Fossil garscales are very common in terrestrial fossil-bearing deposits throughout the late Mesozoic and Cenozoic. Modern *Lepisosteus* specimens of known provenience were studied to determine the relationship between seasonal growth increments in scales and climate/seasonality. Scales from fifteen garfish (*L. ossleus*) from Florida, Kentucky and Ontario were analyzed. Fish from Florida and Kentucky generally had a more constant growth rate compared to fish from Ontario, which generally had slower and more variable growth. The same procedure was repeated for *Lepisosteus* sp. scales collected from the Frenchman Formation of Saskatchewan. Comparison with the modern data implies that the fossil garfish came from environments with marked seasonality, which is consistent with the climate data collected from CLAMP. More data must be collected in order to refine this method, but the preliminary results are encouraging.

AN EXPANDING ROLE FOR THE INTERNET IN EARTH SCIENCE EDUCATION

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The internet has been revolutionizing Earth science education from elementary school to university. At a basic level it provides an extensive repository of (often real-time) data, including on-line collections, megapixel images of samples or field sites, map and GIS data as well as lesson plans linked to books. It allows educators to experiment with dynamic teaching, for example by creating a customized just-in-time collection of texts and videos, taking students on virtual field trips, or developing applications for students' mobile devices. Perhaps most innovative is the ability of educators and their students to interact remotely among one another in online courses and even with others, for example by questioning scientist during virtual visits to museums or receiving feedback on their research during virtual poster sessions. The community is taking steps to assess the effectiveness of such approaches; questions like who uses these data/apps/websites (and how much) and what do our students learn? In this presentation I will show some internet resources I have found useful, consider some questions that can help us determine if this is effective, and offer my biased outlook on what we should do to help push this boundary in a meaningful way.

THE MAZAMA ASH AT SEDIMENTARY AND ARCHAEOLOGICAL SITES ACROSS CENTRAL AND SOUTHERN ALBERTA AND SOUTHWEST SASKATCHEWAN

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The Mazama Ash is one of the mostly widely distributed tephra units in North America, present as a visible ash in sediments of early Holocene age (ca. 7.6 cal yr BP) from Oregon, east to Wyoming and north into central Alberta. In Alberta, the ash is generally seen as a thin (ca. 2 cm) buff coloured silty layer. It is found in a wide range of depositional settings, from peatlands to alluvial fans. Depths to the ash layer vary, depending on depositional context, but it is often within 1 – 3 m of the present ground surface. Therefore, the chance of finding it in archaeological excavations or along cut-banks is quite high. This tephra is considered one of the most important stratigraphic markers for sedimentary and archaeological sites across this region. However, although it is commonly used to prescribe age control to sites, the ash is often identified simply on the basis of field criteria, such as colour, thickness, texture and stratigraphic position, sometimes supplemented by light microscopy. This can be problematic in sites with low sediment accumulation rates and poor radiocarbon chronologies because there is more than one visible ash horizon present in Alberta from late glacial times to present. Besides the Mazama ash, these include, but may not be limited to, Glacier Peak G (ca. 13.5 ka), Mount St. Helens Yn (ca. 3.8 ka), and Bridge River (2.5 ka). Here we present new major-element geochemical analyses on Mazama ash obtained from several sites, including some archaeological sites, across south and central Alberta and southwest Saskatchewan: James Pass, Saskatchewan Outlook, Friday Site, and Abraham Lake Lookout Point. We confirm the presence of Mazama at these sites, helping rectify any uncertainty in their age models and adding to the available set of analytical data for this ash layer. The geochemistry of the ash is consistent across the region, regularly containing a dacitic component that has not previously been reported in distal ash deposits, but is well-described in proximal deposits.

POST-FLOOD SURVEYS ALONG RIVERS IN SOUTHWEST ALBERTA: ARCHAEOLOGY, QUATERNARY PALAEOLOGY AND PALAEOECOLOGY

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The extensive 2013 floods in southwest Alberta caused considerable riverbank erosion, retreat and damage to infrastructure. In

the wake of the floods, a sustained effort has been made to systematically survey several of the major affected rivers (e.g., Bow River, Highwood River) and to assess the effect of the impacts on archaeological, Quaternary palaeontological and palaeoecological resources. These river systems have high known densities of archaeological sites, as well as a lesser number of Quaternary palaeontological and palaeoenvironmental sites.

The freshly flood-exposed river cutbanks offered an unparalleled opportunity to systematically examine exposures with the potential for historic resource deposits. Many archaeological sites are found adjacent to the riverbanks; winter camps are often associated with river valleys where shelter and supplies of wood could be found. River valleys also contain extensive gravel deposits; much of the Quaternary palaeontological record in Alberta is known from fluvial gravel deposits. Fluvial sediments may also contain slack-water or cut-off deposits preserving palaeoecological materials (specifically plant and mollusc macroremains). The window of opportunity for reconnaissance of flood-impacted areas is limited, however, because steep exposures are vulnerable to revegetation, slumping and erosion.

The primary objective for the project is to generate information that can be used to further develop predictive modelling of historic resource sites (archaeological, Quaternary palaeontological, and palaeoenvironmental). The field investigations were undertaken by several heritage consulting firms, with overall project management handled by the Archaeological Survey, Alberta Culture and Tourism. Two years of reconnaissance have been completed, focusing largely on the Bow and Highwood rivers and selected tributaries. Results have shown that some riverbanks experienced upwards of 50 metres of erosion during the 2013 event, leading to significant impact on several known archaeological sites and palaeoenvironmental contexts. At least 140 archaeological sites have been investigated, many of which contain significant cultural information. Palaeoecological sites and vertebrate fossils (e.g., bison) have been found only infrequently, a result that was surprising and unexpected. Overall, the palaeontological and palaeoecological finds have been highly localized, in contrast to the archaeological site distributions which are more widely dispersed. The project is generating valuable insights into site distribution and context, and will provide a strong basis for designing future historical resource reconnaissance and cultural resource management (CRM) efforts.

VOLCANOLOGY OF THE CATHEDRAL CLIFF DIATREME, NAVAJO VOLCANIC FIELD, NEW MEXICO

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The Navajo volcanic field is located in the central part of the Colorado Plateau, mostly in Arizona and New Mexico, USA. It includes over 80 Oligocene to Miocene (28-19 Ma) monogenetic volcanoes and related intrusive features. Only diatremes (including the famous Ship Rock) and igneous dikes are exposed, due to significant post-emplacement erosion. Several diatremes are aligned along the Defiance Uplift, implying an important tectonic control in the area. Minette, a mafic potassic magma, predominates in the Navajo volcanic field. The minette diatreme studied for this MSC project is Cathedral Cliff, located approximately 14.5 km SE of Ship Rock in NM. The erosion level is estimated at ~1 km below the pre-eruptive surface. Therefore, the deeper parts of the diatreme can be observed. The pyroclastic rocks range from bedded to non-bedded, from coarse tuff to tuff breccia, and from lithic-rich to juvenile-rich. Bedded pyroclastic rocks locally display low-angle cross-bedding, suggesting deposition by low-density pyroclastic currents (surges). The presence of bedded pyroclastic rocks at this depth, with very steep inward dips, indicates that there has been significant subsidence of the bedded deposits. Sub-vertical contacts in the non-bedded parts of the diatreme and the presence of sub-vertical columns of non-bedded deposits cross-cutting the bedded deposits

are interpreted as produced by the passage of debris jets through the diatreme. Cathedral Cliff is a good opportunity to understand the transition between the bedded deposits and the non-bedded pyroclastic deposits in diatremes, as well as their relationships and emplacement processes.

ARSENIC IN SALINE TO HYPERSALINE BRINES ON THE BOLIVIAN ALTIPLANO

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High concentrations of arsenic (As) have been observed in some of the lakes and lagunas on the Bolivian Altiplano, and are thought to be a result of weathering of volcanic rocks (Laguna Verde to the south) as well as contamination from mining and metallurgical activities (Lake Poopo to the north). The vast region in between these sites however, has remained relatively unexplored and offers the opportunity to study arsenic adsorption and reactions in natural environments characterized by high concentrations of sulfur (S) and silica (Si), with low concentrations of iron (Fe) and organic matter (OM). Six lagunas were sampled from the Sur Lipez region of the Altiplano: Canapa, Ramaditas, Hedionda, Honda, Chiar Khota, and Challuncani; all of which contain saline to hypersaline, alkaline brines and are located between several mountain peaks including Cerro Canapa, Cerro Caquella, Cerro Jardin, and Cerro Ascotan De Ramaditas. Surface water samples were collected as well as sediment samples from the mudflats of the salars during the dry season of June 2014. The sediments were excavated to the water table or ice and each sedimentary layer was collected separately. Water samples were analyzed for a 30-element suite of cations and anions including (As, Li, B, Fe, Si, S, and P) via inductively coupled plasma optical emission spectrometry. The clay-sized fraction (< 2 µm) of the sediments was separated using centrifugation, and the bulk and clay-sized mineralogy determined using X-ray diffraction. The chemistry and morphology of the sediments were analyzed using a FEI Quanta 650 FEG-ESEM. Dissolved As concentrations in the surface and pore waters were highly variable ranging from 6.67 µM in Hedionda to 454 µM in Chiar Khota with dissolved Fe below detection limits for all of the samples. High As concentrations were associated with high concentrations of dissolved Li, B, and Ca in the surface waters, typical of evaporative basins. Within the sediments, As-rich minerals were mainly found in saturated, yellow, layers up to 15 cm thick as amorphous As-sulfides identified using SEM EDX analysis or in orange layers as realgar (As₂S₃) identified in the XRD patterns. These As-rich horizons were located directly above a coarser, black, layer at the water table. Geochemical controls on the dissolved arsenic concentrations in the surface waters and precipitation of As-rich minerals in the sediments within a low Fe containing system will be discussed.

MID-PALEOZOIC MAGMATISM AND TIMING OF VMS MINERALIZATION IN THE PELLY MOUNTAINS, YUKON: IMPLICATIONS FOR CORDILLERAN TECTONICS AND METALLOGENY

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Felsic volcanic and volcanoclastic rocks of the Devonian-Mississippian Seagull group (informal) are recognized hosts to polymetallic (Zn-Pb-Cu-Ag) volcanogenic massive sulphide (VMS) mineralization in the Cassiar terrane, south-central Yukon. Despite abundant evidence for mid-Paleozoic magmatism and hydrothermal activity along the Cordilleran margin of western Canada, many fundamental questions remain about the precise age of the Seagull group and its genetic relationship with rift-related units of the Yukon-Tanana terrane, Slide Mountain terrane, and ancestral North America. To investigate these questions, we initiated a project to constrain the timing and tectonic setting of Seagull group magmatism in the central Pelly Mountains (NTS 105F and G). At one locality

near the headwaters of the McConnell River, Upper Devonian(?) black to tuffaceous shale and lithic sandstone units at the base of the Seagull group conformably grade upwards into Lower Mississippian(?) lapilli tuff and rhyolite flows. Volcanic rocks at this and other localities yield both non-arc and arc-like trace element signatures that together are consistent with high-temperature felsic magmatism in a continental rift setting. Peralkaline rhyolites at the Wolf VMS deposit in the Finlayson Lake map area (Yukon MINFILE 105F127) are geochemically similar to other non-arc felsic rocks in the Pelly Mountains, including those with Nd-Hf isotope signatures that indicate the sampling of old crustal material during regional magmatism. Notably, this non-arc geochemical fingerprint is also recognized within gossanous, Tournaisian felsic rocks in the Quiet Lake map area that we recently analyzed by chemical abrasion (CA-TIMS) zircon U-Pb geochronology. The available geochemical evidence therefore strengthens the idea that some VMS-associated Mississippian rhyolites in the Canadian Cordillera are the result of crustal melting processes. Our working hypothesis is that Upper Devonian strata of the Seagull group likely comprise part of a turbidite basin that developed during regional extension and initial felsic volcanism, whereas Lower Mississippian strata were deposited in a metalliferous volcanic rift basin that was located behind the Yukon-Tanana continental arc-rift system, along what would become the passive margin side of the Slide Mountain Ocean.

GEOCHEMICAL CHARACTERIZATION OF PHOSPHATE ACCESSORY PHASES THROUGHOUT METASOMATICALLY ALTERED LLALLAGUA TIN PORPHYRY. NEW INSIGHTS INTO ORIGIN OF RICH VEIN MINERALIZATION

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Careful petrological and geochemical characterization of accessory minerals represent a powerful tool in understanding metasomatic and mineralization history of one of the world's biggest tin deposit, Sigo XX, Llallagua, Bolivia. The Llallagua tin deposit is a hydrothermally altered porphyry stock, and is part of the subduction-related Bolivian tin belt. Despite multiple studies, there is still a debate about timing and characteristics of mineralization episodes related to post-magmatic metasomatic activities. A well-documented ~20Ma inconsistency exists among ages determined from the zircon in the least altered porphyry (U-Pb 42.4±4Ma), paragenetically coeval vein minerals, fluorapatite (Sm-Nd 43.8±4.7Ma) and monazite (U-Pb 19±1.6Ma) and altered porphyry minerals (K-Ar c. 20Ma).

Insight into mineralization history is given by study of major and accessory phases including REE-bearing monazite, xenotime and apatite together with characteristic phases which crystallized/re-crystallized through different stage of metasomatic alteration. Results show three distinctive alteration styles with dominant sericitization of ryodactitic porphyry accompanied by local silicification and tourmalinization. Textures were evaluated using a petrographic microscope, a scanning electron microscope and electron microprobe analysis of the mineral assemblage.

The results show an abundance of mineralization and alteration products in relation to the various alteration styles. Early disseminated cassiterite and phosphates, which were introduced in the later stages of metasomatic alteration of primary porphyry, were partially remobilized and concentrated within hydrothermal veins leading to formation of a high-grade ore along with gangue minerals including gem-quality fluorapatite and monazite. This is evident from numerous pseudomorphs and recrystallization textures which can be found within the sericitized and silicified zone of porphyry rock. The primary mechanism of phosphate alteration is identified as dissolution-reprecipitation, which led to HREE exchange by LREE. This is evident by the presence of micro-porosity and the formation of secondary, reaction induced xenotime within the altered monazite grains, and is proposed to be a function of mineral-fluid disequilibrium possibly resulting from a temperature drop and fluid mixing, or later hydrothermal activity. Moreover, the presence of

abundant unaltered vein fluorapatite indicates selective alteration of the monazite-fluorapatite assemblage and may account for the observed 20Ma age discrepancy.

USING REMOTE SENSING PRODUCT TO DETECT GEOHAZARDS IN THE MOUNTAINOUS REGIONS OF NORTHERN BRITISH COLUMBIA

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Northern British Columbia is subject to a diversity of hazards that relate to regions with steep and recently deglaciated terrain. For the most part, these areas are experiencing permafrost degradation, rockwall debutting and ecological succession. Recent studies show that large catastrophic events have been increasing in frequency in British Columbia and pose a concern to increasing pressures from the public and from industry. Landslide frequency is exacerbated by climate and geology, including changes in temperature, precipitation and wind, and the occurrence of earthquakes. Traditional field methodologies are very useful in quantifying the subtleties of an event, though demand important financial resources. This study compares the quantification of the parameters of large landslides from field and remotely sensed products to demonstrate the strengths and weaknesses of each approach. The utilization of remote sensing products is increasing exponentially and the integration of these technologies into decision making and hazard assessments will prove to be critical.

LANDSLIDE RESPONSE TO THE OCTOBER 27, 2012 EARTHQUAKE (Mw 7.7), GWAII HAANAS NATIONAL PARK RESERVE AND HAIDA HERITAGE SITE, HAIDA GWAII, BC

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Understanding the mechanics of earthquake triggered landslides is important in order to assess the geohazard potential of a landscape to future seismic events. Research in this field is difficult because of the unpredictable nature of earthquakes in time and space and the multiple factors that influence slope stability. The three strongest earthquakes recorded in Canada occurred on the Queen Charlotte Fault off the west coast of Haida Gwaii, British Columbia. The most recent occurred on October 27, 2012 and had a magnitude of MW 7.7. Using both airborne and satellite imagery an inventory of landslides in Gwaii Haanas National Park Reserve and Haida Heritage Site has been compiled as well as a baseline dataset of landslides over the period of satellite and air photo observations. Image acquisition dates range from 1937 to 2015 at a variety of resolutions. We analyze the spatial distribution, topographic and geological characteristics of the landslides as well as the weather patterns relating to the events. Haida Gwaii experiences heavy rain and strong winds for much of the year, and in 2012 a 400 mm rainfall event occurred in less than 24 hours not long after the earthquake, confusing the causal relation of the landslides. More than 300 landslides occurred in 2012, mostly debris slides on south or north facing slopes. A large portion of the landslides from the October 27th event occurred in the weeks following. This may suggest that the earthquake may have lowered the threshold for sliding and that the heavy rainfall may have triggered the landslides directly.

THE ORFÉE PROSPECT: A NEOARCHEAN OROGENIC GOLD OCCURRENCE ALONG THE CONTACT BETWEEN THE LA GRANDE AND OPINACA SUBPROVINCES (EYVOU ISTCHEE JAMES BAY, QUÉBEC)

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The Orfée gold orebody (>0.2 Mt at 14.5 g/t Au), part of the La Grande Subprovince, is located 300 m north of the contact with the

Opinaca Subprovince. Many other gold occurrences have been discovered along this contact, but the abundant surface and drilling data at Orfée offers a good opportunity of understanding the gold mineralizing events along the complex La Grande – Opinaca contact.

Mineralization at Orfée, divided into the Orfée and Orfée-East zones, is associated with oxidized/silicate iron formations and with graphitic wackes containing up to 20 % disseminated to semi-massive pyrrhotite, pyrite and accessory arsenopyrite and chalcopyrite. $\delta^{13}\text{C}$ values of -36.05 to 45.28 ‰ to for the carbon in the graphite suggests a biogenic origin. Tholeiitic to transitional amphibolitic basalts displaying an early S_{en} foliation edge the mineralized zones to the north. The early S_{en} foliation is recorded by garnets crystallized during the metamorphism of an irregular Fe, Mn and S pervasive but discontinuous alteration, while the main S_{n} foliation is oriented NW-SE to NNW-SSE. A sodic alteration affects the amphibolites proximal to the mineralized zone. Plagioclase-phyric dioritic dykes dated at 2703 Ma are contemporaneous to the Ell diorite proximal to the Éléonore mine, and cut across the main foliation S_{n} in the amphibolites, but display a $S_{\text{n+1}}$ E-W schistosity. Visible gold is associated with a prehnite alteration in these dykes, as well as with bismuth tellurides. In the iron formations, visible gold is associated with pyrrhotite replacing the magnetite, as well as with chlorite veinlets. To the south of the mineralized zone, a wacke unit is composed of interstratified intermediate and mafic sediments. The amphibolites, the iron formations and the wackes have been injected by a large variety of deformed quartz veins containing up to 2 g/t Au. Sheared and boudinaged granitic pegmatites, dated to 2614 Ma (contemporaneous to pegmatitic granites observed around the Éléonore mine), cut across the wacke and amphibolite units.

The Orfée showing is an example of orogenic gold deposit hosted by volcanic rocks metamorphosed up to the intermediate amphibolite facies. The mineralization seems to have precipitated in a reduced Fe-rich environment, and remobilized along mylonitic corridors in the iron formations and the graphitic wackes. LA-ICP-MS analysis on the sulphides and arsenopyrite dating will provide information on the mineralization style and perhaps on the timing of mineralization in relation with the main deformational event (S_{n} foliation) and the peak metamorphism.

THE PARADISE GRAVEL: EVIDENCE FOR A PRE-WHITE CHANNEL GRAVEL IN THE KLONDIKE

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New stratigraphic interpretations for exposures at Dago, Preido and Paradise hills on lower Hunker Creek suggest a more complex evolution was responsible for the development of high-level bench gravels in the Klondike than has been previously put forward. A highly-altered gravel has formerly been interpreted to be part of the lower White Channel Gravel sequence and its degree of alteration attributed to enhanced groundwater diagenesis near the bedrock contact. New mining exposures indicate this altered gravel, informally termed 'Paradise gravel', is laterally extensive and the alteration is not restricted to the bedrock interface. Furthermore, a cross-section reconstruction shows the White Channel Gravel is stratigraphically inset into the Paradise gravel. Alteration of the Paradise gravel is potentially related to pedogenesis, suggesting a period of landscape stability followed its deposition. This pattern of sedimentation and stability was also repeated within the lower White Channel Gravel and recorded by a zone of clay alteration and iron oxidation.

Identification of an older gravel in the Klondike provides an opportunity to increase our knowledge of Neogene landscapes and the associated climate in Yukon. Future work should focus on reconstructing the fluvial environment and providing dating control. Analyses of potential paleosols identified in both the Paradise

gravel and lower White Channel Gravel present an opportunity to understand the Neogene climate of the Klondike.

ADVANCES IN COMPETENCY BASED-ASSESSMENT FOR PROFESSIONAL REGISTRATION - A REVIEW AND RECENT DEVELOPMENTS ON THE COMPETENCY PROFILE FOR PROFESSIONAL GEOSCIENTISTS AT ENTRY TO PRACTICE

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Geoscientists Canada recently approved the Competency Profile for Professional Geoscientists at Entry to Practice¹. The profile describes the skills and abilities deemed necessary for registration as a P.Geo. The profile was developed by Geoscientists Canada working collectively with, and on behalf of, the provincial/ territorial professional associations responsible for the self-regulation of geoscience practice across Canada.

Subject Matter Experts (SME's) – geoscientists, drawn from a range of Earth science sub-disciplines, from representative employment sectors and from different regions of the country, assembled the initial profile, under the supervision and guidance of an expert in competency mapping for regulated occupations. The SMEs also aided in the refinement process to achieve the final profile. Refinement included extensive consultation with the professional associations and the geoscience community, and a national survey of professional geoscientists.

Now that the profile has been constructed, work will follow to map the profile back to the "GKE" (Geoscience Knowledge and Experience Requirements for Professional Registration in Canada)² – the national standard used by the Geoscientists Canada member organizations in setting their respective admissions requirements for professional registration.

This paper will review the process followed to determine the competency profile. It will briefly describe the profile itself and will explain subsequent work that is now planned.

1 - <http://geoscientistscanada.ca/wp-content/uploads/2015/07/Competency-Profile-for-Professional-Geoscientists-at-Entry-to-Practice-Combined-Doc.pdf>

2 - <http://geoscientistscanada.ca/wp-content/uploads/2014/11/GC-Knowledge-Requ.BKLT-REV-EN-web-final.pdf>

TECTONIC TRIGGER TO EXTENSIVE EOCENE VOLCANISM IN THE CANADIAN CORDILLERA

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Eocene volcanism along the North American Cordillera formed a belt up to 500 km wide, extending from present-day southwest Yukon to Idaho. Eocene volcanic successions, including those of the dominantly silicic Ootsa Lake Group (OLG) in central BC, were erupted ~200-500 km from the active margin during a ~10 Myr epoch, along a continental margin that was under extension. Aerial extent and temporal restriction of the OLG magmatic epoch is not arc-like, but does require a trigger mechanism of plate tectonic-scale.

Previous attempts to explain the widespread Eocene magmatic epoch along the North American Cordillera called upon "slab windows" formed during subduction of spreading oceanic ridges. However, the location of subducted ridges is unconstrained because the oceanic crust that would have recorded their passage has been consumed. A recently developed plate tectonic model for western North America derived from seismic tomography (Sigloch and Mihalynuk 2013) images a "slab gap" bounded by near-vertical slab walls, that formed beneath south-central BC during the Eocene, starting ~55 Ma. Lateral extents of the slab gap approximately correspond to the distribution of the OLG.

Based on this new model geometry, we suggest that OLG volcanism was triggered by the cessation of subduction and slab breakoff, ingress of hot asthenospheric mantle at the expanding break and juxtaposition with overlying, relatively cold, metasomatized mantle wedge. The mantle wedge was forced across the expanding slab gap as North America moved westward in advance of the spreading Atlantic, and the detached slab sank vertically. This likely generated an immediate magmatic response, until thermal reequilibration of the sublithospheric mantle wedge was attained within ~10 Myr, as induced melting of the metasomatized mantle wedge transferred magma and heat across the asthenosphere-lithosphere boundary.

Ponding/intrusion of basaltic melts into the lower and mid-crust may have assimilated and thermally weakened it, facilitating extension and further decompression melting. Thus, the "volcanic arc" geochemical signature of OLG lavas may have been partly inherited from previously formed arc crust. Synchronous extension and volcanism favoured effusive outpourings of silicic lavas, rather than voluminous rhyolitic ignimbrites that would tend to form on already extended crust. Crustal extension generated magma pathways, and extensional basins that contributed to the preservation of volcanic deposits erupting above those pathways.

GROUND-PENETRATING RADAR (GPR) INVESTIGATIONS AT HEALY LAKE, INTERIOR ALASKA

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In 2014, a Ground-Penetrating Radar (GPR) survey was conducted within the Healy Lake Village of Interior Alaska, a location that has played a pivotal role in shaping concepts within Interior Alaskan archaeology and with an extensive record of North American human occupation. Prior to beginning field data collection an open dialog was established in order to provide the community an opportunity to become more familiar with the operation of GPR technologies, field data collection methodology, post-processing training, and interpretation on questions individuals had about the archaeology within their village.

From these initial conversations a three-fold research approach was established and conducted to: (1) determine if GPR technologies can record radar imagery of potential archaeologically-related anomalies from underwater contexts within Healy Lake; (2) establish the placement of unmarked graves based on ethnographic data, as well as detecting marked graves accurately in signal reducing mediums such as the local Fairbanks schist bedrock; and (3) detect other anomalies within loess that could be associated with unexcavated areas near the Old Village Site. During the examination favorable results were reached for all three approaches, which are detailed in this presentation along with data interpretations and their impact on the community.

PRELIMINARY INVESTIGATION OF THE VULCAN CREEK LANDSLIDE, KLUANE NATIONAL PARK AND RESERVE, YUKON

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The 2014 Vulcan Creek landslide was the reactivation of a prehistoric rock slope failure in Kluane National Park and Reserve, Yukon. Vulcan Creek is a tributary of the Slims River near its delta in Kluane Lake. The area is prone to landslide activity due to its high topographical relief, weak rock mass (the tectonic terrane bounding Duke River Fault crosses the landslide) and the seismicity of nearby active Denali Fault. The 2014 landslide dammed Vulcan Creek resulting in the formation of a lake, observed in June 2015 to be 18,000 to 20,000 m².

Lithologies observed near the headscarp include schist, anhydrite and mafic intrusive rocks, while the dominant lithology in the

deposit is reddish volcanic rocks. The landslide source zone has an area of 70,000 m² while the deposit area has an area of 100,000 m². The volume of the landslide deposit is estimated to be at least 500,000 m³. The above normal monthly precipitation for July 2014 (as reported at the Burwash Landing station, 50 km northwest of the study area) is considered to have contributed to the Vulcan Creek Landslide. Based on preliminary joint measurements near the headscarp, planar sliding is a feasible failure mechanism. Based on the rock mass quality observed in the headscarp (Geological Strength Index between 30-50), a pseudo-circular failure due to the low rock mass strength aided by the planar sliding discontinuity is considered to be the most likely failure mechanism.

Clast-content greater than 5 cm was visually estimated to represent 25% of the landslide dam material. Grain-size distribution of samples collected showed the remaining 75% was composed of a well graded gravel with sand. An approximately 500 m long overflow channel established itself in the landslide debris by September 2014 (first reported sighting of the Vulcan Creek landslide-dam). In June 2015 the overflow channel had incised an average 3.5 m in the debris, its width was approximately 7 m and it had an average 8° longitudinal channel gradient. Preliminary assessment using empirical relationship suggests the Vulcan Creek landslide dam is stable. This initial assessment of the stability of the Vulcan Creek landslide dam is associated with considerable uncertainty since hydrological regime and dam material type are not considered in the empirical assessment used.

KEEP IT SIMPLE! THE ADVENTURES OF THE CANADIAN SOCIETY OF EXPLORATION GEOPHYSICISTS (CSEG) FOUNDATION ON HOW TO ORGANIZE AND DISTRIBUTE EDUCATIONAL RESOURCES

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This presentation describes how the CSEG (Canadian Society of Exploration Geophysicists) Foundation currently engages with, raises awareness of, and promotes the science of geophysics for different demographics. The CSEG Foundation has several outreach subcommittees that target different audiences: Kindergarten to grade 12, university students, and the general public. We will briefly discuss each groups' mandate, programs they run, how they share effective (and ineffective) methods of engagement for their respective audiences, and upcoming initiatives to improve the outreach of the CSEG Foundation.

This talk also explores the challenges of efficient organization of online geoscience materials such as educational videos on the CSEG website, lesson plans, activities, and website links to allow for easier navigation. Updated webpage layouts and enhanced social media synchronization aim to reduce the time it takes to access resources. We desire not "to reinvent the wheel" but to allow for more convenient distribution of already existing quality resources. In this discussion the CSEG Foundation outlines what we have found that works, shortcomings, and improvements currently underway to better streamline access of geoscience resources through CSEG digital media.

The ultimate goal is to create an engaging and worthwhile experience to more effectively promote the science of geophysics.

MINERALOGY, MINERAL CHEMISTRY, IN SITU SULFUR ISOTOPES, AND THEIR IMPLICATIONS ON THE GENESIS OF THE PRECIOUS METAL-BEARING MING DEPOSIT, CANADA

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The Ming deposit in the Newfoundland Appalachians is a Cambro-Ordovician, precious metal-bearing Cu volcanogenic massive sulfide deposit that was metamorphosed to upper greenschist/lower amphibolite facies conditions in the Silurian and Devonian. The deposit consists of several, spatially close orebodies.

We applied microscopic (reflected light microscopy, scanning electron microscopy) and micro-analytical methods (electron microprobe analysis, laser ablation inductively coupled mass spectrometry, secondary ion mass spectrometry) to: (1) record ore mineral assemblages and ore mineral textures; (2) analyze ore mineral chemistry; (3) determine the source(s) of sulfur contributing to the overall sulfur budget; and (4) constrain the genesis of the Ming deposit.

Mineralogical observations show that the different orebodies of the Ming deposit consist predominantly of a pyrite-chalcopyrite assemblage with minor sphalerite ± pyrrhotite and traces of arsenopyrite – galena ± cubanite. However, the orebodies vary in particular in their abundance of sulfosalts, tellurides and electrum, and therefore in the abundance of the suite of epithermal elements (As, Bi, Hg, Sb, Sn, Te) and precious metals (Ag, Au). Ore textures are complex and both replacement textures and decomposition/unmixing textures are observed. Mineral chemistry results show: (i) highly variable Fe contents in sphalerite from all orebodies (1.12-11.04wt%); (ii) variations in the content of Te, Bi, Se, Sb, and Ag within galena between the different orebodies; and (iii) variations in Ag and Hg in tetrahedrite and electrum, respectively, between the different orebodies. Results from in situ sulfur isotope analysis on various ore minerals show isotopic sulfur compositions between 0.8-19.6‰.

The different orebodies at the Ming deposit were formed from predominantly reduced, acidic hydrothermal fluids with varying $f_{\text{Te}}/f_{\text{S}}$, $f_{\text{Se}}/f_{\text{S}}$, and $m_{\text{Bi}}/m_{\text{Sb}}$ ratios as temperatures steadily decreased from >300°C to <260°C during ore formation. The variations in these ratios impacted greatly the ore mineralogy and ore mineral chemistry in the different orebodies. The abundant occurrence of elements of the epithermal suite and precious metals as well as low sulfur isotope compositions (<10‰) strongly suggests the contribution of magmatic fluids and/or volatiles to the hydrothermal fluids that formed the Ming deposit. The influence of metamorphism and deformation on the mineralogy, mineral chemistry, and in situ sulfur isotope composition is presumably negligible, although the overall geometry of the deposit and some ore textures were impacted by metamorphism and deformation.

NEW INSIGHTS IN THE ORIGIN OF VMS DEPOSITS IN VOLCANIC BELTS AROUND THE PALAEOPROTEROZOIC KISSEYNEW BASIN OF MANITOBA/SASKATCHEWAN

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Central Manitoba is underlain by the Kisseynew Domain, a large basin structure of 250 × 200 km extent. This structure is flanked by the Palaeoproterozoic Flin Flon- and Snow Lake volcanic belts to the south and the Lynn Lake and Leaf Rapids volcanic belts to the north. It occupies a central part of the Trans Hudson Orogen. The volcanic belts are important present and past metal producers from VMS type copper-zinc-gold deposits, including the large Flin Flon, Ruttan and Lalor deposits. The deposits are hosted in bimodal tholeiitic volcanic or intrusive rocks.

At the outset of this study we asked ourselves three main questions: (i) what is the source of the thermal energy that created the iron-rich and highly fractionated tholeiitic sills?, and (ii) how were the ore metals copper, zinc and gold extracted from the rock and transferred into orebodies?, and (iii) how can we explain why and how the deposits, located hundreds of kilometres away from each other, were formed at nearly the same time?

We found that the Mikanagan Lake tholeiitic sill contains high iron-titanium-phosphorus ferro gabbroic and copper-enriched layers in addition to a highly fractionated leuco-tonalitic phase. This phase is closely related to our ore-associated rhyolites.

We suggest that a large meteorite impact event in a marine environment could indeed have supplied sufficient energy to vaporize enough mafic volcanic source rock to allow for the concentration by condensation of large quantities of copper, gold and zinc. This process is possible if the temperatures are high enough ($>1800^{\circ}\text{C}$) to exploit the presence of a large immiscibility gap in the system Fe-SiO_2 .

We then went and looked through comprehensive assay data from deep drill holes in the Sudbury impact melt sheet. The results impressed upon us that the impact melt sheet at Sudbury was hot enough to induce the important magmatic $\text{Co} > \text{Ni}$ ratio that is found in (nearly) all VMS ores, the high heat allows for the separation of a high silica/low titanium melt or froth that matches our highly fractionated high silica/low titanium rhyolites, and associated ferro gabbros.

In conclusion, we now believe that our model of an impact induced magmatic event at and beneath the deep sea floor in the Kiseeynew Basin area is realistic and verifiable. It offers to us valuable and powerful ways of creating meaningful and predictive ore deposit models that are useful for geological and geophysical follow-up and drill testing.

THE EVOLUTION OF CALCITE-BEARING KIMBERLITE BY ROCK-MELT REACTION DURING ASCENT – EVIDENCE FROM POLYMINERALIC INCLUSIONS WITHIN CR-DIOPSIDE AND CR-PYROPE MEGACRYSTS FROM LAC DE GRAS KIMBERLITES, NORTHWEST TERRITORIES, CANADA

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Megacrystic ($> 1\text{ cm}$) clinopyroxene (Cr-diopside) and garnet (Cr-pyroxene) xenocrysts from Lac de Gras kimberlites (Diavik and Ekati diamond mines) contain fully crystallized melt inclusions that are relatively large (up to 2 mm in diameter) and very abundant (up to 10 inclusions per sample section). These “polymineralic inclusions” have previously been interpreted to form by “necking down” of melts at mantle depths.

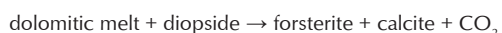
Here, we present a detailed petrographical and geochemical investigation, including EPMA, LA-ICPMS, QEMSCAN, and TIMS, of polymineralic inclusions and their host crystals to better understand how they form and what they can reveal about the evolution of kimberlite melt during ascent.

The “megacrysts” genetically are mantle xenocrysts with peridotitic chemical signatures. Geothermobarometry shows that they originate from within the lithospheric mantle ($\sim 4.8\text{ GPa}$, 1050°C). There is textural evidence for disequilibrium between the host crystals and their polymineralic inclusions (spongy rims around inclusions in Cr-diopside and kelyphite rims in Cr-pyroxene), which is consistent with Sr isotopic disequilibrium (the inclusions being significantly more radiogenic than their hosts). The preservation of compositional and isotopic disequilibrium establishes a temporal link to the kimberlite eruption.

In Cr-diopsides, polymineralic inclusions contain phlogopite, olivine, chromite, serpentine, and calcite. The host Cr-diopsides contain abundant fluid inclusion trails around the inclusions. In Cr-pyroxenes,

the inclusions additionally contain Al-spinel, clinopyroxene, and dolomite. The inclusion phases are broadly characteristic of kimberlite, with their compositions being overall consistent with the early stages of kimberlite differentiation trends. Enrichment of inclusion phases in components more abundant in the host crystals, e.g. Cr_2O_3 and Al_2O_3 , points towards extensive reaction between inclusions and hosts.

Inclusions in Cr-diopside in particular, seem to record certain “decarbonation reactions” for which - although predicted by experimental studies in the 1970s - direct geological evidence has been lacking. The invoked reaction, which is directly represented by the mineralogy of the inclusions and the surrounding fluid inclusion trails (CO_2 -rich), has the form:



The original composition of the inclusion-forming melt is difficult to obtain, but reconstructed bulk compositions bear resemblance to experimental partial melts of carbonated peridotites after the assimilation of mantle minerals. Thus, our study of polymineralic inclusions in megacrysts supports models of kimberlite formation in which a dolomitic primary kimberlite melt reacts during ascent to form a lower pressure melt that crystallizes a calcite-dominated assemblage.

SEISMIC EVIDENCE FOR CRUSTAL-SCALE EXTENSION IN THE INTERMONTANE BELT OF THE NORTHERN CANADIAN CORDILLERA

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The crustal thickness of the Canadian Cordillera, which reached 50-65 km during the Cretaceous, is now only 32-38 km along its length. In the south, extension resulted in the formation of core complexes and crustal-scale extensional shear zones that have been seismically imaged, but in the north evidence for extension is mostly limited to minor basin formation in a late transtensional environment. Using new images of Lithoprobe seismic reflection lines 2a and 3, which have been previously interpreted in terms of terrane accretion, I document evidence for post-accretion crustal-scale extension in the middle and upper crust. During the Middle Jurassic, the Quesnellia and Stikinia arc terranes were accreted to ancestral North America along a crustal ramp, which is imaged in the lower crust. Along line 2a, an extensional shear zone, which extends from close to the surface to 20 km depth, is identified from the geometry of reflections in the overlying basin and a lateral change in seismic velocity. The oceanic Cache Creek terrane, which is $\sim 3\text{ km}$ thick here, was preserved, because it was imbricated with its overlap assemblage and dropped into the 10 km deep basin, whose present surface location is indicated by the combined extent of the Whitehorse Trough and the Cache Creek terrane.

EARLY PALEOZOIC MAGMATISM AND STRATIGRAPHY OF THE KECHIKA GROUP, PELLY MOUNTAINS, YUKON

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Lower Paleozoic strata of the Kechika group (informal) comprise part of the exposed base of the Cassiar terrane in south-central Yukon. The precise age and stratigraphic architecture of key Cambrian-Ordovician volcano-sedimentary successions in this region are uncertain and therefore limit the ability to test and develop new models for Cordilleran tectonics and metallogeny. The significance of long-lived lithospheric structures, such as the Liard Line, to regional magmatism and metal fertility are also unclear. To address these and other questions, a field-based project was initiated to constrain the stratigraphic record, timing, and tectonic setting of Kechika group magmatism in the central Pelly Mountains. The Cloutier formation represents the centre of a Cambrian-Ordovician

volcanic belt and comprises up to 500 m of volcanic and sedimentary rocks in the Cloutier Creek (105F/10) map area. Three principal lithofacies associations (basaltic, volcanogenic sedimentary, and limestone-argillite) were identified during field studies ~10 km east of the Ketzia River mine. The basaltic facies association consists of primary volcanic products such as pillow basalt, vesicular to amygdaloidal massive basalt, and sediment-matrix basalt breccia. The volcanogenic sedimentary facies association likely formed by the reworking of primary products and consists of monomictic basalt breccia and conglomerate. The limestone-argillite facies association occurs near the top of the Cloutier formation and contains limestone, argillite, and minor polymictic conglomerate. To the northeast and southwest of the Cloutier Creek map area, the Groundhog formation consists of up to 800 m of tuffaceous to black shale and intercalated basalt and gabbro that are laterally equivalent to the Cloutier formation. A latest Cambrian age is reported for a pyroxene gabbro stock near Groundhog Creek using chemical abrasion (CA-TIMS) zircon U-Pb geochronology. All mafic rock samples, including the dated gabbro, have alkali basalt (ocean island basalt) geochemical signatures. This has led to the working hypothesis of the melting of an enriched mantle source during Cambrian-Ordovician extension and rifting along the Cordilleran margin. Whole-rock trace element and Nd-Hf isotope geochemical data are further consistent with some mafic intrusive bodies having been contaminated by evolved crustal rocks. Future work will relate the Kechika group with Cambrian-Ordovician stratigraphic units in the northern Cordillera, including the Menzie Creek formation of the nearby Faro District. Plate-scale comparisons will aid in understanding the development of the rifted Cordilleran margin and the role of lithospheric scale structures.

IGNEOUS STRATIGRAPHY AND CU-PD MINERALIZATION AT AREA 41 WITHIN THE EASTERN GABBRO OF THE COLDWELL ALKALINE COMPLEX, CANADA

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The Eastern Gabbro forms the northern and eastern margin of the Coldwell Alkaline Complex and is host to several Cu-Pd occurrences, notably the Marathon Cu-Pd deposit. The Area 41 occurrence is located near the northwestern margin of the complex and was discovered in 2006. The igneous units at Area 41 consist of three series, from oldest to youngest: metabasalt, the Layered Series, and the Marathon Series. PGE mineralization is hosted by the Marathon Series, thus the identification of the Marathon Series is key to exploration. In this study, the Layered Series and the Marathon Series are distinguished through a combination of whole-rock pXRF and benchtop-SEM mineral analyses. The Layered Series displays a relatively smooth normal fractionation trend, indicated by variations in whole-rock Ba, Zr, V/Ti, and Mg# of olivine and clinopyroxene, and by the An content of plagioclase. By contrast, the composition of minerals in the Marathon Series vary significantly over short distances. Lithogeochemical and mineral-chemical stratigraphic sections also indicate the presence of a normal fault.

The PGE mineralization is hosted by a coarse-grained ophitic gabbro, with lesser amounts of mineralization associated with an apatitic clinopyroxenite, an important unit within the Marathon Series. Our results suggest that different processes are responsible for mineralization. The Cu/Pd ratios for the mineralized apatitic clinopyroxenite are typically within the mantle range (1,000 to 10,000). The small range of Cu/Pd of this unit is likely related to a single magma event. By contrast, the ophitic gabbro displays a wide range of Cu/Pd (10 to 100,000), which reflects a large variation in R factor. In the mineralized ophitic gabbro, some chalcopyrite grains occur intergrown with An-rich plagioclase that has replaced earlier less calcic plagioclase, and precious-metal minerals have been observed in association with the chalcopyrite. In addition, the mineralized ophitic gabbro displays significant variations in the Mg# of olivine and clinopyroxene. Thus, PGE mineralization in

the ophitic gabbro appears to be associated with recharge events within a conduit system. The low Cu/Pd ratios (<500) for some of the ophitic gabbro samples may indicate a similar mechanism as was proposed for the W-horizon at the Marathon deposit, namely multistage dissolution upgrading in a dynamic system.

LARGE IGNEOUS PROVINCES AND THE BREAKUP OF NUNA RECORDED BY SEDIMENTARY ROCKS AND URANIUM ORE FORMING PROCESSES IN LAURENTIA'S CORE: EVIDENCE FROM THE ATHABASCA BASIN

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There is a general notion that ca. 1.75-1.50 Ga sedimentary rocks were deposited into the intracratonic Athabasca Basin. In reality, however, the basin contains the remnants of several sedimentary basins each with unique depositional axes and depocentres, the most extensive of which being the Cree Basin. The bulk of the preserved lithostratigraphic units are of the Manitou Falls (MF) Group, the basal part of Cree Basin. The Cree Basin is capped by rocks of the Lazenby Lake (LZ) and Wolverine Point (WP) groups. Although the former contains the typical quartz arenitic strata, the WP group contains relatively abundant mudstone beds, indicating a change in depositional conditions. Furthermore, the basal WP Group contains clasts of ash-fall tuff, which have previously yielded a ca. 1.64 Ga depositional age. Chemostratigraphy for the Cree Basin section indicates a geochemical boundary at the top of the MF Group, with strata of the LZ and WP groups containing comparatively elevated concentrations of a number of elements, including the Rare Earths. There is a corresponding change in the composition of clay minerals across the same boundary. Sm-Nd isotopic results also highlight this boundary with epsilon Nd (ϵ Nd) values (calculated at 1.65 Ga) averaging -6.5 in the MF Group compared with an average of 0.2 in the LZ and WP groups. One explanation for the observed boundary is the emergence of juvenile rocks in the Cree Basin's source region. A single detrital zircon analysis for the WP Group, with youngest detrital zircons between 1.68 and 1.65 Ga, supports this hypothesis because that range is absent in the MF Group. A possible mechanism for the change in source area is the initiation of a nearby large igneous province (LIP), which would provide a source for the WP tuff. Rutile dating in basement to the Athabasca strata has identified a ca. 1.64 Ga silicification event that supports the notion of a local heat source driving fluids from the basement into the overlying sedimentary rocks. We propose a LIP in the Athabasca Basin's source area between ca. 1.68-1.64 Ga. This proposed event is likely the first of many <1.7 Ga LIP events in the region. Compilation of the ages from primary uraninite grains from a variety of deposits establishes a correlation between the age of ore-forming fluid events in the Athabasca Basin and well-known ages of LIPs that drove the breakup of the supercontinent Nuna.

RAE-HEARNE INTERACTIONS SOUTH OF THE ATHABASCA BASIN: NEW PERSPECTIVES ON THE TECTONICALLY UNIQUE RAE CRATON THROUGH TIME

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The Paleoproterozoic history of the WSW Rae Province can be unravelled in the southwestern shield of Saskatchewan. Here, rocks of the Rae and Hearne provinces are separated by the 5-10 km wide, northwest-dipping Virgin River shear zone (VRsz), the most southwesterly exposure of the Snowbird tectonic zone. The hanging wall of this shear zone contains Paleoproterozoic rocks similar in age to those of the Mesoarchean-cored, Taltson basement complex of northeastern Alberta (2.5-2.1 Ga),

which was likely accreted to the proto-Rae craton during the 2.5-2.3 Ga Arrowsmith orogeny. Along the southeastern margin of the hanging wall, the basement complex contains remnants of an LIP event, manifested by a large anorthosite intrusion and a swarm of mafic dykes, diagnostic of rifting along this margin of Rae craton at ~2.11 Ga. This event preceded the Taltson orogeny during which exotic terranes in northeastern Alberta, were welded to the southern Rae with a metamorphic culmination at 1.94-1.93 Ga. The footwall of the VRsz contains rocks of the southern Hearne province, characterized by a basement complex of dominantly >2.70 Ga felsic orthogneisses unconformably overlain by <2.60 Ga supracrustal rocks of continental affinity. Metamorphic ages in this block are <1.865 Ga and derive from the Trans-Hudson orogeny (THO) to the east. Rare dioritic plutons with arc-type affinity were emplaced in the hanging wall of the VRsz at ~1.94 Ga. This contractional regime led to accretion of the Hearne craton along this boundary during the ~ 1.90 Ga Snowbird orogeny. The Snowbird orogeny translated the Rae craton over the Hearne craton, an event indicated by a 5-10 km wide, ductile fold-thrust belt preserved within the VRsz with northwest-over-southeast kinematic indicators. A broad regional fold that distributed Mesoarchean rocks of the Taltson basement complex around the core of the Rae craton also developed at this time. By 1.85 Ga, during the early stages of the THO, the VRsz had transformed into dextral, strike-slip fault zone during which exhumation of the Rae craton continued, leading to development of a gneissic fabric in the southern Hearne craton. This event severely dismembered the Taltson basement complex, leaving a string of Mesoarchean rocks along the Snowbird tectonic zone, including isolated occurrences within the VRsz. By this stage, the Rae occupied an upper plate, distal setting with respect to the THO, experiencing only limited tectonic effects.

MINERALOGY, GEOCHEMISTRY, AND GEOCHRONOLOGY OF ALLANITE PEGMATITES AT THE KIN PROPERTY, BRITISH COLUMBIA

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REE- and Nb-bearing NYF-family pegmatites are located on the KIN property in the Omineca Belt of the Canadian Cordillera, ca. 95 km NE of Revelstoke, British Columbia. The presence of NYF pegmatites is unusual, because the Cordillera has traditionally been associated with LCT-family pegmatites. The KIN pegmatites form lenses and boudins in amphibolite-grade rocks of the Neoproterozoic Horsethief Creek Group; metamorphosed REE-bearing A-type syenites (Trident Mtn. syenite) and undeformed S-type granites are located in their vicinity. The pegmatites contain significant amounts of allanite-(Ce), monazite-(Ce), columbite, amphibole, Mn-rich garnet, chevkinite-(Ce), aeschynite-(Ce), euxenite-(Y), and fluorapatite within a matrix of plagioclase, Ba-rich K-feldspar and quartz. Mineral textures, such as the breakdown of monazite into a corona of apatite and allanite reflect the interaction with Ca, F, and Si-rich fluids presumably during metamorphism.

Geochemical similarities between the pegmatites and syenites suggest a genetic link; however, the intrusion age of the syenite of 378 Ma contrasts with a U/Pb zircon age of 79 Ma obtained from the pegmatites. This age coincides with metamorphism in the area and suggests that the pegmatites were derived by partial melting of the syenites. Moreover, U/Pb zircon ages of 76 Ma from the undeformed granites provide evidence for early post-metamorphic magmatic activity in the area; these intrusions caused re-heating and fluid mobilization in adjacent rocks, including the pegmatites.

SPATIAL AND TEMPORAL LINKS BETWEEN TRANSPRESSIONAL DEFORMATION, LITHOSPHERIC DISRUPTION AND ARCHITECTURE, AND ANORTHOSITE INTRUSION

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New geochronologic results in the Adirondack Region of the Grenville Province indicate that the intrusion of massif anorthosite and related granitic rocks (AMCG Suite) is tied in time and space to a broad (>50 km wide) region of sinistral transpression developed during the Shawinigan Orogeny (1200-1140 Ma). The slightly arcuate Central Adirondack shear system (CAss) spans east-west across the entire Adirondack dome and shows a marked parallelism of lithologic contacts, foliation trends, fold axes, and horizontal lineation trends. A model incorporating convergence, followed by orogen-parallel deformation and lateral propagation of slab detachment, is proposed as a trigger for lithospheric disruption, asthenospheric ascent and decompressional melting, and associated anatexis of the lower crust. Strain, although widely distributed across the Adirondack Region, was focused between ca. 1200-1170 Ma granitic gneisses of the Piseco Lake Shear Zone (PLsz) and remnants of the older (ca. 1350-1300 Ma) Southern Adirondack tonalitic arc terrane that originally rifted from the margin of Laurentia. The focus of constrictional strain between the Piseco batholithic rocks and Southern Adirondack terrane suggests it represents a plate boundary and cryptic suture. This model can account for: the crustal architecture; the transition from arc to AMCG magmatism over a few tens of millions of years; the transition from metasomatized lithospheric to enriched asthenospheric magma source; the distribution of voluminous AMCG rocks; the regional development of a sub-horizontal stretching lineation and localized L-tectonite zones; and the timing of major Shawinigan Orogeny magmatic, deformation, and anatectic events in the Highlands and Lowlands. The scale of transposed nappes, the width of the transpression zone, and the orientation of shear wave splitting trends confirm that deformation extends well into the underlying mantle.

MINERAL CHEMISTRY OF MAFIC SILICATE PHASES FROM THE SATAH MOUNTAIN VOLCANIC FIELD, ANAHIM VOLCANIC BELT, CENTRAL BRITISH COLUMBIA

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The Anahim Volcanic Belt (AVB) is a laterally extensive series of volcanic landforms that spans approximately 300 km, from the central B.C. coast and to Nazko Cone, located 75 km west of Quesnel. The AVB has been previously postulated to be the product of intracontinental volcanism, forming due to the North American plate sliding westward over a hypothesized Anahim hotspot. In this study, rock samples from the Satah Mountain Volcanic Field (SMVF) of the central AVB were recovered and subjected to electron microprobe analysis. Textural and mineralogical observations were recorded to supplement the existing bulk geochemical data for this suite of volcanics, and single-crystal geobarometry was performed on the clinopyroxene. Results confirm that samples from the SMVF are predominantly silica-undersaturated alkali-basalts, with a typical mafic mineral assemblage of feldspars, clinopyroxene and olivine. A wide range of textural characteristics are present in the rocks, from complete interstitial fabric indicative of rapid quenching of the magma, to highly porphyritic with euhedral and resorbed feldspars and olivine. Emerald green-yellow coloured clinopyroxene exists as intermediates of the solid-solution series aegirine-augite, which is characterized by Na and Fe³⁺ enrichment. Crystals with high concentrations of TiO₂ (approximately 6 wt%) are found in the same samples as crystals with low TiO₂ (<1.0 wt%). Preliminary calculations indicate that Ti-rich pyroxenes formed under higher pressure conditions (P = 10.0-11.6 kbar) compared to the

Ti-poor variety ($P \leq 7.3$ kbar). Both plagioclase and alkali-feldspars are present, occurring both interstitially and as phenocrysts. Geochemical analysis of the plagioclase reveals a composition of An_{57} with phenocryst rims that are slightly more calcic (An_{60}). Several centers of the SMVF exhibit extensive iron enrichment, resulting in the unusual pure iron end member of olivine, fayalite. Electron microprobe analyses reveal that some rocks contain nearly Fa_{100} with no reaction rims, while other samples contain zoned phenocrysts with distinct core-rim compositions. The Fe-rich olivines also contain a measureable amount of MnO, approximately 4.0 wt%. In other samples, zoning profiles of some olivine phenocrysts are observed to have Mg-rich cores (Fe_{79}) and slightly less Mg-rich rims (Fe_{60}). Some samples from the SMVF also contain aenigmatite, an unusual titanium silicate mineral ($Na_2Fe_5TiSi_6O_{20}$) that is thought to crystallize due to interaction of aegirine-augite with a Ti-rich melt, late in the cooling history of the rock. Aenigmatite is present as elongate, red-brown crystals that contain inclusions of ilmenite.

STABLE ISOTOPE AND MAGNETIC HYSTERESIS RESPONSES FROM A LATE DEVONIAN (FRASNIAN) CARBONATE PLATFORM, CANNING BASIN, NORTHWESTERN AUSTRALIA

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Devonian reef complexes along the northern margin of the Canning Basin in northwestern Australia are well exposed and considered to be one of the best examples of Paleozoic reef complexes anywhere. Recent studies of the facies architecture of the Hull platform, an Early-Middle Frasnian (conodont Zone MN 2 to base of MN 6) complex developed on a tilted Precambrian block, have recognized the major role of syndepositional faulting on platform evolution. Current work on the Hull platform investigates the influence of eustatic and autogenic processes on platform evolution.

Two 250 m thick stratigraphic sections of the Hull platform in the Hull Range and Guppy Hills, located about 5 km apart, were examined using stable isotope, magnetic susceptibility and magnetic hysteresis analyses, underpinned by biostratigraphy and lithofacies analysis. Stratigraphic plotting of carbon and oxygen isotope results shows shifts in $\delta^{13}C$ values that appear useful for correlation when combined with recognition of exposure surfaces. A prominent positive $\delta^{13}C$ shift at ~170 m above the base of both sections is tentatively interpreted to correspond to the punctata Event, the global-scale $\delta^{13}C$ excursion across the Early to Middle Frasnian transition (conodont Zones MN 4 to 6). As at other locations globally, the excursion recorded in the Hull platform occurs at the start of a transgressive pulse and is associated with an initial peak in magnetic susceptibility values.

Magnetic susceptibility in both sections is characterized by extremely low to negative values ($<0.5 \cdot 10^{-8}$ m³/kg) with localized peaks of $\sim 1 \cdot 10^{-8}$ m³/kg. In combination with hysteresis results, the magnetic data show that the susceptibility in background intervals is dominated by diamagnetic minerals and in the peaks by paramagnetic minerals (clay minerals or pyrite). A very small amount of magnetite occurs in multi-domain grains indicating a detrital origin. Magnetic hysteresis responses exhibit systematic variations through the interval of the punctata Event providing a "magnetic record". Ferrimagnetic susceptibility and saturation magnetization are inversely correlated with the $\delta^{13}C$ values, whereas parameters indicating the presence of coercive minerals, such as high field remanence percentage, are positively correlated with the $\delta^{13}C$ values. The results are interpreted as indicating increased consumption of detrital magnetite by microbially-mediated processes during increased anoxic conditions and preservation of a coercive mineral, greigite or pyrrhotite. The combined isotopic and

magnetic datasets from the Hull platform thus provide a valuable record of the influence of eustatic sea-level changes and global bioproductivity conditions on a tectonically active platform.

CHEMOSTRATIGRAPHY OF THE LOWER TO MIDDLE DEVONIAN SUCCESSION IN THE MOOSE RIVER BASIN, NORTHERN ONTARIO: CORRELATIONS TO GLOBAL EVENTS?

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The Lower-Middle Devonian Kwataboahagan Formation is recognized as the one of the best potential petroleum reservoirs in the Hudson Bay Basin but characterization of this formation and other potential Devonian reservoir rocks is mainly based on seismic and petrophysical data. The adjoining Moose River Basin offers Devonian outcrop exposures and well data that can be used to develop analogues for Devonian reservoirs in the Hudson Bay Basin. This study is a preliminary investigation of the Kwataboahagan Formation and bounding units in selected cores from the Moose River Basin, involving core examination, petrography and stable isotope geochemistry.

The Kwataboahagan Formation is underlain, in descending order, by skeletal limestones and dolostones of the Stopping River Formation (Lower Devonian) and dolostones and mudstones of the Kenogami River Formation (Upper Silurian to Lower Devonian). The Kwataboahagan Formation is overlain by dolostones and nodular to massive gypsum of the Moose River Formation (Middle Devonian). In the Kerr Addison Coral Rapids CR-78-08 core, the Kwataboahagan Formation is about 66 m thick and composed of dolomitic skeletal limestones in the lower part which grade up into microcrystalline to medium crystalline dolostones in the upper part. The limestone units typically have less than 5% porosity, whereas the dolostones have very good (up to 20%) intercrystalline, vuggy and moldic porosity.

Carbon, oxygen and strontium isotope analyses of micrite-rich limestones from three cores were done in order to assess the viability of using chemostratigraphy for correlating Devonian strata in the Moose River Basin. Stratigraphic plots of the results reveal patterns of positive and negative shifts in $\delta^{13}C$ values that may be useful for regional correlation. Furthermore, some of these trends appear to be broadly correlative with the composite Devonian $\delta^{13}C$ curves compiled based on data sets from various localities around the world. Of particular interest is the positive shift just below the contact between the middle and upper members of the Kenogami River Formation, which appears to correspond to the Klonk Event, the well-documented positive excursion across the Silurian-Devonian boundary; and the negative shift observed in the lower part of the Stopping River Formation, which may relate to the Basal Zlichov Event, a negative shift in the lower Emsian (Lower Devonian). These preliminary findings suggest that Lower to Middle Devonian strata in the Moose River Basin have recorded signals of global-scale events, such as eustatic sea-level and faunal changes.

TIMING OF MID-CRUSTAL TECTONO-METAMORPHISM IN YUKON-TANANA TERRANE AT AISHIHIK LAKE, SOUTHWEST YUKON

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There is a paucity of data that constrain the timing and conditions of tectono-metamorphism that affected western portions of Yukon-Tanana terrane in southwest Yukon. This precludes a comprehensive understanding of northern Canadian Cordilleran orogenesis. We describe field and petrological data which reveal a mid-crustal

metamorphic assemblage and tectonic fabric that appear to pre-date the Early Jurassic Aishihik batholith in the Aishihik region of southwest Yukon.

Southwest of the Aishihik batholith, kyanite, staurolite, garnet, biotite, muscovite and monazite define a regional mid-crustal metamorphic assemblage within Snowcap and Finlayson assemblage rocks of the Yukon-Tanana terrane. Peak regional pressure and temperature were approximately 6 to 8 kbar and 600 to 650°C. Within 5 to 10 km of the Aishihik batholith, the regional metamorphic assemblage appears to have been overprinted by a sillimanite-grade contact aureole.

Garnet belonging to the regional metamorphic assemblage contains inclusion trails of quartz and mica (S_1). Inclusion trails are generally discontinuous with a regional transposition fabric (S_2), which dips gently to the east and wraps around garnet, kyanite, staurolite, plagioclase and monazite. Two small late-Permian plutons to the west of the study area have been transposed into the S_2 fabric. Both S_2 and the Aishihik batholith have been overprinted by upright, north-northwest trending open to tight folds and an associated crenulation cleavage (S_3).

Metamorphic monazite from the Aishihik region exhibits up to four distinct chemical domains, with high Y domains rimming matrix monazite in the vicinity of the Aishihik batholith. Rare monazite included in garnet rims lack this high Y domain, and together with the cores of the matrix monazite may provide a means of dating the regional metamorphism that preceded intrusion of the Aishihik batholith. The precise age(s) of monazite chemical domains is currently being determined via in-situ U-Th-Pb dating using SHRIMP.

These preliminary mapping and mineral-fabric relationships suggest parts of Yukon-Tanana terrane in southwest Yukon were tectonically buried to mid-crustal conditions prior to the Early Jurassic and perhaps as early as the Permian. Models will be presented which reconcile the timing and conditions of tectono-metamorphism in the Aishihik region with broader episodic Permian to Cretaceous arc-continent convergence and orogenesis in the northern Canadian Cordillera.

DEVONIAN-MISSISSIPPIAN RIFTING IN YUKON AND NORTHERN BC; IMPLICATIONS FOR EXPLORATION OF SYNGENETIC AND EPIGENETIC MINERALIZATION

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The Devonian-Mississippian Earn Group is a predominantly sedimentary succession that was deposited in extensional basins along the continental margin of Ancestral North America. This sequence marks the end of passive margin style sedimentation that characterized the deposition along the continental margin from Neoproterozoic until late Paleozoic.

Volcanic rocks (ca. 365 to 363 Ma), laterally discontinuous coarse clastic rocks and locally variable stratigraphy of the Earn Group are all interpreted as evidence of Devonian-Mississippian rifting. This rifting resulted in normal faulting characterized by horst and graben geometries, with uplifted blocks providing the source for Earn Group sediment. New mapping northwest of the Anvil District in central Yukon shows that rift-related coarse-clastic and volcanic rocks of the Earn Group are more extensive than previously indicated. This new mapping also provides additional constraints on the structural framework of the northern Cordillera in the Devonian-Mississippian. Influx of chert-rich clastic rocks beginning in the Middle Devonian occurs throughout east central Yukon and parts of northern British Columbia and is inferred to be a response to rifting of the Yukon-Tanana arc terrane away from the Laurentian continental margin and subsequent opening of the Slide Mountain ocean.

Major rift-related Devonian-Mississippian faults controlled the distribution of syngenetic mineralization. They were later reactivated (or inverted) in the Jurassic-Cretaceous and controlled the emplacement of late Mesozoic intrusions and the distribution of epigenetic mineralization. These compound structures therefore constitute major regional metallogenetic features.

BIRTH OF THE NORTHERN CORDILLERAN OROGEN, AS RECORDED BY DETRITAL ZIRCONS IN JURASSIC SYNOROGENIC STRATA AND REGIONAL EXHUMATION IN YUKON

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The Whitehorse trough (Laberge Group) is an Early to Middle Jurassic marine sedimentary basin that overlaps the Intermontane terranes in the northern Cordillera. Detrital zircon dates from eight Laberge Group sandstones from various parts of the trough all display a major Late Triassic – Early Jurassic peak (220-180 Ma) and a minor peak in the mid-Paleozoic (340-330 Ma), corresponding exactly with known igneous ages from areas surrounding the trough. Source regions generally have Early Jurassic (ca. 200-180 Ma) mica cooling dates and the petrology of metamorphic rocks and Early Jurassic granitoid plutons flanking the trough suggests rapid exhumation during emplacement. These data suggest that subsidence and coarse clastic sedimentation in the trough occurred concurrently with rapid exhumation of the shoulders. Isolated occurrences of sandstone and conglomerate units with similar detrital zircon signatures occur west and east of the trough, as well as overlapping the Cache Creek terrane, indicating that either the trough was once more extensive or isolated basins tapped similar sources. Development of these sedimentary basins and accompanying rapid exhumation in the northern Cordillera are coeval with the onset of orogenic activity in the hinterland of the southern Canadian Cordillera, and subsidence in the western Canada foreland sedimentary basin. The Whitehorse trough is interpreted as a forearc basin that progressively evolved into a collisional, synorogenic piggyback basin developed atop the nascent Cordilleran orogen. Upper Jurassic-Lower Cretaceous fluvial deposits overlapping the Whitehorse trough have detrital zircons that were mainly derived from recycling of the Laberge Group, but also contain zircons exotic to the northern Intermontane terranes that are interpreted to reflect wind-blown detritus from the Late Jurassic-Early Cretaceous magmatic arc developed either atop the approaching Insular terranes to the west or southern Stikinia.

APPLICATION OF X-RAY DIFFRACTION- AND μ RAMAN-BASED GEOTHERMOMETERS TO THE FORMATION FLUID-DERIVED GRAPHITE

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X-ray diffraction (XRD) and μ Raman geothermometers have been established and successfully applied to determining crystallization of graphite formed by metamorphism of sedimentary organic matter. However, neither has been widely applied to fluid-derived graphite deposits (i.e., those in which the graphite has been derived via direct precipitation from CO_2 - CH_4 - H_2O fluids). Such deposits can develop in a wide-range of geological environments, ranging from metamorphic (granulite facies) to igneous (volcanic or plutonic). Our study attempts to apply both the XRD and μ Raman geothermometers to constraining the temperatures of formation related to development of the Albany graphite deposit, near Hearst, Ontario, and to evaluate the limitations of both in this environment of formation. The Albany graphite deposit is comprised of two volcanic vent breccia pipes along the southern margin of the Nagagami River Alkali Rock Complex; it likely developed through the ascent of CO_2 - CH_4 - H_2O -F-bearing fluids that exsolved from alkali magmas.

The XRD graphite geothermometer is based on the systematic variation in lattice parameter for the c-axis (determined from the d-spacing of the {0002} lattice plane), which is inversely proportional to temperature. XRD geothermometry of graphite is best performed on relatively pure separates (>90 modal%) to lessen potential peak overlap(s) of associated phases (e.g., feldspars). The μ Raman geothermometer is based on the peak-area ratio of the first-order (1100–1800 cm^{-1}) D1 to G+D1+D2 peaks, the ratio being inversely proportional to temperature. The G peak (1580 cm^{-1}) corresponds to in-plane vibration of aromatic carbons in the graphite structure, while the D1 and D2 peaks (1350 cm^{-1} and 1620 cm^{-1} , respectively) reflect various defects in the graphite structure.

XRD geothermometry of Albany deposit was conducted on a high purity (99.93% Cg) separate prepared from a 5 tonne bulk sample of the eastern breccia pipe. The separate was doped with NIST 640e (a silica standard) to correct for instrument induced peak offsets. $T_{\text{crystallization}}$ of 574°C was calculated determined and is considered to represent the average $T_{\text{crystallization}}$ for the eastern pipe. Non-corrected samples yield lower and more variable temperatures ranging between 366 and 521°C. The μ Raman method offers the advantage of making in situ temperature determinations; however, the accuracy is strongly influenced by graphite microtexture, crystallite size and orientation. The $T_{\text{crystallization}}$ calculated from the Raman data can vary between 488 and 641°C for aggregates of 20 – 100 μm . While the upper temperature estimates from Raman are in agreement with XRD geothermometry, the observed variation in Raman temperatures illustrates the need for careful selection of crystallites and acquisition of a statistically significant number of spectra.

EXTRUSION OF A RIBBON CONTINENT IN A COLLISIONAL OROGEN: EXAMPLE FROM THE SOUTHEASTERN CHURCHILL PROVINCE IN QUEBEC AND LABRADOR

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The Southeastern Churchill Province records a protracted history of crustal and magmatic accretion between ca. 1.87 and 1.79 Ga, a consequence of convergence between the North Atlantic (Nain) and Superior cratons and an intervening Archean to earliest Paleoproterozoic-age ribbon continent (Core Zone) during formation of the Supercontinent Nuna. Current models infer an early, orthogonal collision between ca. 1.87 and 1.86 Ga between the Core Zone and North Atlantic Craton, resulting in intense tectono-metamorphic overprint of the intervening Lac Lomier complex (continental arc root) and the Tasiuyaq Gneiss (accretionary prism). Subsequently, between ca. 1.83 and 1.79 Ga, the Core Zone/North Atlantic Craton collage collided with the Superior Craton and its marginal supracrustal sequences (Labrador Trough) in what was possibly an early westward thrusting event followed by dextral transpression. An effect of this dextral transpression was the southward crustal extrusion of the Core Zone ribbon continent, accommodated by a network of anastomosing, ductile shear zones, some of which may also be ancient sutures. The shear zones separate crustal domains up to about 100 km wide and hundreds of km long, which appear to be “exotic” to one another, suggesting large amounts of lateral displacement. The inter-shear crustal lenses or slices also contain metamorphic assemblages that indicate progressive lowering of Proterozoic-age metamorphic pressure and temperature conditions towards the south, suggesting bulk asymmetrical extension in that direction (top-down to the south). The overall kinematic framework and distribution of metamorphic facies is consistent with crustal extrusion towards the south (present-day coordinates) and possible continental freeboard in that direction at the time of collision.

MANTLE PETROLOGY, MINERALOGY AND MAJOR ELEMENTS GEOCHEMISTRY OF THE NORTHERN CACHE CREEK TERRANE

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The northern Cache Creek terrane extends for more than 500 km in northern British Columbia and southern Yukon. This composite terrane comprises mafic and ultramafic complexes and carbonate and chert assemblages that have been interpreted by previous workers as components of accreted seamounts, spreading centers and rifted arc complexes. Our observations show that mantle facies are widespread and are generally structurally capped by brecciated hypabyssal and volcanic rocks, most with arc affinities. Mafic and ultramafic cumulates occurrences are rare.

Variably serpentinized mantle rocks were sampled in southern Yukon (Jake's Corner area), and northern B.C. (Atlin, Nahlin area and Dease Lake area). Ultramafic to gabbroic cumulates were found at King Mountain and in the Hardluck peak area. Foliated mantle harzburgite tectonite dominates, typically with 25-35% of porphyroclastic orthopyroxene and subordinate chromite. Orthopyroxenite to rare websterite layers are interpreted to be transposed dykes. Subordinate dunite dykes and pods are common. Where present, gabbroic dykes are consanguineous with overlying volcanics.

Chromite is unzoned, with high Cr# from 32 to 58 and low TiO_2 and NiO contents. Olivine composition varies between Fo_{90} to Fo_{92} in the harzburgite and up to Fo_{94} in the dunite dykes. Enstatite and diopside respectively have Mg# of 91.3-91.6 and 92.9-94.2. They have low Al_2O_3 and Cr_2O_3 contents.

These results suggest a large range in degree of partial melting (18-32%) for these peridotites. Such extensive melting is consistent with the scarcity of clinopyroxene and the low modal proportions of orthopyroxene. The involvement of an arc component during melting is suggested so as to explain the extensive melting. Resemblance between Cache Creek mantle rocks and arc-related mantle rocks supports this hypothesis; as does our data from Cache Creek cumulates, hypabyssal intrusions and volcanic rocks.

THE PIKWITONEI GRANULITE DOMAIN, MANITOBA: A COLLISIONAL OROGENIC ZONE ALONG THE NORTHWESTERN MARGIN OF THE SUPERIOR CRATON

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The Pikwitonei Granulite Domain (PGD) is a zone of Archean granulite-facies rocks located along the northwestern margin of the Superior craton in Manitoba. Consistently high-grade metamorphic rocks are exposed over a length exceeding 300 km with a maximum width of 75 km. The PGD is bounded to the northwest by the Paleoproterozoic Trans-Hudson Orogen while its southeastern boundary is defined by an orthopyroxene-in isograd, which is discordant to the east-trending structures of the adjacent granite-greenstone belts of the northwestern Superior craton.

Metamorphic grades appear to increase westward, away from the orthopyroxene-in isograd. Sapphirine-bearing mineral assemblages have been recognized at Sipiwesik and Partridge Crop lakes with the highest grades estimated for Sipiwesik Lake at 900–950°C and 6.0–8.5 kbar. Uranium-lead dating of metamorphic monazite yielded ages ranging from ca. 2665 to 2580 Ma, which combined with previous U-Pb zircon ages of ca. 2695–2640 Ma, indicates a prolonged period of crustal heating. Metamorphic textures observed in outcrops and thin sections suggest a clockwise P-T path, characteristic of collisional orogenesis.

Whole-rock Sm-Nd isotope geochemistry suggests rocks from the northern and central PGD share affinities to the Hudson Bay terrane, while rocks from the southern PGD share affinities to the Oxford-Stull terrane. This indicates the PGD overprints a major crustal domain boundary and post-dates the ca. 2.72 Ga amalgamation of the Hudson Bay and North Caribou terranes of the northwestern Superior craton. Collision between this accretionary complex and an unknown tectonic entity towards the northwest likely began by ca. 2.70 Ga. Heating of the crust through accretionary processes and magmatism at ca. 2.72 Ga may have resulted in an elevated crustal geothermal gradient which contributed to the widespread high-grade metamorphism during the subsequent collision at ca. 2.70 Ga.

STRUCTURAL EVOLUTION OF THE KENO HILL AG-Pb-ZN MINING DISTRICT, YUKON

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The Keno Hill Ag-Pb-Zn mining district of the central Yukon is described as a Mesozoic fault-controlled, vein-hosted deposit located within deformed and imbricated sedimentary rocks, and Triassic meta-gabbro and meta-diorite of the Selwyn Basin. The district comprises several vein-type, silver-rich, base-metal deposits that are typically hosted in the Mississippian Keno Hill Quartzite between the Tombstone and Robert Service thrusts.

Detailed structural mapping of historic open pit mines and the Bellekeno underground workings, two-dimensional analysis of remotely sensed data, and three-dimensional analysis of borehole data has been completed within the Keno Hill area that provides insight into the structural architecture and tectonic regimes in place during the Mesozoic. Evidence for at least two phases of brittle-ductile deformation are preserved within the district. Early deformation (D_1) associated with thrust faulting produced highly strained and transposed strata and was associated with lower to middle greenschist-grade metamorphism. Two phases of north verging, sub-coaxial, tight to isoclinal, recumbent to rarely upright folds (F_1 and F_2) are observed from micro- to meso-scale and are associated with a protracted episode of D_1 movement along the Robert Service and Tombstone thrusts. F_1 and F_2 folds typically plunge shallowly E-W with fold axial surfaces parallel to the primary regional foliation. The regional foliation is a compositional layering that is an intense S_{1-2} differentiation cleavage formed during D_1 . Joint rotation about F_2 fold axes suggests that folds developed at a high structural level, at relatively low temperatures and high strain. Subsequent to D_1 deformation, rotation of the σ_1 far-field stress from approximately N-S to NE-SW produced oblique sinistral strike-slip faults that are associated with base-metal mineralization, late-stage, antithetic, oblique dextral strike-slip faults, and modification of F_{1-2} fold axes by S-SE plunging, open to locally tight, and polyclinal F_3 folds.

Two-dimensional interpretation of magnetic data shows the area of greatest structural complexity is located proximal to the Bermingham deposit. Fold interference patterns and fault relationships are complex in the Bermingham open pit where a rheological contrast between quartzite, and thick packages of graphite and chlorite-muscovite schist permitted F_3 fold tightening. Structural relationships appear simpler along strike, proximal to the Hector-Calumet deposit. It is thought that the localised structural complexity around the Bermingham deposit may be due to the area's proximity to a regional-scale F_3 fold hinge, whereas the Hector-Calumet deposit is believed to be located on the limb of the regional-scale fold.

DESCRIPTION OF A COLLABORATIVE GROUP VIDEO PROJECT IN A SENIOR LEVEL UNDERGRADUATE IGNEOUS PETROLOGY CLASS

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Modern post-secondary students interact with information in video format much more than the previous generation. Recent studies have shown that students are more likely to look up material on the internet than to ask their professor for help. Footage of volcanic eruptions is easy to find on the internet; however, video clips explaining complex processes of igneous petrology are not. In a third-year igneous petrology class, this issue was overcome by assigning projects to small groups of students, whereby they had to create a video on an assigned topic in igneous petrology. The process involved an initial group contract with expectations and consequences, uploading of the videos to a common website, presentation of the videos and discussion during class time, and peer review of the videos via a survey website. In addition, group members rated each other's contributions in an anonymous peer review. Preliminary qualitative feedback from students indicates that they valued the opportunity to be creative with their videos, and they felt they understood the topics better than following the traditional lecture format. A strong motivator for producing high quality videos was the fact that the videos were presented to the entire class, thus there was a degree of peer acceptance and pride. There were no technical issues with video production during the project. Uploading the videos to a common website had the advantage that the students could watch the videos repeatedly for study purposes. Content from the videos was included on the final lecture exam. Improvement on the group video project for the future could include a more transparent assessment scheme, which details the weighting of factors such as peer review via the web survey, peer assessment by the group members, and instructor ranking. A clear rubric on marking criteria for the videos was lacking. Incorporation of student-created videos into the content of a senior level igneous petrology course gave the students a creative outlet, resulted in the production of videos on advanced topics, helped learners who prefer visual media, and gave the students experience in working in a functional group.

DIAMOND GENESIS AND EVOLUTION IN THE FALC AREA OF THE SASK CRATON

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The Cretaceous Fort à la Corne kimberlites intrude remnant Archean crustal domains in the ~1.9 Ga Trans-Hudson Orogen in Saskatchewan. To assess diamond formation and survival in this unconventional geotectonic setting, diamonds contained in 24 microxenoliths (eclogitic n=23; peridotitic n=1), as well as two polycrystalline diamonds were investigated via FTIR (nitrogen aggregation characteristics) and SIMS (stable isotopes).

The studied diamonds range in size from 0.5 to 3 mm and display a large variety of morphologies and resorption stages. The diamonds cover the full range of N aggregation from Type IaA (poorly aggregated; 9%), through Type IaAB (23%), to Type IaB (fully aggregated, 50%); 18% classify as Type II (nitrogen-free). The N-abundance determined via SIMS varies between 0.1 and 1435 ppm. Nitrogen-based time-averaged (2 Ga) mantle residence temperatures range from 1050 to 1370°C and show a bimodal distribution (modes at ~1100°C and ~1300°C). Mineral exchange thermometry on host xenolith minerals yields overall similar temperatures.

Cathodoluminescence (CL) imaging revealed regular, as well as complex internal zoning in the majority of the diamond population. In addition, CL showed the presence of complex internal textures (irregular thin bands and rims exhibiting low N abundances) in all Type IaB diamonds. These unusual textures may represent diamond brecciation followed by annealing during a subsequent

phase of diamond precipitation from a nitrogen poor fluid. Platelet degradation is observed for the entire diamond suite, and similarly to the complex internal textures, could relate to a short-lived thermal and/or deformation event.

The diamonds document a broad range of $\delta^{13}\text{C}$ (-29.2‰ to -3‰) and $\delta^{15}\text{N}$ (-5.6‰ to +9.4‰) values. Three distinct clusters of $\delta^{13}\text{C}$ values with modes at -4.6‰, -16.4‰, -21.5‰ can be identified. For each of these clusters, decreasing $\delta^{13}\text{C}$ is accompanied by increasing $\delta^{15}\text{N}$, with nitrogen exhibiting a much greater variation than carbon. These trends can be explained by Rayleigh fractionation, which predicts an approximately one order of magnitude larger variation of $\delta^{15}\text{N}$ relative to $\delta^{13}\text{C}$, using published N- and C-isotope diamond–fluid fractionation factors. Alternatively, decoupling of carbon and nitrogen isotopes, or mixing of fluids with different C and N isotope compositions could also produce such trends. Initial modeling, however, favours Rayleigh fractionation during diamond crystallization from CH_4 -bearing fluids.

A MULTIPLY PHASE CORRECTED FOURIER TRANSFORM FOR ENHANCED INTERPRETATION OF EXAFS DATA

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The synchrotron Extended X-ray Absorption Fine Structure (EXAFS) method has wide applications in several fields of Geosciences as well as many other sciences. One key step in the analysis of EXAFS data is to recover a Radial Distribution Function (RDF), which has interpretative values. The RDF is typically extracted through inverse Fourier transformation of the EXAFS spectra. Although the main assumption behind Fourier transformation is that the relevant function can be expanded in a series of sine (and cosine) functions. A quick inspection of the EXAFS equation shows that the EXAFS spectra are expressed not as a series of sine functions, but as a series of phase-shifted sine functions, where there are as many phase functions as scattering paths present in an experiment. In some experiments, there may be up to hundreds of scattering paths (and phase functions) involved in forming a single spectrum. Consequently, standard Fourier analysis of the EXAFS spectra does not yield an exact RDF, but a plot of electron density as a function of some combination of distance and phase shifts. In the context of the standard EXAFS interpretation routine, the spectra can be corrected for the phase shift for only one scattering path, but not all of them. Here, we present a new method for EXAFS interpretation where the spectra can be corrected for the phase shifts of all scattering paths, yielding (in principle) an exact RDF. The new method is no more difficult to implement, and does not make any additional assumptions than the standard EXAFS interpretation routine. Hence, this method should provide an important tool in future analysis and interpretation of synchrotron EXAFS spectra in Geosciences as well as many other sciences. The benefits of this new method for analyzing and interpreting EXAFS spectra will be demonstrated by drawing several examples relevant to the natural sciences.

ENERGETIC CONSTRAINTS ON PLATINUM-GROUP-ELEMENT SPECIATION IN CHROMITE

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The speciation of platinum group elements (PGEs) bears relevance to the development of models for early Earth accretion and evolution as well as the formation of magmatic Ni-Cu-PGE deposits. Enrichments in PGE, in particular IPGE (Ir, Os, Ru) are often spatially associated with spinel group minerals (SGM) such as chromite (FeCr_2O_4). Indeed, models for the origin of magmatic Ni-Cu-PGE

deposits emphasize that SGM play a key role as the dominant hosts for PGEs. The IPGE minerals ($[\text{Os}, \text{Ir}, \text{Ru}]_{\text{S}}\text{S}_2$, Os-Ir-Ru alloys) typically occur as small (<10 μm) alloy inclusions in sub to euhedral chromite grains. While these minerals clearly occur as early formed (high-T) inclusions, questions remain regarding the possibility of the IPGE occurring in solid solution in the SGM. The experimental determination of IPGE speciation is particularly challenging due to the extremely low IPGE concentrations even in highly enriched oxides, whose PGE concentrations lie in the range from ~100ppm-ppb. As a result, of the experimental difficulties, *ab initio* methods are attractive for providing information about PGE speciation in chromite. We have conducted such a study, combining methods based on plane-wave as well as localized basis sets and the PBE and HSE06 range-separated hybrid hamiltonian to provide energetic constraints on IPGE speciation in chromite. To this end, we assess the suitability of IPGE incorporation in chromite by comparing the energetics of the unrestricted-wavefunctions and crystal structures obtained with those extracted from incorporation of other common ions (Mg, Mn, Al, Ti, Ni, Zn) in SGM. We envisage that our study will set the stage for future experimental investigations and provides a novel strategy for quantum computations in highly correlated systems. We expect that incorporation of the IPGE will be most energetically favorable in the octahedral Fe site, however all possibilities are considered. We discuss our results and their implications for understanding IPGE distributions in mafic and ultramafic rocks, in particular chromitites, as well as crystal chemistry of SGM.

MINERAL COMPOSITIONS AS GOVERNED BY SPIN-SPIN INTERACTIONS

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One of the most fundamental question in Mineralogy (and geosciences) is why a mineral crystallizes with a certain composition in a given environment. Naturally occurring minerals are disordered and are often found to crystallize with different compositions as a function of environmental variables (bulk composition, pressure, temperature, volatile fugacities, etc...). Despite this, the physical mechanism responsible for driving the variability of compositions remains elusive. Acquiring an understanding of this mechanism is important for making inferences on the environment of formation of minerals and for predicting the composition of minerals in exotic conditions. Here we present a first attempt at answering this question through a theoretical study of Pentlandite (Pn). Pn presents a case of a perfectly disordered distribution of Fe and Ni, where crystal field forces do not change as a function of composition because electrons form a non-symmetric cloud regardless of composition. This means that the optimal composition of a perfectly disordered mineral must not be controlled by changes in the atomic positions (or crystal field forces), but rather by changes in the exchange interactions. *Ab initio* calculations affirm this statement by showing that the optimal Pn composition yields a minimum in both energy and a quantity which we call normalized magnetization (M^* ($\text{Fe}+\text{Ni})/\text{Fe}$ if M is the total magnetization). For the case in which local order exists in the mineral in question, we expect that the optimal composition will be shifted from the one which yields the lowest normalized magnetization and that the shift is proportional to the degree of ordering.

AUTOMATED INTERPRETATION OF AIRBORNE-ELECTROMAGNETIC DATA FROM PARALLELIZED-PARTICLE-SWARM OPTIMIZATION

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The airborne electromagnetic (AEM) method has a wide variety of applications in the geosciences, including environmental protection and hydrology, mining and oil exploration, as well as geological

mapping, where it provides depth information. However, the interpretation of AEM data is difficult as a result of coupling of the target with a complex transmitter-receiver geometry. AEM surveys often contain hundreds of anomalies, so that practically speaking, the interpretation of single anomalies must be fast and effective. As a result, manual interpretation of AEM data is very challenging, if not impossible. Recently, a method has been published for interpreting AEM data automatically. The new interpretation method is the only one that can be used to recover the geometrical parameters of three dimensional targets embedded in a resistive environment. The method has been proven to be highly effective in the sense that the correct parameters are predicted when tested on thousands of synthetic models and two field examples of real data. However, the method is highly inefficient. This is because it involves minimizing a misfit function through sampling on a uniform grid, over a domain of interest. Here, the wallclock time for running the algorithm is decreased by two orders of magnitude through the use of a parallelized implementation of the particle swarm optimization method. The increased efficiency means that the new method could be used for routine interpretation of very large surveys. The decreased wallclock time also opens the possibility of including a higher level of theory (interaction with an overlying horizontal thin sheet, non-dipolar bodies) so that increasingly complex data could be more accurately interpreted. The new algorithm should thus provide the method of choice for interpreting structural features in resistive environments (such as the Canadian Shield) from AEM data.

APPROXIMATE SEMI-ANALYTICAL SOLUTIONS FOR THE ELECTROMAGNETIC RESPONSE OF A SPHERE INTERACTING WITH CONDUCTIVE OVERBURDEN

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Discrete conductor models have important applications for interpretation of data acquired using electromagnetic geophysical methods. Common models include the plate and sphere, which are commonly used for interpretation of borehole, ground and airborne electromagnetic data. In particular, the free-space discrete conductor model is attractive, due to the ease of computation. However, if the geology can be explained using a background or overburden that is conductive, free-space models may be inappropriate for modeling of electromagnetic data. Techniques exist for calculating the response of a discrete conductor interacting with other conductive bodies, although, these methods are generally based on integral forms of Maxwell's equations, which result in costly numerical implementations that have limited applications for routine use. Here, we develop a theory from which the step and impulse responses of a sphere interacting with conductive overburden can be quickly and efficiently approximated. The resulting expressions are called semi-analytical, as all relevant relations are developed analytically, with the exception of the time-convolution integrals. The overburden is assumed to not be touching the sphere, so there is no galvanic interactions between the bodies. We make use of the dipole sphere in a uniform field approximation, however expressions could be obtained for a sphere in a dipolar (or non-dipolar) field using a similar methodology. We show that there is no term related to the first zero of the relevant Bessel function in the response of the sphere alone. However, there are terms for all other zeros. A test on a synthetic model shows that the combined sphere-overburden response can be reasonably approximated using the first-order perturbation of the overburden field. The discrepancy between the approximate and exact responses are believed to be the result of the thin-sheet approximation and numerical errors. A test on field data obtained at the Reid Mahaffy site in Northern Ontario shows that our approximate method is useful for interpreting electromagnetic data even when the background is thick. We use our approach to obtain a better estimate of the depth of the conductor and evaluate the conductance of the overburden.

VOLCANIC RECONSTRUCTION OF THE PALEOPROTEROZOIC STROUD BRECCIA, SNOW LAKE, MANITOBA: UNDERSTANDING THE TRANSITION FROM PRIMITIVE TO MATURE ARC AND IMPLICATIONS FOR RE-DEFINING THE ORE-FORMING ENVIRONMENT OF THE ANDERSON-STALL-ROD VMS DEPOSITS

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The Stroud Breccia is an ~300 m thick, predominantly felsic interval that conformably overlies primitive arc Welch Basalt of the Anderson Sequence and is conformably overlain by mature arc Snell Basalt of the Chisel Sequence. The basal ~200 m of the Stroud Breccia consists of tuff breccia beds (<1-15 m) containing blocks of both aphyric and quartz-feldspar porphyritic rhyolite in a felsic to intermediate, Fe-stained, tuff matrix, commonly intercalated with finely bedded felsic to intermediate tuff, (<2 m) all consistent with proximity to a rhyolite dome complex. Overlying the felsic breccias is an ~25 m thick unit of predominantly plane-bedded mafic tuff, which is locally sulfide-bearing and seldom shows cross-laminations, scour marks and rip-up clasts. The fine mafic tuffs were emplaced via suspension sedimentation (non-erosive) and mass flow (erosive). A strongly quartz porphyritic (0.5 -1.5 cm) felsic breccia, with a thickness of ~20 m conformably overlies the mafic tuff. Along strike an aphyric rhyolite dome with associated flow top breccia occurs. Over-steepening/collapse of the rhyolite dome is interpreted to be the source of the aphyric rhyolite blocks within the felsic breccia, which were re-deposited by mass flows. Both the rhyolite dome and coarse felsic breccia are overlain by fine mafic and felsic tuff, which are conformably overlain by the Snell Basalt.

Along strike of the map area the Stroud Breccia interval is represented by a 1-5 m thick, finely layered, sulfidic, mixed argillite chert known as the "Foot-Mud Horizon", and a 1-2 m thick felsic tuff and rhyolite dome complexes at the Anderson-Stall-Rod volcanogenic massive sulfide deposits (10.1 million tonnes of ore with an average grade of 4.15% Cu, 0.53% Zn and 1.5 g/t Au). Previous workers have interpreted the Stroud Breccia to result from uplift and erosion of the Anderson Sequence and synvolcanic Sneath Lake Pluton, placing it at the base of the Chisel Sequence, above the "Foot-Mud Horizon" and the Anderson-Stall-Rod ore interval. Our work indicates the Stroud Breccia formed during incipient rifting of the primitive arc Anderson Sequence, concomitant subsidence, rhyolitic and lesser mafic volcanism, and VMS formation before renewed mafic volcanism of the mature arc Chisel Sequence. The Stroud Breccia interval represents a change from primitive arc to mature arc volcanism, and it is also the time-stratigraphic equivalent of the Anderson-Stall-Rod ore interval.

PETROLEUM RESOURCE POTENTIAL OF THE ARCTIC CANADA BASIN

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The Canada Basin underlies the continental slope, rise and abyssal plain of the Arctic Ocean, adjacent to the continental margins of northwest Canada and northern Alaska. Seismic reflection and refraction data indicate the basin contains thick sections of Mesozoic syn-rift and Late Mesozoic-Cenozoic post-rift sediments overlying rifted continental and oceanic crust. Northern and southern margins of the basin developed in volcanic and non-volcanic rift settings, respectively. The post-rift Cenozoic sedimentary section contains numerous structural and stratigraphic features that could form hydrocarbon traps, including fault blocks, anticlines, drape folds and facies changes. Potential reservoir rocks include sandstones and siltstones in submarine-fan channels, lobes and sheets, and sandy mass transport deposits. Good quality reservoirs occur in Tertiary deepwater sandstones penetrated by wells in the adjacent Canadian Beaufort-Mackenzie Basin. Potential hydrocarbon source rocks include Jurassic, Upper Cretaceous and middle Tertiary marine shales. Subsidence and thermal history models indicate good potential for oil and gas generation at burial

depths predicted in the basin. Seismic hydrocarbon indicators interpreted in reflection profiles appear to provide evidence of active petroleum systems. Resource evaluations based on global basin analogue data and regional play assessments indicate the Canada Basin has significant petroleum potential.

AEROMAGNETIC OBSERVATIONS RELEVANT TO BEDROCK GEOLOGY AND TECTONICS IN THE TAYLOR MOUNTAIN BATHOLITH REGION, EAST-CENTRAL ALASKA

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Aeromagnetic data provide important constraints on bedrock geology, particularly in regions with strong magnetic property contrasts across adjacent or juxtaposed rock units. Here, we note several fundamental observations of aeromagnetic anomaly character in the region surrounding the Taylor Mountain batholith in east-central Alaska. Aeromagnetic surveys with 400-500 m line spacing were flown in the region in 1998, 2007, and 2015, and the resulting data have recently been digitally merged into one dataset useful for geologic interpretation. The geology in this region is very poorly exposed, but is nonetheless critical to understanding the separate and shared tectonic histories of the allochthonous Yukon-Tanana terrane and parautochthonous North American basement (NAb). The Pre-Late Devonian Lake George assemblage, composed of metaigneous and metasedimentary rocks, is locally representative of the NAb, and is observed to be generally weakly magnetized. The Late Devonian to Early Mississippian Fortymile River assemblage and the enigmatic Mid-Mississippian Chicken Metamorphic Complex, volumetrically dominated by metaigneous and some metasedimentary rocks, are locally representative of the Yukon-Tanana terrane and are also observed to be generally weakly magnetized. However, an aeromagnetic lineament lies along the contact between the Fortymile River assemblage and the Chicken metamorphic complex. The allochthonous Paleozoic assemblages are intruded by generally strongly magnetized Triassic plutons, including the Taylor Mountain batholith. In many places the Triassic plutons are observed to have sharp magnetic contacts with country rocks, and with hypothesized fault zones. Assemblages of the Yukon-Tanana terrane are inferred to be in structural contact with the Lake George assemblage across a low-angle ductile detachment projecting east and south of the Taylor Mountain batholith. A prominent aeromagnetic lineament continues along this trend at least an additional 60 km to the west. The nature of this geologic and geophysical anomaly as a major detachment and/or terrane boundary is poorly understood. The lineament is near, but not necessarily coincident with, the southern margin of the batholith. Other notable aeromagnetic lineaments lie along the northeast trending Kechumstuk and Sixtymile fault zones. Tertiary intrusive and volcanic rocks are observed to be generally strongly magnetized, and some of the volcanic rocks are reversely magnetized.

BASALT PETROLOGY AND TECTONIC CONTEXT FOR THE LALOR Zn-Au-Cu-Ag-Pb VMS DEPOSIT, SNOW LAKE CAMP, MANITOBA

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The Lalor Mine, operated by Hudbay Minerals, is located in the Snow Lake mining camp, in northern Manitoba. Rocks of the Snow Lake camp are part of the Flin Flon Glennie Complex. Lalor is the largest volcanogenic massive sulphide (VMS) in the Snow Lake camp, and is significantly enriched in gold. It was emplaced in a submarine volcanic arc setting (Chisel Sequence) during the Paleoproterozoic.

The host rocks have undergone amphibolite facies metamorphism and several phases of deformation. Furthermore, the Lalor footwall rocks are highly altered due to hydrothermal activity responsible for the formation of the deposit. The changes experienced by rocks in response to alteration and subsequent metamorphism place constraints on the use and analysis of geochemical data.

The current MSc project at INRS-ETE aims to characterize the geochemistry and petrogenetic evolution of the Lalor host rocks. This project complements a study by Caté et al. on the architecture, volcanology, hydrothermal alteration, and metamorphic and structural evolution of the Lalor deposit. Eleven lithological groups with tholeiitic to calc-alkaline affinities were recognized from immobile elements ratios such as Zr/Ti or Nb/Yb and on extended trace elements diagrams. The results presented here focus mostly on two basalts, M1 (Moore basalt) located in the footwall and immediate hanging wall and M3 (Threehouse basalt) in the hanging wall. M1 has a more calc-alkaline affinity whereas M3 has a tholeiitic to transitional affinity.

Geochemical diagrams show a greater fractionation of rare earth elements (REE) in Snow Lake than in the rest of the Flin Flon belt. This may possibly be due to contamination of the arc magmas by existing continental crust, a process which may also have influenced the metal budget (e.g., gold enrichment) at Lalor. To test this hypothesis, geochemical modeling based on assimilation and fractional crystallization (AFC) is underway in order to determine the possible source (s) of basalts and their petrogenetic evolution.

KEY U-Pb GEOCHRONOLOGIC AND ISOTOPIC MILESTONES IN DECIPHERING THE PALEOZOIC TECTONOMAGMATIC AND METALLOGENIC HISTORY OF EAST-CENTRAL ALASKA AND WESTERN YUKON

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Zircon geochronology and Pb isotopic studies of metamorphic rocks of eastern Alaska and western Yukon have been instrumental in understanding the tectonomagmatic and metallogenic evolution of the pericratonic terranes of the ancient Pacific margin. Key discoveries include: 1) Discordant U-Pb ages for zircon fractions from augen orthogneisses in Yukon, reported by Tempelman-Kluit and Wanless in the early 1980s and in 1986–1990 by Mortensen, established Late Devonian–Early Mississippian and Permian plutonism in the Yukon–Tanana terrane (YTT) that was not present in the adjacent North American continental margin. These ages were interpreted to support an allochthonous (rifted) YTT origin. Also in the early 1980s, Aleinikoff and Dusel-Bacon obtained U-Pb discordia for augen gneiss bodies in east-central Alaska with intercepts suggesting Mississippian intrusion with Proterozoic inheritance. 2) Subsequent dating of single zircons from metaigneous rocks in Alaska in the early 2000's by Wooden, Williams, and Aleinikoff using SHRIMP, and in Canada by Mortensen and Gehrels, among others, employing TIMS, together documented prolonged arc magmatism along the continental margin from ~372 to ~340 Ma. The older ages were restricted to rocks interpreted by Dusel-Bacon and coworkers as lower plate parautochthonous North America, with the younger ages characteristic of upper plate allochthonous YTT. 3) A 111 ± 2 Ma U-Pb SHRIMP age of zircon rims by Wooden established the igneous crystallization age for an Alaskan orthogneiss, previously erroneously interpreted by others as Neoproterozoic based on an upper intercept age for zircon fractions. 4) Single grain U-Pb dating, starting in the 1990s, established characteristic Archean and Proterozoic "barcodes" for detrital zircons from the Yukon–Tanana region. 5) Mortensen's U-Pb zircon ages from thin layers of muscovite schist (metatuff) within carbonaceous schist in VMS and SEDEX host rocks and sulfide Pb isotopes, reported in 2006, defined Late Devonian–Early Mississippian and Permian episodes of syngenetic base-metal mineralization. 6) Hansen's 1990 tectonic model for eastern Alaska, continuing to 2006 in papers by Dusel-Bacon and others, employed U-Pb and Ar-Ar geochronology, geochemistry, thermobarometry, and kinematic data to suggest

a Paleozoic–early Mesozoic contractional and a mid-Cretaceous extensional history involving parautochthonous and allochthonous components in the Yukon–Tanana Upland; comparable structures were reported in Yukon by Staples and others in 2013. 7) Permian U–Pb zircon crystallization ages reported by Beranek and Mortensen in 2011 established the Klondike orogeny and arc magmatism; detrital zircon ages from Triassic sedimentary rocks suggest collision of the arc by Middle Triassic.

GEO-CHRONOLOGY OF THE LITTLE JOHN SITE (KdVo-6), A MULTI-COMPONENT HUMAN OCCUPATION IN EASTERN BERINGIA, YUKON TERRITORY, CANADA

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New AMS radio-carbon dates derived from culturally modified bone and charred material in association with artifacts has expanded our appreciation of the antiquity and continuity of occupation at the Little John site, from the early Bolling-Allerod in the Late Pleistocene post-glacial period through the Early and Later Holocene. These new dates, combined with dates from other local sites on the Yukon – Alaska borderlands, allow us to identify a number of discrete chrono-zones at Little John that can be related to, and increase our understanding of, regional vegetation and climate history, major Climate Events, and cultural complexes identified elsewhere in Eastern Beringia. In this paper we present a brief overview of the Little John site and the most recent developed chronology that currently guides our continued excavations and analyses, with a particular attention to component assignment to Alaskan and Yukon Archaeological Cultures.

PHANEROZOIC CONSTRAINTS ON OLDER PLATE MOTIONS AND RECONSTRUCTIONS

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Precambrian plate reconstructions are often ambiguous and constrained by sparse data. Younger, Cenozoic to Mesozoic plate motions may, in some cases provide additional constraints for the older reconstructions. Examples include the pre-Atlantic position of Baltic crustal blocks relative to Greenland and Laurentia; the Jan Mayan microcontinent fragment; Rockall Bank fragments and various crustal blocks linked to South America, Antarctica and India.

Plate motions north and south of the Agulhas – Falklands/Malvinas fracture zone are very different, requiring that southern Patagonia moved independently relative to the rest of South America during Gondwana breakup. This has major implications for Gondwana reconstructions and also affects Rodinia models. Other Cenozoic oceanic features further constrain reconstructions of Gondwana which have not previously been implemented other than at local scale.

OVERVIEW OF THE SLAVE PROVINCE SURFICIAL MATERIALS AND PERMAFROST STUDY

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Historically, in the Northwest Territories' Slave Geological Province (SGP), diamond exploration has consisted of surficial-sediment sampling for kimberlite indicator minerals followed by geophysics.

Such exploration was often performed without a thorough understanding of the region's complex glacial history. Diamond exploration is become increasingly challenged with elusive targets under cover or complex dispersal patterns from unknown sources.

A better understanding of surficial geology in the SGP is being obtained through the Slave Province Surficial Materials and Permafrost Study – a Northwest Territories Geological Survey (NTGS) led government-academic-industry research program. This study will improve the understanding of glacial processes in the SGP, develop innovative exploration methods and will provide regional geoscience data to encourage economic development. The work for this study was carried out in 2015 (data analysis is ongoing), on NTS map sheets 76C and 76D.

Key outcomes include:

- A 3D indicator mineral and till geochemistry database from 235 boreholes and 1131 samples collected from over 50 sites.
- Approximately 2500 km² of field mapping at various scales.
- A 3D geological model of the DO-27 dispersal train based on 94 boreholes and field mapping.
- A study of glacial landforms in erosional corridors based on mapping, sampling, GPR and LiDAR data.
- A study of eskers as mineral exploration tools based on field mapping, sampling, drilling and extensive GPR coverage.
- A comparative study of the Monument and Coppermine indicator trains based on 53 boreholes, field mapping, and remote sensing.
- A case study using various geophysical methods to determine depth to bedrock.
- A case study of geochemical and soil gas signature of the DO-18 kimberlite.
- Compilation and analyses of existing public data.
- Large network of thermistors for permafrost monitoring.

Study collaborators include Dominion Diamond Corporation (DDC), Diavik Diamond Mines Inc. (DDMI), North Arrow Minerals Inc. (NAMI), Peregrine Explorations Ltd., Arctic Star Exploration Corp., New Nadina Exploration Ltd, researchers and graduate students from the University of Waterloo, Simon Fraser University, Carleton University and the University of British Columbia. The Canadian Mining Industry Research Organization (CAMIRO) provided strategic planning and project guidance services. Drilling, geophysical surveys and logistics were carried out by Aurora Geoscience Limited.

CanNor provided funding for this study through its Strategic Initiatives in Northern Economic Development program. The data have been supplemented by the donation of indicator mineral and remote sensing databases from DDC and DDMI and data from the DDC / NAMI Lac de Gras overburden drilling program. Logistical assistance was generously provided by DDC.

AN INTEGRATED VIEW OF TECTONICS IN THE NORTH PACIFIC DERIVED FROM GPS

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The idea that the tectonics of the northeastern Pacific is defined by relatively discrete deformation along the boundary between the Pacific and North American plates has given way to a picture of broadly distributed deformation. This is in part due to a number of studies and initiatives in recent years that have greatly expanded the density of GPS data throughout the region. We present an updated GPS velocity field for Alaska and northwestern Canada as well as a new, integrated tectonic block model for the region.

Rather than discrete plate boundaries, we observe zones of concentrated deformation where the majority of the relative plate motion is accommodated. Within these zones, there are major fault systems, such as the Fairweather-Queen Charlotte transform and the Aleutian megathrust, where most of the deformation occurs along a main structure, but often motion is instead partitioned across multiple faults, such as the fold-and-thrust belt of the eastern St. Elias orogen. Strain is transferred far inboard, either by diffuse deformation or along fault systems such as the Denali fault, and outboard of the main zones of deformation. The upper plate, if it can be called such, consists of a number of blocks and deforming zones with particularly complex deformation surrounding the collisional front of the Yakutat block with southern Alaska.

TRACKING LOW TEMPERATURE TECTONISM OF THE ST. LAWRENCE PLATFORM AND HUMBER ZONE, NORTHWEST APPALACHIANS THROUGH APATITE AND ZIRCON (U-Th)/He THERMOCHRONOLOGY

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The St. Lawrence Platform (SLP) and Humber Zone (HZ) of the northwestern Appalachians has historically been explored as a potential hydrocarbon reservoir. Previous and extensive vitrinite reflectance studies on the basin resolved the degree of thermal maturation yet the timing of the thermal maximum is not well understood. Determining the timing of such low temperature events can allow for a better understanding of the shallow crustal processes that may have allowed for the generation and entrapment of oil and gas. We have employed apatite (A_{He}) and zircon (Z_{He}) (U-Th)/He thermochronometry across a network of late Cambrian to late Ordovician siliciclastic and Grenvillian basement samples (where apatite and zircon cannot be recovered in adjacent sedimentary cover) in order to resolve the history within the ~210-40°C window. Single crystal dates from individual samples show age dispersion by as much as 300 m.y. with a strong positive to negative correlation with increasing eU concentration. A similar positive correlation can be observed when significant intra-sample grain size variation is present. A_{He} and Z_{He} data in the southwestern portion of the basin, near Montreal, allow for thermal maximums of up to 200°C to occur either during the middle Ordovician, as a result of the Taconic orogeny, or from the continued sedimentation into the Devonian as a result of the Acadian orogeny. Maximum heating is followed by a protracted cooling through the Z_{He} partial retention zone (PRZ) into the late Jurassic and early Cretaceous where the cooling rate increases by an order of magnitude through the A_{He} PRZ until ca. 100 Ma. The timing of this increased cooling slightly precedes the passage of the Great Meteor Hot Spot through the area; the cooling may be a result of increased erosion from thermal doming. In contrast, the Grenville basement in the northern most portion of the SLP records A_{He} cooling much earlier, by ca. 200 Ma. Within the HZ, both the external and internal sections experienced rapid cooling through the Silurian after a Taconic thermal maximum. The timing of relatively rapid cooling coincides with documented normal faulting and back-thrusting in the orogen, which is the likely cause of exhumation. The HZ witnessed protracted cooling through the late Jurassic, when there is a one order of magnitude increase in cooling rate until surface temperatures are reached. This increased recognition of these low temperature events has augmented our understanding of the evolution of accretionary orogens and consequently reduce the risks associated with oil and gas exploration.

EARLY PLEISTOCENE GLACIATION AND IMPLICATIONS FOR PLACER GOLD DEPOSITS IN THE MOUNT NANSEN AREA, YUKON

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Yukon has over a century of placer mining history, predominately focused in non-glaciated regions. However, as these deposits are exploited, exploration is targeting more complex landscapes where glaciation has buried, eroded and incorporated placer gold. This study examines how placer gold deposits were influenced by early Pleistocene glaciation in the Mount Nansen area, central Yukon.

Detailed stratigraphic and sedimentological analysis, completed during the 2015 field season, has allowed for identification of three economic phases of placer gold development (pre-glacial, inter-glacial, and post-glacial deposits). Paleomagnetic dating, tephrochronology, and AMS radiocarbon dating provide chronological control. Two glaciations were identified, and one was magnetically reversed (>780 ka). The oldest glaciation may be as much as 2.6 Ma and advanced over a pre-glacial highly weathered surface. Early Pleistocene interglacial gravels were also identified.

Placer gold characterization has been used to identify several gold sources contributing to the placer gold deposits in the Mount Nansen area. Gold grain samples were collected from fluvial gravels representing each phase of placer gold development. To characterize the gold grain morphology SEM images of each grain were analyzed with Scanning Probe Image Processor (SPIP) software. Gold grain morphology highlights variable provenance and transport histories. Laser ablation ICP-MS analysis was used to characterize gold grain trace element compositions. This indicates that most gold grains in the region are sourced from porphyry gold deposits, with minor inputs from epithermal gold deposits.

This study suggests that glaciation can erode, preserve or can generate new 'false bedrock' surfaces that allow for placer gold concentration. The effects of glaciation on placer gold deposit character are controlled by bedrock topography, valley orientation and glacial dynamics. A placer gold development model describing the relationship between placer gold deposits and glacial/interglacial cycles is proposed. While this model is tailored to the Mount Nansen area it could be used as an analogue throughout the glaciated fringe of Yukon. This project highlights that placer gold deposits buried beneath thick till may be common in Yukon.

LITHOFACIES AND ALTERATION OF THE HURRICANE ZONE OF THE BOOMERANG MASSIVE SULPHIDE (VMS) DEPOSIT, TULKS BELT, CENTRAL NEWFOUNDLAND, CANADA

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The Hurricane Zone of the Boomerang volcanogenic massive sulphide (VMS) deposit is part of the Cambro-Ordovician Tulk's Belt, host to numerous VMS deposits. The Hurricane zone is one of three lenses in the deposit and consists of a sub-horizontal (semi-) massive sulphide lens, with combined reserves and resources of 55,100 tons, at an average grade of 13.4% Zn, 7.0% Pb, 1.20% Cu, 159.0 g/t Ag, and 2.00 g/t Au. It is hosted in intermediate to felsic volcanoclastic rocks of the ca. 488 Ma Pats Pond Group (Victoria Lake Supergroup), which is part of a structurally complex, composite collection of Cambro-Ordovician arc-related volcanic and sedimentary rocks.

Preliminary field observations and lithogeochemical results revealed three distinct stratigraphic packages: the (1) hanging wall, (2) mineralized zone, and (3) footwall. The footwall predominantly consists of felsic to intermediate intercalated quartz-bearing crystal tuff and lapilli tuff. The hanging wall consists of felsic to intermediate volcanoclastic rocks, including aphyric to quartz/plagioclase-bearing

tuff, lapilli tuff and breccias, locally intercalated and graded with sedimentary rocks. Two generations of mafic dykes and sills intrude the entire stratigraphic package. The mineralized zone occurs at the footwall-hanging wall interface and consists of (semi-)massive sulphide with fine- to medium-grained bands of red and yellow sphalerite, pyrite and galena with coarse blebs of chalcopyrite. The mineralized zone shows evidence of subseafloor replacement-style mineralization by: (1) the presence of relict quartz crystals in the massive sulphide; and (2) chlorite/sericite replacement of the fine-grained matrix in lapilli tuff. The footwall rocks contain three dominant alteration assemblages, including: chlorite-carbonate, sericite-quartz \pm pyrite, and sericite-chlorite-pyrite.

Lithogeochemistry of samples show the footwall appears to have a strong depletion in Na_2O and an enrichment in Fe_2O_3 - MgO - K_2O -Ba, base metals, and volatiles metals (e.g., Zn, Pb, Cu, Hg). Immobile element systematics of felsic to intermediate rocks within the entire stratigraphic package have subalkaline, tholeiitic to transitional ($2 \leq \text{Zr/Y} \leq 7$) affinities, and are characterized by slightly enriched LREE, flat HREE, and negative anomalies in Nb, Eu, and Ti on primitive normalized plots.

The Hurricane Zone shares stratigraphic and lithogeochemical similarities with the rest of the Boomerang deposit and based on our preliminary results, is interpreted to represent a replacement-style zone to have formed in a back-arc rift basin, adjacent to a volcanic arc, allowing synchronous deposition of volcanogenic sediments. This study is a contribution to the understanding of replacement-style VMS mineralization in volcanoclastic-rich environments.

CENOZOIC EVOLUTION OF ROCK EXHUMATION PATTERN AT THE YAKUTAT-NORTH AMERICAN COLLISION ZONE

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The high mountainous topography of southeast Alaska and southwest Yukon is the result of the ongoing oblique subduction and collision of the Yakutat microplate with the North American Plate. Of particular interest is the region of the St. Elias syntaxis that formed at the eastern corner of the indenting Yakutat microplate. In this region, the strike-slip motion along the dextral Yakutat plate boundary (Fairweather Fault) changes to convergence in a structurally complex pattern that is largely unknown. Numerical modeling studies suggest strain concentration accompanied by high vertical uplift focused in the syntaxis region, and partitioning of strain that is partially transferred farther inboard in the North American Plate. Observational data testing these predictions are limited due to the fact that the St. Elias syntaxis region is characterized by the highest mountain peaks in the areas including Mt. Logan and Mt. St. Elias (>5500 m), and is heavily glaciated comprising the Hubbard Glacier and the Seward-Malaspina Glacier.

Surface uplift combined with erosion results in the exhumation of rocks from deeper crustal levels, which can be quantified by thermochronology. In particular, detrital thermochronology of sediments derived from glaciers has been successful for investigating the spatial and temporal pattern of exhumation in the St. Elias Mountains. Here we present new detrital apatite and zircon fission track data from glaciers draining the northern side of the St. Elias syntaxis (SW Yukon) as well as new bedrock data from the ice-free mountain ridges of the syntaxis. Integrating the new data with previously published thermochronometric data and other geologic and geophysical observations reveal the deformation and thermal history of the different terranes that have been accreted to the North American margin since the late Mesozoic, and the evolution of the localized exhumation at the St. Elias syntaxis in the context of the ongoing Yakutat collision. Our results indicate a migrating focus of the most rapid exhumation from north to south and from the upper (North American Plate) to the lower (Yakutat microplate) plate in the syntaxis region over the past ~10 Myr. This

exhumation pattern is accommodated by an evolving positive, two-sided flower structure that resulted temporarily in localized deep-seated rock exhumation.

POTENTIAL FIELD AND STRUCTURAL ANALYSIS OF THE HOWLEY BASIN, WESTERN NEWFOUNDLAND

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The Howley Basin, part of the composite Maritimes Basin, is a Carboniferous terrestrial, fault-bounded basin, located in western Newfoundland. High-yielding source rocks, thick reservoir rocks, and occurrences of coal and migrated oil along the basin margins, suggest that the Howley Basin is prospective for hydrocarbon exploration. However, the basin is overlain by thick glacial till and a large lake; sparse exposures of bedrock and shallow drilling are limited to basin margins, and previous ground-based gravity surveys were unable to occupy the central region of the basin (over the lake), providing few constraints for interpretations of its internal stratigraphy and structure. As part of Nalcor's Petroleum Exploration Enhancement Project, a detailed mapping project and a gravity survey were conducted to document structures on the basin margins and augment existing gravity datasets.

Structural evidence suggests complex and protracted displacement along branching strike-slip fault systems caused subsidence and deformation in the Howley Basin throughout the Carboniferous. All Carboniferous units show late stage transpressional expressions that obscure earlier extensional structures. Along the western margin of the basin, a NNE trending ridge of tightly folded Anguille Group (Tournaisian) produces fold axes oblique to master faults, suggesting dextral transpressional deformation. On the SE flank of this ridge, inferred NE trending right-stepping splays between master faults bring fault panels of Deer Lake Group Formation (Viséan) and Howley Formation (Westphalian) to surface. Because of contractional structures in the Deer Lake Group panels, and the relative orientation of splays to master faults, these fault panels are interpreted as a strike-slip duplex of R Shears, requiring a localized phase of sinistral transpression post Deer Lake Group deposition. On the eastern margin of the basin, steep beds and fold axes orientations within the Howley Formation suggest dextral transpressional deformation post Howley deposition.

Gravity surveying concentrated on filling in voids in previous surveys and increasing the density of gravity stations in areas of interest. To fill in the large void over the lake, a Ground Penetrating Radar survey was run in conjunction with the gravity survey over its frozen surface, to map its bathymetry and remove the effects of the water column on gravity readings. Newly constrained 2 $\frac{3}{4}$ D forward models of recently acquired high-resolution aeromagnetic data and the new gravity database show that known source rocks, and/or distal organic-rich lacustrine facies of marginal alluvial beds, likely have been buried to within the oil window.

U-Pb AGE AND Hf ISOTOPE GEOCHEMISTRY OF DETRITAL ZIRCON FROM CAMBRIAN SANDSTONES OF SEVERNAYA ZEMLYA ARCHIPELAGO AND NORTHERN TAIMYR (RUSSIAN HIGH ARCTIC) – IMPLICATION TO EVOLUTION OF TIMANIAN OROGEN AND EASTERN PART OF BALTICA

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The Severnaya Zemlya archipelago, northern part of the Taimyr Peninsula and northern Kara Shelf comprise the Kara Terrane. Zonenshain et al. (1990) suggest that the Kara terrane was part of a continent block called Arctida, Lorenz et al. 2008 described

it as a marginal part of Baltica, whilst many other researchers suggest it existed as an independent terrane (Bogdanov et al., 1998; Gramberg & Ushakov, 2000; Metelkin et al., 2005). Here we present new data on U–Pb age and Hf isotope geochemistry of detrital zircon from the oldest strata outcropped across the Kara terrane (Bol'shevik Island, Izvestiya Zik Islands and western part of Northern Taimyr). Previous studies led to the assumption that sampled strata are mainly deformed Proterozoic rock (Markovsky et al., 1999).

The detrital zircon signatures of all dated samples are similar. Archean and Paleoproterozoic grains comprise from 5 to 10 % of the total population and do not form significant peaks. Mesoproterozoic grains contribute 6–21% from peaks at ca 1170, 1190, 1470, 1560, 1610 Ma. Neoproterozoic grains comprise from 55% to 72 % of the zircon population and their ages group at ca 650, 630, 600 and 560 Ma. The Early 8–30% with main peaks at ca 530 and 520 Ma. The youngest DZ peaks within all studied samples vary from Early to Late Cambrian, that pointing on absence of Proterozoic rocks across the Kara Terrane. The age distribution of the main detrital zircon peaks of studied samples matches with the accretional history of Timanian orogen.

Hf isotopic analyses were acquired on detrital zircons with ages between earliest Paleozoic to Neoproterozoic. Cambrian detrital zircons yield a wide range of $\epsilon\text{Hf}(t)$ values from -6 to $+14$. The Early Neoproterozoic zircons (542–700 Ma) show $\epsilon\text{Hf}(t)$ values between $+14$ and -26 . The Late Neoproterozoic cluster of detrital zircon (935–1000 Ma) show narrow range of $\epsilon\text{Hf}(t)$ values -5 to $+4$. Positive $\epsilon\text{Hf}(t)$ values are generally observed for Mesoproterozoic and Paleoproterozoic zircons. The wide range of ϵHf values from positive to strongly negative values observed in the Cambrian–Neoproterozoic population of detrital zircons indicates the presence both juvenile and crustal contaminated zircons. Thus, data presented here show that the Kara terrane in Cambrian was sourced directly from the Timanian Orogen and it located on eastern part of Baltica. Hf data point on wide-spread in Timanian Orogen subduction-related magmatism typical for continental arc.

GEOCHRONOLOGY OF THE GATAGA VOLCANICS OF BRITISH COLUMBIA AND IMPLICATIONS FOR CRYOGENIAN GLACIATION AND RIFTING

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The Cryogenian Gataga Volcanics are exposed at Gataga Mountain in the Kechika Trough of northern British Columbia. A previous study reported a bulk fraction U/Pb TIMS age of 689.1 ± 4.6 Ma from a rhyolite within the Gataga Volcanics. This age has been cited as a constraint on rift-related magmatism on the western margin of Laurentia, and, along with recent age constraints on the Sturtian glaciation (716.5–662.4 Ma), suggests that these volcanics were erupted during glaciation; however, no glacial deposits were previously identified. At Gataga Mountain, three informal sequences are exposed; a basal quartzite, the Gataga volcanics, and an overlying mixed carbonate-siliciclastic succession. We have analyzed detrital zircon geochronological data from the basal quartzite, U/Pb single grain zircon TIMS ages from units throughout the volcanics, carbon isotope chemostratigraphic data from the overlying carbonates, and have updated the stratigraphic and mapping relationships to better understand the tectonic evolution of the western margin of Laurentia during the breakup of Rodinia. The basal quartzite is dominated by cross-bedded sandstone and includes a horizon with mud-cracks, indicative of non-glacial deposition. The overlying Gataga Volcanics are over one kilometer thick, comprising both mafic and felsic units and with volcanoclastic breccia common throughout, additionally, iron formation was identified near the base. We also identified matrix-supported diamictite units with cosmopolitan clasts. These

features suggest that the Gataga Volcanics could have erupted in a sub-glacial environment; however, we acknowledge the difficulty of distinguishing sub-glacial from sub-aqueous explosive volcanic facies. Overlying the Gataga Volcanics, the mixed carbonate-siliciclastic succession contains minor basalt that is geochemically distinct. Based on chemostratigraphic and lithostratigraphic similarities, we suggest that this sequence be correlated with Ediacaran strata to the north. We interpret the cosmopolitan clasts, diamictite and dropstones within the Gataga Volcanics as representing sub-glacial volcanism during the ~55 Myr long Sturtian Glaciation. Additionally, we suggest that the stratigraphy at Gataga Mountain records two episodes of extension, the first indicated by the Neoproterozoic Gataga volcanics and the second by the overlying Ediacaran carbonate-siliciclastic succession with interfingering basalt.

THE ROLE OF A GEOSCIENTIST IN TRAINING PROGRAM IN THE ADVANCEMENT OF A GEOLOGIST'S CAREER AND DEVELOPMENT OF THE GEOSCIENCE PROFESSION

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Upon completion of a bachelor's degree, most Canadian graduates are faced with the prospect of documenting at least four years of geoscience work experience before they are eligible to register with the profession. During this period, geoscientists (geologists, geophysicists or environmental geoscientists) can sign up for the Geoscientist-in-Training ("GIT") program with one of the professional associations that are responsible for the self-regulation of geoscience practice across Canada. These programs can also be useful for non-Canadian geoscientists acquiring the work experience in a Canadian setting required as specified in the Geoscience Knowledge and Experience Requirements for Professional Registration in Canada.

The purpose of the Geoscientist-in-Training Program for the candidate is to aid career development from completion of academic requirements to the point when they have sufficient on-the-job geoscience work experience to be considered for professional licensure and independent practice. While the details at each association may vary, the Geoscientist-in-Training Program is structured to help individuals meet geoscience work experience requirements and develop and demonstrate knowledge of professionalism and ethics. It also helps build an understanding of relationships critical in a professional career - such as relationships with other geoscientists, other professions, with the employer and/or clients, with the greater geoscience community, and with society.

While the Geoscientist-in-Training Program contributes to the building of key relationships in different ways, it is through participation that the GIT becomes the driving force behind his or her own success. The value of the GIT Program to the individual is the guidance provided to help ensure that quality experience is obtained, professionalism and ethics are developed, and licensure is achieved as seamlessly as possible. The program also introduces the concept of lifelong learning to maintain and demonstrate professional competence; it also emphasizes the importance of self-regulation.

The presentation will examine the components of such a program and discuss the benefits to the profession.

AN OUT-OF-PHASE LATE PLEISTOCENE MARINE TRANSGRESSION ALONG THE BEAUFORT SEA COAST?

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In northern Alaska, coastal deposits thought to be last interglacial in age and now 5–10 m above modern sea level form a semi-continuous barrier island system running 200 km across the

Beaufort Sea coastal plain. Limited work has been conducted on reconstructing the paleoenvironment along this coast during the Late Pleistocene, and existing chronologies are based on amino acid racemization, a dating method which relies on assumptions about the temperature history of the shell material being analyzed. Here we present a new optically stimulated luminescence (OSL) chronology and paleoenvironmental reconstruction for a late Pleistocene marine transgression recorded along Teshekpuk Lake's northern shore, 15 km south of the Beaufort Sea coast in Alaska. Our sections show that at 113 ± 18 ka (thousands of years ago) a shift from massive clay (Unit 1) to sandy tidal flat deposits (Unit 2) lying ~ 2.75 m asl occurred. Unit 2 contains well-preserved sedimentary structures associated with tidal flats including flaser, lenticular, and trough crossbedding, as well as infilled dendritic tidal channels. At the base of Unit 2, we found a concentration of woody debris, including well-preserved spruce driftwood trunks up to 10 cm in diameter that yielded radiocarbon non-finite ages. Above this, a 5-m thick gravelly barrier beach (Unit 3) dates to 99.8 ± 16 ka. Unit 3 contains well-preserved marine molluscs, a ringed seal metatarsal, bowhead whale vertebrae, and walrus tusks, in addition to abundant articulated bivalve and complete gastropod shells. Pleistocene-aged ice-rich aeolian silt (yedoma) blankets the marine deposits and dates to 57.6 ± 10.9 ka.

Our interpretation of this chronostratigraphy and sedimentology is that these deposits represent a marine transgression that reached a highstand after the warmest part of the last interglacial. One possible explanation for this local RSL highstand is that our study site was first uplifted by a glacial forebulge produced by the distant margin of the northwestern sector of the Laurentide Ice Sheet, and then brought below sea level by the collapse of this forebulge after MIS5e. This forebulge collapse caused a local marine transgression out of phase with eustatic sea level changes.

STRUCTURAL EVOLUTION OF THE MITCHELL Au-Cu-Ag-Mo PORPHYRY DEPOSIT, NORTHWESTERN BRITISH COLUMBIA

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The Mitchell Au-Cu-Ag-Mo porphyry deposit, hosted by Early Jurassic volcanosedimentary and intrusive rocks in the Stikine terrane of northwestern British Columbia, is considered the largest undeveloped gold resource in Canada. As of 2015 it held a resource of 1777 Mt at 0.61 g/t Au, 0.17% Cu, 3.1 g/t Ag, and 58 ppm Mo (0.5 g/t Au equiv. cut-off; meas+ind). The calc-alkalic deposit is genetically related to multiple diorite intrusions (Sulphurets suite) that cut volcanosedimentary strata of the Stuhini Group (Upper Triassic) and Jack Formation (basal Hazelton Group, Lower Jurassic). Phase 1 plutons (U/Pb, zircon; 196 ± 2.9 Ma and 192.2 ± 2.8 Ma) host Stage 1 potassic and propylitic alteration, veins and copper-gold mineralization. A Phase 2 plug (189.9 ± 2.8 Ma; U/Pb zircon) is central and temporally related to a molybdenum halo (190.3 ± 0.8 Ma; Re-Os, Mo) that is accompanied by phyllic alteration (Stage 2). Phase 3 plutonism is temporally related to diatreme breccia, intrusion breccia dikes and Stage 3 massive pyrite veins and advanced argillic alteration. High-level, gold-rich veins comprise Stage 4.

Three phases of progressive deformation related to the mid-Cretaceous Skeena fold and thrust belt structurally modify the Mitchell deposit. Deformation Phase 1 is characterized by a steep, easterly striking pervasive pressure solution cleavage (S_1) and steeply west-plunging buckle folds in veins (F_1); fold geometry and flattening degree are a function of alteration type. In rheologically weak alteration types a pressure solution cleavage is associated with loss of silica, mechanical remobilization of chalcopyrite-molybdenite, and passive enrichment of chalcopyrite-molybdenite-pyrite along the cleavage planes. Strain intensity (i.e., S_1 development) is

heterogeneous and this greatly affects the shape of the orebody. In Deformation Phase 2, steeply north-plunging F_2 vein folds overprint S_1 and F_1 . The Mitchell thrust fault (Deformation Phase 3) offsets the Snowfield deposit ~ 1600 m to the east-southeast and the Mitchell Basal shear zone displaces the Mitchell deposit from its core zone, located ~ 1 -2 km to the west at a depth of ~ 1 km. It is speculated the Mitchell deposit was emplaced into a structurally influenced, north-trending Jurassic basin and subsidiary east-west structures controlled the intrusion, vein geometry, alteration and metal pattern trends.

DIAMOND RESORPTION FEATURES AS A NEW METHOD FOR EXAMINING CONDITIONS OF KIMBERLITE EMPLACEMENT

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Diamond reaction with kimberlite magma and metasomatic mantle fluids leaves an imprint of resorption features on the diamond surface. Experiments have shown that distinctly different morphological styles of these surface features develop in undersaturated melts, H_2O -dominant, or CO_2 -dominant fluid. However, using diamond morphology as a proxy of kimberlitic fluid requires a method for quantitative characterisation of the effect of the parameters of kimberlite emplacement on diamond resorption features. Here we present the results of diamond dissolution experiments at kimberlite emplacement conditions (1150 - 1350°C , 1 GPa) in COH fluid with XCO_2 (CO_2/CO_2+H_2O , mol%) = 0, 0.5, 0.7, 0.9, and 1, monitored with in-situ entrapment of fluid inclusions. We use crystallographic parameters of trigonal etch pits on {111} diamond faces obtained with atomic force microscopy, and show that the profiles of these pits and the relationship between the diameter and the depth of the trigons on the same diamond crystal changes with XCO_2 in COH fluid and can be used to reconstruct the composition of magmatic fluids in kimberlites. Our experiments show that diamond resorption in kimberlite magma happens in the presence of immiscible aqueous and carbonic fluids, where bulk XCO_2 affects the proportion, but not composition, of these fluids. The volume proportion of the aqueous fluid determines the character of diamond resorption. Application of the experimental results to diamonds from volcanoclastic and coherent kimberlites from Ekati Mine (Canada) shows significant variation of bulk XCO_2 in these magmas. We further examine evolution of fluid system in a complex kimberlite pipe from Orapa field (Botswana) comprised by three facies: two coherent kimberlite facies (CKA and CKB) and one massive volcanoclastic facies (MVK). The diamonds from each of these facies were sampled in 2 – 13 m depth intervals. Diamonds from the three facies show three distinct styles of kimberlite-induced resorption: 1) due to a reaction with COH fluid (MVK), 2) reaction with undersaturated melt (CKB), and 3) an overprint of the fluid-resorption over the melt-resorption (CKA). We discuss how the depth of fluid separation from kimberlite magma affects the composition of the fluid and separation of the rising kimberlite magma column into two-(or three-) phase "bubble-rich" front and volatile depleted tail, which may have different ascent velocities and the timing of arrival at the surface. We extend our model to discuss the relationship between the behavior of the fluid, diamond resorption, and the mechanism of magma emplacement resulting in coherent or volcanoclastic kimberlite facies.

COULD LAURENTIA'S DOUBLE-WIDE, WESTERN MIOGEOCLINE BE A LEFT-LATERAL REPEAT OF ITSELF?

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An integral part of Laurentia's western cordillera is a pair of parallel belts of west-facing, ~Neoproterozoic - Cambrian carbonate platform separated by a shale basin. The inner platform is consistently ~ 25 Ma younger than the outer. The prevailing view is that prolonged rifting created a pair of inward stepping, rift-to-drift transition carbonate platforms that overlapped a very thick,

west-facing clastic wedge whose ~700 Ma base was the beginning of the event. The clastic wedge (essentially the Windermere) might also be seen as the depositional record of an entirely separate, imperfectly preserved Wilson cycle, but the two-phase origin of the capping carbonate platform is still problematic. Some have argued that since the platform's faunas are so different, the outer platform is exotic.

Devonian, left-lateral strike faulting along Laurentia's northern margin coupled with growing evidence that the rift-drift transition recorded in both carbonate platforms gets younger to the south, begs a question. Could there be a 6,000 km-long, Paleozoic, sinistral strike-slip in the shale basin to account for the faunal contrasts, and double-wide nature of the miogeocline? The south end of the ~525 Ma outer platform near Death Valley, California would hypothetically be the "northerly" continuation of the ~525 Ma inner platform of the Mackenzie Mountains in the Yukon. The margin, before being telescoped by strike-slip faulting, would have extended at least 10,000 km between its oldest (~550 Ma) Cassiar Mountains section of the outer platform, and its youngest (~500 Ma) section of the inner platform of southern Arizona.

Laurentia's Pacific margin is, and has been the site of diachronous rifting, collision, and major strike-slip faulting for some time. Large amounts of Mesozoic and younger dextral displacements have been proposed, among other things, to account for the faunal juxtapositions of the outer and inner platforms. Sinistral displacement during the Paleozoic, if large enough, might accommodate the same thing, and offer a more feasible explanation for why the south end of the outer platform's Ordovician Eureka Quartzite has such a distinctive northern Canadian shield (Wopmay orogen) detrital zircon provenance.

Considering that the cordillera has enjoyed multiple phases of orthogonal and margin-parallel displacement since the Mesozoic, the trace of any Paleozoic, strike-parallel, strike-slip fault would be, predictably, highly disjunct. Faults of this ilk are known, but their lack of continuity make them hard to interpret relative to each other, and to the patchwork of upper Paleozoic orogenic belts that populate the same areas.

GEOSTATISTICAL CHARACTERIZATION OF FACIES ARCHITECTURE IN AN UPPER DEVONIAN SYNTECTONIC CARBONATE PLATFORM, CANNING BASIN, NORTHWESTERN AUSTRALIA

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Upper Devonian (Frasnian) reef complexes along the northern margin of the Canning Basin evolved during active rifting of the Fitzroy Trough. Earlier studies of these reef complexes emphasized prominent metre-scale, back-reef cyclicity, but recent investigations of the Lower Frasnian Hull platform have revealed significant lateral and vertical variation in facies arrangements that were controlled by syndepositional faulting. This study uses geostatistical analyses of facies and magnetic susceptibility from three sections along the Hull platform to characterize stratal architecture and test whether a tectonic signal can be distinguished from eustatic and other signals.

Geostatistical analysis of facies thickness reveals an exponential distribution for thin (<3 m) facies, characteristic of stochastic depositional processes, and a predominance of thick subtidal facies toward the hangingwall and thick shallow-subtidal to intertidal facies near the footwall supporting field observations. Wavelet and power spectral analyses of facies and magnetic time series show long wavelength variations that include a periodic component with a wavelength near 40 m. The time series also contains short (10-30 m thick), isolated intervals of enhanced signal at wavelengths of 3 to 13 m defined by increased facies variability and thinner facies (representing amplitude and frequency modulation respectively).

These intervals are not correlated across the platform. Markov analysis indicates weakly ordered, vertical facies transitions that further substantiate the lateral variation across the platform.

The data provide firm evidence for Milankovitch eccentricity signals and an indication of obliquity and precession signals. The results allow confirmation of the time duration of the sections, tuning of the sedimentation rates and compaction factors, and provide evidence of eustatic controls on deposition. The cyclicity is recorded with greater temporal and spatial variation than in many other global locations providing an indication of local control on sedimentation. The results indicate a complex set of controls on deposition on the Hull platform with local tectonic effects having produced spatio-temporal moderation of the underlying eustatic signals. Random distributions of beds at shorter wavelengths and the weak ordering of facies changes suggest the role of additional, possibly autogenic, processes.

THE EFFECT OF PHOSPHOROUS AND BORON ON THE SOLUBILITY OF COLUMBITE AND TANTALITE IN GRANITIC MELTS

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The effects of phosphorous (P), boron (B) and temperature on the solubility of Mn-columbite (MnNb_2O_6) and Mn-tantalite (MnTa_2O_6) were studied in evolved water-saturated granitic melts with varying alkalinity (aluminum saturation indices, ASI = 0.8, 1.0 and 1.2) at 800 to 1000 °C 100 MPa, and an oxygen fugacity buffered at Ni-NiO.

Phosphorous was found to decrease the solubility of Mn-columbite and Mn-tantalite in peralkaline granitic melts. In agreement with previous studies, we suggest that P polymerizes the peralkaline melt structure by forming M^+PO_3 complexes ($\text{M}^+ = \text{K}^+, \text{Na}^+$ etc.), explaining the observed effect. On the other hand, the addition of P had a small positive effect on the solubility of Mn-columbite and Mn-tantalite in subaluminous granitic melts, which became even less significant in peraluminous systems. This is probably related to the formation of AlPO_4 and $(\text{Ta,Nb})\text{PO}_3$ complexes in the melt.

Adding B to P-rich peralkaline melts led to a slight decrease of Mn-columbite solubility but had no effect in subaluminous systems. For peraluminous melts a minor increase of the solubility of Mn-columbite and Mn-tantalite with the addition of B was observed. We propose that the addition of B to the P-enriched systems was compensated by the formation of boro-phosphate (BPO_4) complexes until the B/P molar ratio in the melts reached unity. Once the B/P molar ratio was greater than one, M^+BO_2 complexes were probably formed in peralkaline melts, resulting in a polymerization of the melt and a decrease of the solubility of Mn-columbite, whereas B acts presumably as a network modifier in sub- and peraluminous systems with B/P > 1. The solubility product of Mn-columbite (KspNb) and Mn-tantalite (KspTa) in peralkaline granitic melts increased by ~1.1 and 0.6 log units, respectively, when the temperature was increased from 800 to 1000 °C. The temperature dependences observed for sub- and peraluminous melts were almost identical.

X-RAY VISION: IN SITU X-RAY CT IMAGING AND X-RAY DIFFRACTION OF THE TUCSON IRON METEORITE MINERALOGY AND TEXTURES

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The Tucson iron meteorite, Arizona, is an anomalous ungrouped ataxite that is reported as a Si-bearing or 'silicated' iron, having 5-15% silicate content by volume, lowering its density relative to the <7 g/cm³ typical of iron meteorites. One striking feature of this meteorite is a subparallel alignment of the silicates and metal, delineating a foliation which can be seen macroscopically and

microscopically.

We have examined a 7.41 g specimen of the Tucson 'Carleton mass' from the Smithsonian Institution to non-destructively assess its 3D spatial density distribution, mineralogy and textures using a Nikon XTH 225 ST micro-CT scanner at Sustainable Archaeology, and a Bruker D8 Discover micro X-ray diffractometer (Co K α radiation) at the Department of Earth Sciences at Western University. From measured dimensions, sample USNM 757 has an approximate bulk density of 6.32 g/cm³. Micro-CT imaging was performed using a source beam at 222 kVp and 125 μ A, through a 1 mm copper filter, achieving a voxel resolution of 9.3 μ m. The high power and filtering was necessary to penetrate through the radiodense iron alloy and minimize beam hardening. In situ micro-XRD was performed on the cut surfaces, to investigate textural relationships in the major mineralogy.

Imaging by micro-CT can provide an estimate of both the bulk density of the meteorite and the volume % proportion of silicates and also enables a detailed examination of 3D textural relationships. Low radiodensity silicates are well resolved within the high radiodensity metal alloy. We observe three regions in the flow-banded texture, consistent with those found by other researchers: Silicate-free subrounded metal lenses of mm dimensions, silicate globules of typically 200 μ m diameter, and a dominant matrix of finely-dispersed silicates in metal. The Fe-Ni metal lenses and the silicate globules appear to define a planar fabric, with silicate globules decorating the metal lens margins and sometimes becoming continuous on the order of cm. The matrix dispersion of fine-grained silicates in the metal suggests that the matrix may have been a melt consisting of immiscible liquids.

This enigmatic meteorite was originally thought to represent the core of an early planetary body, but recently this interpretation has been challenged by the view that it is a primitive end-member of CR metal-rich chondrites, perhaps representing a coprecipitation of metal and silicates from the solar nebula gas. We propose that Tucson represents a metal-rich end-member of the primitive achondrites, as a nascent stage of planetary differentiation.

BISON GENETICS AND DISPERSAL THROUGH THE ICE FREE CORRIDOR

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The Ice Free Corridor has been invoked as a route for Pleistocene human and animal dispersals between eastern Beringia and more southerly areas of North America. Despite the significance of the corridor, there are limited data for when and how this corridor was used. Hypothetical uses of the corridor include the first expansion of humans from Beringia into the Americas, northward postglacial expansions of fluted point technologies into Beringia, and continued use of the corridor as a contact route between the north and south. Here, we use radiocarbon dates and ancient mitochondrial DNA from late Pleistocene bison fossils to determine the chronology for when the corridor was open and viable for biotic dispersals. The corridor was closed after ~23,000 until 13,400 calendar years ago (cal yr BP), after which we find the first evidence that bison used this route to disperse from the south, and by 13,000 years from the north. Our chronology supports a habitable corridor by at least 13,000 cal yr BP, just prior to the first appearance of Clovis technology in interior North America, and indicates that the corridor would not have been available for significantly earlier southward human dispersal. Following the opening of the corridor, multiple dispersals of human groups from Beringia into interior North

America may have continued throughout the latest Pleistocene and early Holocene. Our results highlight the utility of phylogeographic analyses to test hypotheses about paleoecological history and the viability of dispersal routes over time.

U-Pb AND Lu-Hf ISOTOPES IN COMPLEX ZIRCON GRAINS FROM EASTERN HALL PENINSULA, BAFFIN ISLAND USING LASER ABLATION SPLIT STREAM INDUCTIVELY COUPLED MASS SPECTROSCOPY (LASS-ICPMS)

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Eastern Hall Peninsula, Baffin Island is dominated by an Archean orthogneiss complex, which was caught in a two-stage, three-way collision between the Superior, Rae, and North Atlantic cratons at ca. 1860 Ma and ca. 1820-1790 Ma. The original configuration of these cratons is not well understood because eastern Hall Peninsula, which lies at the triple junction between these plates, lacks detailed geoscience mapping and geochemical data. Consequently, the paleo-plate tectonic reconstructions of the entire Canadian sub-Arctic region have been hindered, with at least three different locations of crustal sutures on southern Baffin Island proposed recently.

This Archean orthogneiss complex on eastern Hall Peninsula has long been considered to be relatively homogeneous. Previous reconnaissance scale investigation documented tonalite and monzogranite gneisses with U-Pb emplacement ages from ca. 2920 to 2797 Ma and possible tectonothermal overprints at ca. 2770. In this study, detailed mapping (1:6000) along a 700m transect and subsequent analytical work on seven distinct units yielded magmatic crystallization ages from 2976 \pm 4 to 2720 \pm 4 Ma and metamorphic ages from ca. 2720 to 2671 Ma. Subsequent Lu-Hf isotopic work using Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICPMS) was applied to the same zircon domains used for U-Pb geochronology. Most eHf(t) values (+13 to -3) are typical of juvenile, mantle-derived magmas with model ages of extraction from the mantle (TDM) ranging from ca. 2700 to 3420 Ma, however, eHf(t) values from one unit are significantly more negative (-8 to -31) with older TDM ages (ca. 3410 to 3870 Ma), indicating crustal contamination of Meso to Eoarchean crust. Considering the large spread in U-Pb and Lu-Hf data from such a small study area, this Archean orthogneiss complex is far more "complex" than previously recognized and these results may not be representative of the entire region.

To broaden the study, twenty-two regionally representative orthogneiss samples were analyzed using Laser Ablation Split Stream (LASS-ICPMS), simultaneously collecting U-Pb and Lu-Hf isotopes. Preliminary results (U-Pb crystallization ages 2845 \pm 8 to 2686 \pm 10, metamorphic ages ca. 2780 to 2500 Ma, eHf(t) values +14 to -13) generally agree with data from the small study area but provide a tighter link between crystallization age and magmatic provenance. The paired Hf data is also useful in verifying interpretations of exceedingly complicated zircon grains (inheritance vs. magmatic vs. metamorphic domains). The LASS-ICPMS technique is an essential tool to aid in elucidating the geologic histories of large, complex, metamorphic terranes.

NON-HYDROTHERMAL ORIGIN OF APATITE IN SEDEX Zn-Pb MINERALIZATION AND HOST ROCKS OF THE HOWARD'S PASS DISTRICT, YUKON

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The Howard's Pass district comprises 14 Zn-Pb sedimentary exhalative (SEDEX) deposits and is located within the Selwyn basin, Yukon, Canada. Although the HPD is renowned for its large accumulation of base-metal sulfides, in places the Late Ordovician to Early Silurian host rocks also contain abundant (carbonate-bearing)

fluorapatite (CBFA). This mineral is present stratigraphically below, within and above the SEDEX deposits and occurs as fine-grained layers that are interbedded with cherty carbonaceous mudstone. Electron probe microanalysis and laser ablation-inductively coupled plasma-mass spectrometric analysis reveal that mineral compositions and rare earth element-yttrium (REE-Y) systematics, respectively, are remarkably similar throughout the stratigraphic succession. North American Shale Composite (NASC)-normalized La/Sm and La/Yb ratios indicate that the original REE compositions in CBFA have undergone only minor compositional modification subsequent to deposition. Uniformly negative Ce anomalies indicate that the mineral formed in analogous manner to modern and ancient sedimentary phosphorites under suboxic bottom-water conditions. Europium anomalies are mostly absent, indicating that reduced, slightly acidic high-temperature hydrothermal fluids were not a major source of REE-Y to CBFA. The chemical homogeneity of the mineral irrespective of its stratigraphic position indicates that a common process was responsible for its deposition within the sedimentary rocks of the HPD. On the basis of the similarity of the REE patterns to modern and ancient phosphorites, and the absence of positive Eu anomalies, we conclude that the CBFA is of hydrogenous origin, and not hydrothermal as suggested by previous workers. As such, phosphorite formation in the HPD is casually related to SEDEX Zn-Pb deposit formation.

A COMPARATIVE STUDY OF THE MAFIC LITHOLOGIES FROM THE BORDEN BELT AND ADJACENT GREENSTONE BELTS IN THE WAWA-ABITIBI TERRANE

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The Borden belt in the Kapuskasing Structural Zone (KSZ) of the Superior Province of Canada contain mafic lithologies that reached the upper amphibolite to granulite facies of metamorphism. The mafic lithologies are classified as amphibolite with multiple igneous protolith ranging from ultramafic to intermediate sub-alkaline basalt. The geochemical signatures of the mafic lithologies indicate crustal input and shallow mantle marine setting associated with subduction zone magmatism. Comparison of the geochemistry and field relationships of the Borden belt, Michipicoten Greenstone Belt, and the Tisdale assemblage in the Abitibi Greenstone Belt indicate a mafic igneous protolith associated with the formation of a volcanic arc.

RESULTS OF REGIONAL TILL AND MODERN ALLUVIUM SAMPLING IN THE MCFaulds LAKE ("RING OF FIRE") AREA, NORTHERN ONTARIO

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The potential for the McFaulds Lake ("Ring of Fire") area to host a chromite deposit was identified as far back as 2003 following a large scale modern alluvium sampling project carried out by the Ontario Geological Survey in the James Bay Lowland. The results of that study clearly identified the presence of strong chromite anomalies along the upper Muketei River in the vicinity of McFaulds Lake and further to the south on the Attawapiskat River in the vicinity of Highbank and Fishtrap Lakes. The subsequent discovery of a world class chromite deposit in the McFaulds Lake area confirmed the significance of these earlier results.

The results presented here are focused on the recovery of chromite grains from both tills and modern alluvium, with the sampling emphasis placed in the vicinity of the known mineralization in the McFaulds Lake area and also in areas along the Attawapiskat River that were previously identified as highly anomalous. The intention here is to clarify the association between these two anomalous areas. These results confirm the findings of the previous study but also provide some new information pertaining to till stratigraphy, ice flow direction and mineral chemistry that should help to shed new light on the potential for further exploration in the area.

STABLE ISOTOPIC RECORDS OF OTOLITHS IN DETECTING CLIMATE REGIME SHIFTS AND OCEAN ACIDIFICATION

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The use of stable carbon and oxygen isotope ratio ($^{13}\text{C}/^{12}\text{C}$ or $\delta^{13}\text{C}$, and $^{18}\text{O}/^{16}\text{O}$ or $\delta^{18}\text{O}$) analyses in otoliths has received growing attention in recent years in fisheries science and management, particularly in examining climate-related regime shifts and the effects of ocean acidification. In this study, we report an example of using archived otoliths of Pacific halibut, *Hippoglossus stenolepis*, to detect the regime shift impact on British Columbia and the possible ocean acidification along the Washington Coast. In general, the $\delta^{18}\text{O}$ values of halibut otoliths ranged from -1.5 to +2.8 ‰, whereas the $\delta^{13}\text{C}$ values of the same otoliths ranged from -3.3 to +0.9 ‰. Evaluation of the isotopic composition of mature halibut (ages 8-12) indicated that the 1990 regime shift may have a temperature decrease of about 2 °C on the northeast Pacific halibut stocks. Studies from otoliths of tagged halibut suggested that the ocean conditions between the Bering Sea and the Gulf of Alaska were markedly different over the tagging period, but the boundaries between the Gulf of Alaska and British Columbia were not clear. Thus we concluded that stable isotopic records of otoliths are potentially useful in detecting the decadal-scale (e.g., the last 20-30 years) ecosystem changes. Further studies on the most recent regime shifts and the effects of ocean acidification are underway.

PETROGEOCHEMICAL AND GEOCHRONOLOGICAL EXAMINATION OF VARIOUS GRANITE PHASES ADJACENT TO THE MACTUNG TUNGSTEN SKARN DEPOSIT, YUKON-NWT, CANADA

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W-(Au-Cu-Bi) mineralization at Mactung, Yukon, is situated within the eastern flank of the SE-striking polydeformed Selwyn sedimentary basin, in skarnified limestone interlayered with carbonaceous pelitic sedimentary rocks that have been subjected to low-grade regional metamorphism prior to contact metamorphism.

There are two granitoid intrusions that occur within and adjacent to the Mactung skarn tungsten deposits: a leucogranite and a K-feldspar and plagioclase porphyritic biotite granite, with a related plagiogranite and associated undivided granite dykes that are fractionation and alteration products. Major- and trace-elements strongly discriminate between the various phases of biotite granite and the leucogranite. The biotite granite has an arc-like affinity, possibly derived from the recycling of I-type crust. The leucogranite is transitional with a highly fractionated S- and crustal A-type affinity; due to its low Na/K, Zr, REE, and higher Rb, source involving anatexis of a supracrustal sequence in a syn-collisional setting is hypothesized. Tracer isotopes in the Sm-Nd and Rb-Sr systems further indicate a very old continental crust as the likely magma source for the granitoids. Source rocks have crustal residence age of 1.9-2.3 Ga. The $\delta^{18}\text{O}$ values of Mactung granitoids indicate strong metasedimentary contamination from the source region or during magma ascent. Depth of magma generation is more likely deeper than 20km.

U-Pb age data of zircon grains were obtained by ID-TIMS analytical techniques for five samples from three rock types of Mactung granitoids: an aplitic dyke south of the Mactung skarn tungsten deposit yields igneous crystallization age of 97.1 ± 0.2 Ma; porphyritic biotite granite from the main phase of the Mactung pluton gives a crystallization age of 97.6 ± 0.2 and 97 ± 0.1 Ma. Leucocratic granite dyke, a marginal phase in the southeast of the pluton gives an age of 97 ± 0.3 Ma. Ar-Ar dating of micas yielded ages largely falling between 95.6 ± 0.3 to 91.1 ± 0.7 Ma. The Ar-Ar dates demonstrate the reheating of the crust near Mactung and a possible emplacement of late-stage granite phases up until 91 Ma.

The less evolved biotite granite is directly associated with the W-(Cu-Bi-Au) mineralization, based on field relationships, metallogenic aspects of the intrusion, alteration-mineralization effects, and previously published Re-Os dating of molybdenite and new multifaceted geochronological data. The fluorine and chlorine composition of biotites appears to be important prognostic criteria in identifying fertile granities for tungsten mineralization. The IV(F/Cl) versus IV(F) data distribution in biotite from Mactung granitic rocks are uniquely defined, and are different from those of porphyry copper, Sn-W-Bi and porphyry Mo deposit-bearing granites.

RESULTS FROM THE ALPHA PARTICLE X-RAY SPECTROMETER (APXS) ON BOARD NASA'S MARS ROVERS

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The Canadian Alpha Particle X-ray Spectrometer (APXS) is part of the scientific payload of the Mars Science Laboratory (MSL) rover Curiosity, which landed in Gale Crater in 2012. The MSL APXS is the third generation of chemical in-situ instruments of its kind on board a NASA Mars rover. It measures the chemical composition of rocks and soils with x-ray spectroscopy using a combination of PIXE and XRF excitation. The APXS determines the abundance of at least 16 elements, among them important salt forming elements like S, Cl and Br, with high precision.

Within the first 1200 sols at Gale Crater, Curiosity has driven 12 kilometers towards Mount Sharp through a sequence of sedimentary rocks of fluvial, deltaic, lacustrine, and aeolian origin and encountered a remarkable diversity in composition and mineralogy. The APXS has measured so far about 300 samples. It has been used for geological reconnaissance and for selecting the most promising drill samples for in-depth mineralogical, Wet Chemistry and isotopic analysis by the instruments SAM and CheMin. While Curiosity is still several kilometers away from the areas, where evidence from orbit for extended layers with hematite, sulfates and clay minerals led to the landing site selection, it has already made key observations, which indicate that Mars was in its early history a habitable place.

Together with the results from its predecessors on Pathfinder and the two MER rovers Spirit and Opportunity, the APXS data provide a unique data set that is used as ground truth for orbiter instruments, constraining mineralogical results and detailed comparison with SNC meteorites. The APXS data tie together the findings of all landed missions, which represent distinct areas, epochs and environments in the Martian history.

The MSL APXS is managed and financed by the Canadian Space Agency, with MDA as prime contractor to build the instrument. Science team funding is provided by CSA and NASA.

GEOTHERMOMETRY OF GARNET-CLINOPYROXENE AMPHIBOLITES, SILLIMANITE ZONE, MICA CREEK AREA, BRITISH COLUMBIA

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Interlayered metasedimentary and metabasic rocks crop out near Adams River (Lat. 51°37'10", Long 119°12'30"), part of the Mica Creek area, British Columbia. The common mineral assemblage in the metabasic rocks is: garnet (grt)-clinopyroxene (cpx)- hornblende (hb)-plagioclase (pl)- titanite (tn)- ilmenite (ilm) ± quartz (qtz). Orthopyroxene is absent and the assemblage in metapelites is: muscovite (ms)-qtz-grt-biotite-sillimanite (sil). At higher grade K-feldspar appears and ms disappears. These mineral assemblages are indicative of the upper amphibolite facies and not the granulite facies. Clinopyroxene-garnet occurs only on the high-grade side of the kyanite (ky)-sillimanite isograd and there is no evidence for large influx of external metamorphic fluids. Hb-pl geothermometry yields temperatures (T's) of 709 ± 25°C at 8 kbar. Grt-cpx-pl-qtz geobarometry yield a pressure (P) of 8 ± 0.4 kbar at 700°C.

Intersection of garnet composition contours yield a pressure of 7.9 kbar at 700°C. The occurrence of sil and the absence of ky suggests minimum T's and maximum P's of 650°C at 6.9 kbar and 700°C and 7.9 kbar. Rocks containing ky-sil-bearing assemblages across the Purcell fault and the North Thompson fault equilibrated at lower P than in the Mica Creek area.

NEW RE-OS GEOCHRONOLOGICAL CONSTRAINTS ON THE EVOLUTION OF THE BYLOT SUPERGROUP IN THE BORDEN BASIN, BAFFIN ISLAND

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The ca. 1200-800 Ma Bylot Supergroup in northeastern Canada is a critical archive of information recording early eukaryotic diversification and accompanying redox changes in the Proterozoic ocean, as well as the tectonic evolution of northern Canada spanning Grenvillean orogenesis. Robust interpretation of data from the Bylot Supergroup and correlation with other late Mesoproterozoic-early Neoproterozoic successions in Rodinia require an accurate chronology. We present newly acquired Re-Os geochronological data from the Borden Basin, Baffin Island, which is one of several coeval basins in northeastern Canada and northwestern Greenland collectively referred to as the Bylot Basins. The opening of the Bylot Basins is putatively linked geodynamically to the emplacement of the ca. 1267 Ma large igneous province (LIP), based on similarity of paleomagnetic poles between Mackenzie dykes and basalts of the Nauyas Formation at the base of the Bylot Supergroup. Consequently, fossils of Bangiomorpha pubescens—a primitive sexually reproducing, multicellular red alga and the earliest documented crown group eukaryote—recovered from the Angmaat Formation and equivalent strata of the middle Bylot Supergroup have long been considered to be ca. 1.2 Ga. Similarly, sedimentary evidence and sulfur isotope data from the Angmaat Formation have been used to argue for an increasing marine sulfate reservoir ca. 1.2 Ga. However, our new Re-Os data from organic-rich shales of the Arctic Bay Formation, which directly underlies the Angmaat Formation and temporally equivalent units, indicate a maximum age for the Angmaat Formation of ca. 1.05 Ga, consistent with recently acquired whole-rock ²⁰⁷Pb-²⁰⁶Pb isochron and ²³⁸U-²⁰⁶Pb and ²³²Th-²⁰⁸Pb errorchron ages (Turner and Kamber, 2012, Precambrian Research, 208, 1–18). These new radiometric ages require a recalibration of key late Mesoproterozoic biospheric events and records of secularly evolving seawater chemistry (e.g. δ¹³C, δ³⁴S, and ⁸⁷Sr/⁸⁶Sr). They also provide a more robust basis for correlating the Bylot Supergroup with other late Mesoproterozoic-early Neoproterozoic strata in Arctic Canada and Siberia and for testing models that link the origin of the Bylot Basins to the emplacement of the Mackenzie LIP and the Grenville orogeny.

AN INTEGRATIVE APPROACH TO UNDERSTANDING VERTEBRATE MICROFOSSIL MATERIAL FROM THE BELLY RIVER GROUP, DINOSAUR PARK FORMATION (CAMPAIAN) OF SOUTHWESTERN SASKATCHEWAN, CANADA

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The Belly River Group comprises an eastward thinning paralic to non-marine Campanian clastic succession in the Western Canadian Sedimentary Basin. Three formations are formally recognized in the western Canadian Plains. In ascending order, these are the Foremost, Oldman, and the Dinosaur Park formations. In Alberta, the Group is well known for its rich and diverse vertebrate fauna, and is one of the most productive dinosaur bearing units in the world. Though exposed in Saskatchewan, outcrop is sparse, widely distributed, and often difficult to access. Despite this, recently several microfossil sites have been identified throughout southwestern Saskatchewan, Canada. The Saskatchewan sites produce a rich vertebrate record including chondrichthyans, osteichthyans, turtles, champsosaurs,

crocodiles, salamanders, birds, mammals and dinosaurs. Integration of geological and paleontological information to place these sites into a geological context, as well as a meaningful microfossil database, is ongoing. Due to the provinces proximity to the transgressive Bearpaw Sea paleocoastline, these sites offer a unique opportunity to test paleoecological hypothesis regarding community response to sea level rise and inundation across the coastal and alluvial plain of Western Canada. Sequence stratigraphy, biostratigraphy and ichnology are being integrated with the paleontological data to provide a full understanding of the region during this time.

STRATIGRAPHY AND SEDIMENTOLOGY OF THE BELLY RIVER GROUP (CAMPANIAN) IN THE CYPRESS HILLS REGION, SOUTHWESTERN SASKATCHEWAN, CANADA

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The Belly River Group comprises an eastward-thinning paralic to non-marine Campanian clastic succession in the Western Canadian Sedimentary Basin. Three formations are formally recognized in the western Canadian Plains. In ascending order, these are the Foremost (paralic to non-marine), Oldman (alluvial to paralic), and the Dinosaur Park (alluvial, estuarine, and paralic) formations. Each is bounded by a disconformity, and has distinctive sedimentological characteristics and stratigraphic signatures that reflect tectonic control of sediment supply. The Foremost Formation, which interfingers with the underlying marine Lea Park Formation, records a period of regression. Maximum regression of the Western Interior Seaway is displayed in the Oldman Formation, whereas the transgressive Dinosaur Park Formation interfingers with sediments of the overlying marine Bearpaw Formation.

Previous regional surface and subsurface correlations of the Belly River Group confirm its presence in the Cypress Hills. In Saskatchewan, no attempt has been made to subdivide the Belly River Group into the three formations recognized in Alberta. Surface and subsurface analysis has shown that mapping the three formations is difficult, but nonetheless possible. This revision will change the nomenclature used for this unit. Fitting the Group into a sequence stratigraphic context across southwestern Saskatchewan and southern Alberta provides opportunity to understand the effects of sea level changes from the coastal plain into terrestrial deposits not in direct contact with marine waters.

DETRITAL GOLD: DOWN TO THE MICROMETER!

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Gold grain dispersion in sediments is a well established exploration method, widely used by the industry since the last 40 years. As any other analytical methods, its efficiency is limited by its robustness and detection limits, here dictated by the capacity to recover and count micrometer-sized gold particles. A compilation based on hundreds of ore petrography study indicates that gold grains in source rocks, in various type of deposit, are dominantly smaller than 50 μm , although such fine gold do not account for a large proportion of the mass balance. Since the exploration technique is based on grain counting, lowering the detection limits requires the reduction of recoverable grain size. A compilation of thousands of grain counts conducted by leading laboratories, extracted from assessment files, indicates a collapse in recovery below 50 μm , below which counts are erratic. Aside from recovery issues with conventional techniques, grain identification at such small size is not reliable under conventional binocular microscope. Pushing down the recovery size required a new design of the sample processing, as well as the observation methods, putting aside the conventional shaking table and binocular. A new recovery technique, involving minimal human intervention, has been developed and extensively tested. This technique enables recovery of gold grain down to a

size of about 5 μm , with a 80-90% efficiency. Automated SEM-based grain counting procedures were implemented, with automated high magnification imaging of the grains enabling classification. Other very heavy minerals, such as platinum group metal, tungsten minerals, galena, baryte, sulfosalt, monazite and metal chips are automatically counted along side. The SEM-based technique is currently being tested against automated optical hyperspectral and micro-CT techniques. Developing such methods did required the development of a reference material for laboratory quality control, made of spikes with a counted and imaged number of micrometer size grain. A review of the effect of natural elutriation affecting the sample will be discussed, since natural grain size distribution in various type of sediment needs to be re-evaluated. Various case studies will be presented.

A NEW METHOD FOR QUANTIFYING $^{87}\text{Sr}/^{86}\text{Sr}$ MEAN DISTRIBUTION ON THE LANDSCAPE FOR PALEO-MIGRATION STUDIES

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Strontium isotope analysis ($^{87}\text{Sr}/^{86}\text{Sr}$) is becoming one of the primary methods for characterizing past human and animal mobility patterns. $^{87}\text{Sr}/^{86}\text{Sr}$ values vary across the landscape as a function of bedrock geology and those values are incorporated into skeletal materials in a 1:1 correlation; this relationship permits a direct association between measured $^{87}\text{Sr}/^{86}\text{Sr}$ values in skeletal material and physical locations on the landscape. However, geographical variability of $^{87}\text{Sr}/^{86}\text{Sr}$ can be high, even within small regions, and that variability is difficult to quantify for migration studies. This poster presents a new method for quantifying the mean distribution of $^{87}\text{Sr}/^{86}\text{Sr}$ values by clipping a recently-published $^{87}\text{Sr}/^{86}\text{Sr}$ isoscape for the state of Alaska and Yukon Territory (Bataille et al. 2014) into small sub-regions in ArcGIS 10.2, and then calculating the mean and standard deviation for each sub-region to produce a mean-value trend-line radiating out from a sample locale. This method was then tested using *Bison priscus* specimens from the Lost Chicken Creek paleontological site, and the results indicate that this method can be useful for future paleo-migration studies as a way to quantify $^{87}\text{Sr}/^{86}\text{Sr}$ variability on the landscape.

CHARACTER AND AGE OF THE WEST BUCHAN AND EAST BUCHAN METAMORPHIC SEQUENCES, NE SCOTLAND

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The West Buchan metamorphic sequence in NE Scotland is a classic area for Buchan style (cordierite-andalusite-sillimanite) metamorphism. It is similar to the East Buchan metamorphism except for possible polymetamorphism on the western end of the sequence where staurolite occurs in the rocks. Both metamorphic sequences are developed in sedimentary rocks of the Dalradian Supergroup. Mineral assemblages, textural observations, rock and mineral compositional data and phase equilibrium modeling are used to discuss the petrology and age of the West Buchan metamorphic sequence in comparison to the East Buchan sequence. One controversial aspect about both sequences is the origin of migmatitic gneisses that occur at the high grade end of both: the Cowhythe gneiss in the West Buchan sequence, and the Ellon gneiss in the East Buchan sequence. Some suggest that the gneisses represent older basement upon which the sedimentary rocks of the Dalradian Supergroup were deposited. Others suggest that they represent Dalradian rocks that experienced partial melting at the high grade end of a normal Buchan metamorphic sequence. Petrological evidence is consistent with, if not definitive, of the latter suggestion. Preliminary chemical dating of monazite from the Cowhythe and Ellon gneisses suggests a mean age range of approximately 460 to 490 Ma, similar to ~470 Ma estimates of

Barrovian and Buchan metamorphism elsewhere in northeast Scotland. The combined evidence therefore favours the gneisses being highly metamorphosed Dalradian rocks.

GEOCHEMICAL AND PETROLOGICAL EXAMINATION OF Fe-OXIDE-BEARING HYDROTHERMAL BRECCIAS FROM THE MORAN LAKE C-ZONE DEPOSIT, AND THE POZ POND, TROUT POND AND ARMSTRONG LAKE OCCURRENCES

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Within the Moran Lake area, located in the Central Mineral Belt of Labrador, are several Fe-oxide-bearing hydrothermal breccia occurrences enriched in U, V, Cu, and/or Ag. These types of breccias are significant because they are a key characteristic of Iron Oxide-Copper-Gold (IOCG) deposits. IOCG deposits are high tonnage deposits containing vast quantities of metals; a type example of this deposit is Olympic Dam located in Australia. Occurrences examined in this project are the Moran Lake C-Zone deposit, and the Poz Pond, Trout Pond, and Armstrong Lake showings; all hosted by Joe Pond Formation mafic volcanic rocks. Discriminant diagrams indicate that the unaltered host rocks have an island arc tholeiite to MORB signature. Mineralized samples and a chlorite breccia from the Moran Lake C-Zone exhibit similar geochemical patterns to the unmineralized host rocks except for U and Pb enrichments and MREE and HREE depletions. Gold values ranged from below detection limit to 58ppb.

Petrographic work indicates that the protolith Joe Pond Basalts underwent greenschist facies metamorphism, along with multiple stages of alteration ranging from, 1) widespread albite dominated metasomatism with specular hematite, 2) widespread carbonate flooding/overprint, 3) chlorite dominated brecciation, and 4) late vein-hosted sulfides. Autoradiographs indicate that U mineralization at the C-Zone deposit, and Poz Pond and Trout Pond occurrences is predominantly breccia hosted, whereas at the Armstrong Lake showing, it is predominantly fracture-hosted, associated with local dark staining in a zone of intense albitization. MLA-SEM analysis defines the predominant U-bearing phase as uraninite with the exception of Armstrong Lake which is brannerite dominated. Vein-hosted sulphide phases at Armstrong Lake are sphalerite-dominated whereas other occurrences are chalcopyrite-dominated. Vanadium is geochemically associated with hematite fractures and veins. Modal mineralogy maps show intense carbonate overprint composed of ankerite with the exception of the mineralized Armstrong Lake sample where initial albitization is prominent. This study suggests that U was introduced in the system late, but vein-hosted sulfides were introduced even later. The Armstrong Lake occurrence seems to represent a lower temperature system that deposited sulfides.

STRUCTURAL CONTROLS ON THE KIGGAVIK BASEMENT-HOSTED UNCONFORMITY-RELATED URANIUM DEPOSITS (NE THELON AREA, NUNAVUT)

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In the Athabasca Basin, unconformity-related uranium deposits are commonly hosted within the Athabasca sandstones (eg. Shea Creek), at the sub-Athabasca unconformity (eg. Cigar Lake), and within the basement (eg. Eagle Point). The several unconformity-related deposits at Kiggavik, immediately south of the NE Thelon Basin, are entirely hosted within the basement metasedimentary rocks of the Meso-Archean Woodburn Lake Group. This location suggests that the study of the structural controls may allow better understanding of basement-hosted unconformity-related deposits. This work focuses on the structural controls of two recently discovered occurrences at Kiggavik: the Contact deposit and 85W showing. It aims to structurally characterize fracture networks that control both mineralization and alteration, including type,

orientation, paragenesis, etc. A combined multi-scale structural, mineralogical, and geochemical approach is used.

In relative importance to mineralization, but not in relative chronology, the structural controls are:

- A quartz-healed fracture network and cataclastic faults dominantly oriented ENE-WSW and NE-SW. The fracture network exhibits pitchblende replacing/co-precipitating with various sulphides (pyrite, chalcopyrite, bravoite). Field and drill-core oriented data indicate the presence of an array of Riedel-shears along dextral fault zones. Whole-rock geochemistry shows anomalous values of mineralization-related elements as Ag, V, Sr and Mo, and low values of non-mobile elements like Al and Ti. Elevated values are also observed for B, Ba, Co, Ni, Pb, Se, Sn, Y, and Yb. These structures were conduits for hydrothermal fluids that precipitated the first generation of pitchblende.
- NW-SE faults. These later faults associate redox fronts (rich in goethite) with alteration and remobilization of previous hydrothermal minerals and uranium re-precipitation in the form of uranium fronts and nodular-spherulitic pitchblende, with Al-Mg-chlorite (sudaite). The NW-SE faults also constrained later reducing fluids that argillized, and removed Fe-oxides/hydroxides from the earlier uranium-bearing redox fronts without any significant uranium remobilization/precipitation. Whole-rock geochemistry shows lower values in many elements (Fe, Ag, V, Sr, and Mo) and an increase in non-mobile elements (Al and Ti) as a result of the loss of mobile elements during argillization.
- Major NE-SW- and E-W-trending, thick, quartz-rich breccia structures that appear to form the lower boundary of most of the Kiggavik deposits. This quartz-sealed breccia acted as transversal barrier for fluids responsible for mineralization/alteration, leading to spatial convergence of both mineralizing and alteration fluids and the development of the uranium deposits.
- Joints. They control a late sooty black remobilization (coffinite/pitchblende?). Mineralization coats multidirectional joints associated with limonitic alteration.

INSIGHTS INTO RESOURCE UTILIZATION, DISTRIBUTION AND EXCHANGE: GEOCHEMICAL ANALYSIS OF DACITE ARTIFACTS FROM A TRANSPORTATION HUB, PUNCHAW LAKE, NORTH-CENTRAL BRITISH COLUMBIA

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Paleogene dacite is known to be the dominant rock type used in the manufacture of lithic artifacts at numerous archaeological sites in the southern interior of BC, but previous studies focussed on "mining" sites. We acquired a 47 element geochemical data set for 18 dacite artifacts randomly selected from 6000 recovered at the Punchaw Lake Village archaeological site in the north-central interior of British Columbia. This site represents a transportation hub; it occurs at the meeting point of pre-contact, north-south and east-west trails transecting the province. The artifacts plot as a group showing little or no geochemical overlap with dacite from the southern interior of BC. However, the diversity of compositions is as large as for the entire southern interior, and there are 3 populations of Punchaw Lake artifacts that are so geochemically distinct that they probably came from 3 different Paleogene volcanic complexes. We hypothesize that the complexes are in the north-central interior. Random sample selection, combined with petrography, reveals that the dominant type of artifact has textural traits that yielded superior "workability" (e.g., finer-grained). Thus, proximity to Punchaw Lake may not be the only factor influencing the percentages of artifacts

at the site. Two (11%) artifacts geochemically resemble artifacts from the southern interior, 500 km away. The results indicate that dacite artifacts at a transportation hub are dominantly of regional origin, as opposed to entirely local, and a small but significant number are of distal origin.

HYPGENE GOLD MINERALIZATION AT THE COFFEE DEPOSIT, DAWSON RANGE, WEST-CENTRAL YUKON, CANADA

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The Coffee deposit is a unique gold-only deposit in the Dawson Range, west-central Yukon, Canada. Coffee is a near-surface, oxidized deposit with a large (5 Moz) global high-grade (1.31-1.41 g/t Au) resource that consists of gold in solid solution within arsenian pyrite, and where oxidized, as microparticles within oxidized pyrite rims.

The host rocks to mineralization are biotite monzogranite (~99 Ma Coffee Creek pluton), psammite and semi-pelite (pre-Late Devonian Snowcap assemblage), and K-feldspar augen bearing, feldspar-quartz-biotite schist (Late Permian Sulphur Creek Suite).

Two styles of auriferous pyrite mineralization are identified at Coffee: 1) disseminated pyrite that selectively replaces biotite adjacent to fault/fracture zones, and; 2) polyphase breccia hosted mineralization that is spatially associated with gabbro to diorite dyke emplacement. Fine-grained, "sooty" arsenian pyrite is the dominant hypogene ore mineral at Coffee, with lesser chalcopyrite and arsenopyrite. In thin section pyrite forms euhedral to needle shaped grains that locally exhibit growth rims and compositional zoning.

The typical alteration assemblage is quartz+illite+kaolinite ± dolomite. Pyrite is intimately associated with pervasive illite and kaolinite alteration, and is also observed replacing laths of white mica (phengite). Very fine framboidal pyrite also occurs within pyritic veinlets. In breccia, pyrite is commonly observed within quartz-rich matrix, and within clasts of altered and mineralized wall rock within a quartz-carbonate-clay matrix. Rare realgar is observed locally within kaolinite-rich matrix in breccia.

Late carbonate and carbonate-quartz stringers cross cut mineralization and result in pervasive illite-carbonate alteration of the host rock and breccia zones.

The presence of pyrite associated with quartz+illite+kaolinite ± dolomite indicates a moderately acidic 220° to 250°C fluid penetrated the host rocks along fractures and faults resulting in the sulphidation of biotite and the formation of auriferous pyrite. The Si-CO₂-rich fluid caused significant quartz and carbonate alteration of the host rock and breccia; however the relationship between fault/fracture and breccia hosted mineralization is unclear at this stage. An influx of Si-CO₂ fluid is recorded by carbonate-quartz stringers that cross-cut mineralization.

Hypogene mineralization at Coffee is variably oxidized along mineralized structures, resulting in an oxidation profile as deep as 300 m below surface. Oxidation led to the liberation of gold from solid solution, and the formation of gold microparticles on oxidized pyrite growth rims, which results in rapid and complete metallurgical recovery via cyanide leach. Although the oxidation process led to the liberation of gold there is no evidence for supergene enrichment or depletion in the deposit.

STRUCTURAL AND GEOLOGICAL EVOLUTION OF THE COFFEE GOLD DEPOSIT, DAWSON RANGE, WEST-CENTRAL YUKON, CANADA

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The Coffee gold deposit, located in the Dawson Range in west-central Yukon, is unique as a gold-only, near surface, oxidized deposit, with a large, 5 Moz, high-grade (1.31-1.45 g/t Au) resource that will add significant economic value to Yukon.

Coffee represents a complex tectonic history from crustal thickening, oroclinal terrane closure, and rapid unroofing of the Yukon-Tanana terrane in the Early Jurassic to the northwestward extrusion of the Intermontane terranes in the Cretaceous.

Coffee is hosted both in mid- to late-Paleozoic rocks of the allochthonous, pericratonic Yukon-Tanana terrane, and in mid-Cretaceous subduction-related arc plutonic rocks of the Coffee Creek pluton. The basement Yukon-Tanana psammite, semipelite, and orthogneiss preserve a Late Permian amphibolite facies transposed S₁ and S₂ foliation (D₂). These basement rocks were deformed and thrust stacked under greenschist facies conditions during Jurassic convergent deformation (D₃), along with emplacement of ultramafic rocks. Brittle kink folding and fracturing (D₄) developed, locally infilled by orogenic quartz veins. Extensional tectonics dominated from Early to Late Cretaceous resulting in the emplacement of the Dawson Range batholith and Coffee Creek pluton, re-activation of sinistral Jurassic faults as dextral faults, and associated orogenic gold mineralization (e.g., Boulevard; 95.9±0.9 Ma).

Coffee is hosted on the southern limb of an open, gently plunging (D₃) anticline, cut by numerous fracture arrays. Aeromagnetic data highlights a regional-scale, magnetite-destructive, E- trending structure (Coffee Creek fault) south of the main deposit, with N-W-trending horse-tailing fault strands that splay from the main first-order structure. The structural setting of the deposit is inferred to represent the termination of a dextral strike-slip fault system, with mineralized structures interpreted as high order fracture arrays within the main fault termination zone. However, interpretation of soil geochemical data over the deposit indicates apparent sinistral offset across the Coffee Creek fault that is interpreted as Middle to Late Jurassic sinistral movement across the structure.

Mineralization at Coffee occurs in steep brittle N-S- trending brecciated and silicified fracture zones, and E- trending faults and fractures, which cut the southern limb of the folded basement rocks, and the 99 Ma Coffee Creek pluton. Exhumation of the Dawson Range occurred after cessation of mid-Cretaceous arc magmatism, accompanied by brittle deformation and fluid flow. At Coffee alteration (quartz-illite ± dolomite) and mineralization (auriferous arsenian pyrite) is indicative of a shallow level hydrothermal system. The mineralized structures subsequently acted as conduits for meteoric water, resulting in a significant oxidation profile to the deposit.

CHEMICAL COMPOSITION OF INDICATOR MINERALS FROM OROGENIC GOLD DEPOSITS AND GLACIAL SEDIMENTS, VAL-D'OR, QUÉBEC

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In the Val-d'Or district, tourmaline is a common vein mineral in fault-fill, extension, and hydrothermal breccia veins. The tourmaline needles are black and usually show a blue core and a brown rim zonation in thin section. The rim is characterized by a high concentration of Fe, Ti, Ca, and Na and a low concentration of Al and Si. The dominant cation in the x-site is Na and the tourmaline

composition varies along the solid solution schorl-dravite. Five glacial sediment samples were collected, forming a transect oriented NE-SW, following the ice flow of the area. The first sample is located up-ice, north of the Val-d'Or district. Three samples are located across the district and one sample is located approximately 4 km south of the Larder Lake-Cadillac Fault Zone (LLCFZ). In glacial sediments, tourmaline is recovered from the 0.25 to 0.5 mm size fraction of the heavy mineral concentrates. The number of grains increases from 18 in the up ice sample to 39 in the northernmost sample within the Val-d'Or district before decreasing gradually to 13 grains in the southernmost sample. Scheelite is an accessory mineral in quartz-tourmaline-carbonate veins of some deposits in the Val-d'Or district. Scheelite is beige-white in color and form aggregates of centimetric grains. In glacial sediments, three grains of scheelite were recovered from the 0.25 to 0.5 mm size fraction in the samples located within the Val-d'Or district and in the southernmost sample. Scheelite is absent in the up-ice sample. Magnetite is rare in quartz-carbonate-tourmaline veins and occurs as finely disseminated grains near pyrite. However, the granodioritic-dioritic intrusion, hosting the quartz-tourmaline-carbonate veins, contains larger (≤ 0.5 mm) euhedral magnetite grains. Magnetite recovered from glacial sediment samples occurs in polymineralic and monomineralic grains. Arsenopyrite occurs in deposits located near or within the LLCFZ. Arsenopyrite occurs as finely disseminated grains or clusters in mineralized zones and altered wall rocks. Arsenopyrite was not recovered from the heavy mineral concentrates of any of the till samples. The size of gold grains recovered from glacial sediments is less than 250 μm . The number of gold grain increases from 6 in the up ice sample to 43 in the northernmost sample within the Val-d'Or district before decreasing to 4 in the sample located down-ice. Gold grains recovered in samples within the district show pristine, modified, and reshaped forms while the samples located up-ice and south of the LLCFZ shows reshaped grains only.

HIGH-RESOLUTION, 3D SURFICIAL GEOLOGY MAPPING APPLIED TO THE INTERPRETATION OF KIMBERLITE INDICATOR MINERAL DATASETS IN THE LAC DE GRAS AREA, NORTHWEST TERRITORIES

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In the central Slave Craton, Northwest Territories, glacial sediments obscure many diamond-bearing kimberlites. Diamond deposits in the Lac de Gras area were discovered in the early 1990s by drift prospecting. The intricate ice and meltwater processes caused by glaciation resulted in complex sediment deposition that is not completely understood. Detailed surficial geology mapping and sedimentology can aid in more accurate drift prospecting interpretations.

As a part of the Slave Province Surficial Material and Permafrost Study (SPSMPS), a research initiative lead by the Northwest Territories Geological Survey, we have mapped the surficial geology of a 225 km² area on the north side of Lac de Gras at a 1:20 000 scale. We used a high-resolution LiDAR digital elevation model and orthoimagery provided by Dominion Diamond Corporation for this mapping. These datasets were digitally combined using SummitTM software to produce 3D images of the landscape. This imagery has allowed us to map in more detail than has previously been possible in northern Canada. Mapping has been ground proofed with 180 km of foot traverses and supplemented by ground-penetrating radar profiles ($n = 21$) as well as matrix grain size analysis and pebble counts from hand dug pits ($n = 47$). The surficial geology of the Lac de Gras area is characterized by wide-spread till, draping the bedrock topography as a veneer or blanket. The till is dissected by glaciofluvial corridors where till has been eroded, bedrock is exposed and glaciofluvial sediments, including eskers and enigmatic mounds, have been deposited.

Our results indicate that the area affected by subglacial meltwater reworking is greater than previously recognised. Also, raised beaches and other shoreline features are common up to 25 m above the present lake levels, suggesting reworking may have been significant. Derivative maps of sampling suitability are being created to highlight areas where till is best preserved and indicator mineral and pathfinder element signatures may best reflect a local bedrock source. These results are being used to reinterpret existing drift prospecting datasets from the area, as well as to interpret kimberlite indicator mineral and pathfinder element results acquired from till using RC drilling as part of the SPSMPS project.

This study demonstrates that access to high-resolution spatial data allows for detailed mapping and more accurate analysis of drift prospecting datasets. As the cost of collecting remote sensing imagery falls, similar work will be possible across the North.

CANMARS 2015: GOING TO UTAH TO BRING BACK MARS

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Returning samples from Mars remains one of the highest priorities of the international planetary science community. To help prepare for any such Mars Sample Return (MSR) campaign, space agencies throughout the world have embarked upon a variety of activities addressing the scientific, technical, and programmatic challenges that lay ahead.

Integrated field exercises in advance of planetary missions serve several purposes, including (i) science: testing of hypotheses and defining measurement requirements; (ii) technology: demonstrating the capabilities of next-generation flight instrument or system prototypes; (iii) operations: training flight mission operations teams and developing advanced operational concepts, and; (iv) education: providing high-fidelity training for the next generation of planetary scientists and engineers.

In the fall of 2015, the Canadian Space Agency (CSA), in partnership with the NSERC CREATE Technologies and Techniques for Earth and Space Exploration team led by Western University, conducted a two week training and technology demonstration field deployment emulating portions of an MSR sample caching mission. This activity aimed to characterize the "landing site's" geological history and assess signs of potential habitability using a rover outfitted with a combination of integrated and hand-held instruments and sampling tools.

A competitively-selected team, also from Western, had previously identified a field site near Hanksville, Utah and developed a science operations scenario for the deployment. Subsequent field reconnaissance by CSA confirmed that the location satisfied the project's scientific, technical, and logistical requirements.

The mission science team was composed of 35 CREATE students and post-doctoral fellows. Unaware of the selected location, they were provided with a nominal landing ellipse and a variety of data products equivalent to those available for a landed Mars mission, with which they performed a pre-landing assessment and prepared the rover's baseline mission scenario.

During operations, the team conducted remote operations from London, ON, including: setting strategic and tactical objectives, generating a daily science plan, and interpreting the returned data. CSA and industry engineers in St. Hubert, QC validated the daily plans and commanded the rover, while a small field team provided a communications link and ensured the safety of the rover.

After 12 'sols' of activity, four samples were successfully collected and the team provided a rational interpretation of identified features of interest from the mission data. Science team follow-on activities will include laboratory characterization of the returned samples. CSA anticipates conducting an expanded MSR campaign involving international collaborations in November 2016.

NEW ISOTOPIC DATA ON THE HEMATITE CREEK GROUP, WERNECKE MOUNTAINS, YUKON: IMPLICATIONS FOR THE AGE AND CORRELATION OF EARLY NEOPROTEROZOIC STRATA IN NORTHWESTERN CANADA

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Here we present stratigraphy, stable isotopic data and a new Re-Os age for the Hematite Creek Group, east-central Yukon. The little-studied Hematite Creek Group forms the base of the Tonian Mackenzie Mountain Supergroup in the Wernecke Mountains and is thought to correlate with the Tsezotene Formation in the nearby Mackenzie Mountains to the southeast. The contact between the Hematite Creek Group and the underlying Pinguicula Group appears to be an abrupt flooding surface in places, and possibly unconformable elsewhere, similar to the contact between the Tsezotene Formation and the underlying Tabasco Formation (Turner, 2011. In: Yukon Exploration and Geology 2010, p. 207–231). The Hematite Creek Group comprises sub-littoral organic-rich shales at the base (Dolores Creek Formation), which grade upward into muddy peritidal carbonates and mud-cracked shales (Black Canyon Formation). These in turn transition into interbedded fine-grained quartz sandstone and siltstone with minor thin dolostone beds (Tarn Lake Formation). The upper Hematite Creek Group is itself transitional into the quartz sandstone-dominated Katherine Group above. Given proposed stratigraphic correlations between the Hematite Creek Group in the Wernecke Mountains, the lower Mackenzie Mountains Supergroup in the Mackenzie Mountains and the upper Rae Group in the Amundsen Basin, as well as other radioisotopic constraints from these successions, the preliminary Re-Os data support an age of > ca. 900 Ma for the Hematite Creek Group. Carbon isotope data from the Hematite Creek Group carbonates reveal that the moderate amplitude fluctuations and near 0‰ average values characteristic of late Mesoproterozoic seawater continued until about 900 Ma. Correlation of the Mackenzie Mountains Supergroup in the Wernecke Mountains with the Coal Creek Inlier to the west, where the Hematite Creek Group is absent and the contact between the lower Fifteenmile Group and underlying Pinguicula Group is a high angle unconformity, suggests this region was influenced by an early Neoproterozoic orogenic event. Hence, the Hematite Creek Group and equivalent strata provide a rare window into the early Neoproterozoic Era and promise to shed light on the tectonic evolution of northern Canada during this time.

ELEMENTAL ANALYSIS OF BASALTIC MATERIALS FROM THE LITTLE JOHN SITE (KdVo6), YUKON TERRITORY, CANADA

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In this paper we report on the utility of portable X-Ray Florescence (pXRF) technology to distinguish intra-site variability of a large sample of archaeological basalts recovered at the Little John site (KdVo6) both within and between components dating from the Late Pleistocene to the Late Holocene. Our principal interest was to assess whether geochemically distinct basaltic materials, that dominate the earliest components of the site, are identifiable through the application of pXRF technology. These materials are expected to reflect aspects of the technological organization of a highly mobile founding population migrating into a region unfamiliar to them. Of additional interest were questions related to continuity of basaltic source material through time, in particular whether later populations, more intimately familiar with their geological surroundings changed from advantageously exploiting accessible stone to pursuing individual sources for preferable qualities. We will first provide a brief introduction to the site and nature of the

assemblage in order to provide context to the analyzed subsample and set out the goals of the present study. This will be followed by an account of instrumentation and analytical procedures, which included classification of the sample using traditional visual morphological attributes and subsequent groupings based on elemental spectra generated through pXRF examination. We then discuss the implications of these results for basaltic use at Little John across the site and through time. We conclude the paper with a critical review of the limitations of our methods and make recommendations for improving its application in future research at Little John and elsewhere.

POLYMETALLIC (U-As-Ni-Co-Ag-Bi-Sb) VEIN MINERALIZATION IN THE EAST ARM OF GREAT SLAVE LAKE, NWT, MAY PRESERVE EVIDENCE OF BASEMENT INFILTRATION OF FORMATION BRINES FROM FORMER OVERLYING INTRACRATONIC SEDIMENTARY BASINS

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Polymetallic, uranium-bearing “five-metals” type hydrothermal vein systems overprint intrusive, metasedimentary and metavolcanic rocks of the Southern Slave Province, Great Slave Lake Supergroup and Compton Intrusive Suite in the East Arm of Great Slave Lake. These occurrences (e.g., Copper Pass, Blanchet Island) are very low in grade and tonnage at their surface expression, and lacked productive U and Ag ore stages but have similar overall paragenetic characteristics to former world-class deposits at Great Bear Lake (Eldorado-Echo Bay, Contact Lake, Terra-Norex, Silverbear, Normin). Petrographic and thermometric (CL, SEM, fluid inclusion microthermometry) and in-situ isotopic methods (SIMS, LA-ICPMS) are being used to revise the current model for this deposit style, specifically with respect to metal sources, metal precipitation mechanisms, the timing of metal precipitation, and the reasons for variability in metal tenor on a regional scale. Preliminary research has focused on characterizing the onset of uranium and Ni-Co arsenide coprecipitation, recorded in solid mineral inclusions trapped with bitumen in late growth zones in quartz predating a more productive, but U-free arsenide-silver-carbonate stage.

In the quartz growth zones, major compositional changes to metal-carrying fluids are evident. Primary fluid inclusion salinities (~20-30 wt% CaCl₂ eq.) and entrapment conditions (< 0.5 kbar and 200°C) varied little with time during vein formation. However, values of $\delta^{18}\text{O}_{\text{quartz}}$ ranged from 4 to ~25‰, increasing from core to rim. Correlation of cathodoluminescence imaging with O isotope data demonstrates a marked increase in $\delta^{18}\text{O}_{\text{quartz}}$ coinciding to U-Ni-Co-As-bitumen precipitation in the quartz. Integration of all data types strongly suggests that the precipitation of metals and bitumen was triggered by isothermal mixing of basement (metal-free) and basinal-type (metal-rich, hydrocarbon-bearing) brines with the latter fluid derived from suspected overlying outliers of the Athabasca-Thelon sedimentary basins, modified through interaction with organic metalliferous black shales.

Coprecipitation of metals and bitumen highlight the role of hydrocarbons or organic ligands in transporting and precipitating uranium and other metals in polymetallic veins systems. Furthermore, the integration of fluid inclusion data with stability constraints for hydrocarbons coeval with mineralization provides quantitative maximum constraints on the thickness of overlying sediments at the time of polymetallic vein formation.

GEOLOGIC SETTING AND TECTONIC EVOLUTION OF EAGLE PLAIN BASIN, NORTHERN YUKON, CANADA: IMPLICATIONS FOR PETROLEUM POTENTIAL

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Eagle Plain in northern Yukon is underlain by an intermontane petroliferous sedimentary basin that has been shaped by multiple tectonic events throughout its Phanerozoic history. These events

intimately affected the generation, migration and distribution of petroleum accumulations in the basin. Major advances in understanding the basin's structural evolution provided impetus for the Geological Survey of Canada to re-evaluate the petroleum potential of the basin incorporating newly-identified exploration play concepts.

All discoveries to date are located in southern Eagle Plain and were drilled on large Laramide surface structures.

Eagle Plain is located within the Cordilleran Orogenic system of northern Canada characterized by marked crustal instability. Angular unconformities, diverse structural trends, fold bundles, and extension, contraction and transcurrent faults are common features of the region.

During Late Devonian time, south-directed Ellesmerian tectonism affected the region. Broad east-west trending open folds are preserved in the subsurface of northeastern Eagle Plain Basin.

In the basin, a major northeast-southwest feature called Eagle Arch, a pre-Mesozoic upwarp of Paleozoic strata, marks the northern limit of erosional edges of various Upper Paleozoic successions. The Arch was active during Late Carboniferous to Early Permian time resulting in erosion of the Carboniferous succession to the north. Early Permian Arch movement uplifted northern Eagle Plain resulting in bevelling of underlying Paleozoic strata beneath the sub-Mesozoic unconformity.

Early stages of the Cordilleran orogenesis produced Jurassic and Cretaceous mountain ranges to the south of Eagle Plain region. These ranges were the source areas for clastic debris that shed northward into the foredeep region through Late Cretaceous time.

Broad north-trending folds detached by décollements within the Proterozoic succession were formed in Eagle Plain. To the west, more intense deformation produced mainly thrust faults. In northeastern Eagle Plain, Laramide thrusting and folding of Mesozoic strata form Tertiary triangle zones marginal to the basin.

Stratigraphic and combination traps are also present in Eagle Plain. These trap configurations include updip basinward facies changes, subcrops of Upper Paleozoic reservoirs beneath the sub-Cretaceous unconformity and carbonate-to-shale facies changes in Lower Paleozoic strata.

The probabilistic assessment of total oil and gas potential (discovered and undiscovered) for all Phanerozoic sedimentary strata in the basin is $52.2 \times 10^6 \text{ m}^3$ (329 MMBO) of oil and $96.7 \times 10^9 \text{ m}^3$ (3.4 Tcf) of gas (in-place mean volumes).

MID-CRETACEOUS PLUTONIC EVOLUTION OF ALASKA AND YUKON

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Twenty-five Early and mid-Cretaceous plutonic suites, defined on the basis of lithological, geochemical, isotopic, and geochronometric similarities, comprise four belts that record the evolution of the most significant magmatic episode in Alaska and Yukon. Plutonism records more than 55 million years of evolving continental margin arc formation and extension-related crustal melting. Plutonic belts were built across Insular, accretionary wedge, Intermontane, pericratonic and miogeoclinal tectonic elements across Alaska/Yukon during the final stages terrane accretion, related deformation and subsequent orogenic collapse.

Notably, the source melts for each of the plutonic suites can additionally be characterized by their primary oxidation state which can be determined by their aeromagnetic characteristics, magnetic susceptibility and whole-rock ferric:ferrous ratios which distinguish them as magnetite- or ilmenite-series.

Overall temporal trends define older, more mafic magnetite-series belts that young inland, with younger, more felsic ilmenite-series belts further cratonward. The oldest and most seaward plutonic

episodes (145–125 Ma) are arc-type magnetite-series and may include pre-accretionary arc elements in Insular terrane rocks. Successive, more inboard continental arc magmatism (118–99 Ma) is also magnetite-series, with metaluminous calc-alkaline plutonism. Ilmenite-series felsic plutonism, initiated at about 112 Ma in response to crustal thickening, was dominated by the formation of large, slightly peraluminous batholiths. Younger plutonic suites (109–96 Ma) are similarly dominantly felsic and slightly peraluminous, but are more oxidized forming hybrid weakly magnetite-series belts. A final magmatic episode led to the emplacement of inboard, widely scattered, ilmenite-series granitoids during a late, minor extensional event at 98 to 92 Ma. During latest extension, magnetite-series alkaline plutonic suites and lamprophyres were emplaced at 92–90 Ma in the most inboard locations.

ARE COLLISIONAL OROGENS COMMONLY PRECEDED BY AN ACCRETIONARY PHASE?

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Classic orogenic belts commonly are made up of a foreland fold-thrust belt, a deformed continental margin and thrust belt that involves basement and increasing metamorphic grade that transitions into a metamorphic core of thermally altered continental margin sedimentary rocks and continental crust-derived plutons, a hinterland of head-on and transpressional accreted terranes, and either a younger accreted orogen or a colliding continent.

Accretionary orogens involve development of subduction-related island- or continental-arcs and deep-ocean sediments and ophiolites that are obducted onto the continental margin. These can be recognized by their stratigraphy and imbricate structure in both ancient (Wopmay, Appalachians, Caledonides, Variscides) orogens, young orogenic belts (North American Cordillera, Andes, and modern island arcs).

Collisional orogens commonly involve initial subduction and closing of small to large oceans, occasionally involving ophiolite obduction, followed by continent-continent or large composite terrane collision (Alps, Appalachians, Caledonides).

Some orogens are either dominated by strike-slip deformation (Trans-Hudson) or contain a major component of strike slip deformation involving transpressional (occasionally transtensional) processes (Alps, Appalachians, North American Cordillera). The transpressional components commonly indicate oblique or zippered collision of continents, large composite terranes, or complex ocean-continent interactions. Composite behavior commonly indicates the poly-orogenic event character of many orogens (Alps, Appalachians, Caledonides, Variscides, North America Cordillera).

Some collisional orogens (Alps) do not contain evidence of an earlier accretionary phase, whereas many orogens (Appalachians, Caledonides, Variscides, Urals?) do contain an accretionary component, frequently the product of an earlier orogenic event.

SURFICIAL GEOCHEMISTRY OF TELLURIUM IN A SEMI-ARID CLIMATE

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Tellurium is a near-critical element increasingly used in high technology applications, which can be more toxic than arsenic or selenium if present as Te^{IV} . Under surficial environmental conditions both Te^{IV} and Te^{VI} are predicted as dominant species by different thermodynamic datasets. This highlights the necessity for direct field observation, as Te^{IV} is $10\times$ more toxic than Te^{VI} . Tellurium-enriched mine tailings were collected from historic gold-silver telluride deposits across the Western United States and Te speciation and mineralogy are being assessed as a function of climate to assess the environmental health implications of Te

release into the surficial environment. The first site characterized is semi-arid Delamar, NV, 450,000 tons of circum-neutral (pH 7.4-8.3) residual tailings are enriched in Te (up to 267 mg kg⁻¹ relative to an average crustal abundance of 3 µg kg⁻¹) and other toxic metal(loid)s (e.g., Pb, Bi, Cu, and As). Electron microscopy and x-ray absorption spectroscopy data indicate the accumulation of less toxic Te^{VI} in surficial tailings, principally associated with iron (oxy)hydroxide minerals. Some Te-bearing particles are tiny (> 3 µm) that may be readily transported by wind or surface water. Examination of metal(loid) concentrations downstream suggest substantial transport of Te and other metal(loid)s offsite, which may lead to human exposure by inhalation during popular off-roading activities. Aeolian transport is also an important dispersion mechanism of metal(loid)-bearing particles with enrichments observed in a northeastern to northwestern direction. These data are consistent with HYSPLIT modeling, indicating predominant winds from the southwest, and short-term anemometer data demonstrating a southeastern origin. The bioaccessibility of metal(loid)s in two tailings piles and streambed sediments, assessed by physiologically-based extraction tests mimicking conditions in the stomach and alveolar macrophages, generally indicate increasing metal(loid) bioaccessibility with increasing distance from the site as well as differences between the two tailings piles. Taken together, these results indicate that the environmental impact of Te in the tailings at Delamar is of moderate concern.

EARLY-CAREER UNDERGRADUATE ENGAGEMENT IN RESEARCH USING A TIERED MENTORING MODEL

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Incorporating research into undergraduate curricula has been linked to improved critical thinking, intellectual independence, and student retention, resulting in a graduating population more ready for the workforce or graduate school. Similarly, mentoring has been linked to enhanced self-efficacy, persistence, and desire to pursue graduate studies. We have designed a three-tiered course model of undergraduate chemistry courses that engages students in self-directed research projects and nucleates mentoring relationships with faculty, near-peers, and peers. Early-career undergraduate students, with no previous research experience, receive formal training in the scientific process from a faculty process mentor while working with a graduate student content mentor to develop an independent research project and write a proposal, and embedding themselves in an active research group. Advanced undergraduates further develop their research independence performing student-designed projects with faculty and/or graduate student collaboration. Further, graduate students gain experience in mentoring though formal training, as well as through actively mentoring mid-career undergraduates.

The first offering of this course was in Spring 2015, and resulted in 100% of students agreeing with the statements "I would recommend this course to my peers," "I learned new skills and developed a research project," and "I feel more prepared for CHEM 488" a research course for advanced undergraduate students required for graduation. The mentoring relationship was both appreciated by undergraduate students and was reported to be key to learning new skills and successful project development. Mentors also appreciated the course and agreed with the statements "I learned new skills as a result of working with my mentee and the mentoring discussion group," and "this course has refined my own research skills." The course also resulted in funding of 100% of proposals, which were submitted by 63% of the undergraduate students and persistence of 50% of the mentoring relationships beyond the course. This novel, integrated approach fosters undergraduates in developing and executing independent projects with the support of empowering mentoring relationships.

CHEMICAL VARIATIONS WITHIN AND BETWEEN CLASTS AND MATRIX OF THE ABE E METEORITE BRECCIA REVEAL ENIGMATIC ASPECTS OF ITS PETROLOGIC HISTORY

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Abee is an enstatite-chondrite breccia with rounded clasts up to 20 cm long, some of them with pronounced rims. We examined spatial compositional variations to find out more about the petrological processes that produced this rock, particularly the relationship between the clasts, their rims and the matrix. The initial assumption was that all components come from a single protolith. A block (75 × 45 × 8 mm) was analysed using focussed X-ray fluorescence at a resolution of 60 micrometres to give images of each side of 1024 × 800 pixels. The characteristic lines of major and trace elements were used to compile greyscale images. All individual clasts that could be identified optically (209; all > 2 mm) were outlined and the mean grey-scale values calculated. Zoned clasts (18) were also separated into a rim and core. The data have not yet been fully corrected or calibrated, but grey-scale values are assumed to correlate closely to the actual composition. There are considerable compositional variations between clasts, commonly over a factor of 2 or 3. Fe and Ni are well correlated, showing that they are both in a single metallic phase. Other element pairs are less well correlated, commonly with outliers, suggesting minor contributions from other sources. Chemical variations between rims and cores of zoned clasts parallel in general the compositional variation between different unzoned clasts. I will now consider only the Fe content for brevity. Larger clasts tend to have lower Fe contents than smaller clasts and almost all clasts have more Fe than the matrix. Clast rims were consistently richer in Fe than the cores. This cannot reflect reaction between the rims and the matrix because the latter is much poorer in Fe than almost all the clasts, both rims and cores. Hence, the production of the rims must reflect a process that occurred before the clasts were mixed with the current matrix and after they were rounded. The variation of Fe content with clast size suggests that all clasts may have been affected in the same way. Part of the petrological history of this meteorite must have included brecciation of a parent body, rounding of the fragments, infiltration of Fe into the clasts from an external source, mixing of the clasts with a low-Fe matrix and finally lithification. The nature of the Fe enrichment process is unknown at this time.

NEW METHODOLOGIES AND DIAGRAMS FOR UNDERSTANDING THE TEXTURAL DEVELOPMENT AND PETROLOGIC HISTORY OF GRANITOIDS AND FELSIC VOLCANIC ROCKS

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The qualitative and quantitative study of granitic textures (microstructures) has been somewhat neglected, as compared to mafic rocks, largely for methodological reasons: most major minerals in granitoids (quartz, plagioclase and K-feldspar) are colourless with low birefringence. An alternative approach is to use cold-cathode cathodoluminescence (CL). This microscope-based method easily distinguishes these three phases and can also identify alteration. Apatite, zircon and other minor phases are also imaged, but all silicate minerals that contain iron do not luminesce. A combination of CL and transmitted light images can be used to map crystals of all major phases thin sections.

Intervals along the solidification path of an igneous rock can be identified by examining the textures of crystals enclosed within later phases. Position along the path is defined loosely using a 'solidification progress parameter' which can be mapped non-linearly to both time and crystallinity (total phase abundance). Graphs of this parameter versus phase abundance and abundant crystal size range can be interpreted to estimate the profile temperature evolution during solidification. These ideas are first developed for

a megacrystic dacite lava, where solidification has been interrupted by eruption. Small plagioclase crystals are trapped with the Ksp megacrysts, showing that initial cooling to Ksp saturation was rapid. In contrast, plagioclase in the matrix has been coarsened, as has the Ksp megacrysts. A similar behaviour is seen in a megacrystic granodiorite. This begs the question as to how two phases with such different saturation temperatures are both coarsened. Perhaps temperature swings were very large or nucleation of new plagioclase crystals was absent at Ksp saturation. A granodiorite with oikocrystic, but not megacrystic, Ksp also preserves small plagioclase crystals, suggesting a somewhat similar solidification path. However, some granodiorites have dispersed Ksp, suggesting a much slower cooling path. CL images also reveal a range of intriguing qualitative observations: almost all apatite is enclosed within amphibole crystals in all felsic rocks so far examined. Plagioclase in some granitoids has a glomeroporphyritic texture, as is more commonly observed in felsic volcanic rocks. Dispersed Ksp appears to have grown initially along the faces of existing feldspar and quartz crystals and then filled in remaining spaces. Hence, the zonation of these Ksp crystals must be interpreted in exactly the opposite way to zoning of crystals in volcanic rocks.

THE OSIRIS-REX MISSION'S SAMPLING OF THE REGOLITH OF ASTEROID 101955 BENNU IS AIDED BY DEVELOPMENT OF A HYDRATED CARBONACEOUS CHONDRITE LITHOLOGIES (HCCL-1) REGOLITH SIMULANT

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Planned for launch in September, 2016, N.A.S.A.'s Origins, Spectral Interpretation, Resource Identification, Security, Regolith Explorer (OSIRIS-REx) mission will map, explore and sample near-Earth asteroid 101955 Bennu. Canada is participating in the mission via the Canadian Space Agency (CSA) contributing the OSIRIS-REx Laser Altimeter (OLA) to help map the shape of the asteroid, and funding additional investigations on the returned samples. The latter include spectral characterization and physical property determination including bulk and grain density, microporosity, elastic/seismic properties, compression and shear strengths, dielectric (relative permittivity) and magnetic properties. The CSA has also funded development of a simulant for the rock composing asteroid Bennu and its regolith known as HCCL-1. This simulant's mineralogy is based upon the composition and physical properties of the ungrouped C2 Tagish Lake meteorite; this meteorite was recovered quickly after its fall allowing better constraints on the characteristics of weak classes of hydrated carbonaceous chondrite lithologies.

The HCCL-1 simulant is composed of commercially available components: by volume 85% saponite (mixed Na, Mg), 10% magnetite, 5% charcoal, and a trace of India ink. The saponite is quarried in Montana and some minor variation in simulant density from different product lots has been found. The v. f. grained component sizes appear to help produce a relatively strong and uniform simulant. After dry and wet mixing the simulant requires ~1 month to dry (in individual lumps large enough to produce the required clast sizes), although drying time can be altered by providing minor amounts of heating and ventilation. After drying the simulant is crushed to produce more realistic clast shapes.

The bulk density and grain density range from 1.65 to 1.8 gcm⁻³ and 2.65-2.7 gcm⁻³; microporosities are 34-40%; seismic velocities are V_p 1.46-1.59 kms⁻¹ & V_s 1.0-1.05 kms⁻¹; uniaxial compression failure strengths are 22-37 MPa.

Tests of OSIRIS-REx's sampling device, the Touch-and-Go Sample Acquisition Mechanism (TAGSAM) developed by Lockheed Martin (the OSIRIS-REx prime contractor), have been done with HCCL-1 in specified size distributions largely in 1g environments, but also in microgravity environments (during parabolic flight). Based upon

desktop experiments, the macroporosity of the Bennu regolith is expected to be 40-50% similar to values observed for the lunar regolith. The simulated regolith p wave velocity is measured at ~100 m/s also consistent with that of the lunar regolith. Experiments in simulated regolith will help interpret the physical parameters of Bennu regolith as revealed by the cavity size and shape excavated by the TAGSAM.

LATE MESOPROTEROZOIC NITROGEN CYCLING AND OCEAN REDOX, ARCTIC BAY FORMATION, NUNAVUT

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Mesoproterozoic ocean redox is poorly constrained, with different sedimentary successions indicating different redox conditions, from oxic, to anoxic, to euxinic. Here, the redox state of the late Mesoproterozoic ocean is further constrained through the application of high-resolution chemostratigraphy to the ca. 1.05 Ga Arctic Bay Formation (Borden Basin), Baffin Island, Nunavut. The Arctic Bay Formation is approximately one kilometre thick, was deposited dominantly below storm-wave base, and contains abundant organic-rich shales (up to 16 wt% TOC), with interbedded siltstone and sandstone beds. Two stratigraphic sections were measured along a 150 kilometre E-W dip transect; the eastern section is interpreted as having been deposited close to the shelf break, and the western section in a basinal setting. A total of 81 shale samples were analyzed for nitrogen and organic carbon isotopes, iron speciation, Fe/Al, organic carbon content, carbonate content, and sulfur content. In the shelf-break section, $\delta^{15}\text{N}$ ranges from 0.8 to 4.8‰, and TOC ranges from 0.3 to 16.6 wt% (modal value ~1 wt%). Iron speciation data indicate oxic to ferruginous conditions. An approximately 100 m-thick interval of highly organic-rich sediments is clearly anoxic, and shows a distinct trend of increasing $\delta^{15}\text{N}$. The geochemistry of the basinal section broadly resembles that of the organic-rich interval in the shelf-break section. $\delta^{15}\text{N}$ values steadily increase from ~1.4 – 4.5‰, TOC values range from 0.3 – 16.7 wt% (modal value ~6 wt%), and iron speciation data show a transition from oxic conditions near the bottom of the section to sustained anoxic conditions. The nitrogen isotope and iron speciation trends in both sections coincide with facies variations. We identify three depositional environments with distinct redox characteristics. An upper, oxic, sub-littoral shelf environment is characterized by shallowing-upward parasequences and relatively low TOC. A more distal and deeper environment near the shelf break, is characterized by high organic carbon contents (up to 16 wt%) and little coarse siliciclastic material. We interpret this environment as an oxygen minimum zone, which likely lies at depths close to storm wave base. The deeper part of the basin was ferruginous and dominated by pelagic sedimentation with intermediate organic carbon contents (~6 wt% on average) and stable $\delta^{15}\text{N}$ of approximately 2.5‰.

GEOCHEMISTRY AND GEOCHRONOLOGY OF THE CERRO CASALE AU-CU-PORPHYRY SYSTEM, CHILE: IMPLICATIONS FOR TECTONIC EVOLUTION AND MINERALISATION

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The Casale district is located at the southern end of the Maricunga belt, near the northern boundary of the modern nonvolcanic, flat-slab region of the Chilean Andes (28-33°S), and is comprised of the

Casale, Roman, Eva, Estrella and Anfiteatro dioritic to granodioritic plutons. The Cerro Casale porphyry Au-Cu deposit (1300 Mt @ 0.7 g/t Au and 0.35% Cu) and associated potassic and phyllic alteration are all hosted in the Casale diorite porphyry.

The volcanic and intrusive rocks from the district are predominantly medium-K andesites and diorites and show a trend to increasing Gd/Yb_n ratios in younger samples. Similar trends in igneous rocks related to porphyry mineralization have been interpreted to be the result of subduction of aseismic ridges and associated slab flattening. Epsilon Nd values for the intrusive rocks are uniformly negative (-0.6 to -2.8), consistent with contamination by older crustal sources, and show a weak trend to less negative values with time. ⁸⁷Sr/⁸⁶Sr_i values range from 0.70490 to 0.70547 and increase in younger intrusions. The less negative εNd in the younger intrusions in conjunction with a slight increase in Ni contents suggests a more primitive source for the mineralizing magmas. The trend at Casale to less negative Epsilon Nd values but increasing ⁸⁷Sr/⁸⁶Sr_i suggests that the isotope systematics have been decoupled.

Laser ablation ICPMS U-Pb zircon geochronology for the granodiorite in the Casale intrusion yielded an age of 13.9 ± 1.1 Ma whereas the Casale diorite porphyry yielded an age of 14.4 ± 1.0 Ma slightly younger than the Estrella (15.0 ± 0.8 Ma) in the east and Eva (15.8 ± 0.9 Ma) porphyries in the north. Diorite porphyries from the Roman and Romancito prospects in the north, yielded older ages of 17.2 ± 0.5 and 17.4 ± 0.6 Ma, whereas diorite samples from the barren Eva (19.9 - 28.0 Ma) and Jotabeche (27.6 - 28.0 Ma) intrusions yielded older ages.

The combination of low cost geochronology and routine whole rock geochemistry provide a powerful tool for evaluating the tectonic evolution of a geologically complex terrane.

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DETRITAL ZIRCON LINEAGES IN THE ALLOCHTHONOUS YUKON-TANANA TERRANE AND PARAUTOCHTHONOUS NORTH AMERICAN BASEMENT, EASTERN ALASKA AND WESTERN YUKON

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Detrital zircon (DZ) provenance studies are a powerful tool to determine source terranes, and terrane-sediment pathways. Distinct cratonic DZ signatures and inferred pathways are herein referred to as lineages. The allochthonous Yukon-Tanana terrane (YTT) and parautochthonous North American basement (NAB) in eastern Alaska and western Yukon contain multiple Neoproterozoic through Paleozoic metasedimentary successions. Basement successions are largely Laurentia-derived and can be correlated across the Tintina fault to the Selwyn basin and cratonic sources farther into North America. However, DZ age spectra for metasedimentary rocks throughout the Yukon Tanana upland indicate multiple North American lineages, with regional implications for sediment transport pathways and recycling histories. For example, the Neoproterozoic-Cambrian Wickersham unit contains detrital zircon of 2.8-2.5 Ga and 2.0-1.7 Ga. The Fairbanks Schist is distinct from the Wickersham because it contains additional DZ age populations between 1.6-0.9 Ga. The Devonian-Mississippian Chatanika assemblage contains peaks spanning 2.7-0.9 Ga, suggesting a mixture of the Wickersham and Fairbanks DZ lineages.

Systematic DZ age determinations in metasedimentary rocks throughout the Yukon-Tanana upland are essential for determining regional provenance patterns and discriminating between allochthonous versus parautochthonous parts of the YTT tectonic collage. Geochronology is essential for mapping and geologic interpretations because many, if not most, litho-tectonic assemblages in the region contain similar lithologies, were multiply deformed and metamorphosed, and were intruded during protracted

Mesozoic-early Cenozoic magmatism. Samples of pelitic schist and meta-quartzite from the central Tanacross quadrangle yielded only Precambrian DZ, with distinctive populations between 2.6-1.8 Ga. We interpret these rocks as part of the Wickersham unit regionally and, locally, as part of the Lake George assemblage of NAB. Other samples, which are structurally separated from the Lake George assemblage by low-angle high-strain zones, have distinct 360-350 Ma DZ age populations in addition to bimodal secondary peaks at 2.8-2.5 Ga and 2.0-1.7 Ga. Because the presence of 360-350 Ma DZ age populations is a distinctive characteristic of rocks in Late Devonian-Early Mississippian assemblages of the allochthonous YTT, we interpret these rocks to belong to the same marginal basin as the regionally extensive Fortymile River assemblage. The bimodal Precambrian populations are similar to the Wickersham unit signature found in the Lake George assemblage, suggesting that allochthonous and autochthonous assemblages share similar lineages because 1) both are derived from the same Laurentian sources and/or 2) autochthonous basement assemblages were recycled into younger allochthonous successions during rifting of the YTT from northwestern Laurentia.

BORON, CARBON, AND OXYGEN ISOTOPE COMPOSITIONS OF CARBONATITES FROM WORLDWIDE SOURCES

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The origin of carbonatites and their associated alkaline silicate rocks has been linked to metasomatized upper mantle sources and related to mantle plume activity. However, the exact origin (lithospheric or asthenospheric?) of the carbon contained within mantle-derived carbonatite melts is still under debate. Previous radiogenic isotope investigations (Nd, Sr, and Pb) of young (<200 Ma) carbonatites share affinities with oceanic island basalts (OIBs), which indicate derivation from a sub-lithospheric mantle source. It is well documented that the global boron geochemical cycle is closely tied to recycling of geological material via subduction processes. Therefore, it is hypothesized that investigation of boron isotope systematics of carbonatites will aid in testing for a recycled component present in carbonatite magmas; this provides a unique way of evaluating their mantle sources. In this study, carbonatite samples from 12 different worldwide localities have been analyzed for their stable C and O isotope ratios and for the first time, boron (B) isotope compositions. Carbonatites investigated here span a wide range of emplacement ages (~40 Ma to ~2600 Ma old), and therefore provide insight into the temporal evolution of their mantle sources. Prior to B isotopic analyses, detailed petrographic examination of each sample was conducted, which also included micro-XRF chemical imaging to ensure crystal pristinity and lack of hydrothermal and/or low-temperature alteration. δ¹³C and δ¹⁸O (‰) values define a restricted range and overlap with the fields for primary mantle carbonatites and the "mantle box" (based on OIBs), which confirm the lack of subsolidus alteration. B abundances were also determined in the carbonatites investigated here and these range between 0.04 and 2.0 parts per million (ppm), well within the range reported for mantle-derived rocks. δ¹¹B values for the carbonatite samples define a large range between +5.5‰ and -8.6‰. These seem to define a bimodal distribution: one group is characterized by more negative δ¹¹B values (< -4.0‰), which suggests derivation from typical asthenospheric (depleted) upper mantle source, whereas samples belonging to the second group record more positive δ¹¹B values (> -4.0‰) and indicates involvement of subducted (crustal) material. The latter may be sampled by carbonatite melts associated with mantle plume activity, and their corresponding emplacement ages coincide with major tectonic events in Earth's history; these may be linked to episodes of supercontinent formation and consequently significant periods of subduction at a global scale.

THE YUKON PERIGLACIAL LANDFORM ATLAS AND THE USE OF ESRI STORY MAPS TO INCREASE NORTHERN LANDSCAPE GEO-LITERACY

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The Yukon Periglacial landform atlas is an online web-atlas of periglacial landforms created with the goal of increasing understanding of the distribution, development and processes impacting cold climate landforms. The website is an online portal that combines authoritative maps with narrative text, photographs and references to the scientific literature surrounding cold climate landforms in Yukon for academia, K-12 teachers and the public. The webpage utilizes the visually appealing ESRI Story Map medium; a web mapping application built using ESRI's ArcGIS Online platform. One of the advantages of this platform is that its structure enables the inclusion of material that can appeal to a breadth of users from professionals & senior undergraduates to elementary school students. With the proper data, Story Maps can be deployed within hours to days. This presentation will give an over-view of the resources available to build ESRI Story Maps and will take the audience along on a small tour across Yukon of various landforms from the atlas.

INTER AND INTRA SITE PATTERNS OF THE LATE PLEISTOCENE FAUNA FROM LITTLE JOHN (KdVo6), A MULTI-COMPONENT EAST BERINGIA SITE IN YUKON TERRITORY, CANADA

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The Little John site holds an extensive record of human occupation spanning 14,000 years ago to the most recent past. Due to a combination of taphonomic factors, the Late Pleistocene deposits are particularly rich in culturally modified faunal remains related to the subsistence economy of the founding and early human occupants of the upper reaches of the Tanana River Valley of interior Alaska and Yukon through the Bolling-Allerod, Younger Dryas, and Milankovich Thermal Maximum climatic periods. In this presentation we report on the current results of our analyses of the Little John fauna, including identified species and element distribution, evidence of taphonomic and cultural modification, and apparent changes in subsistence through time at the site within the context of the dynamic climatic fluctuations of the Late Pleistocene – Early Holocene transition. We conclude with a comparison of the Little John fauna with faunal remains from a set of contemporary Late Pleistocene sites in East Beringia.

CONTROLS ON LABERGE GROUP RESERVOIR DISTRIBUTION AND QUALITY, NORTHERN WHITEHORSE TROUGH, YUKON

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The Whitehorse trough is an Early-Middle Jurassic synorogenic marine basin that overlaps the Intermontane terranes in the northern Cordillera of Yukon and British Columbia. It is prospective for hydrocarbons, predominantly gas, but lacks systematic petroleum system studies (except for source rock potential) due to an absence of industry activity and limited survey fieldwork. Current work is focused on quantitative reservoir characterisation of coarse-grained, marginal marine Laberge Group sandstones in the north of the basin. In addition, a conceptual evolutionary model for axial deposition of the Laberge Group has been developed from reconnaissance observations and the literature to aid interpretation of these reservoir data.

Conceptually, the Whitehorse trough evolved from a high shelf-basin relief (SBR) margin with a high accommodation/sediment supply (A/S) ratio to a low SBR margin with a low A/S ratio during shoaling and oroclinal closure of the Cache Creek 'ocean' in the Middle Jurassic. Depositional processes and environments in the northern part of the trough were predicted for both margin models using coastal morphology classification matrices, paleogeographic interpretations and Jurassic wind directions. Modelling suggests that these proximal Laberge Group sandstones were deposited primarily during the low SBR, low A/S regime by tidal-dominated and fluvially-influenced coastal processes.

High-resolution grain size logs from outcrop and coal-exploration borehole cores indicate an average net/gross ratio of 52% for Laberge Group strata in the northern trough. Average plug porosities (3.9%, range 0.7-10%) and permeabilities (K_{max}: 0.32mD, range 0.003-3.75mD; K_v: 0.13mD, range 0.003-3.16mD) are low. Net/gross ratios and conglomerate proportions decrease down depositional dip to the south, however both porosity and permeability (especially K_{max}) increase, although most data typically fall within 'tight gas play' petrophysical parameters. A strong diagenetic constriction on pore throat diameter is hypothesised for these coarser northern facies, and thin section, XRD and SEM analytical data are forthcoming with which to test this.

Outcrop-scale intra-reservoir barrier/baffle thickness and frequency increases to the south, and is reflected in plug-scale average K_v/K_{max} ratios that indicate increasing permeability anisotropy down depositional dip. Reservoir sandstones in these less proximal, coal and shale-bearing coastal plains that characteristically develop during shoreline progradation and aggradation on a low SBR margin, although heterogeneous, will exhibit better horizontal fluid flow potential than those to the north.

LOWER CRUSTAL FLOW AND DETACHMENT IN THE NORTH AMERICAN CORDILLERA: A CONSEQUENCE OF CORDILLERA-WIDE HIGH TEMPERATURES

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I make the case for widespread lower crustal flow and detachment in the North American Cordillera that result from Cordillera-wide high temperatures, and discuss some of the consequences. Accumulating seismic structure data show the surprising result that the crust is thin and the Moho flat in most of the Cordillera in spite of a complex history of normal faulting, shortening deformation, and terrane accretion. It has been previously concluded that the high elevations result from thermal expansion due to Cordillera-wide high temperatures, not a crustal root. I now argue that the constant crustal thickness and flat Moho result from lower crust flow associated with the high temperatures. Lower crust flow is inferred for Tibet and high Andes where the crust is thick, and in the Basin and Range of western US where high temperatures are inferred to result from ongoing extension. However, there are now adequate thermal constraints to show that most of the Cordillera is uniformly hot in common with other backarcs, 800-850°C at the Moho, and seismic structure data to show the crust in most of the Cordillera from Mexico to Alaska is uniformly thin, 33±3 km, with a remarkably flat Moho. The uniform crustal thickness results from flow in the hot weak lower crust. The backarc Moho can be viewed as almost 'liquid' lower crust over low-viscosity upper mantle. The Moho boundary relaxes to a nearly-horizontal gravitational equipotential over a few 10s of m.y. The high temperatures in the Cordillera and other backarcs are concluded to be due to small scale convection in the shallow, 60 km, asthenosphere from viscosity reduction by water from the dehydrating current or past subducting plate.

Some of the important consequences include: (1) Stress can be transferred long distances across the whole Cordillera through just the upper crust. For example, the current Yakutat terrane collision results in seismically active thrusting in the Mackenzie Mountains

800 km to the east. (2) In southeastern BC, the Cordillera upper crust has overthrust the strong adjacent craton in the Rocky Mountain fold and thrust belt; detachment in the Cordillera weak lower crust joins the thrust belt basal detachment over the craton. (3) The upper crust of oroclines such as Johnson's Cordilleran Ribbon Continent and Great Alaska Terrane Wreck likely move independently of the upper mantle. (4) Significant mountain belt elevations within the Cordillera backarc last only a few 10s m.y. unless maintained by ongoing slow shortening.

DEEPLY CHanneled PRECAMBRIAN RIVERS DEPICTED IN THE 1.9 Ga BURNSIDE FORMATION OF KILOHIGOK BASIN (NUNAVUT, ARCTIC CANADA)

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We present outcrop evidence for deeply channeled fluvial drainage in the 1.9 Ga Burnside River Formation of Kilohigok Basin (Nunavut, Arctic Canada), a feature that contrasts with the dominant sheet-like geometry observed in many ground-based studies of Precambrian fluvial sandstones. In the Burnside River Formation, sheeted sandbodies with ubiquitous cross-bedding observed at the outcrop scale are at first consistent with classic, unconfined depositional models. However, satellite and oblique-aerial imagery of sections up to 15 km wide and 500 m thick reveals the occurrence of incised paleovalleys hosting clustered, km-scale, channel bodies with attached large foreset bars, sand sheets with width to thickness ratio > 2500, and scattered eolian intervals. The association of these architectural elements points to the coexistence of fluvial piedmonts generated by braidplain channels, at time wind-winnowed, and weakly-sinuuous channel belts up to 25 m deep. Channel geometries comparable to those of late Paleozoic to modern braided channels disprove the inference that all Precambrian streams readily widened in response to increased discharge.

The current facies models for large-scale Precambrian sheet-dominated fluvial sandstones did not include large channel forms because the latter could not be resolved by ground-based observations alone. Based on the abundance of architectural elements with very high width to thickness ratio, and on their limited geomorphic variability in fluvial style, we recommend that large sheet-braided fluvial systems should still be considered a separate entity from post-Silurian (i.e., vegetated) and modern braided rivers. Parallels between sheet-braided and modern dryland rivers do not reconcile with the deep and perennial channelized morphodynamics evident from the Burnside River Formation. On the other hand, the distal and sand-bed reaches of modern humid sandur plains bear possible analogies to Precambrian sheet-braided rivers. This conclusion contradicts the assumption that all Precambrian rivers simulated seasonal behaviors independently from their original climate regime.

A NEW MODEL FOR THE STRUCTURAL-STRATIGRAPHIC CONTROL OF VEIN-FAULT MINERALISATION AT KENO HILL, YUKON

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The Keno Hill Silver Mining District is located in the northwestern part of the Selwyn basin in sedimentary rocks that underwent deformation and metamorphism to lower greenschist facies during the Middle Cretaceous. Silver-lead-zinc mineralisation is located within fault-hosted veins situated within the lower member of the Mississippian Keno Hill Quartzite, the Basal Quartzite Member. Despite the long history of mining here, the ore controls have never been well understood. The scientific understanding of the mechanics of fault development have advanced within the last few decades, along with the emergence of 3D modeling capabilities, this has permitted the application of new concepts to the district and to a new interpretation of the structural-stratigraphic ore controls at Keno Hill.

This study applies current concepts of fault growth, especially within mechanically heterogeneous host lithologies, to the structural geometries observed at Keno Hill. 3D modelling of vein-fault surfaces shows that they are highly non-planar, and that wide vein mineralisation is located on steep dipping and more northerly striking fault elements. Therefore, understanding the specific cause of acute variations in strike azimuth and dip along fault surfaces at Keno Hill is potentially important in targeting future exploration.

At Keno Hill, the non-planar geometry displayed by the vein-faults reflects the fundamental process of their development through the growth of incipient Riedel shear arrays and their subsequent linkage. This process repeats at different scales and is strongly influenced by the mechanical properties of the host stratigraphy. Lithological competency variations cause a vein-fault to develop as a series of stacked, stratigraphically-bound arrays, where array geometries vary from level to level depending on the thickness and gross strength of their host lithologies. Continued deformation eventually necessitates the linkage of arrays to form larger, through-going, composite faults. It is a mechanically heterogeneous stratigraphy at Keno Hill that controls the location and geometry of initial fault segmentation, later linkage, and a resultant highly non-planar fault surface, which in turn controls the location of dilation, fluid flow and mineralisation. The model presented here may be used as a predictive tool in district mineral exploration, and is likely applicable in other similarly hosted vein-fault deposits.

LATE CRETACEOUS ARC DEVELOPMENT AND IMPLICATIONS FOR INTRUSION-RELATED MINERALIZATION IN THE NORTHERN CORDILLERA

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Early Late Cretaceous (79-74 Ma) magmatism and related mineralizing systems are well characterized in western Yukon (e.g. Casino; Sonora Gulch; Nucleus/Revenue; Klaza); however, this age of magmatism was previously thought to be spatially and volumetrically restricted. Newly identified Late Cretaceous plutonic and volcanic rocks as well as newly dated rocks that were previously assigned either mid-Cretaceous or Paleogene ages in southwest Yukon significantly increase the areal extent of this magmatism and the potential for intrusion-related mineralizing systems.

Existing data suggests that a magmatic arc was built upon the Yukon-Tanana terrane in southwest Yukon, east-central Alaska, and northwest British Columbia. The arc was the response of east/northeast (today's coordinates) dipping subduction between ca. 79-74 Ma.

A limited amount of deformation and erosion of the arc has occurred since the Late Cretaceous in central, southwestern Yukon and Alaska; however, igneous rocks of the same age along strike to the south are generally gneissic and are interlayered with strongly deformed and metamorphosed rocks. Much of the known early Late Cretaceous mineralization in west-central Yukon is considered to be intrusion-related (i.e., porphyry, epithermal) and as such indicate a relatively shallow depth of emplacement and little post intrusion deformation. The presence of gneissic textures and structural interlayering with metamorphic rocks suggests either a change in depth of emplacement, accompanied by deformation occurred that was not seen in the main centre of the arc, or a significant amount of post-Late Cretaceous deformation affected this portion of the arc.

A strong structural control appears to be important in the spatial distribution of the mineralizing plutons, as exhibited by northwest alignment of many of the mineral systems and their associated intrusions. Several large northwest striking structures appear to control the location of mineralization, including the Big Creek and Serpent Head Lake faults. These structures are seldom observed at surface but are clearly identified in new geophysical surveys and models.

The 79-74 Ma arc appears to follow the overall northwest Cordilleran trend into eastern Alaska where plutons and volcanic rocks of this age become scarce, likely due to extensive Quaternary cover in the Yukon-Tanana Uplands. Late Cretaceous ages once again appear in Alaska along a southwest trend west of Anchorage (e.g. ~76 Ma Whistler porphyry). Restoration of 400 km of dextral offset along the Denali fault aligns the Yukon trend and southwestern Alaska trend suggesting there is continuous Late Cretaceous magmatism greatly enhancing the mineral potential for intrusion related systems within Yukon and Alaska.

THE LEECH RIVER COMPLEX – A CRETACEOUS ACCRETIONARY WEDGE ON SOUTHERN VANCOUVER ISLAND

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The Leech River Complex (LRC) on southern Vancouver Island is part of the Pacific Rim Terrane of the North American Cordillera. In the Port Renfrew area it comprises mylonitic tightly folded black schists and meta-sandstones of the Leech River Schist (LRS), which underthrust meta-mudstones, ribbon cherts, and meta-volcanics of the Pandora Peak Unit. The onset age of LRS deposition is unknown but deposition continued until after 103 Ma. Subsequently the LRC was buried, metamorphosed at greenschist-amphibolite facies conditions, and truncated by the 88 Ma Jordan River Metagranodiorites and the 51 Ma and Walker Creek Intrusives.

We suggest that the LRC in the Port Renfrew area represents the vestiges of a Cretaceous accretionary wedge. The cataclastic mylonites of the LRS formed during frontal accretion and underthrusting of water-rich and only poorly consolidated mudstones and sandstones beneath an already active Pandora Peak Unit accretionary wedge. LRS development marks an important change in sediment-influx in the middle Cretaceous. Similar successions have been reported from several localities along the northwestern margin of the Cordillera, e.g. the Chugach accretionary wedge in Alaska, and may reflect uplift of the hinterland related to the collision of the Insular and Intermontane terranes.

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CONTRASTING GLACIAL DISPERSAL PATTERNS OF TWO KIMBERLITE INDICATOR MINERAL TRAINS, LAC DE GRAS REGION, NWT

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In the diamondiferous area of Lac de Gras, despite significant exploration, a number of known dispersal trains still have no identified source, highlighting the local glacial complexity. New innovative techniques and additional knowledge about the local glacial geology are needed to advance exploration efforts. The purpose of this study is to investigate the surficial geology and dispersal patterns of kimberlitic material. Our study compares the Monument indicator mineral train that has a known source, with the Coppermine indicator mineral train which is currently lacking a known source. This research focuses on reconstructing dispersal patterns using till geochemistry and kimberlite indicator minerals (KIMs) in the Coppermine area to the west of Lac de Gras. Our study uses till samples retrieved from reverse circulation (RC) boreholes as a means to delineate dispersal patterns at depth in addition to traditional two dimensional mapping techniques. In total, 52 boreholes have been drilled that range in depth from 1.1 m to 25 m with a median depth of 3.6 m. The sediment samples are recovered in 1.5 m intervals. This technique captures compositional variations in the subsurface left from older ice

flows and sediment re-entrainment processes on the formation of dispersal trains. In addition to the results from the drilling program, we also integrate publicly available data from NTGS GoData online open database. This collection contains the Kimberlite Indicator and Diamond Database (KIDD), as well as the Kimberlite Indicator Mineral Chemistry database (KIMC).

Through identifying the geochemical and KIM signature in both the surface and in the subsurface we can characterize the dispersal plume in three dimensions. Comparing and contrasting the geochemical and KIM compositional signatures of the Monument and Coppermine trains will determine if a genetic similarity exists, indicating either similar or dissimilar sources. Furthermore, this comparison will enhance our understanding of the complex depositional history and processes that most influence the shape and dispersal of the indicator mineral trains.

HYDROTHERMAL CASSITERITE OF THE LATE-VARISCAN SN-POLYMETALLIC “FELSITZONE” MINERALIZATION, GROSSSCHIRMA, FREIBERG MINING DISTRICT, ERZGEBIRGE, GERMANY

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The Sn-polymetallic “Felsitzzone” mineralization of Großschirma is situated in the northern part of the Freiberg mining district. The mineralization is hosted by metamorphic rocks of the “Preßnitz Group”, consisting predominantly of two-mica gneisses and mica schists and is characterized by intercalations of amphibolites and muscovite gneisses (meta-rhyolites). All metamorphic units are deformed by several NE-SW striking fault zones.

Applying whole-rock geochemistry, light microscopy, and SEM-MLA of selected drill core samples from Großschirma, we show that the “Felsitzzone” mineralization is structurally controlled. Hydrothermal Sn-bearing fluids migrated within shear and breccia zones that developed primarily at the contact between gneisses and meta-mafic rocks. These zones are characterized by a strong pervasive metasomatic alteration with replacement of rock-forming minerals by ore and gangue minerals.

Bulk geochemistry of samples from shear and breccia zones indicates the metasomatic alteration with grades up to 0.28 wt. % Sn, 0.15 wt. % Cu, 300 ppm Pb, 140 ppm Zn, 1.1 wt. % F, 250 ppm Li, 820 ppm Rb, 90 ppm Cs, and 130 ppm W.

Three different mineralization stages can be distinguished within these altered zones. Fine-grained Fe-rich chlorite and quartz as well as some cassiterite, fluorite, rutile, apatite and scheelite are associated with the first mineralization stage. Cassiterite might be occurred in two generations: acicular (1-100 µm) and isometric cassiterite (50-650 µm). The second stage is characterized by large amounts of pyrite, while marcasite, chalcopyrite, pyrrhotite, galena, sphalerite, arsenopyrite, and bismuthinite appear only subordinately. The third one is dominated by different carbonates and fine-grained Fe-oxides.

The LA-ICP-MS trace element composition of selected isometric cassiterite grains comprises of 0.5 wt. % Fe, 0.1 wt. % Ti, 730 ppm W, 140 ppm V, 60 ppm In, 50 ppm Zr, 40 ppm Mn, 25 ppm Ga, 15 ppm Nb and 1 ppm Ta. Higher Fe in addition to very low Nb + Ta contents indicate a hydrothermal origin of these cassiterites (in relationship to pneumatolitic cassiterites, e.g. Ehrenfriedersdorf). Enriched Fe, Ti and W concentrations infer that the “Felsitzzone” cassiterites likely belong to a cassiterite-sulfide paragenesis.

An enrichment of Sn, F, Li, Rb, Cs and W suggests a genetic link between the Sn-polymetallic “Felsitzzone” mineralization and the late-Variscan Sn-W association, which is common in the Erzgebirge. The origin of the ore-forming fluids remains unexplained. They might be associated with several rhyolitic dikes in the Halsbrücke area that are probably related to larger late-Variscan granitic intrusions in the Erzgebirge.

TECTONO-METAMORPHIC EVOLUTION AND GEOCHRONOLOGICAL CONSTRAINTS OF THE PRE-ATHABASCA BASEMENT WITHIN THE WOLLASTON-MUDJATIK TRANSITION ZONE, SASKATCHEWAN

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The Paleoproterozoic tectono-metamorphic evolution of the pre-Athabasca basement (~1.7 Ga) within the Wollaston-Mudjatik Transition Zone (WMTZ), and the timing of this evolution has been characterized using both exposed basement, in the Cochrane River area and along the shores of the Wollaston Lake, as well as drill cores from the Wolly-McClean exploration drilling project located in the eastern part of Athabasca Basin. The main goal is to better understand the role of the basement in the formation of the unconformity-type uranium deposits of the Athabasca Basin.

The finite ductile strain pattern of the WMTZ results from the superposition of two tectono-metamorphic events M₁-D₁ and M₂-D₂. M₁-D₁ is associated with the development, at ca. 1.81 Ga, of a gently-dipping foliation striking N90°-100° and a southwestward decrease in peak pressures from up to 10 kbar in the Cochrane River area down to 6 kbar in the Wolly-McClean exploration drilling project. These M₁-D₁ features are interpreted as the consequence of the burial, via southward thrusting during the early collision stage of the Trans-Hudson Orogen, and the formation of a thrust stacking wedge in which Archean granitic gneiss typical of the Mudjatik Domain alternates with Paleoproterozoic Wollaston Group metasediments. M₂-D₂, occurring between ca 1.79 and 1.77 Ga, is responsible for the main northeasterly structural trend of the WMTZ that developed in a sinistral transpressional tectonic regime during the final oblique collision of the Trans-Hudson Orogeny. Thermobarometric estimations on M₂-D₂ assemblages show that the WMTZ in the studied area re-equilibrated at about 4 to 5 kbar and 750-825°C. This pre-Athabasca basement has thus been affected by a differential isothermal decompression event between D₁ and D₂ that allowed the juxtaposition of the deepest north-eastern areas (Wollaston Lake and Cochrane River) and the Wolly-McClean exploration drilling project area, at the same structural level corresponding to a depth of 12-15 km.

These structural and thermobarometric results suggest that the basement exposed to the north-east of the Athabasca Basin is not a direct analog of the basement located beneath the eastern Athabasca Basin where uranium-enriched granitic pegmatites and granites are known, although similar lithologies are observed. We also suggest that uranium-enriched melt produced beneath the present eastern Athabasca Basin during the early M₁-D₁ stage of partial melting (ca. 1.81 Ga) in the deep crust was transferred to the mid-crust, thanks to D₂ shear zones, where it differentiated to produce uranium-bearing pegmatites.

MARINE ISOTOPE STAGE 5 SEDIMENTARY RECORDS ACROSS EASTERN BERINGIA

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Marine Isotope Stage (MIS) 5e, the period of peak warmth during MIS 5 often referred to as the last interglacial, is the focus of many research studies in eastern Beringia. However, outside of the Klondike, there has been little recognition of the breadth of MIS 5, sensu lato, including younger MIS 5 sedimentary records from other substages. While deposits in the central Yukon clearly attributable to MIS 5e are less common and MIS 5a deposits are more abundant,

virtually all published sites in interior Alaska document only MIS 5e. Sites describing both MIS 5e and 5a are even more limited; the White River site in SW Yukon and Togiak Bay in SW Alaska are two rare examples. Recent developments in MIS 5 teprostratigraphy combined with re-examination of magnetic susceptibility records in interior Alaska show that younger MIS 5 deposits are likely more common than previously recognized. For example, the discovery of Sheep Creek-Klondike and Dominion Creek tephras, both MIS 5a marker horizons, at the Halfway House site near Fairbanks shows that paleosols previously attributed to the mid-Wisconsinan are from MIS 5a. Re-assessment of the site shows strong paleosol development during MIS 5e and 5a, with loess accumulation during MIS 5d, but little loess deposition or soil formation in MIS 5c or 5b. This pattern of deposition and soil formation can be correlated to other Alaskan sites through magnetic susceptibility. Tephra records identify a similar sedimentary sequence at White River and into the Klondike: if present, MIS 5e is generally a thaw unconformity overlain by silts deposited during MIS 5d, and a prominent MIS 5a thaw unconformity or vegetation accumulation overlies MIS 5d with limited expression of MIS 5b/5c. The strong relations between glacial silt production and loess sedimentation suggests that the widespread evidence of loess accumulation during MIS 5d could result from greater ice-extent during this time relative to MIS 5b. This is in contrast to inferences from other sedimentary and paleoenvironmental archives in Europe that support more intense glaciation during MIS 5b. The lack of paleosol development or thaw unconformities clearly attributable to MIS 5c suggests a cooler climate over this period compared with MIS 5e or 5a. Overall, careful re-examination of MIS 5 sedimentary records in Yukon and Alaska in light of improved chronologies offers the opportunity for new insights into orbital-scale climate variations and their regional expression in northern Canada and Alaska over this time period.

CAN STRUCTURALLY CONTROLLED HOT AQUEOUS FLUIDS PRODUCE THE STEEP METAMORPHIC FIELD GRADIENTS FOUND IN HTLP REGIONAL AUREOLES? EVIDENCE FROM WONGWIBINDA, NSW, AUSTRALIA

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The Wongwibinda Metamorphic Complex is located in the Carboniferous accretionary prism of the New England Orogen, the youngest of a series of orogens that comprise the Tasmanides of eastern Australia. Metasedimentary rocks ranging in grade from biotite facies to migmatite are associated with a wide zone of ductile shearing and S-type granitoids.

A recently mapped, structurally separated, block west of the main complex reveals a steep metamorphic field gradient (>70 °Ckm⁻¹) along the Aberfoyle River. The well-exposed metasedimentary rocks progressively increase in metamorphic grade from biotite- to garnet-cordierite-bearing rocks over a traverse of approximately 2 km. The Aberfoyle transect lacks the intrusive rocks that are common elsewhere in the complex.

Evidence for the role of hydrous fluids in the metamorphism is provided by whole rock XRF and isotopic analyses of samples from the Aberfoyle transect. There is strong positive correlation between metamorphic grade and potassium content, ⁸⁷Sr/⁸⁶Sr and δ¹⁸O. In contrast, there is a negative correlation between grade and sodium content, calcium content and ¹⁴³Nd/¹⁴⁴Nd.

Higher-grade rocks of the main complex are exposed approximately 14 km further east in a second steep metamorphic field gradient that builds to metasedimentary migmatites. The migmatites are spatially associated with a broad shear zone. Garnet and/or cordierite surrounded by leucosome in metasedimentary rocks and abundant dykes and small bodies of two-mica granite suggest that anatectic melt formed in situ and was also injected into the migmatite. Muscovite-bearing granite is consistent with high water contents and links to the influx of hot aqueous fluids inferred in

the Aberfoyle transect. Abundant collapse structures trace magma pathways through the migmatite.

The mechanisms of heat advection at Aberfoyle and in the migmatites of Wongwibinda are interpreted to be part of a continuum. The source of fluid is proposed to derive from the first metamorphic cycle of the accretionary complex of the New England Orogen during crustal thinning caused by subduction roll-back. Early metamorphic fluid produced in the deeper accretionary complex is channelled up fault zones, advecting heat to shallower crustal levels. As metamorphism in the deep crust progresses, partial melts produce S-type magma that migrates up the same channels, further advecting heat. The decreasing availability of water in the deep crust as metamorphism progresses self arrests the system, resulting in short-lived (<10 m.y.) metamorphism in the shallow crust that produced steep metamorphic field gradients of narrow extent.

LITHOSTRATIGRAPHIC AND STRUCTURAL CONTROLS OF URANIUM MINERALIZATION IN THE KIGGAVIK EAST, CENTRE AND MAIN ZONE DEPOSITS, NUNAVUT

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The Kiggavik uranium (U) deposits are located in the central part of the Rae subprovince, approximately 80 km west of Baker Lake, Nunavut, and are primarily owned by and operated by AREVA Resources Canada Inc. The deposits are hosted in highly-deformed Archean and Paleoproterozoic rocks proximal to, and underlying, the Thelon Basin. The tectonic history of these rocks is remarkably protracted and complex, extending from the Archean (2.8 Ga) to the Mesoproterozoic (1.5 Ga). This complexity has led to uncertainty regarding the affiliation of rock units and the controls on U mineralization at Kiggavik. The aim of this study is to better determine the lithostratigraphic and overall structural relationships of rocks hosting the Kiggavik East, Main, and Centre Zone deposits.

In 2015, detailed drill-core investigation and mapping around the Kiggavik East, Main, and Centre Zone deposits reaffirmed the presence of <2.7 Ga metasedimentary rocks of the Archean Woodburn Lake group (WLg), ~2.6 Ga metavolcanic rocks of the Snow Island Suite (SIS), and quartzite belonging to the early Paleoproterozoic Ketyet River group (KRg). Further, this study revealed that an unusual unit of metavolcaniclastic rocks, inferred to be of epiclastic origin and part of the SIS suite, is more extensive than previously thought. This unit occupies intervals up to 100 m thick and appears to be a major host of U mineralization.

Drill-core investigation in the Kiggavik East area also verified that the KRg quartzite, and other rock types define a homoclinal sequence of alternating gently NNW-dipping units. Assuming that regional age/stratigraphic relationships are correct, there are numerous down-hole younging direction reversals, suggesting that these repetitions are tectonic. A tectonic origin is also supported by the ubiquitous strong transposition of primary bedding and highly-strained contacts parallel to foliation as well as the presence of ENE-trending mesoscopic-scale isoclinal recumbent folds. The current geometry of these units is therefore attributed to regional-scale early ductile D₁ or D₂ structures with nappe folding along a décollement, with possible local over-thrusting of the basement WLg. The degree of control of the U mineralization by older ductile structures versus younger brittle structures remains unclear. For example, while mineralization is localized in part along early ductile contacts, especially in the epiclastic unit where it is next to the quartzite, it also bears a close spatial relationship to larger regional-scale brittle structures (ENE- and NE-trending faults). Future study will be aimed at better determining these respective controls.

LITHOTECTONIC ASSOCIATIONS OF THE LADUE RIVER UNIT AND IMPLICATIONS FOR THE STRUCTURE OF THE YUKON-TANANA TERRANE BOUNDARY IN EASTERN ALASKA

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The Ladue River unit (LRu), mapped across >750 square kilometers in the Tanacross quadrangle of eastern Alaska, was originally correlated with the Permian Klondike assemblage of western Yukon, Canada. The Klondike assemblage, comprising metavolcanic rocks and co-magmatic plutons (now schist and orthogneiss), is a well characterized regional litho-tectonic unit of the allochthonous Yukon-Tanana terrane (YTT). The Klondike assemblage is economically important as the primary lode source for placer gold in the Klondike district. Despite its regional significance, correlation of the Klondike with the LRu remains uncertain, and published map compilations show the two units in abrupt contact along the international border. Recent studies of the LRu in eastern Alaska provide a critical test of cross-border correlations. Limited, discontinuous LRu exposures include quartz-mica schist, locally Cr-rich chlorite schist, biotite schist, and amphibolite. Along the Alaska-Yukon border, LRu exposures are mostly chlorite schist distinguished by abundant euhedral magnetite crystals up to 1 cm. We interpret these rocks as Klondike assemblage on the basis of lithologic similarities and structural data consistent with published mapping in the westernmost Stewart River quadrangle, Yukon Territory. Other LRu exposures to the west are more lithologically heterogeneous, and detrital zircon ages from quartzose schist are more consistent with rocks of the Late Devonian to Early Mississippian Fortymile River and Finlayson assemblages of Alaska and Yukon, respectively. Thus, we interpret much of the LRu to be correlative with the Fortymile River assemblage and not the Klondike. Geochemical data that will help to test these interpretations are forthcoming. The entire LRu overlies broad areas of coarse-grained to K-feldspar-megacrystic augen gneiss with shallowly dipping foliation. Multiple augen gneiss samples yield consistent Late Devonian U-Pb zircon ages, suggesting that they are part of the Lake George assemblage of the parautochthonous North America basement. The contacts between the LRu exposures and underlying Late Devonian orthogneiss are generally low-angle with pervasive mylonite and abundant quartz veins up to a half meter thick. We interpret LRu exposures to represent thin (up to a few hundred meters as exposed) structural panels of allochthonous YTT assemblages--both Fortymile River and Klondike--that were emplaced on top of more deeply exhumed Late Devonian basement assemblages. These structural panels are volumetrically small and record predominately high-temperature, ductile deformation and associated metamorphism, in contrast to lower-temperature thrust sheets of similar assemblages exposed in the Klondike district to the northeast.

USE OF ACTIVE TEAM-BASED LEARNING IN THE GEOPHYSICS CLASSROOM: A CASE STUDY

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A primary goal in the science classroom is to develop inquiry skills that will have value beyond the scope of an individual course. The traditional lecture format, while an efficient means for summarizing discipline-specific facts and theories, is deficient in developing such skills, and does not necessarily incorporate assessment of whether students develop inquiry skills outside of the classroom. Active team-based learning in the classroom is a research-supported approach that is at least as effective as the lecture format at delivering core course content, but much better at developing inquiry skills. Use of team-based activities also improves students' engagement and ability to communicate their understanding with their peers. This

talk presents a case study of the use of active team-based learning in a senior undergraduate geophysics course on potential field (gravity and magnetic) survey methods. Core course content delivery used a blend of course notes prepared by the instructor, online lecture videos, textbook readings and links to supporting online resources. Students reviewed the background material prior to classroom activities, where they would solve inquiry problems based on the content in teams. Assessment of understanding occurred weekly using a pair of Readiness Assurance Tests (RATs). At the end of each module, the students completed the RAT individually and immediately afterward as a team. In addition to the individual quiz results, weekly peer assessments evaluated preparedness and contribution to the team RAT. Comparison of the data from the paired RATs demonstrates statistically significant improvement in performance following the team-based discussion. In addition, frequent data on student performance allowed the instructor to focus in-class discussions on the most challenging concepts. Student feedback indicates that the team-based activities improved engagement in the classroom and developed both deeper understanding of the course content and communication skills. The talk will include examples of course materials comprising a typical module along with demonstrative individual and team performance on the RATs. The presenter will also discuss both perceived and real challenges involved in using this approach compared with a traditional lecture format.

DISTRIBUTION AND CHARACTERIZATION OF AREAS THAT HAVE POTENTIAL FOR Sn-W-Ta AND REE-U-Th-Nb MINERALIZATION IN ALASKA: IMPLICATIONS FOR METALLOGENESIS

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Areas in Alaska that have potential for Sn-W-Ta and REE-U-Th-Nb mineralization are associated with magmatic belts that include both peraluminous and alkaline granites. The granites are similar in age and isotopic signature (Sr and Nd), but vary in composition. Peraluminous phases contain elevated Sn-W-Ta concentrations, and alkaline phases contain elevated REE-U-Th-Nb concentrations. A geographic information system (GIS)-based analysis using lithology, geochemical, mineral occurrence, and geophysical databases for identifying areas that have potential for high concentrations of these elements in association with igneous rocks was applied to Alaska. Datasets were ranked according to selected parameters, and the scores were projected on maps using ArcGIS to show inferred potential for the two deposit groups across Alaska. Areas identified by this analysis coincide with known mineralized areas such as the Seward Peninsula, the Hogatza belt, the Kokrine-Hodzana belt, the Kuskokwim Mountains belt, the Alaska Range, and the Coast Mountains; this analysis also identified new areas in the Yukon-Tanana uplands and the western and northern Alaska Range that have potential for mineralization. In addition, this approach demonstrates that potential granitic hosts of Sn-W-Ta and REE-U-Th-Nb deposits spatially overlap within the magmatic belts that underlie these areas. The co-location of the two deposit types associated with distinct compositions of similar-aged fractionated granites within these magmatic belts suggests a common geologic setting. Host rocks to these magmatic belts consist of Paleozoic volcanic rocks and sedimentary rocks containing detrital zircon populations that include Proterozoic and Archean ages, suggesting that they were deposited in continental margin settings. The distribution and ages of the mineralized magmatic belts correspond to the location of inferred arcs of Mesozoic to Early Cenozoic age. Previously published initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratios ranging from 0.7055 to 0.7235, initial $^{143}\text{Nd}/^{144}\text{Nd}$ ratios ranging from 0.51150 to 0.51232, and low to moderate $\delta^{18}\text{O}$ ranging from +6.5 to +8.6 from these magmatic belt granites support local involvement of continental crust. In some places, dike orientations and high-temperature mineral lineations support syntectonic magma emplacement. Cooling ages of minerals in regional greenschist to amphibolite

grade host rocks that match pluton ages locally indicate mesozonal depths of pluton emplacement. Various lines of evidence suggest these deposits formed in magmatic arcs hosted by thickened continental margin crust. Incompatible elements such as Sn-W-Ta and REE-U-Th-Nb may have been derived from host rocks or subducted material and concentrated in late-crystallizing phases of fractionated magma.

U-Pb GEOCHRONOLOGY AND GEOCHEMISTRY OF THE POVUNGNIK GROUP OF THE CAPE SMITH BELT: A PART OF A CRATON-SCALE CIRCA 2.0 Ga LARGE IGNEOUS PROVINCE (LIP), NORTHERN SUPERIOR CRATON

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Magmatism of the Povungnituk Group of the Cape Smith belt, northern Superior craton, was formed in three magmatic events: (i) early alkaline magmatism and carbonatites, (ii) main flood basalt package (Bauparlant Formation) and (iii) a late stage alkaline pulse (Cecilia Formation). Previous geochronological studies permit age interpretations that range from ca. 2040 to >1990 Ma to 1960 Ma. A new baddeleyite age of 1998±6 Ma has been obtained from the uppermost section of Bauparlant Formation. This age has regional significance because it matches the previously obtained 1998±2 Ma age for the Watts Group ophiolite of the northern Cape Smith belt and the 1998±2 Ma U-Pb age of the Minto dykes in the craton to the south. The Bauparlant Formation is composed of tholeiitic basalts. Major and trace element geochemistry display variable compositions that show a consistent distribution between endmembers. Nb/Yb and Th/Yb ratios plot within the mantle array with compositions ranging from MORB- towards OIB-like. This is also apparent in La/Yb_N ratios, which vary from 1.09 to 9.86. Initial epsilon Nd isotope values range from +2.6 to +4.3, indicating the absence of contamination by any crustal component, consistent with the lack of any negative Nb - Ta anomaly.

Geochemical comparison of the Watts Group ophiolite and Minto dykes with the Povungnituk basalt chemistry show similar groupings, with samples subdividing between a more and less depleted source; both in major and trace element chemistry as well as Nd isotopes. Additionally, the Minto dykes have previously been paleomagnetically linked to the Eskimo volcanic rocks of the Belcher Islands. However, the composition of the Eskimo volcanics indicates significant crustal input. If confirmed as part of the combined Povungnituk - Watts - Minto - Eskimo large igneous province (LIP), then the Eskimo component would belong to a distinct magmatic suite within this >400,000 km² LIP.

EXHUMATION, DEPOSITIONAL HISTORY AND POSSIBLE SOURCES OF ECLOGITE PEBBLES IN THE WHITEHORSE TROUGH, NORTHERN CORDILLERA: IMPLICATIONS FOR COLLISION AND TERRANE ACCRETION

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Eclogite pebbles preserved in a conglomeratic horizon of the Laberge Group, Whitehorse Trough in northern British Columbia, record exhumation, transport and syn-orogenic deposition of high pressure rocks during the accretion of Stikinia to the Laurentian margin in the early stages of the Cordilleran orogen. Detrital zircons from the well-known eclogite pebble horizon at Eclogite Ridge, BC, are dominated by an Early Jurassic population reflecting a local Mesozoic arc source, with the youngest zircons indicating a maximum depositional age in the Pliensbachian, consistent with known fossil constraints.

Several possible sources for the eclogite pebbles have been suggested, such as the Pinchi Lake eclogite, but correlations have been hindered by precise pressure-temperature-time (P-T-t) constraints. Due to the high-variance paragenesis of the eclogite (garnet+omphacite+rutile+quartz), we apply phase equilibria modeling to bracket P-T. This process requires knowledge of rock bulk composition, which is relatively unconstrained in this case because of the mm size of the eclogite pebbles. By modeling a range of effective bulk compositions calculated from in situ compositional analyses and a plausible range of modal abundances, we demonstrate that the stability field of the observed equilibrium assemblage is largely insensitive to variations in modal abundance at >670 °C and 1.6-2.8 GPa.

Dating of the eclogite pebbles presents both a logistical and an analytical challenge, due to a paucity of datable phases, and limited available material. We present in situ SHRIMP U-Pb ages for several rutile grains contained within pristine eclogite pebbles. The resulting age data form an apparent single age population that is within 10 m.y. of the depositional age of the eclogite-bearing horizon, indicating rapid exhumation rates. Through modeling of possible cooling and exhumation histories for the eclogite pebbles, we explore potential source regions, and discuss the consequent implications for accretion of the Intermontane terranes during formation of the Cordillera.

IDENTIFYING AND INTERPRETING THREE DIMENSIONAL DISPERSAL PATTERNS IN USING TILL GEOCHEMISTRY AND INDICATOR MINERAL INFORMATION, NORTHEASTERN NWT

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Drift prospecting is a commonly used tool in mineral exploration in Canada's north, and is based on the core concept that material from relatively small sub-cropping mineralization is entrained by overriding ice sheets, transported down ice flow and deposited, leaving a compositional footprint over a much larger area. This core concept has been employed in the Lac de Gras kimberlite field with great success in recent decades, with numerous kimberlite pipes found. However, as the more straightforward deposits have been discovered, innovative techniques are required to better understand the complex interplay of multiple ice flow, variable basal thermal regime, and post glacial reworking which complicates drift prospecting efforts. Toward this point, here we construct a three dimensional model of glacial sediment dispersal utilizing 94 reverse circulation (RC) drill holes drilled in March of 2015, to examine dispersal down ice flow from a known kimberlite. Samples were collected continuously down the drill holes, with each sample representing a 1.5 m interval, creating a record of till composition through the entire till column. We employ both till geochemistry, as well as indicator mineral counts, to define the extent and geometry of dispersal kimberlitic material. The data is first analyzed using multivariate statistics, such as principal component analysis and weighted sum index, and results are then plotted back into their spatial context. Our examination of this multi-proxy dataset in both the traditional map view, as well as downward through the till column, allows us to determine in three dimensions the role of bedrock topography, variable ice flow direction, and discontinuous till production on the dispersal pathfinder elements and indicator minerals in the natural laboratory of the Lac de Gras area.

MASS MOVEMENT RISK IN OLD CROW: AN EXAMPLE OF THERMALLY-CONTROLLED LANDSLIDES IN A REGION OF CONTINUOUS PERMAFROST

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Mass movement events in the community of Old Crow were investigated with detailed surficial geological mapping facilitated by recently acquired LiDAR data. Abundant surface ruptures, slumps,

slides, and thaw detachments were documented along a fluvial escarpment above the community. Recent shallow translational flows have impacted roads, trails, culverts, and deposited debris within 20 metres of a residence.

While there are a number of mechanisms for mass movement along the escarpment, new work has shown that large-magnitude events are likely controlled by stratigraphy, slope steepness, and both short and long-term weather patterns. Thaw detachments occurring after peak summer rainfall events are capable of entraining additional downslope material and have potential for significant run out distances. Projected changes to regional climate include increasing frequency of summer storm events which can saturate already wet soils at the peak of summer active-layer thicknesses.

This talk will describe stratigraphic controls on landslide activity, methods of mapping existing and potential high-risk zones, as well as outline examples of communicating risk to home owners and community members.

THE EASTERN TAIMYR FOLD AND THRUST BELT: TECTONIC EVOLUTION FROM NEOPROTEROZOIC TO MESOZOIC

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The Taimyr Fold and Thrust Belt (FTB) contain evidence for Neoproterozoic, late Paleozoic and Mesozoic orogenic events. During Neoproterozoic, northern margin of the Siberian Craton (modern coordinates) was a continental arc, where several stages of deformation are recognized. Provenance studies show that Neoproterozoic molasse-like red beds up to 1 km thick consist of products of erosion of underlying metamorphic rocks, ca. 850-830 Ma granites and crystalline basement of Siberian Craton. Ediacaran (Vendian) clastic and carbonate rocks overlap older units with angular unconformity at the base pointing to termination of the accretion-related deformations.

Ediacaran to Devonian sedimentary rocks do not contain significant hiatuses and were deposited in the passive margin environments with gradual transition from shallow-marine carbonates to relatively deep-marine black shales. No evidence of the Late Devonian rifting, widely distributed on the eastern margin of Siberian Craton, is recognized in Taimyr area.

Late Paleozoic (Hercynian) compression event was related to the Kara-Siberia collision, started in Early Carboniferous and continued up to the beginning of Permian. During Carboniferous, products of erosion of Hercynian orogen were transported by a wide river system to sedimentary basin on the east margin of Siberian Craton, whereas in Permian clastic deposition was controlled mainly by erosion of orogens on the western and, probably, southwestern margins of the Siberian craton. During late Paleozoic both Southern and Central zones of the Taimyr FTB were lowlands and likely were not significantly affected by Hercynian tectonic event.

Modern structure of the Taimyr FTB was formed in Mesozoic. Structural studies point to occurrence of at least two deformation events. An older deformation corresponds to widely distributed pre-Jurassic unconformity and ca. 180 Ma cooling/uplift event documented by apatite fission track (AFT) study. This deformation event is close in age to deformation events in Novaya Zemlya and Polar Urals. Wide distribution of conglomerate units in the Middle and Upper Jurassic rocks evidence for continued deformations in the Taimyr FTB. According to AFT study, the youngest compression deformation and related cooling/uplift event occurred at ca. 100 Ma and correlates with closure of the South Anyui Ocean and thrusting in the Verkhoyansk FTB. The Late Cretaceous to Cenozoic normal faulting is likely related to the Laptev Sea opening.

**EARTHLEARNINGIDEA: A GLOBAL WEB-BASED RESOURCE OF GEOSCIENCE
TEACHING IDEAS - AN ANALYSIS**

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Earthlearningidea was an International Year of Planet Earth (IYPE) initiative that has been maintained ever since. Following a failed bid for IYPE funding, the idea evolved of publishing a new school-level teaching idea each week during IYPE, by three Earth Science Education Unit facilitators working on a voluntary basis.

In the lead up to IYPE (2008), the Earthlearningidea name was coined and a website was developed; then a new Earthlearningidea (ELI) was published every Monday during the IYPE itself. The early Earthlearningideas were aimed primarily at teachers in developing countries and so used relatively simple ideas, and equipment and materials likely to be readily available. When a colleague in Argentina offered to translate the activities into Spanish, his offer was readily accepted. Regular publication continued post-2008 and, when it became clear that the activities were being widely accessed in the more developed world, Earthlearningidea plus (ELI+) activities were added, using more abstract ideas and equipment likely to be available in a school science laboratory.

Each ELI is presented as a free-to-download pdf file, with the activity described in accessible English, usually on a single page. A second page carries teacher backup information including pupil learning outcomes, age range, timing, principles addressed, resource lists and the 'answers'. Analysis has shown that nearly half the activities involve physical models used for illustrative purposes, whilst other activities focus on thought experiments, investigations, observational approaches, diagrammatical models and developing basic skills. Early years ELI (ELI Early years) activities have been added recently.

By January 2016, 225 activities had been published in English at a current rate of one every two weeks. More than 2 million pdfs had been downloaded at a rate of nearly 50,000 per month and the blog had been accessed in 198 countries; Canada was fourth in the list of 'top ten' countries (after the US, the UK and India but ahead of Spain, Australia, Italy, the Philippines, Germany and New Zealand). The ideas had been translated into ten different languages with the website carrying nearly 700 translations, whilst the activities had been used to train teachers in at least ten countries.

The unexpected success of the initiative may result from the interactive, hands-on nature of the activities, deliberately devised to develop subject knowledge and develop critical thinking skills by deep questioning; it may also be the result of the considerable voluntary effort of all those involved.

OUR 'INTERNATIONAL YEAR OF EARTH SCIENCE EDUCATOR STORIES' PROJECT

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The author, together with other Earth science educators around the world, are at or near retirement age or have already retired. As they retire there is a real danger that all their good work, wisdom and enthusiasm will be lost, if a way cannot be found of passing these on to the next generation.

With this in mind, the author was inspired by a talk by Marina Cantacuzino on her 'Forgiveness project' work, (where people who have been dreadfully wronged are greatly helped by telling their own stories of forgiveness), to realise the power of people telling their own stories. A strategy for disseminating the stories was suggested by the Earthlearningidea experience, where a new Earth science teaching idea is currently being published every two weeks, and they are currently being downloaded at a rate of nearly 50,000 per month across 198 countries.

The stories were to be written specifically to inform and inspire the next generation, encouraging even those of a modest disposition

to contribute. Anybody who felt that he/she had contributed something to Earth science education was regarded as an 'Earth science educator'.

The idea was floated with the International Geoscience Education Organisation (IGEO) Senior Officers, who not only approved the project, but agreed to make the regular IGEO website postings. With this backing, the idea was broadcast widely, and enough people had responded positively by the end of 2015 to allow weekly publication.

Each 'storyteller' is invited to suggest the names and contact details of others who might be invited too, so that a personal invitation can be sent to them. No offers of stories have been refused. Suggestions of the names and contact details of other potential 'storytellers' are still welcome. Each story is a maximum of 1000 words long, with photographs of the 'storyteller' 'doing something'. At the time of writing (mid-January 2016), 70 people from 22 countries had offered their stories, including six Canadian educators, four of the stories had been published and 20 others had been written and edited ready for publication.

The stories received so far give fascinating insights into the factors that have caused people to become Earth science educators of note. In future the stories may be analysed for common threads for guidance to the coming generation. This work should allow the baton to be passed on to those who will follow, allowing them to achieve even greater things.

**FREE-D: AN INTRODUCTION TO PLOTTING SPATIAL DATA USING FREE
SOFTWARE (UP TO FOUR DIMENSIONS)**

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2D and 3D GIS software are powerful tools for geologists, and most projects are expected to use and present their data using these platforms. The cost of these ubiquitous products can range from hundreds to tens of thousands of dollars per year. These costs are a barrier to extracting knowledge from valuable data for academics (particularly students), mineral exploration companies, and the public; however these platforms are essential to optimizing the use of public and private data.

This presentation summarizes Open Source and/or free 1D, 2D GIS, and 3D and 4D visualization tools from academic and industry sources, that are becoming increasingly available, with the goal of making these spatial data platforms available for all to use and interpret data.

Summaries and examples include: The Kansas Geological Survey 1D tool, Open Source 2D QGIS, Mira Geoscience's 3D Geoscience Analyst, Geosoft's 2-3D Oasis montaj Viewer and UNAVCO's 4D GEON IDV software tools. Examples will be taken from mineral exploration and geologic mapping projects and tectonic reconstructions.

In addition to enhancing data interpretation these tools can be used to promote understanding and communication between all stakeholders: the general public, non-earth scientists, students, academics, industry, etc...

**MAGMATISM AND METALLOGENY OF THE DUBLIN GULCH AREA, YT, CANADA:
INSIGHTS FROM Nd AND Sr ISOTOPES, AND U-Pb GEOCHRONOLOGY**

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Dublin Gulch is an important type example of an intrusion related gold system (IRGS), and one of many IRGS now recognized within the Tombstone Gold Belt (TGB). The Dublin Gulch deposit shows strong evidence that significant gold deposition was associated with a second hydrothermal episode that overprinted initial porphyry style veining within the Dublin Gulch Stock (DGS) and overlying

country rocks. So considerable curiosity exists both as to the relationship between the DGS and spatially-related igneous rocks, and as to the possible similarities between the DGS and the parent plutons for other TGB deposits.

Three groups of intrusive rocks are currently recognized at Dublin Gulch, based on field and spatial relationships; the main phase DGS granodiorite; a series of equigranular to porphyritic dacitic dykes; and a series of porphyritic andesitic to dacitic dykes. U-Pb dating of zircons from these rocks suggests emplacement during a short-lived igneous event at 95-93 Ma. All three groups are metaluminous, and are characterized by SiO_2 of 58.6 to 65.5 wt.%; $\epsilon\text{Nd}(i)$ of -14.4 to -11.6; and $^{87}\text{Sr}/^{86}\text{Sr}(i)$ of 0.71362 to 0.71726. All of the rocks analysed are subalkaline, calc-alkaline, high-K, and magnesian on standard classification plots. Major elements show distinct trends vs. SiO_2 that are consistent with fractional crystallisation. However, highly incompatible element ratio patterns, and the observed $\epsilon\text{Nd}(i)$ and $^{87}\text{Sr}/^{86}\text{Sr}(i)$ ranges, are not consistent with fractional crystallisation as the sole process that generated compositional differences.

The geochemical signatures of igneous rocks from Dublin Gulch were compared to published data for Scheelite Dome and Brewery Creek. All three deposits share an intrusive history in which early, more voluminous plutons gave way to less extensive phases and dykes. Samples from the three deposits combined cover all four broad groupings on the modified alkali lime index (MALI) plot (calcic, calc-alkalic, alkali-calcic, alkalic). Nonetheless, all samples have similar trace element, REE, and $\epsilon\text{Nd}(i)$ and $^{87}\text{Sr}/^{86}\text{Sr}(i)$. All of the assumed parent intrusions share geochemical and isotopic characteristics consistent with emplacement in a post-collisional tectonic regime, with melt generation in response to heat flow associated with mantle upwelling following delamination of the crust. However, their wide dispersion on major element plots also suggests that the precise bulk composition of the TGB parent intrusions may be less important to gold metallogeny than factors such as water, halogen, and sulfur contents, and the depth of pluton emplacement.

KEY PARAGENETIC FEATURES OF THE DUBLIN GULCH GOLD DEPOSIT: AN IMPORTANT TYPE EXAMPLE OF AN INTRUSION-RELATED GOLD DEPOSIT IN THE TOMBSTONE GOLD BELT, YUKON, CANADA

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The Dublin Gulch property is located approximately 85 km north-northwest of the town of Mayo, Yukon. The granodioritic, mid-Cretaceous Dublin Gulch Stock (DGS) hosts an Intrusion-Related Gold System (IRGS) that comprises a number of auriferous zones, the most notable of which is the 3.3 Moz Eagle Zone. A detailed paragenetic sequence for the Dublin Gulch IRGS has been developed using traditional petrography, SEM-EDX, and IR spectroscopy for determinative mineralogy and textural analysis, supplemented with SIMS microanalysis of sulphur isotopes.

Intrusion of the DGS produced a contact aureole marked by hornfelsing of the surrounding Hyland Group metapelites during emplacement (Stage 1). Pene-contemporaneously, the Wolf W Skarn (Stage 2) replaced a large roof pendant of an adjoining carbonate horizon within the Hyland Group, appearing to pre-date a series of vein-bound stages elsewhere at Dublin Gulch. A network of partially aligned, closely-spaced quartz-K-feldspar veins (Stage 3) are the first expression of brittle-fracture hydrothermal activity, followed by less strongly aligned quartz-chlorite-calcite veins (Stage 4).

Higher grade "sheeted" auriferous veins (Stage 5a) – averaging 5-50 cm in width and spaced 30-50 meters apart - cross-cut and replace Stage 3 and 4 veins. Stage 5a veins are dominated by arsenopyrite and quartz, with lesser pyrite and native gold. Intense wallrock alteration (muscovite/phengite-dickite-kaolinite-pyrophyllite with

calcite) is characteristic of Stage 5b – which hosts the bulk of Au mineralization, as native gold and electrum, as well as Pb-Fe-Bi-Sb-As-sulphosalts and bismuthinite. Pyrite, sphalerite, jamesonite, and boulangerite, with minor native gold and electrum, comprise Stage 6 veins, which cross-cut Stage 5. The final veining event at Dublin Gulch is represented by numerous carbonate crack-seal veins (Stage 7), which are observed to cross-cut all earlier vein stages and rock types. Supergene alteration and/or shallow weathering (Stage 8), causing oxidation of host rocks and ore minerals, notably scoroditization of arsenic minerals, is restricted to 50 m from present surface.

Geostatistical analysis of drill core assay data corroborates the association of gold with specific paragenetic stages. In combination with sulphur isotope microanalyses of major phases, the observed paragenesis strongly implies two discernible fluid pulses from the DGS (or a closely associated intrusive phase), with the second pulse responsible for significant Au delivery during Stages 5 and 6.

CIM DEFINITIONS, STANDARDS, BEST PRACTICES, NI43-101 AND THE ROLE OF THE PROFESSIONAL

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NI43-101, introduced in the 1990's, is a prescribed format and detailed set of rules to guide the reporting of resources. In addition, the basic principles of "best practices" have been created to guide the practitioner in all aspects of mineral resource evaluation from data management, data analysis, geological modeling, domaining, estimation and classification. As professionals and practitioners we must defend and uphold standards to insure public protection. This presentation is a discussion of NI43-101, CIM Definitions, Standards and Best Practices along with the role of the "Professional".

FINDING PLATINUM GROUP MINERALS IN HEAVY MINERAL CONCENTRATE – EXAMPLES FROM THE MARATHON DEPOSIT AND AREA 41 MINERALIZED GABBRO, COLDWELL ALKALINE COMPLEX, ONTARIO

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Platinum group elements (PGE) are the rarest rock-forming elements in the Earth's crust and even in deposits where they are concentrated (e.g., layered intrusions) minerals that host them are extremely small ($\leq 200 \mu\text{m}$) and hard to find. In this study we were looking for platinum group minerals (PGM) in drill core samples from three different mineralized gabbroic intrusion zones (Main, Area 41 and W-horizon) of the Coldwell Alkaline Complex, Ontario. Twelve drillcore samples, each $\frac{1}{2}$ m long, weighing < 1 kg, of the Main and high-grade W Horizon ore zones of the Marathon Cu-Pd deposit and the Area 41 mineralized zone were separated by electric pulse disaggregation (EPD) and concentrated. Up to 33,000 grains per sample from the non-magnetic fraction (grain sizes from 10 to $200 \mu\text{m}$) of heavy mineral concentrate were mounted in epoxy and scanned by SEM with special software to obtain compositional data for all stable elements from carbon to bismuth in 0.2 seconds per grain. These scans were extremely fast (a few hours per sample) and also produced a grey scale image of the entire surface of the grain mount with each grain identified as a "feature" that could be located via the scanning software. The data obtained gave the overall composition of each "feature" (i.e. grain) identified in the grain mount. These compositional data were further processed to separate out all potential ore minerals (sulphides, arsenides, alloys) from gangue minerals (zircon, monazite etc.) by only considering those that contained S, Fe, Co, Ni, Cu, Zn, Ga, Ge, As, Se, Ru, Rh, Pd, Ag, Cd, In, Sn, Sb, Te, Os, Ir, Pt, Au, Hg, Pb, or Bi. The sum of these elements to was normalized 100%. For monomineralic grains these data were generally sufficient to confidently identify the mineral except in cases where several minerals have very similar compositions (e.g. Pd-arsenides) or polymorphs exist. Composite (polyminalic) grains containing precious metals were examined

more closely by SEM using the “mapped” location of the grain. Their individual components were analyzed either by SEM (semi-quantitative EDS) or quantitatively by electron microprobe (WDS). Using this approach we were able to identify over 65 different sulphides, arsenides, tellurides and alloys in the Marathon deposit (particularly the W horizon) of which almost two thirds were PGMs, including several Rh-sulphides and a few hitherto unknown or unnamed species.

THERMOTECTONIC EVENTS IN THE SOUTH RAE CRATON ALONG ITS EASTERNMOST MARGIN IN SASKATCHEWAN

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The southeastern Rae craton, adjacent to the Snowbird tectonic zone, hosts an unusually large number of Ni-Cu occurrences in mafic and ultramafic rocks extending discontinuously over a 150 km strike length. This study aims at understanding their regional and tectonic context using 1:20000 scale bedrock mapping and follow-up SHRIMP geochronology. Study areas include: the Tantato Domain, east of the Grease River shear zone, and the Dodge Domain to the northwest.

The southern Tantato Domain experienced multiple granulite to eclogite facies metamorphic events involving widespread mylonitization. The oldest recognized rocks are 2739 ± 24 Ma garnetiferous granitic orthogneisses. Abundant psammopelitic gneisses, yield $^{207}\text{Pb}/^{206}\text{Pb}$ ages with the majority of detritus falling between 2.7 and 2.9 Ga. A gabbroic anorthosite phase of the Ni-Cu bearing mafic granulites that intrudes the paragneisses crystallized at 2639 ± 19 Ma, suggesting the metasedimentary rocks were deposited between 2740 and 2640 Ma. Zircon overgrowths at 2585 ± 12 Ma in the garnetiferous granitic orthogneiss indicate Archean metamorphism followed by a 1903 ± 5 Ma Paleoproterozoic event.

The Dodge Domain is a granulite facies terrane composed of intermediate to mafic intrusions, mixed metasedimentary rocks, and mafic to ultramafic dykes. Diorite and tonalite end members of a tonalite to gabbro unit returned crystallization ages of 2650 ± 16 Ma and 2603 ± 85 Ma respectively, with the tonalite being metamorphosed at 1905 ± 12 Ma. Detrital zircon results from the metasedimentary rocks have distinguished two distinct successions. A psammopelitic gneiss sample from the older and most regionally extensive succession has $^{207}\text{Pb}/^{206}\text{Pb}$ ages very similar to those of the Tantato paragneiss, with the majority of detritus between 2.7 and 2.9 Ga. An intrusive norite yields a ca. 2640 Ma age, similar to the Tantato gabbroic anorthosite, with a metamorphic overprint at 1891 ± 9 Ma. The younger sedimentary succession is exposed in a tightly constrained fold interference pattern. It contains basal quartzite, minor psammitic gneiss, and dominant psammopelitic rocks, but is not intruded by the Ni-Cu bearing mafic rocks. The quartzite was deposited after 2283 ± 24 Ma and metamorphosed at 1970 ± 22 Ma and 1940 ± 12 Ma. $^{207}\text{Pb}/^{206}\text{Pb}$ ages for detritus from a psammitic gneiss has a youngest reproducible detrital zircon age of 2030 ± 12 Ma. The older sedimentary succession probably correlates with Archean paragneisses in the central Beaverlodge Domain, whereas the younger succession has lithological and temporal similarities to the Murmac Bay group. Emplacement of Ni-Cu bearing mafic to ultramafic rocks at ca. 2640 Ma indicates an Archean mineralizing event affected the eastern margin of the southern Rae craton.

MINERAL CHEMISTRY OF GREENROCK ALTERATION ASSOCIATED WITH THE PORPHYRY Cu-Mo MINERALIZATION AT THE GIBRALTAR DEPOSIT, SOUTH CENTRAL BRITISH COLUMBIA, CANADA

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The Gibraltar Cu-Mo porphyry deposit with the geological reserves (past production plus reserves) of 2.8 Mt Cu is hosted in the late Triassic Granite Mountain batholith the Quesnel Terrane. The batholith, which has the surface exposure of $15 \text{ km} \times 10 \text{ km}$, is mostly composed of tonalite with minor variation in modal abundances of felsic and mafic minerals. Igneous minerals are plagioclase, quartz, biotite, hornblende, with minor amounts of titanite, zircon, apatite and magnetite. Bulk rocks show a typical subduction-related geochemical signature with negative anomalies of high field strength elements, such as Nb, Ta and Ti, with minor positive and negative Eu anomalies ($\text{Eu}/\text{Eu}^* = 0.09\text{--}1.2$). The mineralization is accompanied by extensive alteration in the tonalite, which produced illite, quartz, rutile, titanite, magnetite, apatite, chlorite and epidote. The high-temperature potassic alteration zone was likely present in the centre of the current mining operation, but the alteration has been obscured by the replacement of secondary biotite by chlorite. Among alteration minerals, epidote and chlorite are ubiquitous in the tonalitic rocks in and around the mine, producing green rock alteration. Epidote group minerals primarily replace plagioclase. Chlorite is also common after hornblende and biotite, and a mixture of titanite and rutile replaces biotite and hornblende. Epidote minerals are light grass green in hand specimens and also thin sections. They show a large compositional variation even within one sample from Al-rich (high clinzoisite component) to Fe-rich epidote, suggesting multiple alteration events or reflecting varying fluid composition within a hydrothermal system. Some are yellowish in thin sections and they contain significant allanite component with high La_2O_3 (up 9.54 wt%) and Ce_2O_3 (up to 14.7 wt%). These Ce-La-rich epidote grains contain higher concentrations of other REEs, Mn, Y and Th than Fe-rich epidote. These LREE-rich epidotes form isolated grains within chlorite aggregates in epidote-rich tonalities. In contrast, Fe-rich, REE-poor epidote is abundant and preferentially replaces plagioclase. Igneous titanite (up to 2 mm) is low in Al_2O_3 (~1.2 wt%) whereas hydrothermal titanite contains high Al_2O_3 ranging from 2 to 6 wt%. Hydrothermal titanite is more abundant than its igneous counterpart, and shows a wide compositional variation of Mg and Fe. Rocks with greenrock alteration show high abundances of U, Pb and K in bulk rocks compared to epidote-poor samples. The enrichment of U and Pb in bulk rocks is likely due to their incorporation in epidote as minor components.

A RAYLEIGH DISTILLATION MODEL TO EXPLAIN LARGE VARIATIONS IN OXYGEN ISOTOPE DATA FOR OROGENIC GOLD VEINS

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Formation of orogenic gold vein systems involves repeated infiltration of overpressured and heated fluids to form fault fill and extensional vein arrays in mixed sequences of deformed and metamorphosed rocks. The internal textures of the veins (e.g., ribbon or crack seal) attest to the cyclicity of vein formation with precipitation of quartz \pm carbonates \pm sulfides followed by injection of a new fluid. In order to infer the nature of the fluid and origin of the gold mineralization, stable isotopes, in particular $\delta^{18}\text{O}_{\text{quartz}}$ in conjunction with fluid inclusion thermometric studies are commonly used. The limitation to this approach relates however to the temperature dependent fractionation of oxygen isotopes between minerals and water, here the vein fill and the fluid, and the pressure dependence of fluid inclusion thermometry (i.e., P correction).

Thus, for a typical orogenic gold quartz vein having $\delta^{18}\text{O}_{\text{quartz}}$ values of +14‰ the equivalent $\delta^{18}\text{O}_{\text{H}_2\text{O}}$ values for the fluid are about +10, +8.7 and +7‰ for formation at 400°, 350° and 300°C, respectively. The latter illustrates the significance of constraining temperature since these $\delta^{18}\text{O}_{\text{H}_2\text{O}}$ values are interpreted very differently. Here we introduce yet another potential variable not previously considered in these systems as far as we know. This variable is fluid distillation commensurate with precipitation of the vein fill. The process, also known as Rayleigh fractionation, is suggested to possibly be relevant in interpreting the well documented range of $\delta^{18}\text{O}_{\text{quartz}}$ compiled for orogenic gold systems. In the model proposed, we note that these veins do not represent continuous flow through system, but instead are better modeled as closed systems, or at least closer to the latter than the former. Thus assuming an initial vein fluid of $\delta^{18}\text{O}_{\text{H}_2\text{O}} = +10\text{‰}$, in a closed system at 400°C only the initial quartz to precipitate will have $\delta^{18}\text{O}_{\text{quartz}}$ of +14‰ with the subsequent quartz to precipitate having diminishingly lower values as the $\delta^{18}\text{O}_{\text{H}_2\text{O}}$ falls depending on the amount of vein fill (i.e., f value in distillation equation). Thus, using the Rayleigh distillation equation and assuming a vein formation at 400°C, $\delta^{18}\text{O}_{\text{quartz}}$ values can vary by up to 10‰ for $f = 1$ to 0.1 whereas at 300°C the variation is 16‰. Results of several studies on mineralized vein systems, including orogenic gold, using SIMS data are used to argue that fluid distillation occurs and that traditional bulk sampling methods may have been averaging the predicted isotopic variation.

DOCUMENTING THE COMPLEX EVOLUTION OF A RARE-METAL PEGMATITE SWARM: THE LITTLE NAHANNI PEGMATITE GROUP, NWT, CANADA

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The LNPG comprises hundreds of LCT-type dike rocks exposed in the Fork anticlinorium of the Mackenzie Mountains of the northern Canadian Cordillera. The dikes strike uniformly NW, cut a thick package of metapelites and sandstones of the Hyland Group and extend ca. 15 km. No progenitor intrusion is known in the area and uniform trace elements chemistry (Li (150-250 ppm), Rb (2500-5000 ppm), Cs (<100 ppm), Ga (<50 ppm)) of K-feldspar ($n=11$; Kf) reveals no regional fractionation trend. Extreme fractionation of the dikes is also reflected in flat chondrite normalized profiles for Kf (~0.001). Timing of dike emplacement is constrained at ca. 83 Ma by previous work on tantalite (81.6 ± 0.5 Ma, U-Pb TIMS) and new U-Pb data for magmatic zircon (85 ± 2 Ma, LA ICP-MS). A post-emplacement thermal overprint of the area to >350°C is suggested, however, by plateau ages of ca. 68 ± 2 Ma for micas from within (muscovite) adjacent (biotite) the pegmatite. An older published apatite age of ca. 90 is attributed to common Pb from the wall rocks, as suggested from Kf Pb isotope data. The dikes are variable in thickness (cm s to <10 ms) with a generally uniform mineralogy (Qtz-Kf-Spd-Alb) and comb textures; trace lepidolite is noted along with convolute aplitic layering, but pocket zones are absent. The presence of micro-dendritic apatite grains associated with calcic plagioclase reflects early local contamination. Rare metal mineralization (Sn, W, Ta, Nb) is complex and protracted, occurring as early acicular textured micro-inclusions, but most commonly is associated with zones of secondary albite and rarely where intense muscovite alteration is seen. Fluid inclusion and isotopic (C, O, D, Sr, Pb) studies reveal chemical variability (e.g., $\delta^{13}\text{C}$ of -9.7 to -27.7‰ for inclusion extracts; $\delta^{18}\text{O}_{\text{Alb}} = +0.4$ to +14.9‰; Sri (Kf, Musc) = 0.700 to 0.88) due to syn- or post-emplacement exchange of the dikes, either as melts or solids, with the wall rock sediments during emplacement and initial cooling at 82 Ma or during the later thermal disturbance at 68 Ma. These data reveal several important aspects relevant to formation and interpretation of rare-metal pegmatite systems: 1) a complex history of post-crystallization sodic metasomatism and fluid:rock interaction; 2) contamination of

LCT melts may be more common than considered; and 3) ingress of wall rock derived fluids may be an overlooked phenomenon in fluid inclusion studies.

ARE MANTLE ECLOGITES GEOPHYSICALLY MAPPABLE?

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Many studies invoke spatial localization of eclogites to explain observed changes in geophysical properties of the mantle. To check if eclogites at depth can be mapped geophysically, we compared seismic discontinuities and conductivity of the Slave lithospheric mantle with the spatial distribution of eclogites observed petrologically. We reconstructed the spatial distribution of eclogites in the cratonic mantle based on thermobarometry for ~240 xenoliths in 4 kimberlite pipes from different parts of the Slave craton (Canada). The depth estimates are based on new data on mineral chemistry and petrography of 148 eclogite xenoliths from the Jericho and Muskox kimberlites of the northern Slave craton and previously reported analyses of 95 eclogites from Diavik and Ekati kimberlites (Central Slave). Mossbauer estimates of Fe^{3+} in eclogite minerals allowed us to test the accuracy of the Nakamura (2009) thermometer accounting for $\text{Fe}^{3+}/\text{Fe}^{2+}$ mineral ratios. We also tested and rejected the Beyer et al. (2015) barometer as it suggested the thermal disequilibrium between intercalated eclogites and peridotites and a lower geotherm in the asthenosphere than in the lithosphere. The accuracy of depth estimates is ensured by the use of a recently calibrated thermometer, projection of temperatures onto well-constrained local peridotitic geotherms, petrological screening for unrealistic temperature estimates, and internal consistency of all data. The majority of Northern Slave eclogites of the crustal, subduction origin occur at 110-170 km, shallower than in the majority of the Central Slave crustal eclogites (120-210 km). The identical geochronological history of these eclogite populations and the absence of steep suture boundaries between the central and northern Slave craton suggest the lateral continuity of the mantle layer relatively rich in eclogites. We explain the distribution of eclogites by partial preservation of an imbricated and plastically dispersed oceanic slab formed by easterly dipping Proterozoic subduction. The depths of eclogite localization do not correlate with geophysically mapped discontinuities of the Northern and Central Slave, a near horizontal boundary at 140-160 km and a discontinuity dipping from 85 to 110 km to the southeast. The base of the eclogite-bearing slab coincides with the petrological lithosphere-asthenosphere boundary, which is geophysically invisible in the Slave and globally. A correlation between anisotropy and the presence of eclogites may be more feasible.

GEOPHYSICAL INVERSION OF MAGNETIC AND GRAVITATIONAL FIELD DATA AT THOR LAKE, NT

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The Nechalacho deposit located at Thor Lake, NT is one of the world's largest undeveloped heavy rare earth element deposits. The rare earth element minerals are hosted by a hydrothermally altered cumulate sequence of the Nechalacho syenite, which lies beneath the Thor Lake syenite. Due to the extensive alteration and the close association between the major alteration mineral magnetite with rare earth mineralization, this site is an excellent target for geophysical inversion of magnetic field data. Constrained geophysical inversion of the deposit using drillhole susceptibility measurements yields a relatively flat lying anomaly of high magnetic susceptibility at depths between approximately 50 and 200 metres and extends for over 1500 metres laterally. The anomaly corresponds with the current best geological interpretation of the basal zone where large concentrations of heavy rare earth elements

occur. According to the geophysical model developed from the airborne magnetic surveys, the zone of mineralization could extend up to 2000 metres laterally implying that additional mineralization could lie to the north of current geologically interpreted boundaries. In addition to inversion of magnetic field data, gravitational field data can be used to further delineate the deposit. Due to the cumulative nature of the rare earth element host layers, these regions are often accompanied by higher densities, producing a high gravitational anomaly. A statistical weighted average method based on core sample density measurements has been implemented in order to horizontally extrapolate the starting model beyond the dimensions of the drillholes. Constrained geophysical inversion of the airborne gravity data yields similar results to the magnetic inversion, with a horizontal high density anomaly at depths ranging from the surface down to approximately 250 metres, extending for 1800 metres laterally. Successful and complementary results from individual constrained inversions of the magnetic and gravitational data highlight the potential for their joint inversion to define the physical limits of the deposit.

MAGMATIC AND STRUCTURAL CONTROLS ON HYPOGENE MINERALIZATION AT THE CARMACKS COPPER DEPOSIT

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Late Triassic to Early Jurassic magmatism is responsible for many of the porphyry deposits in British Columbia. Same age intrusive rocks in west-central Yukon host several Cu-Au deposits such as Minto and Carmacks Copper. Both of these examples of mineralization are overprinted by deformation and metamorphism that obscure the genesis of the deposits.

Copper sulphide mineralization at the Carmacks Copper Cu-Au-Ag oxide deposit is located within a 3 km-long, ~20 to 100 m-wide northwest trending corridor of deformed amphibolite-facies metavolcanic rocks. These rocks occur as enclaves within arc granitoids of the Late Triassic to Early Jurassic Minto plutonic suite (204-195 Ma).

The Carmacks deposit has a complex history of polyphase deformation that is punctuated by discrete intrusive events. An early metamorphic fabric in the metavolcanic rocks comprises NNW-trending, steeply dipping foliation. This early fabric envelops boudined diorite dykes that represent the earliest intrusive phase. Tightly folded diorite dykes commonly cross-cut earlier boudined dykes and are interpreted as a result of a second deformation event. Finally, granodioritic magma engulfs the amphibolite rocks and cross-cuts all metamorphic fabrics and pre-existing magmatic units. Previous studies on this intrusive phase reported zircon dates of 197.3 ± 1.5 Ma with a pressure during crystallization of at least 6 kbar. Most of the hypogene mineralization occurs as stringers of chalcopyrite parallel to the dominant metamorphic fabric within the amphibolites. This sulphide texture is interpreted to represent a pre-Early Jurassic mineralizing system that occurred prior to or during ductile deformation and metamorphism of the volcanic host rock. Close to the contact with the batholith, foliated amphibolitic rocks change gradationally into granoblastic microdiorite and migmatite. Field relationships suggest that heat from the intrusion of the batholith may have been sufficient to generate partial melts of the amphibolitic rocks to modify their texture and perhaps remobilize some of the hypogene mineralization. Where these rocks have undergone recrystallization and partial melting to form microdiorite and migmatite, mineralization characteristically forms discordant veinlets and net-textured chalcopyrite and bornite. This distinct ore facies is likely associated with the generation of partial melt which has led to the remobilization of sulphides.

Most porphyry deposits in British Columbia formed during a ~15 M.y. time period, with ~90 % of known copper resources generated between 202 and 208 Ma. However, foliation-parallel

chalcopyrite veinlets in the amphibolitic rocks suggest that hypogene mineralization is pre-Early Jurassic and that post mineralization modification of hypogene mineralization likely explains its seemingly enigmatic origin.

LATE- AND POST-VARISCAN TIN AND TUNGSTEN DEPOSITS OF THE ERZGEBIRGE AND CORNWALL, EUROPE

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Important Late Paleozoic tin and tungsten mineralization of the Erzgebirge and Cornwall is associated with granite batholiths intruding the internal and external zones of the European Variscides, respectively. Mineralization in both regions has been traditionally explained as the result of the Variscan orogeny lasting from 400-300 Ma. Intrusion ages, however, do not support this view and instead demonstrate that the granites of the Erzgebirge (325 - 320 Ma) and Cornwall (293-275 Ma) evolved during two subsequent and genetically unrelated tectono-thermal events, i.e., late orogenic HT/LP metamorphism (Erzgebirge) and mantle upwelling due to post-orogenic extension (Cornwall).

Comparing mineralization of the Erzgebirge and Cornwall in terms of (i) source rock enrichment, (ii) source rock accumulation, and (iii) metal mobilization, the two areas differ mainly in the thermal history of tectonic source rock accumulation and of heat input for source rock melting.

The granites of both regions evolved from Peri-Gondwana continental crust. Early Paleozoic Peri-Gondwana shelf deposits contain voluminous detritus of Sn-W enriched weathered sediments. The redistribution from the continent interior to the continent margins occurred at c. 490-470 Ma and resulted in sedimentary accumulation of the source rocks on thinned continental crust. During the Variscan orogeny these sediments were tectonically accumulated. In the internal zone of the orogen (e.g. Erzgebirge) collisional tectonics caused pervasive nappe stacking and culminated in the formation of intracontinental subduction zones at c. 340 Ma. In the external zones (e.g. Cornwall) the formation of fold-and-thrust belts caused the tectonic accumulation of Peri-Gondwana sediments until 300 Ma.

Isothermal exhumation of deeply subducted and, thus, hot continental crust to mid-crustal levels occurred between 340 and 330 Ma and caused the late orogenic HT/LP metamorphism that was immediately followed by voluminous granite intrusions (e.g. Erzgebirge). This type of granites exclusively occurs in the internal part of the orogen. The low-grade metasedimentary rocks of the external fold and thrust belts are not affected by such a thermal event. Plate tectonic reorganization caused the termination of the Variscan orogeny and the formation of the late Paleozoic European Extensional Province at 300 Ma. Heat advection due to upwelling of the asthenosphere caused bimodal magmatism and caused the melting of Sn/W enriched sediments of the preexisting fold and thrust belt in Cornwall. Because post-Variscan extension affected also the crust of the Erzgebirge a second magmatic pulse shows some Sn/W mineralization in the region.

THE ISOTOPIC ADVANTAGES AND DISADVANTAGES OF TRACING CRITICAL FLUIDS IN CANADA

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Hydrogen isotopes in hydrous minerals are the most definitive indicator of the origin of aqueous fluids that have affected rocks because water/rock ratios are usually high enough, and the hydrogen contents of most rocks low enough, that the D/H ratios of rocks are determined by the fluid. We normally assume that the D/H ratio of the mineral has remained unchanged since the mineral

originally formed. However, in Canada, where most groundwaters since the Tertiary have had relatively low $\delta^2\text{H}$ values, retrograde H-isotope exchange with meteoric waters at low temperatures in near-surface environments and along faults, is occasionally evident. The mechanism involves exchange with OH-sites, and is distinct from the D/H changes that accompany recrystallization or neoformation, both of which are associated with obvious crystal chemistry changes. Selective $\delta^2\text{H}$ shifts are documented in U-deposits, serpentinites, authigenic clays, hydrous minerals in shear zones, and gold deposits that originally formed fluids with high $\delta^2\text{H}$ values, but now have low $\delta^2\text{H}$ values because they are in Canada. Similar effects rarely have been observed elsewhere. If unrecognized, secondary H-isotope exchange may lead to invalid interpretations of the isotopic composition of fluids involved in primary formation of hydrous silicate minerals.

MINERALOGY, SULPHUR ISOTOPES, AND GENESIS OF BARITE ASSOCIATED WITH VOLCANOGENIC MASSIVE SULPHIDE MINERALIZATION IN THE LEMARCHANT DEPOSIT, CENTRAL NEWFOUNDLAND

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The Central Mobile Belt in Newfoundland is host to several volcanogenic massive sulphide (VMS) deposits. The Cambrian Tally Pond group in the Central Mobile Belt hosts the bimodal felsic, Zn-Pb-Cu-Ag-Au-Ba Lemarchant VMS deposit. The Lemarchant deposit has a complex mineralogy consisting of sulphides, sulphosalts, and precious metal phases, all intimately associated with barite. Despite the presence of barite in the deposit, the detailed relationships to mineralization, textural variations, and genesis are not well understood. Barite in the Lemarchant deposit is generally massive and locally bladed. Massive barite is associated with sphalerite, galena, pyrite and minor chalcopryrite whereas bladed barite often occurs with sulphosalts and Cu-rich assemblages. S-isotope results on bladed and massive barite show a mean value of 27‰, which is similar to Cambrian seawater sulphate. Preliminary fluid inclusion petrography in barite show that most of the fluid inclusion assemblages are primary and have consistent two-phase (liquid+vapor) ratios, with the vapor bubbles dominantly composed of CO_2 . Coexisting liquid-rich and vapor-rich fluid inclusions and assemblages of liquid-rich only inclusions has been locally identified in bladed barite, and may suggest boiling of fluids. Microscopic sulphide phases are often found within primary fluid inclusions in bladed barite. High-resolution and quadrupole ICP-MS analyses of barite crystals indicate that barite is remarkably homogeneous and contain only Ba, S, Sr and minor Au. Little to no other trace elements are present in barite crystals. The results presented herein indicate a complex origin for the barites indicating input from Cambrian seawater sulphate from mixing with VMS-related hydrothermal fluids. Furthermore, the presence of bladed barite with complex fluid inclusion assemblages and intergrowths with sulphosalts are potential indicators of fluid boiling and magmatic fluid input. These results illustrate that barite in VMS deposits is useful for recording physical and chemical processes associated with the formation of VMS deposits.

EVALUATING THE POTENTIAL FOR COLOMBIAN-TYPE HYDROTHERMAL EMERALDS IN NORTHWEST CANADA

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Vast exposures of black shale in Northwest Canada have the potential to host Colombian-type emerald deposits. We examine the genesis of known beryl in this region and the potential for further mineralization. In Colombia, emeralds formed in hydrothermal quartz-carbonate-pyrite veins hosted in metalliferous black shale, sandstone and limestone. Elsewhere in the world, emerald formed at the contact between granitic pegmatites and mafic country rock, or in metamorphic settings.

Beryl has been found in Canada's Mackenzie Mountains associated with sandstone and black shale units. The genesis of this beryl locality has not been clearly determined, but isotope data ($\delta^{18}\text{O}$, $\delta^{34}\text{S}$) for the Mountain River Beryl occurrence are consistent with modified Colombian emerald formation. The Lened occurrence is the object of current study.

The Lened beryl occurrence is located in vanadiferous black shale near the Lened pluton, NWT. Green beryl occurs in quartz-carbonate veins emplaced in a fractured garnet-diopside skarn at the contact with Rabbitkettle black shale. Fieldwork in 2015 resulted in the discovery of prolific tourmaline inclusions in quartz-calcite veins, as well as a second outcrop bearing sub-millimetre scale beryl and tourmaline. Results of mineral chemistry (beryl, micas, and accessory phases) and boron stable isotope analysis ($\delta^{11}\text{B}$) are pending, and will clarify the origin of the Lened green beryl with respect to a hydrothermal evaporitic origin versus a magmatic fluid source.

Na/K ratios have been used successfully in Colombia to delineate areas of albite alteration that are highly correlated with emerald mineralization. Our geostatistical analysis (principle component analysis, Kriging interpolation, etc.) of regional stream sediment geochemical data delineates anomalous values of Na and rare earth elements (REE) in Earn Group black shales of Selwyn Basin, YT and clastic sedimentary units across the Mackenzie Platform, NWT. Our analysis constrains the potential area of hydrothermal emerald occurrence. Individual deposits such as Lened would not be predicted with this model.

In addition to stream sediment geochemistry, we propose the potential for heavy mineral concentrate sampling as a hydrothermal emerald exploration tool. Microanalysis of black shale samples from Muzo, Colombia confirms the presence of a 0.05 mm scale Ce-Al-phosphate mineral within metres of a mineralized vein. Parite-(Ce), is also spatially associated with high-value emerald mineralization in Colombia. If Colombian-type emerald is present in Northwest Canada, these relatively dense associated REE minerals are likely to be detected in heavy mineral concentrates of streams in prospective drainage basins.

MULTIPLE GENERATIONS OF MONAZITE GROWTH IN THE TANTATO DOMAIN, NORTHERN SASKATCHEWAN: IMPLICATIONS FOR A COMPLICATED TECTONIC HISTORY

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Geological mapping of the Tantato Domain, Northern Saskatchewan, has documented four to five stages of deformation, primarily recognizable based on differences in folding styles and orientations. Detailed U-Th/Pb analysis of monazite within these multi-deformed rocks reveals distinct age peaks consistent with the recognition of multiple events observed in the field. Monazite grains in a psammopelitic gneiss collected near Axis Lake, in the Upper Deck of the Tantato Domain of northern Saskatchewan, were raster age-mapped using LA-MC-ICPMS with a spot size of ~8 μm . Approximately 500 data points outline a range of $^{206}\text{Pb}/^{207}\text{Pb}$ ages from 2.738 Ga to 1.905 Ga.

The geochronologic data indicate a minimum age of deposition of ca. 2.605 Ga for the psammopelitic protolith, followed by prominent peaks at ~2.5 Ga and ~1.9 Ga, which correspond to previously identified granulite-facies metamorphic episodes. The dates extracted from the specimen also appear to record other distinct tectonic events that affected the southern Rae province, which have not previously been recognized in the Tantato Domain. Dates between ~2.45 and 2.3 Ga may represent the easternmost

reaches of the Arrowsmith Orogeny within the Rae, while a spread of ages from 1.989 Ga to 1.966 Ga may reflect the earliest phases of the Taltson Orogeny. The combined fieldwork and U-Th/Pb dating carried out in this study demonstrate that the Tantalum Domain has experienced a complicated, protracted tectonic history.

FLUID CHARACTERISTICS OF A QUARTZ-CARBONATE VEIN IN THE CANADIAN ROCKY MOUNTAINS

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Fluid flow through crustal rocks plays a key role in processes such as crustal deformation, crustal growth, and the transport of chemical species. Complex vein systems can be found as evidence for extensive fluid flow, and mass transfer through the crust. Veins record information about the composition, temperature and pressure conditions of the original fluid that was passing through the crust. It is then of interest to establish the origin of the primary fluid; whether it is of meteoric or of metamorphic origin; and to determine the pressure and temperature conditions at the time of the mineral precipitation from that fluid.

This study aims to characterize vein-wall rock interactions and origin of fluids involved in the emplacement of a vein system located in the Southern Canadian Cordillera, east of the Rocky Mountain Trench. Previous studies propose deeply convected surface waters to play a primary role in the vein formation. This interpretation, however, is based on bulk rock isotope analysis, which can be problematic because primary and secondary fluid inclusions are analyzed from a bulk sample. Late meteoric fluid infiltration along faults will potentially allow for the interaction of meteoric water with the rocks, and the formation of secondary fluid inclusions that now carry the meteoric isotopic signature.

At this stage of the study, we present the petrographic analysis of thin sections, compositional trends of vein carbonates, and we will present fluid inclusion data that we currently obtain by microthermometry of quartz and carbonate minerals. The sedimentary rock hosting the vein contains mm-sized clusters of pyrite, and is rich in apatite and monazite. Potentially different vein generations are found within the vein system. A section of massive calcium carbonate vein, with a relatively low SrO content of 0.22 wt% that shows little variation and a relatively low MgO content of 0.43 wt%, is crosscut by a carbonate-bearing quartz vein. This crosscutting vein yields a greater range and higher content of SrO and MgO of 0.22-0.41 wt% and 0.58-0.64 wt%, respectively. The calcite in the samples yield compositions of FeO ranging from 0.93-1.20 wt%, MnO ranging from 0.33-0.40 wt%, and CaO ranging from 51.63-53.76 wt%. Quartz does not significantly vary in composition. Texturally, quartz enclosed by calcite does show less signs of deformation, whereas subgrain rotation is common within other quartz grains. The contacts between vein and wall rock are generally sharp.

THE SILURIAN SAYABEC FORMATION RESERVOIR POTENTIAL IN THE LOWER ST. LAWRENCE RIVER AREA, QUÉBEC, CANADA

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Over the past 10 years, the hydrocarbon potential of the Gaspé Peninsula and adjacent Lower St. Lawrence River area has been the subject of numerous works, whether from an industrial or academic research perspectives. Little is known about the specific sector of the St. Lawrence River area located between Temiscouata and Matapédia lakes, partly because of its structural complexity. Oil and gas operators have more recently demonstrated their interest and drilled stratigraphic wells for over 6000 meters in this specific area. Several of them revealed oil or gas shows associated with

naturally fractured zones within the Saint-Léon, Sayabec and Val-Brillant formations. Thanks to a new Industry-Academy research partnership, 1500 meters of cored Silurian sequences from six different wells were made available for detailed stratigraphy of the carbonate Sayabec Formation and subsampling for microfacies analyses. Our goal is to estimate the reservoir potential of the Sayabec Formation within a prospective play, the Massé structure. The Sayabec Formation, lower Silurian in age, corresponds to peritidal carbonates deposited at the end of a regressive cycle initiated in the late Ordovician. The Massé structure is limited by two normal faults and its sedimentary sequence was preserved in situ, with little amount of deformation and only local brecciation and fracturing occurrences. In the Massé structure area, the Sayabec formation is 300 meters thick in average. The upper part of the Sayabec Formation display fine-grained carbonate facies, ranging from well sorted peloidal packstone to poorly sorted packstone with crinoids and bioturbated mudstones. These carbonate facies are interbedded with plurimetric layers of siltstones. Locally, metric units are made of corals, stromatoporoids and bryozoan baffestones and/or framestones where intraparticules porosity is often preserved. The size of individual fossil could reach up to 8 cm in diameter and appear much larger at the outcrop scale (up to several tens of centimeters). However, the lateral extents of these bioconstructed facies still need to be resolved. Bitumen residues are common in bioclastic packstone facies and mudstone facies and mainly associated with secondary porosity related with fractures. The lower part of the Sayabec and its transition with the underlying clastic Val-Brillant Formation are the most promising interval thanks to highly fractured metric intervals where first porosity estimates are up to 20%. Integration of core logging, fieldwork observations and structural interpretation of available seismic lines is used to propose a 3D model of key reservoir units within the Sayabec Formation in the Massé play.

METAMORPHISM AND TECTONICS OF THE ATHAPAPUSKOW LAKE AREA, MANITOBA

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The Athapapuskow Lake area is a Paleoproterozoic tectonic-collision, situated in the western Flin Flon greenstone belt, Manitoba. It is a well exposed amalgamation of accreted terranes, comprising Archean island-arc and ocean-floor assemblages intruded by successor-arc plutons, preserved at relatively low metamorphic grade. The 1.92-1.88 Ga juvenile island-arc and ocean-floor rocks were probably juxtaposed as a consequence of arc-arc collision about 1.88-1.87 Ga. 1.87-1.83 successor-arc magmatism resulted in the emplacement of calcalkalic plutons. The area consists of blocks bound by faults and major shear zones which post-date all the intrusions.

The metamorphic grade of these rocks generally increases northwards from where they emerge from beneath overlying Paleozoic sediments in the southern part of Athapapuskow Lake, changing from prehnite-pumpellyite-, through greenschist- to amphibolite-facies.

Amphibolite facies rocks are also preserved in the south-western part of the study area. Rocks in this area show a consistent foliation steeply dipping toward NNE, characterized by alignment of relatively fine grained (ferro-)hornblende crystals, which display an increase in grain size toward the Kaminis Lake pluton. To the north there is a transition into the greenschist-facies, which is abruptly cut by the West-Arm shear zone, north of which prehnite-pumpellyite-facies assemblages are found.

A steady increase in metamorphic grade from prehnite-pumpellyite- to greenschist-facies characterizes the eastern part of the study area. In contact aureoles around Lynx Lake pluton, Mink Narrows

Pluton and Neso Lake pluton a change in mineral assemblage from actinolite+albite+chlorite(+epidote+prehnite) to (ferro-) hornblende+albite(+epidote), and an increase of hornblende grain size, is observed. Mafic domains in rhyolites locally contain biotite and garnet.

Late shear zones deform the margins of the plutons and the contact aureoles. Mylonites in the North-East-arm shear zone show alignment and stretching of hornblende and biotite grains, and deformation of feldspar porphyroclasts. In some rocks, small, undeformed, garnet and apatite crystals overgrow the foliation in the shear zone, implying growth during or after shearing.

Relationships between the regional metamorphism, the contact metamorphic aureoles associated with successor-arc plutons, and shear zone development will be discussed.

ALASKA RANGE EXHUMATION PATTERNS DURING MICROPLATE COLLISION, RESTRAINING BEND UPLIFT, AND GLACIATION: INSIGHTS FROM DETRITAL GEO- AND THERMO-CHRONOLOGY

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Cenozoic growth of the Alaska Range created the highest topography in North America, but the space-time pattern and drivers of exhumation are poorly constrained. We analyzed U/Pb and fission-track double-dates of detrital zircon and apatite grains from 12 catchments that span a 450 km length of the Alaska Range to illuminate the timing and extent of exhumation during different periods. U/Pb ages indicate a dominant Late Cretaceous to Oligocene plutonic provenance for the detrital grains, with only a small percentage of grains recycled from the Mesozoic and Paleozoic sedimentary cover. Fission-track ages record exhumation during Alaska Range growth and incision and reveal three distinctive patterns. First, initial Oligocene exhumation was focused in the central Alaska Range ca. 30 Ma and expanded outward along the entire length of the range until 18 Ma. Oligocene exhumation, coeval with initial Yakutat microplate collision >600 km to the southeast, suggests a far-field response to collision that was localized by the Denali fault within a broad, weak Mesozoic suture zone. Second, the variable timing of middle to late Miocene exhumation suggests that there were independently-evolving histories influenced by local structures. Time-transgressive cooling ages suggest successive rock uplift and erosion of Mts. Foraker (12 Ma) through Denali (6 Ma) as crust was advected through a restraining bend in the Denali fault and indicate a long-term slip rate >4 mm/yr. Third, Pliocene exhumation is synchronous (3.7-2.7 Ma) along the length of the Alaska Range but only occurs in high relief, glacier-covered catchments. Pliocene exhumation may record an acceleration in glacial incision that was coincident with the onset of northern hemisphere glaciation.

Our study provides an example of how microplate collision can drive deformation far afield. We highlight similarities between the collision of the Yakutat microplate with the southern Alaska margin and the preeminent example of large-scale continental collision: the indentation of India into Asia, creating the Tibetan-Himalayan orogen. In both Alaska and Tibet, far-field deformation is coeval with initial collision and localizes where strong objects encounter weaker material, consistent with geodynamic models of large-scale collisional orogenesis. In general, both the Yakutat and India collisional systems follow a common evolutionary sequence despite differences in indenter size and geologic substrate. Initial regional exhumation is coeval with collision and later transitions to localized exhumation related to strike-slip faulting.

NEAR-SURFACE GEOPHYSICAL INVESTIGATION OF A GRAVEL SITE NEAR WHITEHORSE, YT

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Three near-surface geophysical surveys – electrical resistivity tomography, seismic refraction tomography, and ground-penetration radar – were conducted along a 96 m profile to compare the suitability of these methods in determining the thickness of a gravel layer at a site near Whitehorse, Yukon. Electrical resistivity tomography (Wenner array with 48 electrodes spaced 2 m apart) shows 3 distinct layers: a low resistivity layer (~800 Ωm) to 2 m depth, a high resistivity layer (~4000 Ωm) at depth 2m-8m, underlain by a third layer with resistivity 400 Ωm. Seismic refraction tomography (hammer and strike plate as source with shots every 10 m and 4.5 Hz vertical geophones spaced 2 m apart) also shows a layered subsurface. Velocities below 500 m/s dominate the top 2 m, while at depth 2m-8m we encounter velocities between 500 m/s and 1300 m/s, between the depth of 8-15m velocities around 2000 m/s are present, and below this depth, the velocity increases to approximately 7000 m/s at depth 25 m. Ground-penetrating radar with 100, 200, and 400 MHz antennas show sub-horizontal reflections to 30 ns two-way time and dipping undulating reflections below to 120 ns where we see a distinct horizontal reflector. Through a buried bottle, we were able to determine the dielectric constant of the surface material and estimate that the first layer correspond to 0 m to 1.5 m depth while the second layer is around 1.5 to 7 m. We tentatively interpret the top 2 m as soil and the middle layer to ~8 m as gravel underlain by glacial till and bedrock, but we are unsure how the presence of permafrost may affect our results.

SEISMICITY, GEODYNAMICS AND SEISMIC HAZARD IN YUKON-WESTERN NORTHWEST TERRITORIES

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There is substantial earthquake occurrence and hazard in Yukon and western Northwest Territories that is not always appreciated. We describe the distribution of past earthquakes and hazard estimates based on the earthquake data file, geophysical and geological constraints and geodynamic models. There is exceptional seismicity in SW Yukon, adjacent Alaska and BC where the Yakutat terrane is colliding with the continental margin in the Gulf of Alaska, pushing up the spectacular St. Elias Mountains including Mt. Logan, Canada's highest mountain. The region has had numerous recorded magnitude 7 to 8 earthquakes in adjacent Alaska. Less well known is the strong seismicity in the Mackenzie Mountains, Richardson Mountains, and the Beaufort Sea regions, with a number of magnitude 6 to 7 recorded earthquakes. The earthquake record and high-precision GPS data support a tectonic model of the Yakutat terrane collision driving the northern Cordillera Yukon block to the north-northeast. The collision drives transpression in SW Yukon, thrust faulting in the Mackenzie Mountains, and dextral strike-slip faulting in the Richardson Mountains region that may extend northward to the continental margin through the Eskimo Lakes Fault zone. The Richardson dextral motion coupled with sinistral motion in the Canning displacement zone in eastern Alaska implies an intervening northward-moving crustal block and active convergence at the Beaufort Sea continental margin. Although there have been no historical large events, the Mackenzie Delta thrust front may be capable of infrequent but large thrust earthquakes with associated tsunamis. The northerly motion also may be responsible for the concentration of seismicity in the Beaufort Sea. There is steady improvement but still limited seismograph

station coverage in northwestern Canada which limits the epicentre accuracies, correlations with mapped faults, and calculation of other earthquake parameters. Only earthquakes above about M3 are consistently located, and there is limited depth resolution and rupture mechanism determination. There have been significant recent advances in modelling the ground shaking hazard in the area, from better earthquake data, GPS data, and tectonic models. There are also better models that estimate the attenuation of strong ground shaking with distance, but the hazard characterizations are still only very regional. Future seismic hazard models for the region would benefit from an improved seismotectonic model of the region based on neotectonic evidence of active faulting and enhanced seismic and GPS observations.

CHARACTERIZING THE DISTRICT-SCALE ALTERATION SURROUNDING A LARGE PORPHYRY CU SYSTEM: THE FOOTPRINT OF HIGHLAND VALLEY COPPER, BRITISH COLUMBIA

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The Highland Valley Copper (HVC) district near Kamloops, British Columbia, is a porphyry copper district hosted in the Late Triassic Guichon Creek batholith. The HVC site was chosen to study what controls the extent and shape of porphyry deposit footprints, and to determine what is the footprint signature to distances up to 13 km away from the mineralized centers. The Guichon Creek batholith is ideal for this study because its geology is well known and shows minor lateral variability: only six major granitoid units are mapped across the batholith. The main alteration assemblages observed at the district scale include potassic (K-feldspar-biotite), sodic-calcic (albite-actinolite-diopside-garnet-chlorite-epidote), muscovitic (muscovite-quartz), and intermediate argillic characterized by either illite-chlorite-prehnite or kaolinite-dickite-smectite alteration. K-feldspar veins extend to a distance of up to 4.5 km. Sodic-calcic alteration overprints potassic alteration, covers a larger area than potassic alteration, and follows northeast- and northwest-oriented structures related to regional stresses at the time of hydrothermal activity. Muscovitic alteration, interpreted to be the main copper introduction event, post-dates sodic-calcic alteration, is primarily observed within and very close to the mineralized centers, and is locally present at district showings. Intermediate argillic alteration is interpreted to post-date muscovitic alteration. Illite-chlorite-prehnite alteration is widespread in the district, whereas kaolinite-dickite-smectite alteration is almost exclusively observed within the mineralized centers. Hydrothermal alteration associated with copper introduction (i.e., potassic and muscovitic alteration) typically shows elevated concentrations of Mo, W, Ag, Se, Te, Bi, As, Tl, Hg, Cs, Au, and Rb to distances up to 4 km from mineralized centers. White micas (i.e., muscovite, illite, phengite, and paragonite), which are abundant throughout the HVC district, can be used as an exploration tool for porphyry deposits because their chemical composition is partly determined by the hydrothermal fluid temperature and pH. White micas are typically muscovitic to paragonitic within and proximal to the ore zones due to high temperature and low pH fluids, whereas distal white micas are phengitic due to lower temperature and rock-buffered fluids. The Al-OH absorption feature wavelength (2200 nm) of white mica measured by short-wave infrared (SWIR) is a proxy for their chemical composition. SWIR measurements in the HVC district show an increase in the Al-OH feature wavelength from an average of 2197.2 nm at distances <1 km from the Valley or the Lornex mineralized center to an average of 2202.3 nm at distances >10 km, consistent with muscovitic proximal white micas and more phengitic distal white micas.

PETROLOGY OF MAGMATIC Ni-Cu-PGE ORE SYSTEMS

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The geochemistry and isotopic compositions of magmatic Ni-Cu-PGE ores and their host rocks allow us to constrain the abundances of metals in the magma sources, the mechanisms of partial melting, the degree of fractional crystallization of silicates ± sulfides during magma emplacement, and the amounts of magma that equilibrated with the sulfide melts. Field relationships, textures, mineralogy, and geochemistry record a wide array of ore-forming and ore-modifying processes, including silicate – sulfide liquid immiscibility, sulfide melt – wallrock ± xenolith ± xenocryst ± xenomelt ± xenovolatile interactions, sulfide melt infiltration and percolation, MSS ± ISS fractional crystallization, subsolidus recrystallization and exsolution, and subsequent metamorphism and deformation. Our understanding of these processes is constantly improving through continued study of the deposits and advances in imaging (e.g., 3D X-ray tomography), rock analysis (e.g., MC-ICPMS), mineral analysis (e.g., LA-ICPMS), laboratory analog modeling, computational fluid dynamic modeling, and experimental work (e.g., influence of f_{O_2} / f_{S_2} volatiles, and semi-metals on phase equilibria). For example, there is new field evidence that mineralization may be generated not only by interaction of magmas with sulfide xenomelts (which we believe occurred in most Ni-Cu-PGE deposits) or exsolution of small amounts of sulfide from the magmas (which we believe occurred in some Ni-Cu-PGE deposits and most PGE deposits), but also by interaction of magmas with cognate xenoliths/xenocrysts. New fluid dynamic studies suggest that some sulfide melts previously thought to have been transported upwards more likely moved downwards during countercurrent flow of denser sulfide melts and less dense silicate melts, and that some sulfide droplets may have been floated by vapour bubbles. We now know that sulfide melts can fractionally crystallize on large scales, not only within vein systems but also within silicate cumulate networks. There is new field, petrographic, and geochemical evidence that Fe-Ni-Cu sulfide melts can react with wall rocks to produce bornite-millerite-rich assemblages that do not lie on normal sulfide liquid lines of descent. We continue to find evidence that some sulfide melts contained significant amounts of volatiles. These advances show that there is still much to learn about the geology, mineralogy, geochemistry, and petrology of magmatic Ni-Cu-PGE deposits, and significant opportunities to discover new settings and styles of mineralization.

UNDERSTANDING EARTH'S 4D SUPERCYCLES THROUGH IGCP 648

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Key clues for answering the question of what drives plate tectonics lie in geological and palaeomagnetic records of evolving global palaeogeography and related tectonic processes, records of mantle plume activities in both the continental and oceanic realms through time, and clearer pictures of the physical and chemical structure and dynamic interactions of the Earth's interior. Major breakthroughs over the past 30 years put us in a position to make a major stride in answering this question. These include: (1) widely accepted cyclic occurrences of supercontinent assembly and break-up (i.e., supercontinents Pangea with a life span of 320–170 Ma, Rodinia 900–700 Ma, and Nuna/Columbia 1600?–1300? Ma); (2) seismic tomographic discoveries of two equatorial and antipodal large low seismic velocity provinces (LLSVPs) that dominate the lower mantle and appear to have been the base for almost all mantle plumes since the Mesozoic, and of subduction of oceanic slabs all the way to the core-mantle boundary, which together suggesting whole-mantle convection; (3) the recognition of possibly cyclic occurrence of global plume activities that may have been related to the LLSVPs and even supercontinent cycles (Earth's coupled supercycles); (4) the recognition of true polar wander (TPW– rotation of the

entire mantle and lithosphere relative to the planetary rotation axis) as an important process in Earth history, reflecting Earth's major internal mass redistribution events such as those related to the supercycles; and (5) rapidly enhancing computer modeling power enabling us to simulate all aspect of Earth's dynamic inner working. Although some believe that the two LLSVPs or superplumes are long-lived in Earth history and are thus independent of the plate system, here I present a self-consistent working hypothesis that features the followings: (a) supercontinent and superplume events are both cyclic and coupled in time and space (the supercycles); (b) circum-supercontinent subduction leads to the formation of two antipodal superplumes, corresponding to the positions of the supercontinent and the superocean, respectively; (c) superplumes can bring themselves and the coupled supercontinents to equatorial positions through TPW events, and eventually lead to the breakup of supercontinents; and (4) the breakup of a supercontinent gradually changes the Earth from a dominantly circular subduction system to scattered multiple-subduction systems, thus weakening the antipodal superplumes until after the formation of the next supercontinent. IGCP project No. 648 was formed to coordinate a global cross-disciplinary effort to test this and other geodynamic models.

THE NEOPROTEROZOIC AND PALAEOZOIC OF THE CENTRAL EUROPEAN VARISCIDES IN THE SCALE OF THE SUPERCONTINENT CYCLE

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The dispersal of Rodinia was followed by a plate tectonic re-organisation, which resulted in the formation of the Gondwana supercontinent formed in a time period of c. 750 to 600 Ma. Subsequent Late Ediacaran plate interactions at the margins of the supercontinent were responsible for the origin of the composite microcontinents of Cadomia and Avalonia. Both microplates show differences concerning the zircon populations which were inherited from their primary cratonic hinterland. Inheritance characteristics are provided by U-Pb ages and Hf-isotopes of detrital and magmatic zircon. Cadomia shows a clear reworking of a West African crust, which is characterized by Palaeoproterozoic and Archaean crustal growth. In contrast, Avalonia shows strong recycling of a crust, which is dominated by Mesoproterozoic tectonomagmatic events. Thus, Avalonia is exotic concerning its inherited cratonic zircon populations in comparison to crustal fragments derived from a West Gondwanan crust (West African-Amazonian). These differences of Avalonian and Cadomian zircon populations we use for plate tectonic reconstructions in Palaeozoic mobile belts such as the Variscan orogen in Central Europe, in which Cadomian and Avalonian basement rocks had been involved. Zircon provinces (U-Pb, Hf) of (micro-) continents like Avalonia, Cadomia, south Baltica, West Africa, and Amazonia allow a detailed reconstruction of Variscan orogenic processes preserved in Central Europe. Plate tectonic processes are very much more complex than shown in previous models.

MINDY F-B-Sn SKARNS, SE YUKON

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The Mindy prospect is a greisen-altered skarn. Primary high temperature calc-silicate assemblages have been formed in and peripheral to extensional faults above a postulated shallow-buried stock. Andradite-grossular garnet, pyroxene and amphibole assemblages have been replaced by Fe-rich greisenized F-B-Sn skarn minerals. The skarns may have a variety of tin minerals apart from cassiterite: vonsenite $[3(\text{Fe,Mg})\text{O} \cdot 2\text{Fe}_2\text{O}_3 \cdot \text{SnO}_2 \cdot 3\text{B}_2\text{O}_3]$, hulsite $[(\text{Fe}^{2+},\text{Mg})_2 \cdot (\text{Fe}^{3+},\text{Sn})\text{BO}_3]$ nordenskiöldine $[\text{CaSn}(\text{BO}_3)_2]$ which are

associated with fluoborite $[\text{Mg}_3(\text{F,OH})_3\text{BO}_3]$ and abundant fluorite. The borate and silicate tin minerals are metallurgically refractory and only the cassiterite is of economic interest. Structural control on emplacement of the skarn was not investigated during the original 1981 evaluation of this prospect.

The skarns of the main horizon are developed in a marble unit adjacent to extensional faults. Textural evidence indicates that the original protolith controlled much of the skarn mineralogy and that migration of many chemical components during contact metamorphism and metasomatism was on a small scale. An example is fine-grained hornfels where S-C fabric that developed during imbrication of the sedimentary package is preserved in calc-silicate mineralogies.

The process of skarn formation has had an obvious structural control. Development of successive retrograde and greisenized skarn assemblages has each accompanied fracturing of earlier skarn. Cataclasis of the pyroxene that has a range of compositions from diopside to hedenbergite indicates continued early brecciation. Disequilibrium in composition over the scale of a thin section is quite usual in the central mineralized part of the skarns. The most striking texture of later greisenized skarn is intricately banded 'wrigglite'. Wrigglite consists mostly of contorted layers of magnetite and sulphides with phengite or talc, lesser amounts of fluorite and fluoborite which contains corroded relicts of chondrodite and vesuvianite. The zones of wrigglite are obviously discordant to bedding of the host rock, hence representing fracture systems and the wrigglite layers themselves may be cut by several generations of microfractures < 1mm to 3mm wide that carry phengite, talc and scarcer ferrophengite or serpentine.

Chemistry of both primary and retrograde mineral assemblages progressed from magnesian to iron-rich pyroxenes and amphiboles. Greisen skarn alteration formed a wide range of fluorine and boron bearing minerals, which contain approximately half the tin content of the skarns.

TIN GRANITES OF THE SE YUKON

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The Seagull suite of anorogenic one-mica granites is a peculiar feature of mid-Cretaceous magmatism in the SE Yukon. The Seagull and Hake batholiths, Ork and Thirtymile stocks are B-F enriched granites associated with various forms of tin mineralization. The granites are metaluminous to weakly peraluminous and conform to type A1 of Eby and plot in the A-type field of discriminant diagrams.

The Seagull batholith is composed of two mappable biotite granites. Miarolitic cavities and pod pegmatites containing tourmaline, fluorite and cassiterite are common, indicating shallow depth of emplacement. Tin mineralization as skarn, greisen and sheeted veins is distributed around the margin. The Hake batholith also has peripheral Sn, Cu and Au skarn prospects. It has a rapakivi-textured marginal lithofacies but no miarolitic cavities have been observed i.e., it was likely emplaced at greater depth than the other plutons.

The Thirtymile Range contains 101 Ma stocks. Two biotite-only granites make up the bulk of the Thirtymile Stock, with a hornblende-bearing porphyry as a disaggregated syn-plutonic dyke which is the only amphibole-bearing lithofacies in the suite. An alkali feldspar granite *sensu stricto* crops out at the SE corner of the stock with peripheral 1-5 m scale dykes and sills. The just-exposed Ork stock and dykes are 4km to the SE. Thirtymile and Ork leucogranites consist of a quartz-albite-orthoclase-zinnwaldite-topaz-fluorite assemblage with accessory fergusonite. They are the most chemically evolved granites in the Northern Cordillera with Rb/Sr ratios exceeding 3000 and might be considered the plutonic analogue to topaz rhyolites, emplaced at shallow depth (≤ 2 km) as indicated by miarolitic cavities. The magmas were highly enriched in Rb, Li, B, F and Cl. That enrichment would have allowed the granitic magma to remain as a melt to 650 °C, producing a compositional trend different to quartz enrichment. Biotite compositions indicate

that the magmas were reduced: biotite $\{Fe^{2+}/(Fe^{2+} + Fe^{3+})\} = 0.811-0.965$, magma $f_{O_2} \leq$ NNO buffer. Halogen-bearing granites fractionate to albite-enriched compositions and due to protracted melt / aqueous fluid and fluid / vapour fractionation and their reduced nature concentrate Sn, Nb and Ta into a hydrothermal phase.

The A-type affinity of the Seagull granites is consistent with their being the one Cretaceous suite in the northern Cordillera principally associated with Sn-F mineralization. The question as to the tectonic significance of this anorogenic event remains to be elucidated.

HYDROCLIMATE VARIABILITY DURING THE PAST MILLENNIUM: A NEW RECORD FROM WEST BASIN LAKE, VICTORIA, AUSTRALIA

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Our understanding of the long-term climate variability in Australia is limited by the number of high-resolution climate reconstructions. High-resolution palaeoenvironmental studies in Australia spanning more than a millennium are required to identify regional coherency among records and to identify possible relationships between climate and environmental conditions. This research project investigates the nature of decadal-centennial scale climate and hydroclimate variability in south-eastern Australia during the past millennium and the impact of European settlement on climate in this area. We develop a record of hydrological change for the past millennium at West Basin Lake, a maar lake located in western Victoria, approximately 150 km west of Melbourne. Palaeoclimate variability is inferred from sedimentary diatom analysis to reconstruct lake water salinity as diatom distribution is correlated to the hydrochemistry of a lake. These data are interpreted in conjunction with major and trace element concentration data in lake sediments. The palaeoenvironmental record indicates that West Basin Lake underwent hydrological variability on a decadal-centennial timescale. The diatom record indicates a more variable climate during 932-550 cal BP and less saline conditions from 500-100 cal BP. The record also identifies a multi-decadal period of increased salinity from 625-575 cal BP. Overall, these data provide a regionally coherent palaeoclimate reconstruction of the last millennium for western Victoria and indicate a highly variable climate during the past millennium.

THE KWANIKA ALKALIC PORPHYRY COPPER DEPOSITS, CENTRAL BRITISH COLUMBIA

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The Kwanika porphyry deposits occupy the western margin of Quesnel terrane, a Late Paleozoic to mid Mesozoic volcanic arc terrane that hosts numerous alkalic and calc-alkalic porphyry Cu±Au-Mo-Ag deposits extending north from the British Columbia-Washington State border for more than 1,000 km. It formed adjacent to ancestral North America in response to eastward-dipping subduction of the Tethyan oceanic Cache Creek terrane. At Kwanika, Cu-Au±Mo mineralized Late Triassic to Jurassic Takla arc volcanic and marginal phases of the Hogen batholith are structurally dismembered and preserved adjacent to Cache Creek rocks along the Eocene Pinchi Fault.

Kwanika mineralization consists of a South Zone hosted by equigranular quartz monzonite and characterized by Cu-Au-Mo

with locally elevated Zn, Pb and As; and 2 km northwest, a Central Zone hosted by a quartz monzonite porphyry plug and-dike complex characterized by Cu-Au. Early Jurassic U-Pb crystallization (198 ± 0.4 Ma and 199 ± 0.4 Ma) and Re-Os mineralization (199 ± 1 Ma) ages, suggest Cu-Au and Mo mineralization accompanied crystallization of the quartz monzonites. Un-mineralized pyroxenite (180 ± 1 Ma; Ar-Ar) in the Central Zone has an age identical to Phase 1 pre-mineral pyroxenite at the Lorraine Cu-Au porphyry in the core of the Hogen batholith. Older porphyry Cu-Au mineralization associated with monzonite (204 Ma) occurs on the eastern side of the batholith at Cat Mountain.

The Central Zone has an inner and outer potassic core that hosts pyrite>chalcopyrite>bornite quartz vein mineralization and a 100 m propylitic envelope. It is dissected, down-dropped to the west and overlain by a north-trending, westward-deepening Early Cretaceous (Valanginian-Early Albian) sediment filled graben that preserves a 5-70 m thick supergene blanket above the hypogene mineralization. The western side of the Central Zone is cut off by a steep brittle fault zone that juxtaposes it with Cache Creek rocks. Behemoth-sized (50+ m) mineralized and un-mineralized Takla volcanic and intrusive slabs within the sedimentary basin suggest steep fault-scarp topography and periods of tectonic instability to facilitate introduction of large slabs into the basin. Shearing is common along the basal contact separating the Early Cretaceous sedimentary rocks from the highly oxidized supergene zone of the Central Zone and likely reflects basin inversion in the Mid-Cretaceous. Following the Mid-Cretaceous, motion along major strike-slip faults in the Canadian Cordillera was primarily dextral. Thus exploration for the faulted-off western side of the Central Zone should focus north and west of the Pinchi Fault.

PRINCIPAL COMPONENT ANALYSIS OF MINERAL LIBERATION ANALYSIS DATA ON ANGULARITY, SIZE DISTRIBUTION AND MINERAL ASSOCIATIONS OF MAGNETITE AND HEMATITE FROM THE IZOK LAKE VMS DEPOSIT (NUNAVUT, CANADA) AND LOCAL TILL

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Mineral Liberation Analysis (MLA) is a precise automated technique to identify indicator minerals in bedrock and till samples and obtain information regarding their physical properties. In comparison with conventional data presentation methods such as box and whisker diagrams or histograms, analyzing MLA datasets by Principal Component Analysis (PCA) can reduce the complexity of such data, and identify variables useful in classifying sources of indicator minerals in sediments. In this study, 0.25-2.0 mm ferromagnetic heavy mineral fractions from 12 bedrock and 9 till samples collected from the Izok Lake volcanogenic massive sulfide deposit area were investigated using MLA. Magnetite and hematite mineral associations, grain sizes, and angularities were studied by PCA. Samples sharing similar characteristics, including Massive Sulfides (MS), Iron Formations (IF), and Sulfidic Breccia Pipes in basalt (SBP), plot near each other in PCA latent variable space. Bedrock mineral associations of magnetite and hematite are similar to till samples collected down ice from the deposit. PCA of iron oxide mineral associations indicates that a high proportion of magnetite and hematite grains in till were derived from gabbro, Gahnite-rich Dacite (GD) and IF, whereas a low percentage may have originated from Sulfidized Felsic Metavolcanic (SFM) rocks.

PCA shows that grain sizes in till samples closely resembles that of MS, GRD, and SBP samples (median size: 212 to 7100 µm). In contrast, rhyolite and SFM samples contain higher proportions of fine-grained hematite (median size 13.5 µm) that is underrepresented in 0.25-2.0 mm heavy mineral fraction of Izok Lake till samples. Magnetite in mineralized schist is also fine-grained (median size: 8.1 µm). The results indicate that the geochemical and morphological characteristics of small magnetite and hematite grains from the

gabbro, IF, and metapelite samples (median size: 27 to 75 μm) will not be detected in the standard grain-size fraction of till processed for heavy mineral separation. The angularity range of magnetite and/or hematite aggregates in till samples comprises that of all bedrock samples other than mineralized schist. One of the SBP samples also shows a wider angularity range as it contains higher proportion of iron oxides with high angularity values. In summary, PCA of iron oxides' angularity and grain sizes discriminates MS and GD from the other bedrock samples, and detects the signature of these bedrock samples in till. PCA of Izok Lake magnetite and hematite MLA data is an innovative exploration method to distinguish the origin of indicator minerals in unconsolidated sediments.

INDICATOR MINERAL EXPLORATION IN THE KIGGAVIK URANIUM DEPOSIT AREA (NUNAVUT, CANADA) USING MAGNETITE AND HEMATITE CHEMICAL COMPOSITIONS

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Magnetite composition has been widely used for sediment provenances and/or exploration for various mineral deposit types. However, the chemistry of magnetite and hematite from uranium deposits is poorly known. In this study, 46 magnetite and hematite grains from 11 bedrock samples, and 706 grains from 0.25-2.0 mm ferromagnetic heavy mineral fractions from 10 till samples collected from the Kiggavik uranium deposit area were investigated for their chemistry using electron probe micro-analyzer (EPMA). The geochemical censored data were imputed by the R-package robCompositions, and then transformed by centered log-ratio to eliminate the closure effect. The transformed data were studied by Partial Least Squares Discriminant Analysis (PLS-DA) to yield discrimination models classifying sources of iron oxides in local till. The results in PLS-DA latent variable space (t1-t2) shows that magnetite from diabase are characterized by high Ti values, hematite from quartz arenite by high Mn values, and hematite from alkali granite by enrichment in Al. PLS-DA shows that the bedrock samples forming overlapping clusters in t1-t2 can also be classified with their distinct mean compositions. For instance, the field for hematite from altered metawacke overlaps that for quartzite in t1-t2, however, higher Si, and lower V and Mn separate metawacke hematite from quartzite hematite. Magnetite and hematite compositions from till were projected into the t1-t2 space defined by different bedrock samples. PLS-DA distinguishes chemical signatures of all bedrock lithologies in till, though, a high proportion of Kiggavik till grains remain unclassified. Hematite in the bedrocks and till commonly contains higher Si and/or Al relative to magnetite.

To evaluate the potential of iron oxides' chemistry for further mineral exploration in the Kiggavik area, the data from the Kiggavik bedrock and till samples were compared with that from the Izok Lake and Halfmile Lake volcanogenic massive sulfide (VMS) deposits as well as the Thompson Ni-Cu deposit. The PLS-DA results reveal that a high proportion of Kiggavik till grains show the chemistry typical of iron oxides in the mineralized bedrocks of the VMS deposits. This may suggest the occurrence of VMS mineralization in up-ice from the Kiggavik deposit that has been eroded by glaciers through time. This is in contrast to magnetite and hematite from till from the Izok Lake, Halfmile Lake and Thompson areas that mainly carry the signature of local bedrocks. PLS-DA of the Kiggavik data establishes classification methods to distinguish the origin of iron oxides in unconsolidated sediments for mineral exploration.

NEW AGE CONSTRAINTS ON VOLCANIC ROCKS FROM THE OGILVIE MOUNTAINS, WEST-CENTRAL YUKON

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Volcanic rocks traditionally assigned to the Dempster volcanics in the western Ogilvie Mountains, Yukon, consist of a diverse package of subaqueous pillow basalts and breccias, gabbroic dikes, and minor felsic rocks that were erupted along the northern edge of the Ediacaran-Paleozoic Selwyn basin, straddling the Dawson fault. These volcanic rocks appear to record episodic early Paleozoic magmatism along the northwestern passive margin of Laurentia; however, current age constraints on these volcanic rocks are limited to a rough stratigraphic location between the Ediacaran Hyland and early Paleozoic Road River groups. In 2015, various outcrops of volcanic rocks within the western Ogilvie Mountains were examined for petrographic, geochemical, and geochronological characterization. Two samples of rhyolitic breccias from the western Coal Creek region yield U-Pb chemical abrasion-isotope dilution-thermal ionization mass spectrometry (CA-ID-TIMS) ages on zircon of 718.13 ± 0.28 Ma and 718.12 ± 0.21 Ma, which suggests these localized felsic rocks belong to the nearby Neoproterozoic Mount Harper Group rather than the Paleozoic Dempster volcanics. Further east near the Dempster Highway corridor, new trilobite collections were extracted from carbonate debris-flow horizons within pillow basalts and breccias of the Dempster volcanics. These collections contain more than 15 genera and include several species that assign them to the uppermost Bolaspidella Zone and/or basal Cedaria Zone (Marjuman Stage, Lincolnian Series, global Series 3). These new geochronological and biostratigraphic data require significant changes to regional map units, including the location of the Dawson fault in the western Ogilvie Mountains, and provide new insights into early Paleozoic volcanism at the northern edge of the Selwyn basin.

INDICATOR MINERALS OF THE MELIADINE OROGENIC GOLD DEPOSIT (NUNAVUT, CANADA)

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The Meliadine deposit is located about 25 kilometres north of Rankin Inlet, in the Kivalliq region of Nunavut (Canada). The bedrock is composed of greenschist facies metamorphosed sedimentary rocks including Banded Iron Formations (BIF) and greywackes, interbedded with mafic volcanic rocks. This assemblage belongs to the Archean Ennadai - Rankin Inlet greenstone belt. Auriferous mineralization is associated with the NW-SE 80 kilometers long Pyke Fault. Magnetite-rich iron formations and weakly magnetic iron formations, intercalated with mafic volcanic rocks, host the gold mineralization composed of sulfide rich mesothermal quartz veins associated to the fault system. Gold is mainly disseminated in BIF and quartz-carbonate veins. Arsenopyrite, pyrrhotite and pyrite are disseminated in the walls of the veins as well as in the BIF.

Core samples from eighteen drill holes document five deposits along the Pyke Fault: Tiriganiaq, Pump, F-zone, Discovery and Mustang. Eleven rock samples were submitted to Electric-Pulse Disaggregation to extract more indicator minerals. Preliminary Electron Probe Micro-Analyser (EPMA) analyses show that tourmaline grains have heterogeneous tenors in titanium and vanadium, whereas arsenopyrite grains show a variation in cobalt and nickel values. Their chemical composition will be compared to the composition of grains extracted from till samples. The composition of magnetite, scheelite and galena will also be investigated by EPMA and Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS).

Seven till samples were collected parallel to the direction of iceflow at the Mustang showing, along a 2 km transect. Two samples are located up-ice, the others up to 1 km down-ice. Along the profile, the number of gold grains increases from a background mean value of 7.5 grains (normalised to 10 kg) immediately down ice of the showing to reach a maximum value of 19.1 at the end of the profile. The number of pristine shaped gold grains reaches the maximum of 2.1 at 200 meters down-ice of the showing. Modified shape grains culminate with 6.4 grains at 300 m whereas reshaped grains reach a maximum of 13.0 grains at 1 km down-ice.

In the 0.5 to 1.0 mm grain-size fraction, the number of magnetite and tourmaline grains reach maximum values of, respectively, 374.6 and 4.8 grains at 600 m down-ice whereas scheelite grains are only found in samples 1 km down-ice (0.8 and 0.9 grain). In the smaller grain-size fraction (0.25 to 0.5 mm), scheelite grains reach a maximum number 3.5 grains at 1 km down-ice.

ALASKA'S NORTH SLOPE AFTER 45,000 YEARS AGO

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Much of Alaska's North Slope, the region between the Brooks Range and the Arctic Ocean, was ice-free during the Late Wisconsin, and so it contains a rich archive of non-glacial, sedimentary deposits and mammal bones. Here we review how ecosystems changed there after 45 ka (45,000 calibrated yr BP) based on floodplain dynamics, shifts in aeolian deposition, and changes in mammalian megafauna. Warming triggered thermokarsting, which increased sediment input into streams, resulting in floodplain aggradation. Colder climates stabilized hillslopes, which caused incision of floodplains. Major changes in tundra floodplains occurred most recently during the Bølling-Allerød (aggradation), Younger Dryas (incision), and the earliest Holocene (aggradation).

Sand dunes, sand sheets, and their marginal loess belts cover much of the North Slope today. In the Carter Section, located at the southern edge of the former Ikpikpuk Sand Sea, fluvial, sand sheet, and loess deposition alternated over the last 45,000 years. In contrast to the present-day landscape, well-drained, largely peat-free soils existed at this site between 45 and 8 ka. Graminoids were abundant, and soil development was minimal. Maximum expansion of the sand sea occurred between 18 and 15 ka, out of phase with the global LGM.

Based on the age distribution of hundreds of ¹⁴C-dated bones, steppe bison, muskoxen, and caribou fluctuated markedly in their abundances during the Late Wisconsin, with bison disappearing ca. 12.4 ka. Horses increased steadily in abundance after 45 ka, peaking between 20-15 ka, before disappearing ca. 12.4 ka. The rise of horses was paralleled by increasing numbers of lions. Mammoth persisted in steady numbers throughout; the youngest mammoth dates to 13.5 ka.

Megafaunal abundance tracked shifts in vegetation caused by changing climate. Brief (500-1000 yr) peaks in bone abundance record transient periods of greener pastures occurring at the onsets of interstadials. These short-lived warming phases allowed proliferation of palatable graminoids across landscapes while soils and permafrost were briefly out of equilibrium with climate. Reflecting this temporal instability in ice-age vegetation, times of peak megafauna abundance were short-lived. Recognition of boom-and-bust cycles on the Mammoth Steppe may help reconcile the decades-long disagreements between botanists and zoologists about the nature of this vanished biome.

IMPACT OF THE YAKUTAT INDENTOR CORNER ON PRESENT-DAY TECTONICS AND FAULT ACTIVITY IN SE ALASKA – SW YUKON

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We present an active tectonic model of the SE Alaska – SW Yukon region based principally on the integration of recent GPS velocity data and new fault-slip rates derived from geomorphology. In this region, the Yakutat collision results in complex tectonics with patterns of strain localization and strain partitioning that strongly vary across the various mountain ranges and active faults. We propose that deformation and fault activity in the St. Elias and Chugach Mountains are primarily controlled by the eastern syntaxis of the Yakutat collision, which produces a semi-radial tectonic pattern: Velocities, principal horizontal shortening rates, and maximum horizontal stress orientations rotate by 60 – 80° around the syntaxis, from roughly parallel to the relative Pacific – North America motion at the front of the collision to roughly orthogonal southeast of the syntaxis. The interaction between this strain pattern and major inherited tectonic structures inland of the collision zone (i.e., Denali and Duke River Faults) results in various reactivation modes of these structures. Specifically, the Denali Fault shows a very pronounced lateral variations of activity from ~12 mm/a of dextral slip rate in its central section to ~1 mm/a of mostly shortening slip rate along its southern section. This marked change of activity is associated with a possible relay system where the Duke River and Totschunda Faults accommodate a major part (8 – 14 mm/a) of the inland strain transfer directly in front of the syntaxis. This new tectonic model retains some questions, in particular regarding the mechanisms of deformation and strain transfer (1) from the syntaxis to the Duke River – Totschunda system and (2) at the junction between Totschunda and Denali Faults. Numerical models of present-day deformation may help address these issues and provide information about relative strength of the various crustal and inherited fault elements of this system.

AUTHIGENIC GROWTH OF GOLD AND MARCASITE IN PALEOPLACERS OF EAST CENTRAL ALASKA

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There has been longstanding debate over the processes responsible for the accumulation of gold in placer gold deposits. Many researchers suggest that gold is entirely concentrated through physically processes, whereas others invoke chemical concentration of gold through authigenic growth. Here we present evidence that gold in bench gravels at Lost Chicken Hill, Eagle quadrangle, Alaska was concentrated by a combination of both processes.

The deposit is hosted in 5-8 m thick Pliocene to Pleistocene gravels that overlie heavily fractured diorite and quartz diorite and capped by 17-20 m thick loess/peat. Placer gold is concentrated in the lowermost 0.3-1 m of gravels and in cracks in underlying diorite. Gold occurs as flakes and nugget, some of which are encrusted with oxidized material.

Our SEM and EDS analyses reveal that the placer grains are a composite of electrum, gold, and marcasite. Large electrum cores (average fineness of 790) are rimmed by a 1-10 micron thick layer of pure gold; boundaries between these phases are sharp. Colloform marcasite with minor kaolinite, quartz, and native sulfur encapsulate the composite electrum-gold grains. Similar textural relationships have been recognized in other paleoplacer and gold laterite grains in New Zealand, California, and Australia.

The occurrence of pure gold rims on electrum has been attributed to the leaching of silver by low temperature groundwater. However,

some suggest at low temperature both silver and gold are soluble if thiosulfate or organic ligands are available. In this model, high fineness gold is more likely to precipitate as the result of reduction of organic-gold complexes that had formed in an alkaline to acidic, mildly oxidizing environment aided by a fluctuating water table redox boundary.

The sharp boundaries between electrum and gold rim is authigenic growth rather than the preferential leaching of silver. Local abundance of both organic material (peat) and sulfide (in peat and underlying altered diorite), could be the source of reductant and both organic and thiosulfate ligands. Moreover, the enigmatic marcasite overgrowths +/- native sulfur and gold suggest a low pH sulfidic environment with changing redox conditions during or after gold deposition. Based on these relationships we suggest a preliminary model: 1) weathering of electrum from gold-bearing veins, 2) burial of electrum by gravels, peat, and loess, 3) interaction and dissolution of gold in groundwater enriched in organic and/or thiosulfate ligands, and (4) the reprecipitation and concentration of gold and marcasite at redox boundaries in this complex system.

TRACKING PLEISTOCENE MEGA-FAUNAL MIGRATION USING DENTAL ENAMEL

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Beringia was a refugium for mega-fauna during Pleistocene glaciations, including several taxa that are still present in the region. However, it is not known how ice-sheet proximity and deglaciation would have affected movement patterns of taxa that presently have well-defined migratory patterns, such as caribou (*Rangifer tarandus*). We are assessing a geochemical approach for determining the geographic mobility of Pleistocene caribou, which in turn may be applied to other taxa in the rich Pleistocene fossil collection of the Yukon.

We analyzed the strontium (Sr) isotope composition of dental enamel from GPS-collared caribou of the Forty Mile and Porcupine herds to assess how enamel isotope composition tracks bedrock geology in the study region, with respect to contemporary migration patterns. We also analyzed fossil remains, with ^{14}C dates on ultrafiltered collagen of 1305 ± 15 to $42000 \pm 1400\text{BP}$, recovered from placer gold mines in the Klondike region (historically occupied by the Forty Mile and Porcupine herds). Molars were extracted from the modern and fossil caribou mandibles and sectioned longitudinally along the length of the dental enamel. Strontium isotope composition of the sectioned enamel fragments was determined by isotope-dilution TIMS. Preliminary results indicate relatively large shifts in $^{87}\text{Sr}/^{86}\text{Sr}$, from 0.71148 to 0.71220. In contrast, a modern bovine with no allochthonous dietary inputs yielded mean $^{87}\text{Sr}/^{86}\text{Sr}$ of 0.70825 ± 0.00012 ($n=11$). The subtle variations in Sr isotope composition from the modern bovine, compared to fossil and modern caribou, reveal how Sr isotope composition of caribou tissue is affected by migration over bedrock with different Sr isotope composition. The fossil caribou enamel Sr isotope compositions will be compared to mapped and modeled bedrock Sr isoscapes to evaluate potential spatial patterns of paleo-migration.

A COMPARATIVE STUDY OF GLACIOVOLCANIC PALAGONITIZATION OF THOLEIITIC AND ALKALINE SIDEROMELANE AT HELGAFELL, ICELAND AND WELLS GRAY, BC CANADA

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During the Pleistocene, glaciovolcanic eruptions occurred frequently beneath continental-scale ice sheets that periodically covered Iceland and British Columbia. The eruptions produced significant

vitric, fragmental volcanic deposits that are highly susceptible to hydrothermal alteration that partly transformed sideromelane (basaltic volcanic glass) into palagonite (a mixture of clay minerals, zeolites, and cryptocrystalline material). The controlling mechanisms of this evolutionary, dissolution-precipitation process are not fully understood, although previous studies have shown that the most important variables are the original sideromelane and fluid compositions, porosity, pH and temperature during alteration. This study compares sideromelane and palagonite from Wells Gray, BC, where extension-driven glaciovolcanism produced mainly alkali olivine basalt, to that of Helgafell, Iceland, where a subglacial fissure eruption formed tholeiitic basalt. Our main preliminary conclusions are that starting compositions (alkaline vs. tholeiitic) and primary textures (esp. degree of vesicularity) are important controls on the chemical variations we have documented.

Four samples from each location were analyzed using a variety of techniques, including optical petrology, SEM, EPMA, LA-ICP-MS and whole rock analysis. The majority of investigated basaltic glass from both locations is sideromelane (honey-coloured, isotropic), although tachylite (opaque, cryptocrystalline, non-vesicular) is also present. Generally, sideromelane from all samples have similar textures, including concave crenulated edges, microbial textures, channels linking vesicles, spherical devitrification and zoned palagonite rims. But Wells Gray glass is more microlite-rich (primarily olivine and plagioclase) and is more sharply defined with palagonite, and has relatively thicker rims (~10-20 microns) and lower vesicularity. In contrast, Helgafell glass grains have much higher vesicularities and the thinner (~6-10 microns) palagonite rims are more commonly located within vesicles, not at the edge of glass grains. Despite the primary variations, all samples show variable gel-like to fibrous textures, possibly due to differing degrees of dissolution-precipitation as sideromelane progresses from non-crystalline glass to a thermodynamically stable crystalline structure of secondary minerals. Interstitial minerals are pyrite, chalcopyrite, Fe-oxides and other alteration products.

The palagonitization process is characterized by the release of elements from the glass concurrent with hydration of the glass (H_2O : 19.5 - 30.2 wt.%). Elements whose relative apparent concentrations decrease during palagonitization are Si, Al, Mn, Mg, Ca, Na, K, P whereas Ti, Fe and F variably decrease or increase. The apparent concentrations of trace elements in palagonite are mostly enriched compared to sideromelane. Multi-dimensional scaling has shown that glass and palagonite are geochemically unique between locations. The stoichiometry of palagonitization processes are being explored using Gresens-style isocons.

MANY METEORITES IN ONE: SPATIAL SCALE AND RANGE OF VARIATION IN BULK PHYSICAL AND LITHOLOGICAL PROPERTIES OF THE TAGISH LAKE C2 CHONDRITE

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The Tagish Lake (hydrous C2) carbonaceous chondrite fell in northern BC on January 18, 2000 as a major fireball event, producing a large strewnfield of meteorite fragments on the frozen lake surface. Two separate collection phases in January and April/May 2000 recovered ~11 kg of Tagish Lake material. The initial collection of nearly 1 kg of "pristine" individuals and fragments was done while they remained frozen, whereas the later collection recovered many more samples that were observed to have variously disaggregated in meltwater. The Tagish Lake meteorite possibly represents the most porous, primitive chondritic material yet reported: Early work on both pristine and degraded samples ranging between 13 g and 77 g showed a mean bulk density of $1.64 \pm 0.02 \text{ g/cm}^3$ and porosity of 40%. More recent work done exclusively on 13 frozen pristine samples with masses between 8 g and 158 g revealed a higher mean bulk density of $1.81 \pm 0.05 \text{ g/cm}^3$ and porosity of 30%. In this study, we report magnetic susceptibility, bulk density and grain density for a large number

of meteorite individuals and fragments from the April/May 2000 recovery effort, with masses ranging from 1 g to 110 g. We in particular use medical X-ray computed tomography (micro CT) to obtain 3D reconstructions of larger Tagish Lake samples for the first time to investigate lithological variation within and between samples as well as to obtain bulk volume and other physical textural characteristics. With these non-destructive methods, it seems possible to define and explore the spatial scale and range of lithological variation in Tagish Lake meteorite. Preliminary data show that 17 larger samples have a mean bulk density of $1.61 \pm 0.08 \text{ g/cm}^3$, 23 samples provide a mean grain density of $2.74 \pm 0.05 \text{ g/cm}^3$ and in five individuals so far where a direct comparison can be made, the calculated porosity is $42 \pm 2\%$. These results are similar to earlier reports, and imply that the frozen pristine samples are systematically different in some way. Magnetic susceptibility measurements of a large suite of 760 fragments from 86 different Tagish Lake sample sites have an average $\text{SI } 10^{-9} \log? = 4.81 \pm 0.17$, with some lithologically distinct samples showing markedly lower values. Even allowing for outlier values, Tagish Lake best resembles CM chondrites in grain density and magnetic susceptibility, but has amongst the lowest bulk density of any meteorite, reflecting its consistently very large porosity.

SHEAR ZONE-HOSTED ORE SHOOTS AT THE ARCHEAN INTRUSION-HOSTED RENABIE GOLD DEPOSIT: THE END PRODUCT OF STRUCTURAL INHERITANCE

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The geometry of mineralized zones in hydrothermal ore deposits reflects that of paleo-fluid conduits, and the effects of superimposed deformation. Ore shoots, or mineralized zones with a dominant linear direction, often correspond to the intersections of paleo-fluid conduits (e.g. the intersection lineation of different vein sets), the orientation of releasing and restraining jogs in fault zones, fold hinges, or the orientation of the stretching lineation along a host structure. The latter often controls the geometry of shear zone-hosted ore shoots, which commonly form during hydrothermal activity synchronous with shear zone deformation. Shear zone-hosted ore shoots within the ca. 2.72 Ga Missinaibi Lake batholith at the former Renabie gold mine (Missanabie, Ontario, Canada), are defined by domains of laminated, saccharoidal-textured quartz veins bounded by zones (~2-10 m in width) of phyllic alteration, which are deformed into quartz-sericite-pyrite schist. Whereas the ore shoots are hosted within reverse-sinistral shear zones, the veins and their phyllic halos are deformed by older structures, suggesting that the veins and their related alteration pre-date regional deformation and the formation of the shear zones. The veins formed in older structures, possibly as intrusion-related sheeted veins, and were subsequently folded and sheared during regional deformation. Thus, the plunge of the ore shoots does not correspond to paleo-fluid conduits along the shear zones, rather their geometry is the result of a protracted history of superimposed deformation.

USING MULTIPLE GEOCHEMICAL TOOLS TO DISCRIMINATE MULTISTAGE GOLD MINERALIZATION AT THE ARCHEAN INTRUSION-HOSTED RENABIE GOLD DEPOSIT, MISSANABIE, ONTARIO, CANADA

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A primary objective in studying hydrothermal gold deposits is to link mineralization to either magmatic or metamorphic processes. The results have direct implications for exploration as intrusive suites and/or syn-metamorphic structures can be implicated as prospective. Although the ideal scenario is to identify dateable hydrothermal phases (e.g., monazite, titanite) that are paragenetically linked to gold, such cases are rare. Instead, geochemistry is used as a proxy,

but a lack of unequivocal discriminators remains an outstanding issue. This study applies a discriminatory approach to two well-constrained gold events within a ca. 2.72 Ga tonalite batholith at the former Renabie gold mine. Here a pre-regional deformation event resulted in the formation of gold-bearing laminated-quartz veins with quartz-sericite-pyrite (Py1) alteration zones, whereas a late- to post-deformation event is characterized by gold-bearing pyrite (Py2) veins overprinting ca. 2.56 Ga K-feldspar-chlorite-titanite-hematite retrograde alteration zones. Techniques applied to discriminate between the two events include: 1) mass balance of the different alteration types; 2) whole rock analysis of gold-bearing samples; 3) SIMS $\delta^{18}\text{O}$ analysis of vein quartz; 4) fluid inclusion microthermometry and SEM-EDS mound analysis; 5) S isotopes for Py1 and Py2; and 6) LA-ICP MS trace element mapping of Py1, Py2, and gold alloys. Results display similar elemental signatures for each gold event ($\text{Ag-Bi-Te} \pm \text{Pb} \pm \text{W} \pm \text{U}$), generally overlapping isotopic signatures, and strong K enrichment with corresponding Ca-Na depletion in both types of alteration. In contrast, fluid inclusion chemistry differs with the laminated-quartz veins hosting a $\text{H}_2\text{O-CO}_2\text{-NaCl}$ fluid ($\text{XCO}_2 = 0.1\text{-}0.15$, 6 wt. % eq. NaCl), and a quartz-breccia vein in a retrograde alteration zone containing a $\text{H}_2\text{O-NaCl-CaCl}$ fluid (avg. 19 wt. %, $\text{Na}/(\text{Na}+\text{Ca}) = 0.28$). These results indicate that while fluids responsible for different gold events and alteration types may differ chemically and in their genesis, they can yield similar elemental associations and alteration signatures. Furthermore, SIMS $\delta^{18}\text{O}$ analysis and trace element mapping highlight two issues: 1) a large range in $\delta^{18}\text{O}$ values (7‰) on the scale of individual quartz crystals; and 2) disparate Au trace element associations between whole rock assays and laser-mapped pyrite. These two issues further complicate attempts to chemically fingerprint different gold events and styles: 1) a high geochemical variability at the mineral scale, and 2) scale/phase dependant elemental associations affect the consistency and reproducibility of results. Thus this study provides further evidence that available techniques rarely provide unequivocal results that can confidently be used to discriminate between magmatic and metamorphic fluid origins.

GEOCHEMICAL AND GEOTHERMOMETRIC CONSTRAINTS ON THE HISTORY OF THE NAHLIN ULTRAMAFIC BODY, CACHE CREEK TERRANE, NORTHWESTERN BRITISH COLUMBIA

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The Nahlin ultramafic body within the Mississippian to Lower Jurassic Cache Creek terrane represents the largest and best-preserved of the Cordilleran ophiolites. Despite its importance in understanding Cordilleran terrane accretion, the Nahlin body has been relatively understudied. Recent bedrock mapping approximately ~100 km southeast of Atlin, British Columbia, at Peridotite Peak (NTS 104K15) and the Menatatlune Range (NTS 104K16), shows that the ophiolite body consists of structurally disrupted fragments of oceanic lithospheric mantle, lower crustal intrusions, diabase dykes, voluminous mafic volcanic rocks, and sedimentary rocks. This project aims to constrain the tectonic setting of mantle melting and ophiolite emplacement using the thermal history of the Nahlin body and its geochemical relations to the spatially-related lower crustal gabbroic intrusions and supracrustal mafic volcanic rocks.

Whole rock geochemistry of the spinel harzburgite and rare ilherzolite samples from Peridotite Peak and the Menatatlune Range indicate that the Nahlin peridotite has been strongly depleted by melt extraction (<1 wt % Al_2O_3 and ~45 wt % MgO). Analyses of olivine, spinel, clinopyroxene and orthopyroxene by LA-ICP-MS and electron microprobe will be utilized in several geothermometers. Temperature-grain size relations for four different thermometers (2Px solvus, 2Px REE partition, Al-in-Ol and Ol-Sp Fe-Mg) with varying closure properties can potentially be used to interpret the cooling history of the ophiolite, which can be related to possible

modes of exhumation. Preliminary results indicate that Ol-Sp Fe-Mg exchange thermometers record cooling to 695 and 750°C, whereas 2Px solvus and Al-in-Ol thermometers record 750-935°C and 818-984°C, respectively. Results can be compared to the wet and dry peridotite solidi to discriminate between a possible suprasubduction zone and mid-ocean ridge setting. Inversion modelling of the clinopyroxene REE data will yield theoretical melt compositions in equilibrium with the ophiolite mantle, for comparison with trace element patterns in the proximal mafic intrusive and volcanic rocks of the Cache Creek terrane.

INCORPORATING CLIMATE CHANGE PROJECTIONS INTO GEOHAZARD MAPPING FOR THE STEWART-KENO TRANSMISSION LINE

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Yukon Energy Corporation is planning to replace an aging 69 kV transmission line between Stewart Crossing and Keno City, in central Yukon, with a new 138 kV transmission line in order to improve the reliability and capacity of electrical power for customers in the area. The existing transmission line was constructed in the 1950s across a region of discontinuous permafrost. Maintenance requirements have since increased in response to climate-driven degradation of permafrost, dominantly in valley bottoms and on north-facing hillsides. In order to inform route alignment, engineering design, maintenance schedules and the environmental assessment for the project, geohazard mapping was completed along the 112 km-long transmission line corridor. Interpretations were made using high-resolution aerial photography and LiDAR-derived elevation data, and verified with field observations. Six types of geohazards were identified, described and evaluated (percentage of hazard polygons in parentheses): (1) wet, compressible soils with ice-rich permafrost susceptible to thermokarst (35%); (2) actively eroding stream channels and floodplains (31%); (3) loose sand and gravel slopes susceptible to ravelling (19%); (4) incising drainage swales perched on permafrost (12%); (5) steep permafrost slopes susceptible to active-layer detachments and slumping (2%); and (6) steep bedrock slopes veneered with colluvium (1%). Of the six types of identified geohazards, three are associated with permafrost and are expected to intensify in response to projected warming temperatures, altered precipitation patterns and increased forest fire activity in the region. Each geohazard was classified according to its likelihood and potential consequence of occurrence, accounting for the influence of ground disturbance during construction and maintenance of the transmission line and its access from the adjacent highway. The proportional breakdown of the likelihoods of occurrence were high (31%), moderate (49%) and low (20%), and of the potential consequences were high (10%), moderate (79%) and low (11%). This advance knowledge of the characteristics and distribution of thaw-sensitive terrain allows for design and implementation of adaptive measures that mitigate risk during construction and maintenance of the transmission line, where geohazards cannot reasonably be avoided.

GEOMORPHOLOGICAL MAPPING OF LAND SURFACE DISTURBANCE HISTORY FOR OPTIMIZED ARCHAEOLOGICAL INVESTIGATIONS

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Selecting sites for archaeological field investigation requires consideration of landscape morphology and evolution, in addition to knowledge of cultural heritage and habitation site preferences. Geomorphological mapping can be used to identify areas with or without the potential to preserve archaeological evidence (e.g., artifacts, anthropogenic disturbances), in order to focus assessments of archaeological resource potential. A desktop-based Geomorphic Overview Assessment (GOA) was applied

along three pipeline corridors proposed across northern British Columbia: Kinder Morgan's Trans Mountain Expansion Project (TMEP), TransCanada's Coastal GasLink Project (CGLP) and Spectra Energy's Westcoast Connector Project (WCCP). The GOA enabled more confident prioritization of sites, depths and methods for field investigation. Through the interpretation of aerial photography and high-resolution topographic (LiDAR) data, the landscape within each of the three corridors was divided into areas (polygons) according to surficial materials, geomorphic processes, relative ground surface age, approximate preservation depth, and taphonomic processes. Based on consideration of these five parameters, each polygon was classified according to its potential to preserve an archaeological site, whether or not one was ever present. Further distinction was made between areas with 'potential at surface' (<0.1 m), such as a Late Pleistocene glaciofluvial plains composed of well drained, sandy soil (67% TMEP, 83% CGLP and 75% WCCP, by area), and areas with 'potential at depth' (<5 m), such as stable, mid-Holocene river terraces blanketed in fine-grained sediments (17% TMEP, 2% CGLP and 5% WCCP, by area). Inclusion of interpretations of the depth of archaeological evidence provides advance knowledge of where deep testing may be required in areas of thick Holocene sediments. Any archaeological evidence within areas classified as having 'no potential' was interpreted to have been destroyed, significantly displaced, or buried substantially deeper than 5 m (16% TMEP, 15% CGLP and 20% WCCP, by area). This geomorphological mapping increased the efficiency of the archaeological field programs by justifying exclusion of approximately one-fifth of each study area from detailed investigation.

INQUIRY AS AN EFFECTIVE TOOL IN GEOSCIENCE EDUCATION

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As Geoscience Educators, we strive to provide opportunities for building foundational knowledge about the Earth, its natural processes and their impact on society. While the increasing availability of great digital resources allows us to do more in our classrooms than ever before, there still remains no substitute for the understanding gained when we bring our natural curiosity to the field. And while we all strive to build and use "hands-on" experiences to engage that curiosity, rarely do we allow learners the time and space to actually discover concepts for themselves. This is the realm of inquiry-based learning, which places the learner's wonder and ideas at the centre of the learning experience. This type of learning is transformative; it has the power to build long lasting understanding because the knowledge is built by the individual learner.

This past June I was privileged to participate in the University of Nebraska-Lincoln's annual Methods in Geoscience Teacher field course. Advertised as "a mental boot-camp to discover Earth history as written in the rock record, and to explore effective means of science instruction", this field course allowed me to see first-hand what it takes to teach using inquiry and how the participants reacted to inquiry-based teaching.

I had the opportunity to observe the development of the teachers' understanding, from confusion and frustration at not being given "the answers" to the excitement they felt at building their own hypotheses and logical connections between what they were observing in nature and what processes might have taken place. The idea was that the teachers should understand what it might feel like for their students to be asked to learn by inquiry, and what it would take to create an environment in their classrooms where students would feel comfortable to question and share thoughts without judgement from their peers. The teachers were able to see how this could be possible, the value of this kind of collective learning, and the challenges inherent in this process. As well, it reminded us all the importance of getting out of the classroom and into nature.

We have since made meaningful and effective adjustments to both our own student field trip experiences as well as our Outreach Program, to take advantage of the benefits of inquiry learning. We plan to build our own inquiry-based Earth Science teacher field course, the first edition of which will run in spring of 2017.

STRUCTURE AND DEFORMATION OF THE NORTHWESTERN CANADIAN CORDILLERA: INSIGHTS FROM RAYLEIGH WAVE TOMOGRAPHY

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Due to the ongoing collision of the Yakutat block with the North American plate in southeastern Alaska, a significant amount of deformation is occurring in the northern Canadian Cordillera. The stress transfer associated with the accretion of this terrane is thought to be responsible for widespread seismicity across the region. Estimates of crustal structure within the Mackenzie and Richardson Mountains provide constraints on models describing the evolution of crustal roots responsible for supporting such belts that transmit tectonic stresses over long distances (>1000 km); unfortunately, current seismic velocity models used to map crustal structure have limited resolution due to sparse coverage by seismograph networks. Crustal structure can be obtained from 3-D seismic velocity models determined from the inversion of surface-wave dispersion data. In this work we present results of a regional Rayleigh-wave tomography study of northwestern Canada, encompassing the northern Canadian Cordillera, using dispersion curves derived from ambient noise cross-correlations in addition to teleseismic two-station interferometry. We collected all available vertical component seismic data from stations located in the Yukon and surrounding regions including those from a new regional seismograph network (Yukon-Northwest Seismograph Network – YNSN), the USArray Transportable Array in Yukon and Alaska, as well as permanent stations. Using this data set, we first cross-correlated hour-long segments of ambient seismic noise between all available station pairs with common data availability to obtain virtual Rayleigh waves with energy spanning over periods of 10-50s, predominantly sensitive to crust and uppermost mantle. This data set is complemented by Rayleigh-wave dispersion measurements, spanning the broad period range 25-250s, derived by cross-correlating vertical component data from teleseismic earthquakes ($M > 5$) lying along the great circle path between individual station pairs. We then measured group and phase velocities from these Rayleigh wave data sets and did a full tomographic inversion to produce the first regional, high-resolution, azimuthally anisotropic 3-dimensional shear-wave velocity models of northwestern Canada. The model features relative low velocities beneath the Cordillera and fast velocities in the adjacent Canadian Shield, with a transition that coincides approximately with the deformation front. Upper mantle anisotropy correlated qualitatively with major fault systems (Tintina and Denali faults) in the Cordillera. Our results provide support to the thermal isostasy model that explains large-scale dynamic support of the Cordillera, although it remains unclear if crustal fabrics can be associated with a pervasive lower crustal detachment zone separating a rigid upper crust from ductile lower crust.

FINGERPRINTING AND PROVENANCE DETERMINATION OF GOLD, COLTAN, CASSITERITE, AND WOLFRAMITE: MULTIVARIATE ANALYSIS OF LASER-INDUCED BREAKDOWN (LIBS) SPECTRA

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The strategic elements gold, tantalum, tungsten, and tin are used in the manufacture of many high-tech items, making them sufficiently valuable to be treated as conflict minerals in some areas. Thus, it is important to be able to identify the provenance, either country of

origin or mine of origin, of the ore minerals gold, coltan (columbite-tantalite), wolframite, and cassiterite. In this study, we determined the mine of origin for 162 samples of gold from six mines in five countries (Brazil, Italy, North Korea, United States, Unknown), 264 samples of coltan from 12 mines in seven countries (Brazil, Canada, Democratic Republic of Congo, Mozambique, Norway, Sweden, United States), 90 samples of wolframite from three mines in two countries (Great Britain, United States), and 150 samples of cassiterite from five mines in five countries (Bolivia, Great Britain, Namibia, North Korea, and United States). This study was conducted using the premise of Quantagenetics®, that all materials, natural or synthetic, contain a record of their origin and history; this unique fingerprint can be acquired by using Laser-Induced Breakdown Spectroscopy (LIBS). LIBS spectra were acquired by collecting photon emission from a cooling laser-induced plasma. These spectra contain an immense amount of information, reflecting the compositional, isotopic, and structural properties of the material analyzed. A multivariate statistical method was applied to single-shot spectra which compares a spectrum, pixel by pixel, to spectra of the reference sets of each location using standard full cross-validation. Success rates are calculated as the percentage of the spectra comprised of the true positive and the true negative results. For gold, every spectrum was correctly classified, with a 100% success rate. Success rates for coltan varied between 96.6% and 100.0%, averaging 98.7%. Three coltan mines in the study are from the Democratic Republic of Congo; these mines have success rates of 99.6%, 100.0%, and 97.0%. Success rates for cassiterite range between 91.3% and 95.3%, averaging 93.6%. Success rates for wolframite range between 97.8% and 98.9%, averaging 98.5%. These highly accurate results, coupled with the ease and speed of LIBS analysis, demonstrate the usefulness of this technique for fingerprinting strategic minerals.

SYSTEMATIC HANDHELD XRF ANALYSIS: IMPLICATIONS FOR IDENTIFYING FAVOURABLE HOST VOLCANIC STRATIGRAPHY AT THE MYRA FALLS VOLCANIC-HOSTED MASSIVE SULFIDE DISTRICT, BRITISH COLUMBIA, CANADA

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The Myra Falls volcanic-hosted massive sulfide (VHMS) district, located on central Vancouver Island, is one of Western Canada's most productive VHMS mining camps. Hosted in volcanic strata of the Sicker Group, polymetallic mineralization occurs in two ore-horizons (L-M-P and H-W Horizons) and as of April 26, 2013 surpassed 30 Mt of production at 1.6% copper and 5.5% zinc. Intense hydrothermal alteration and development of post-mineral deformation fabrics make protolith identification challenging at Myra Falls. In an effort to improve rock identification from drill core, a systematic study utilizing a handheld XRF was undertaken.

Important VHMS stratigraphy of the Mid-Paleozoic Sicker Group consists of andesitic volcanic rocks of the Price formation, and felsic to intermediate volcanic and volcano-sedimentary rocks, with marine argillite, of the Myra formation. A scoping study of 187 samples from 6 drill holes in the Ridge Zone of the H-W Horizon was completed. These drill holes intersected stratigraphic footwall and mine sequence rocks. The primary footwall rock type is coherent, porphyritic andesite of the Price formation. The mine sequence consists of polyolithic sandstone and conglomerate, coherent quartz-feldspar phytic rhyolite, and quartz crystal-rich rhyolite volcanoclastic rocks of the Myra formation. Polymetallic, zinc-rich massive sulfide is locally present in coherent and volcanoclastic rhyolite rock types.

Drill core samples were collected every 3 meters and analyzed with a Niton XL3T handheld XRF. Three spot measurements were collected on groundmass or matrix material for each sample for a 80s runtime. Certified standards were analyzed prior to each session and after every fifth sample. Titanium-zirconium (Ti-Zr) immobile element ratios were used to characterize the stratigraphic

footwall and mine sequence rock types. Ninety percent of coherent and volcanoclastic rhyolite samples have Ti:Zr ratios between 5 and 12. Seventy-five percent of massive sulfide samples have Ti:Zr ratios between 6 and 10, which overlaps the signature of the host felsic stratigraphy. Polyolithic sandstone and conglomerate samples have Ti:Zr ratios between 20 and 28. Coherent andesite stratigraphic footwall samples have a bimodal distribution, with 75% of the samples with Ti:Zr ratios between 25 and 37, and 62 and 71. Handheld XRF results from this study correlate well with previously published geochemical data for equivalent rock types. Results from this study indicate that systematic handheld XRF analysis of drill core can discriminate hydrothermally altered and deformed volcanic host-rock types at Myra Falls, and demonstrates the applicability of this method in mineral exploration.

MESOPROTEROZOIC BASINS OF NORTHWESTERN LAURENTIA AND THEIR POSSIBLE CONNECTION TO AUSTRALIA

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Two Mesoproterozoic basins in northern Yukon, Canada record activity on the margin of northwest Laurentia from ~1.5-1.3 Ga. The PR1 basin of the Coal Creek inlier was deposited sometime after 1.46 Ga and has a near-unimodal detrital zircon population (1499±3 Ma) that lies within the North American magmatic gap (NAMG; 1610-1490 Ma) and is considered exotic. The younger Pinguicula basin, in the Wernecke and Hart River inliers, was deposited sometime after ~1322 Ma and also has exotic zircon with ages in the NAMG.

A number of lines of evidence, including possible igneous sources, paleomagnetic data, and structural interpretations indicate that sediment in the PR1 basin was probably derived from north Australia, positioning northwest Laurentia directly adjacent to northeastern Australia around 1460 Ma. The timing of deposition of the PR1 basin coincides with Mesoproterozoic basins in southwest Laurentia including the Belt-Purcell basin, the Trampas basin, and the Hess Canyon basin, all of which contain sediment from the NAMG that was likely derived from north or west Australia and the Mawson continent. Notably, after ~1.45 Ga southwestern Laurentian basins no longer record detrital input from an exotic source. This change in provenance has been attributed to the breakup of supercontinent Columbia and movement of the Australia and the Mawson continent away from Laurentia. In northwest Laurentia, however, the younger Pinguicula basin has NAMG detrital zircon grains, although fewer than the older basins. In addition, the Pinguicula basin also has grains from the Australian magmatic gap, ca. 1.5-1.35 Ga, that were probably derived from the southwestern US granite-rhyolite province.

Two explanations may account for the presence of NAMG detrital zircon grains in the Pinguicula Group. In one, the grains were derived directly from Australia. In this model, Australia would have remained as a proximal highland to Laurentia in the north, even though it and the Mawson continent had already separated from more southern parts of western Laurentia. In the other model, the NAMG detrital zircon grains were recycled from older Mesoproterozoic successions in southwest and/or northwest Laurentia, and Australia need not have been proximal to Laurentia. Possible sources in northwest Laurentia include unit PR1 and successions that may have existed but were subsequently removed by erosion. Both scenarios for the Pinguicula Group apparently require a drainage pattern that involved transfer of sediment to the north and/or east and then to the south into the southward-deepening Pinguicula basin.

MINERALOGY AND GEOCHEMISTRY OF THE NAVAN DEPOSIT, IRELAND: IMPLICATIONS FOR THE ORIGIN AND DISCOVERY OF SEDEX DEPOSITS

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The Navan orebody, comprising >110 Mt at 10% Zn+Pb before mining, is the largest of the Irish-type ore deposits, which have been compared to SEDEX deposits but are distinguished by being carbonate-hosted and mainly replacive. The Navan deposit formed at the edge of an evolving basin subject to repeated normal faulting. Most mineralization is hosted by and replaces the Pale Beds, Courcean shallow water carbonates, with some ore deposited in hydrothermal karst cavities. Subordinate mineralization in overlying early Arundian rocks, including a submarine debris flow and the lowermost basal rocks, formed partly during seafloor exhalation. Navan mineralization formed where metal-rich but sulphide-deficient hydrothermal fluids mixed with seawater-sourced brines carrying bacteriogenic sulphide, the latter supplying >90% of ore sulphide. The possible implications of Navan mineralogy and geochemistry for the origin of, and exploration for, SEDEX deposits will be discussed.

In the Arundian debris flow, hydrothermal Zn-Pb mineralization formed by overgrowth and replacement of pre-existing sedimentary framboidal pyrite, followed by diagenetic pyrite and marcasite crystallization. Sedimentary, diagenetic and hydrothermal iron disulphides have distinct minor element concentrations and Fe-S isotope compositions. The minor elements are overwhelmingly of hydrothermal origin. Iron is partly directly hydrothermal in origin and partly precipitated from a euxinic basin that had formed before base metal mineralization began.

Zn-S isotope analysis shows that Zn isotope fractionation accompanied the rapid crystallization of finely banded sphalerite in the Pale Beds, where metal-bearing hydrothermal fluid mixed with fluid carrying bacteriogenic sulphide. By preferential removal of isotopically light Zn into sphalerite, heavy Zn remained longer in the fluid. This supports the feasibility of vectoring to sphalerite mineralization using Zn isotopes as previously proposed for the Red Dog SEDEX deposit.

A geochemical halo to a satellite of the Navan Pale Beds orebody, hosted by overlying deep-water basal limestones, formed syngenetically, based on textural evidence. This syngenetic halo hosts Zn-Pb mineralization with a dominantly hydrothermal sulphide signature whereas overlying pyrite has a bacteriogenic sulphide signature, indicating that the bacteriogenic sulphide-bearing fluid did not mix here with the hydrothermal Zn-Pb-bearing fluid. This suggests that in rocks inaccessible to bacteriogenic sulphide-bearing fluids, base metals remained in solution until they interacted with bacteriogenic sulphide-bearing fluids at or near the seafloor, a scenario that may be relevant to other SEDEX deposits. The role of normal faulting in bringing together metal- and sulphide bearing fluids at Navan will also be explored.

TIN, TUNGSTEN AND TANTALUM – RARE, SPECIALTY, CRITICAL OR STRATEGIC METALS?

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Tin, tungsten and tantalum have more in common than just starting with the same letter. All three metals have been identified in the Dodd-Frank Act in the USA as produced from conflict minerals as a result of production in areas of Africa subject to war. All three metals are however used in a wide range of advanced technologies in both civil and defence applications.

The three metals are also identified as strategic or critical by government agencies. Strategic or critical designations result from a

combination of necessity for advanced technologies, with few or no substitutes and with vulnerabilities in their supply chains including dominance by one or two countries. Dominance of supply from areas of the world considered unreliable can enhance the criticality of a metal. As such, their importance in advanced industrial and defence applications can enhance a country's concern about the strategic role of a metal.

Substitution can reduce criticality of metals. Ta can be cheaply substituted in capacitors, however much less so in aerospace applications. There are several viable substitutes for Sn for some applications. Substitution for W in cemented carbides, a major use of W, is only possible at higher cost or performance deterioration.

From another supply chain perspective and environmental consideration, Ta has the least recycling potential while Sn and W are far more recyclable.

China dominates global supply of both Sn and W at 42% and 83% of world supply respectively. The second largest global supplier of Sn is Indonesia and of W is Russia. Africa's potential conflict regions of Rwanda and Congo produce 67% of the world's Ta supply along with Sn and W. All of these countries, except Indonesia, is classed as "Not Free" by the Freedom House NGO which ranks countries by human rights and political freedom.

Over the past 50 years, Ta and W prices have increased over 2000% whereas Sn has increased about 600% in nominal dollars. For comparison, copper has increased just over 600% from 1959 to 2015. Thus Ta and W have increased far more than most base metals. In conclusion, Ta and W appear to have been somewhat immune to the recent drastic drops in metal prices.

With this supply/demand and policy framework as context, this paper will comment on possible future trends for these three strategic/critical metals and the opportunity, or not, for Canadian mineral exploration and development.

ENHANCING MINERAL EXPLORATION HEALTH AND SAFETY IN CANADA THROUGH THE PDAC-AMEBC ANNUAL SURVEY

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The Prospectors and Developers Association of Canada (PDAC) has brought its corporate social responsibility initiatives under the umbrella of E3 Plus. E3 Plus covers community engagement, environmental excellence and health and safety. It comprises a set of principles, the Principles for Responsible Exploration, and guidance in the form of toolkits or manuals. The health and safety material is actually the largest amount of material in E3 Plus.

The objectives of the PDAC Health and Safety (H&S) committee are zero fatalities and reduced incidents in exploration. This is a serious undertaking as at times the mineral exploration industry has had a relatively high rate of incidents compared to the number of people and the number of working hours, and far too high a rate of fatalities, especially in periods of increased exploration activity.

A major initiative of PDAC with the Association of Mineral Exploration British Columbia (AMEBC) has been the annual survey of mineral exploration incidents, which now comprises a ten year database of thousands of individual incidents and a thirty year database of fatalities. Through this lagging indicator data, over mineral exploration activity cycles, patterns are emerging that cause serious concern. In times of increased exploration activity, not only do incidents increase, but the rate of occurrence of incidents increases. It is believed that this is due to a number of causes, including influx of less experienced workers into mineral exploration in boom times, plus possibly a relaxation of attention on health and safety.

Recently, PDAC-AMEBC have started to collect leading indicators for H&S performance. The data shows an increase in awareness of the importance of H&S within individual companies. However,

there are clear indications in the data that not all companies are taking appropriate actions.

The author has chaired the PDAC H&S Committee for the past ten years since the survey commenced and the conclusions are his from study of the data. The paper will present the detailed data from the survey, along with conclusions as to the actions required both by the exploration industry but also by the individual geoscientists, in order to reach the goal of zero fatalities and zero lost time injuries. The fundamentals of health and safety in the field are similar for industry, academia and government geoscientists.

THE EAST KEMPTVILLE TIN-ZINC-COPPER-INDIUM DEPOSITS, NOVA SCOTIA, CANADA

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The East Kemptville property, a former tin-zinc-copper producer, is located in southwest Nova Scotia. Greisen-style tin mineralization was discovered in 1978 by Shell Canada Resources. The mine operated for six years from 1985 producing tin, zinc and copper concentrates and closed due to low tin prices. The concentrator was removed and the site closed except for ongoing environmental remediation. Avalon Rare Metals Inc. acquired mineral rights in 2006.

On mine closure, the reserves were by no means exhausted, and Avalon has estimated that there remains an Indicated Mineral Resource of 18.47 million tonnes averaging 0.176% tin, 0.173% zinc and 0.064% copper and an estimated Inferred Mineral Resource of 16.95 million tonnes averaging 0.148% tin, 0.122% zinc and 0.062% copper at a 0.10% tin cutoff grade. Recent work has determined that significant levels of indium are associated with the zinc (sphalerite) mineralization.

The project is within the Cambro-Ordovician aged, Meguma Terrane, a succession of interbedded, metasedimentary rocks and granitoid intrusive. Tin greisen mineralization is associated with late phases of the Devonian-Carboniferous South Mountain Batholith. The mineralization is believed to be part of the same metallogenic belt of Variscan/Hercynian age tin deposits that stretch from the Erzgebirge in Germany to the Canadian Maritimes.

Tin and base-metal mineralization is associated with northeast-trending, subvertical and zoned, quartz-topaz, sulphide-bearing greisens veins and stockworks that occur primarily in the altered (sericitization, silicification, topazification) portions of the leucogranite near its contacts with the surrounding metasediments. Mapping of the deposit in the early 1990's (Kontak, 1990) suggests that structural controls related to a major shear zone may control some of the higher-grade mineralization at East Kemptville. There is potential to increase resources on strike with the known deposits, in the sediment hosted Duck Pond Tin Deposit (for which there is no previous NI 43-101 resource) and tin intercepts in drill holes outside the known deposits that were not followed up in the past.

Avalon has completed drill programs (2014 and 2015) and mineralogical studies (Qemscan and hyperspectral). The drill programs have increased geological knowledge of the deposits, verified the historic drill data, upgraded the resources and provided metallurgical sample.

The paper will present an overview of the history of the project, geological setting of the deposit, results to date and future plans for re-development.

SYNVOLCANIC GOLD IN THE ARCHEAN: EVIDENCE FROM LA-ICP-MS MAPPING, SEM ANALYSES, AND IN-SITU SIMS $\delta^{34}\text{S}$ ISOTOPE ANALYSES OF PYRITE – EXAMPLES FROM THE LARONDE PENNA GOLD-RICH VMS DEPOSIT AND RAINY RIVER GOLD PROJECT, SUPERIOR PROVINCE

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The southern Superior Province hosts numerous major gold deposits of various styles, including some of synvolcanic origin. Most of these synvolcanic Archean systems are moderately to intensely strained and located in proximity to major deformation corridors that are commonly associated with orogenic gold. The overprinting deformation is responsible for significant modifications to the primary (synvolcanic) or pre-main deformation features of inferred synvolcanic gold deposits and prospects, including remobilization of gold into syn- to late-main deformation sites. This often leads to contradictory interpretations and/or uncertainties about the timing of gold introduction.

The LaRonde Penna deposit and Rainy River gold project, both located in the southern Superior Province, are good examples of deformed synvolcanic auriferous hydrothermal systems.

The LaRonde Penna deposit (~9 Moz gold; Abitibi greenstone belt, Québec) consists of a 2,698 Ma deformed gold-rich VMS deposit in which gold has been demonstrated to be synvolcanic based on numerous lines of geological evidence. These include the presence of gold-rich sulphide clasts in talus breccias, the overall distribution of gold and its association with base metals, pre-main deformation alteration and crosscutting relationships, and a general lack of correlation between gold and deformation-related features (e.g., veins and high-strain zones) at deposit scale. Further evidence for auriferous synvolcanic hydrothermal activity is provided by the study of zoned pyrite nodules present in black argillite lenses located within the upper part of the main massive sulphide lens at LaRonde Penna. A combination of quantitative, 2-D laser-ablation (LA)-ICP-MS mapping, SEM analyses, and in-situ SIMS $\Delta^{34}\text{S}$ isotope analyses of two perfectly preserved nodules clearly indicate an early (syngenetic) enrichment of gold, along with a series of associated trace elements, in the core of the nodules, and a late, barren, isotopically slightly heavier, syn-main deformation overgrowth.

The Rainy River gold project (~6.2 Moz gold; western Wabigoon subprovince, Ontario) consists of a highly-strained, $\leq 2,716$ and $\geq 2,693$ Ma, dominantly dacite-hosted, disseminated±stockwork subseafloor replacement-style gold system. Gold at Rainy River is considered to be synvolcanic, primarily based on crosscutting relationships. This preliminary interpretation is further supported by LA-ICP-MS mapping and analyses that indicate an early auriferous event preserved in the core of pyrite crystals that were partly recrystallized and flattened/stretched into the main fabric.

These two examples indicate that various styles of major synvolcanic gold deposits existed in the Archean, and also illustrate the importance and power of micro-analytical techniques as tools to better constrain the timing of gold introduction in ancient, highly-strained gold deposits, especially when these techniques are combined with field mapping and applied in areas with first-hand understanding of the geological setting.

GEOARCHAEOLOGY OF THE LITTLE JOHN SITE (KdVo-6), YUKON TERRITORY, CANADA

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The Little John Site (KdVo-6), Yukon Territory, Canada, contains the presence of Chindadn complex (East Beringian Tradition), Denali complex (Paleoarctic Tradition), Northern Archaic Tradition, and

Late Prehistoric artifacts in unique stratified contexts. The site contains loess/paleosol stratigraphic sequences dating back to the Wisconsin Interstadial c. 42-44,000 years ago, and cultural deposits from the Late Pleistocene c. 14,000 years ago to the recent past. A new multidisciplinary study is helping improve understanding of the geologic context of the site. Detailed grain size analyses, loss-on-ignition data, and petrographic information from a number of excavated columns help inform an updated soft-sediment stratigraphic model for the site, and a large-scale bedrock map provides baseline information on the underlying lithology and structure. A detailed electrical resistivity tomography (ERT) survey conducted in 2014 and 2015 helps constrain the bedrock-overburden contact and the size and location of permafrost ice wedges. Updated optically stimulated luminescence (OSL) and accelerator mass spectrometry (AMS) radiocarbon dates provide important chronological constraints on the established stratigraphy. A holistic consideration of ancient and contemporary peri-glacial processes is also presented to illuminate the environmental and depositional history of the site's geologic context and archaeological materials.

THE RELATIONSHIP BETWEEN CADWALADERITE $\text{Al}(\text{OH})_2\text{Cl}\cdot 4\text{H}_2\text{O}$ AND LESUKITE, $\text{Al}_2(\text{OH})_5\text{Cl}\cdot 2\text{H}_2\text{O}$ AS INVESTIGATED BY SEM, XRD, FTIR, TGA AND RAMAN SPECTROSCOPY

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Cadwaladerite ($\text{Al}(\text{OH})_2\text{Cl}\cdot 4\text{H}_2\text{O}$) collected from Cerro Pintados, Chile by Gordon in 1941 is designated as "doubtful" by the International Mineralogical Association Commission on New Minerals, Nomenclature and Classification. Material collected from the same locality in 2015 resembling the description of cadwaladerite gave a powder XRD pattern similar to lesukite ($\text{Al}_2(\text{OH})_5\text{Cl}\cdot 2\text{H}_2\text{O}$). However, Gordon provided no X-ray data for the material from Cerro Pintados. In order to determine whether cadwaladerite and lesukite are the same mineral species, measurements were made on a suite of samples from various localities. A portion of the material collected by Gordon in 1941 was also obtained from the Mineralogical Museum of Harvard University. Type material of lesukite from a fumarolic environment at the Tolbachik Fissure in Kamchatka, Russia was obtained as well as lesukite from the Maria Mine, Chile (Arica Province) and a previously undescribed locality for lesukite (Barranca del Sulfato, Mejillones Peninsula, Antofagasta Province). All samples are yellow to yellow-orange in colour and all exhibit small cubic crystals (up to 50 μm). The Chilean samples are all associated with halite and sometimes with gypsum.

These five samples were studied by SEM, FTIR, powder XRD, Raman and TGA methods. A ratio of Al:Cl close to 2:1 was observed for all the samples, including measurements made on the sample collected by Gordon and reported by him to have a Al:Cl ratio of 1:1. SEM-EDS analyses also showed all samples to have minor iron substitution, as well as copper substitution in two samples. FTIR spectra are very similar for all samples. TGA results measured on the lesukite collected in 2015 from Cerro Pintados indicate 2 H_2O molecules per formula unit and is similar to that expected for lesukite and significantly less than the 4 H_2O molecules described by Gordon.

ISOTOPIC COMPOSITIONS OF PLANTS AND POOP PROVIDE INSIGHTS INTO PAST ENVIRONMENTS

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Carbon isotope analysis of animal remains (e.g., bone collagen, tooth enamel bioapatite) is an accepted method for reconstructing paleoclimates and paleoenvironments. When preserved (e.g., in

permafrost or dry cave environments), the isotopic compositions of plant remains may also provide useful insights into past environments. The isotopic compositions of charred plant remains are increasingly used in archaeology to reconstruct ancient diets and agricultural practices, but an early study suggested that values obtained from ancient uncharred plant remains are unreliable. This supposition has not been adequately explored, in part because uncharred botanical remains are rarely preserved. Here, we describe carbon and nitrogen isotope analyses of uncharred plants, coprolites, and other animal remains (collagen, keratin) recovered from dry caves in Glen Canyon National Recreation Area (Arizona and Utah), ranging in age from >40,000 to about 7,000 14C yr BP. Although the nitrogen isotope compositions of the plants and dung are questionable, several lines of evidence suggest that the original biogenic carbon isotope compositions have not been substantially altered. Thus, carbon isotope analyses of ancient uncharred plants and animal dung may be useful for reconstructing the environments of the Colorado Plateau during the late Pleistocene. This approach may also be applied to botanical remains from other exceptional contexts, such as are present in some parts of Beringia.

NON-DESTRUCTIVE METHODS FOR IDENTIFYING MEGAFAUNAL HAIRS FROM BERINGIA AND BEYOND

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Typical methods for identifying hairs in wildlife or forensic studies require destruction or chemical alteration of the specimens (e.g., embedding in chemical media, gold-coating, sectioning). For rare or isolated paleontological, archaeological, or museum hair specimens, methods that do not involve physical or chemical alterations would be preferable. Here, I present non-destructive methods for the identification of mammalian hair, including the hair of several species of extinct megafauna: woolly mammoth (*Mammuthus primigenius*), steppe bison (*Bison priscus*), Yukon horse (*Equus lambei*), and Shasta ground sloth (*Nothrotheriops shastensis*). Unknown hairs obtained from dry caves in Glen Canyon National Recreation Area (Arizona/Utah), and associated with the dung of extinct megafauna, were identified as *Mammuthus* spp., *Bison* spp. and human (likely intrusive). These methods may be applied to hairs derived from Beringian permafrost deposits or other special preservation contexts.

ISOTOPIC INVESTIGATIONS INTO THE TRIASSIC TECTONIC SETTING OF THE SVERDRUP BASIN AND ARCTIC PLATFORM USING NEW DETRITAL ZIRCON U-Pb, Hf, AND (U-Th)/He DATA, CANADIAN ARCTIC

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The tectonic setting of northern Laurentia prior to the opening of the Arctic Ocean has long been complicated and contentious to resolve. Initial rifting of land masses north of the Sverdrup Basin, located in Arctic Canada, occurred in the Jurassic with the onset of seafloor spreading beginning in the Cretaceous. The pre-rift history that led to the opening of the Arctic Ocean or the pre-rift tectonic setting of the Sverdrup Basin is not well defined in the literature.

New detrital zircon U-Pb age data from Lower Triassic to Lower Jurassic strata in the Canadian Arctic combined with previously published detrital zircon data from the Sverdrup Basin have identified two distinct provenance signatures. The first assemblage comprises an age spectrum identical to that of the Devonian clastic wedge. In contrast, the second assemblage is dominated by a broad

spectrum of near syn-depositional Permo-Triassic ages derived from north of the basin. Triassic strata of Arctic Alaska exhibit a similar dual provenance signature, whereas northeastern Russia contains only the northern source.

Complementary Hafnium isotopic data on Permo-Triassic zircon have eHf values that are consistent with the common evolved crustal signature of the Devonian clastic wedge detrital zircon grains and basement rocks in the Arctic Alaska-Chukotka microcontinent. Previous studies have suggested that the source of these ages could be from Siberia/Urals, but the Hf data suggests otherwise. As initial rifting isolated the Permo-Triassic source from the Sverdrup Basin, Permo-Triassic zircon decrease substantially in Early Jurassic strata implying the diminution of the sediment source.

The diffusion of radiogenic helium in zircon provides the useful application of zircon (U-Th)/He thermochronology (ZHe) to test the extent of uplift from rifting. Samples from the Arctic Platform, south of the Sverdrup Basin extending towards the Canadian Shield, would provide a record of cooling after the onset of initial rifting in the Jurassic. The ZHe cooling ages and time-temperature model from Late Devonian strata on Banks Island, close to the rifted margin, suggest a thermal maximum at 140°C at 200 Ma, with cooling of >100°C prior to reburial in the Cretaceous. This implies the removal of 3-4 km of Carboniferous to Triassic strata, no longer preserved on the Arctic Platform. A similar thermal trend is seen away from the rifted margin, on Victoria Island and the Brock Inlier, but with cooler maximum burial and less sediment removal after Early Jurassic rifting.

PRIMITIVE ARC MAGMATISM IN NORTHERN STIKINIA: INSIGHTS INTO THE MIDDLE TO LATE TRIASSIC SUB-ARC MANTLE

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Volumetrically minor, primitive (MgO ~16 wt. % LOI-free), olivine-phyric, picritic magmas were erupted explosively in the northern Stikine terrane (Stikinia) of the Canadian Cordillera during the Middle to Late Triassic. These pyroclastic picrite deposits occur within the Stuhini Group and comprise upward-fining sequences of normally graded tuff breccia to olivine tuff, capped by rhythmically stratified ash tuff. The tuff is largely altered to serpentine, chlorite and clay, but preserves primary textures, including pseudomorphed olivine-rich lapilli, devitrified scoria, and cusped bubble-wall glass shards. Isolated flows, breccia, and sills of broadly similar age and geochemical character are also known from the central and southern Quesnellia [1,2]. Comparable magmas are rare in modern arc settings and limited to several spatially and temporally restricted occurrences in the Solomon Islands (~14 wt.% MgO), Vanuatu (15 wt.% MgO), Lesser Antilles (>12.5 wt.% MgO), Japan, and the Aleutian Islands (>16 wt.% MgO). The unusually primitive (high-MgO) chemistry of these occurrences has been attributed to anomalously high geothermal gradients associated with subduction of young, hot oceanic lithosphere and spreading ridges [3, 4] or rapid mantle wedge counter-flow [5].

The Stikinia pyroclastic rocks have high, but variable MgO concentrations (22-38 wt.%) and relatively constant FeO_{TOT} contents (9-10 wt.%). Within-suite geochemical variation reflects variable amounts of olivine accumulation (20-65%) into a parental liquid with MgO content of ~16 wt. %. The estimated composition of accumulated olivine (Fo₉₁), and the Mg-number (Mg/(Mg+Fe²⁺) of the calculated parental liquids (≥0.74), suggests that the pyroclastic picrites formed directly from a primary magma that has undergone minimal fractionation. The high degree of melting required to generate the Middle-Upper Triassic picrites and their inferred high volatile contents suggest that these magmas were potent carriers of metals from the mantle and may have been key in the metallogenic endowment of the Stikinia.

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THE ENGINEER MINE, BRITISH COLUMBIA: AN EXAMPLE OF EPITHERMAL AU-AG MINERALIZATION WITH MIXED ALKALINE AND SUBALKALINE CHARACTERISTICS

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Low-sulfidation (LS) epithermal precious metal deposits can be subdivided into deposits related to subalkaline and alkaline volcanism. This distinction is based on the cognition that these deposit types exhibit differences in, e.g., their proximal alteration minerals and ore and gangue phases. Alkaline LS epithermal deposits are for example characterized by telluride-rich, selenide-poor mineralization and the widespread presence of roscoelite (V-mica). In contrast, subalkaline LS epithermal deposits contain minor tellurides, selenides are common and V-mica is absent.

The Engineer Mine, British Columbia, is related to early Eocene Sloko-Skukum Group volcanism and is hosted by Late Jurassic Laberge Group sediments. Based on mineralogical and textural investigations, fluid inclusion, as well as stable isotope studies we provide evidence that the principal ore assemblage at the Engineer Mine precipitated during a single hydrothermal event in response to boiling. During boiling, the ore-forming fluid had a temperature of ~220 °C and an isotopic composition ($\delta^{18}\text{O}$ and δD) similar to meteoric water. Furthermore, carbon and oxygen isotope analyses of vein and sedimentary carbonate minerals indicate that the hydrothermal fluid attained its $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ composition due to prolonged interaction with the host sediments. Due to this interaction and the fact that the Sloko-Skukum Group volcanics are borderline subalkaline to alkaline in character, the Engineer Mine shares similarities with alkaline, as well as subalkaline epithermal LS deposits, e.g., in terms of ore and gangue phases and fluid inclusions. Alkaline attributes include the wide-spread presence of V-mica and the lack of selenides, whereas the presence of only minor tellurides and salinities of <0.7 wt% NaCl equiv. are typical for subalkaline LS deposits.

U-Pb MONAZITE SHRIMP GEOCHRONOLOGY OF THE NORTHERN THELON TECTONIC ZONE - INSIGHTS INTO THE METAMORPHIC AND TECTONIC HISTORY OF THE SLAVE-RAE BOUNDARY ZONE

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The Thelon Tectonic Zone (TTZ) is a complex >500km long boundary zone between the Rae craton to the east and the Slave craton to the west, located near Bathurst Inlet, Nunavut. The TTZ has been interpreted as a ca. 2000 Ma continental arc on the western edge of the Rae craton, deformed during collision with, and indentation of the Slave craton ca. 1970 Ma. Alternative models propose that the TTZ represents an interior mountain belt far removed from an active plate boundary, possibly following crustal thinning.

The Thelon Tectonic Zone is composed of N-NNE striking domains with contrasting magnetic anomalies. Results of an ongoing GEM-2 project north of 65°N indicate the region comprises three belts of ca. 2.0 Ga plutonic rocks. An extensive ca. 1910 Ma leucogranite belt marks a major tectonic boundary within the zone. Other suites of syn- to post-tectonic 1940-1890 Ma plutons also occur. A short-lived period of extension is marked by 1950 Ma ultramafic-mafic volcanic belt interlayered with psammitic metasedimentary rocks within the narrow Ellice River domain. Paleoproterozoic supracrustal

rocks within this domain record deformation and metamorphism at ca. 1814 Ma, and appear to have been structurally juxtaposed against higher grade domains.

Metamorphism within the TTZ is upper amphibolite (migmatite) to granulite-facies, and reflects multiple high-grade events, including the ca. 2.35 Ga Arrowsmith orogeny documented in the western Rae. High-grade migmatitic paragneiss were chosen for U-Pb monazite SHRIMP geochronology to constrain the timing of metamorphism across geological domains. Garnet-bearing migmatitic paragneiss assemblages are muscovite absent, and variably contain biotite, sillimanite, cordierite, spinel and orthopyroxene. Mineral assemblages, specifically spinel-quartz assemblages, are consistent with low pressure-high temperature conditions. Future work will focus on constraining pressure-temperature-time paths for these samples.

Matrix monazite grains in 5 samples yield mean $^{207}\text{Pb}/^{206}\text{Pb}$ ages ranging from 1914-1879 Ma. Monazites included in garnet porphyroblasts of 6 samples yield $^{207}\text{Pb}/^{206}\text{Pb}$ ages of ca. 1955-1904 Ma. These data indicate that the most widespread high-grade regional metamorphism occurred at ca. 1900-1910 Ma, was syntectonic in nature, and extending into the western Rae craton. An earlier ca. 1950 Ma metamorphic event, recorded at two localities, is contemporaneous with extension-related volcanism in the Ellice River domain; however, the significance and extent of this event is not yet understood.

SN-W-MO-BEARING MINERALIZATION IN THE LATE DEVONIAN MULTIPHASE MOUNT DOUGLAS LEUCOGRANITE, SOUTHWESTERN NEW BRUNSWICK, CANADA: U-Pb GEOCHRONOLOGY OF GRANITES AND MINERALIZATION

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New Brunswick's complex geological history has created a diversity of metallic mineral resources, including granophile elements (Sn-W-Mo), base-metals, and U associated with granitic bodies throughout the province. The Late Devonian Mount Douglas (MD) leucogranite, located in the eastern part of the Late Silurian to Late Devonian Saint George Batholith in southwestern New Brunswick, has the potential to host endogranitic granophile-element deposits as well. Magmatic systems in the MD suite have undergone extreme differentiation producing three mappable subunits, including Dmd1, Dmd2, and Dmd3, and variably mineralized mineral occurrences.

Subunit Dmd1 forms an elongate pluton along the southeastern margin of the MD suite and consists of an assemblage of pink to gray, coarse crystalline granite, ranging from syenogranite to monzogranite. This unit is essentially devoid of significant mineral occurrences and a new crystallization age derived from in situ laser ablation inductively coupled plasma-mass spectrometry (LA ICP-MS) U-Pb monazite dating, guided by scanning electron microscope-back-scattered electron imaging (SEM-BSE) yielded an age of 368.0 ± 1.8 Ma. Subunit Dmd2 has a sub-equigranular, medium- to fine-grained texture and comprises the majority of the MD pluton. A new LA-ICP-MS U-Pb date on monazite suggests an age of 368.2 ± 2.6 Ma. Subunit Dmd3 forms a northeast-trending body in the south portion of the MD suite and a smaller body along the northern margin. This subunit consists of an assemblage of pink to grey, fine- to medium-grained granites, ranging from syenogranite to monzogranite with porphyritic and equigranular textures and new crystallization age of 369.9 ± 1.7 Ma. Most Sn-W-Mo mineralization within the MD is associated with highly differentiated phases, subunits Dmd2 and Dmd3, in which the mineral occurrences are typically associated with greisen and stockwork veining. The main minerals are quartz and fluorite, commonly associated with pyrite, arsenopyrite, and magnetite, and minor cassiterites, Ta-rich wolframite, In-rich sphalerite, chalcopyrite, bornite, galena, and uraninite.

**TA-RICH WOLFRAMITE FROM THE Sn-W-Mo-BEARING MOUNT DOUGLAS
LEUCOGRANITE, SOUTHWESTERN NEW BRUNSWICK, CANADA: A SEM AND
LASER ABLATION ICP-MS STUDY**

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The Late Devonian Mount Douglas (MD) leucogranite, located in southwestern New Brunswick, forms the eastern part of the Late Silurian to Late Devonian Saint George Batholith, and represents significant potential for endogranitic granophile-element deposits. Former studies subdivided the MD pluton into three mappable subunits, including Dmd1 (coarse-grained granite), Dmd2 (medium-grained granite), and Dmd3 (red fine-grained porphyritic granite). Extreme fractional crystallization from Dmd1 to Dmd3 produced variable economically interesting endogranitic Sn, W, and Mo occurrences that are associated with greisen and stockwork veining. The preliminary results show that both subunits Dmd2 and Dmd3 offer considerable potential for granophile-element deposits.

To determine the geochemistry and economic potential of the MD pluton, new studies were performed using in-situ laser ablation ICP-MS guided by SEM-BSE imaging. Measurements were performed on target minerals, including wolframite, sphalerite, pyrite, arsenopyrite, magnetite, uraninite, galena, and chalcopryrite found in greisen, sheeted veins or stockwork veins that were sampled throughout the pluton. However, for this study, emphasis was placed on the composition of wolframite $[(\text{Fe}, \text{Mn})\text{WO}_4]$, the most important ore mineral in tungsten deposits that has long received a great deal of attention. Laser ablation measurements were performed on wolframite in an earthy-red greisen vein from very fine-grained porphyritic granite of subunit Dmd3, near Disappointment Lake area. Associated minerals in this vein include pyrite, arsenopyrite, fluorite, and sphalerite, and minor chalcopryrite, bornite, and galena. The tabular wolframite (0.5mm in length) is homogeneous and contrast-adjusted BSE images do not reveal any internal zoning, which can be attributed to a relatively uniform composition of the mineralizing fluid. The wolframite composition is consistent with ferberite (Fe²⁺-rich) rather than huebnerite (Mn²⁺-rich) and exhibits a negative correlation of Fe and Mn with Mn/Fe ratios ranging from 0.41 to 0.54, which demonstrates Mn and Fe substitution. Tantalum is the major trace element within the wolframite (41-246 ppm) followed by Pb and As, and up to 0.06 wt.% U and a range of 2.73-510 ppm Th. Positive correlation of W with Ta and Sn is evident since Ta substitutes for W and Sn, which may enter into the wolframite lattice accompanied by Fe-Mn substitution.

**(U-Th)/He THERMOCRONOLOGY OF THE KLONDIKE PLATEAU, DAWSON
RANGE AND AISHIHIK BATHOLITH, CENTRAL YUKON: RESOLVING THE TIMING
OF SHALLOW CRUSTAL TECTONISM**

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During the Late Paleozoic through the Cenozoic, terranes were episodically accreted onto the western margin of North America. Zircon and apatite (U-Th)/He thermochronologic investigations of the Yukon-Tanana terrane (YTT) and successor rocks can provide insight into the low-temperature (<200°C) window of Jurassic-Cretaceous tectonism and crustal exhumation. Samples were collected in an attempt to build a network of low-temperature thermochronometers across the major faults and crustal blocks to resolve their crustal levels during mineralization episodes in the region. For the study, we attempted to sample plutonic bodies that are characterized by low ductile strain, possess single populations of zircon and apatite (exhibiting typical igneous zoning and lacking metamorphic overgrowths), and likely have straightforward cooling

histories. Thirty Paleozoic and Mesozoic granitoids were sampled from the Klondike Plateau and in the Dawson Range south of the Tintina fault, and ten granitoid samples were collected from the Jurassic Aishihik batholith (190-180 Ma), southeast of the Dawson Range. The nature of the northwestern contact of the Aishihik batholith is equivocal, and samples have been taken on either side to investigate whether it is a structural discontinuity. Although proposed to be structurally emplaced via thrusting against Yukon-Tanana terrane, recent mapping suggests that the northwestern margin of the Aishihik batholith is an intact intrusive contact, which has implications for the level of crust that is preserved from Jurassic time. Preliminary zircon (U-Th)/He analysis for samples from the Klondike Plateau and Dawson Range yield single grain dates that reflect an age dispersion between Early Jurassic to Early Eocene that exhibit a relationship with effective uranium (eU), a proxy for radiation damage. The cooling ages generally can be resolved into a domainal pattern, which is defined by fault-bounded crustal blocks that become progressively younger towards the southwest. Zircon cooling (~180°C) dates in the central Klondike Plateau are >135 Ma; samples west of the Teslin fault have cooling ages <110 Ma, whereas west of the Yukon River, which possibly follows a strand of the Teslin fault, samples have cooling ages that are <75 Ma. We are testing whether the (U-Th)/He age pattern that is evident in the Dawson Range extends southward, to the region of the Aishihik batholith, or if an older (eg. Jurassic to mid-Cretaceous) exhumation history is preserved.

**REGIONAL SCALE 3D GEOLOGICAL MODELLING OF THE NEW QUÉBEC
OROGEN, KUUIJUAQ REGION, QUÉBEC, A PALEOPROTEROZOIC ACCRETIONARY
TERRANE**

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An area of geoscientific and economic significance in the Canadian Shield is the Southeastern Churchill Province in northeastern Québec and Labrador. The New Québec Orogen is noteworthy as it exposes a rare view of mid- to deep-crustal tectonic deformation during crustal accretion. Recently, exploration efforts in the New Québec Orogen have been reinvigorated with new discoveries of gold and rare earth elements, drawing attention to this complexly deformed region. Increased activity has allowed for the improvement of stratigraphic columns, fault geometries and deformation models throughout the orogen. These new discoveries and models, along with the modern data that supports them, has provided the Geological Survey of Canada (GSC), in collaboration with the Ministère de l'Énergie et des Ressources Naturelles du Québec (MERN), with the means to construct a 3D model of the geometry and architecture of the crustal assemblages across the belt near Kuujuaq, QC. This model will attempt to reconcile existing aeromagnetic surveys, airborne gravity surveys and field observations collected by the GSC and MERN with cross section interpretations and deformation models. The Kuujuaq region was chosen because the GSC and MERN have developed a publically available, extensive and mature regional dataset which includes geophysical studies and surface observations, providing the necessary tools for 3D visualization. Additionally, this region is currently the target of new, multi-scale bedrock mapping by MERN and GSC, and benefit from having locally preserved depositional structures and marker horizons which provide additional control on structural geometries. The 3D model will leverage existing data sets and expert knowledge to promote a better understanding of geometry in accretionary terranes and collisional orogens. The spatial relationships resolved through our modelling also have the potential to provide a better understanding of deep crustal processes during accretion tectonics in a transpressional regime.

EVIDENCE FOR LATE QUATERNARY RUPTURE OF THE LEECH RIVER FAULT, SOUTHERN VANCOUVER ISLAND

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The seismic potential of crustal faults within the forearc of the northern Cascadia subduction zone has proven difficult to quantify, due in large part to the recent Cordilleran glaciation. The seismic potential of the Leech River fault has remained elusive in particular, despite its close proximity to Victoria, British Columbia. In this study, we use lidar and field data along the Leech River fault to identify >60 individual, sub-parallel, steeply-dipping, linear scarps, sags and swales that occur in an echelon arrays and offset both bedrock and Quaternary deposits within tens of kilometers of downtown Victoria. We suggest that these features are products of mesoscale faults that together make up a steeply dipping fault array that is up to ~1 km wide and at least 30 km long (but most likely >60 km long). Reconstruction of fault slip across a deformed post-LGM (last glacial maximum) colluvial surface across the fault indicates ~6 m of dip displacement of the colluvial surface, and ~4 m of displacement of intervening channels. Collectively, these data argue that the Leech River fault has experienced at least two M6-M7 earthquakes since ~15 ka, and is likely one of a network of active crustal faults in the Canadian forearc. The existing data suggest that the active Leech River fault array accommodates forearc transpression and may merge along strike with active faults identified in western Washington state, USA, such as the Devil's Mountain and South Whidbey Island Faults.

LOW PRESSURE METAMORPHISM OF THE ROSSLAND GROUP, SOUTHEASTERN BRITISH COLUMBIA

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The area around the towns of Salmo and Nelson in southeastern British Columbia contains metamorphosed early Jurassic volcanic and sedimentary strata, and several large mid Jurassic intrusions belonging to the Nelson Suite. This study area is a zone of particular interest due to its proximity to the Waneta Fault, which separates the rocks of the ancestral North American miogeocline from the oceanic rocks of the Quesnel terrane. The collision of these two bodies initiated the Cordilleran orogenic event in the area.

The youngest member exposed in the area is the Hall formation, composed of argillites, siltstones, and conglomerates. The middle member is the Elise Formation, containing basaltic flows and tuffs. Below the Elise Formation is the Archibald formation, another sedimentary layer containing argillite, siltstone, and conglomerates. These units are intruded by a number of Jurassic plutons, the two largest being the Nelson batholith and Bonnington pluton, and have been metamorphosed to sub-greenschist through amphibolite facies. There is uncertainty as to whether the changing metamorphic grades are due to regional burial metamorphism or contact metamorphism from the intruding bodies, and the depths to which these rocks were buried during Cordilleran orogenesis.

Due to the challenges in differentiating between different amphiboles and other important metabasalt minerals in hand sample or by petrographic microscope, there is considerable uncertainty in the identification of the locations of mineral-in and mineral-out isograds. This study has used both the petrographic microscope and the electron microprobe to examine a newly collected suite of samples, and some samples collected previously. This has allowed for mineral assemblages to be identified, and for mineral isograds to be located with increased confidence, allowing for the creation of a new metamorphic map incorporating metavolcanic and metapelite assemblages. The spatial pattern of mineral assemblages suggests that the main driver for metamorphism was heat provided by the multiple intrusive bodies at shallow depths within the crust.

Parts of the field area have been metamorphosed to P-T conditions that lie within the transition zone between the greenschist and amphibolite facies, which is an important metamorphic facies boundary, commonly associated with economic mineralisation. This study forms part of a broader study of greenschist and amphibolite metamorphism, and has implications for the nature of important devolatilisation reactions and the evolution of mineral assemblages and textures across this key metamorphic transition zone.

NEW CONSTRAINTS ON THE AGE AND ORIGIN OF QUESNELLIAN BASEMENT ASSEMBLAGES IN SOUTHERN BC AND NORTHERN WASHINGTON FROM DETRITAL ZIRCON, LITHOGEOCHEMICAL AND FOSSIL AGE studies

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Paleozoic rock units that form the basement of Quesnellia from southern British Columbia to northernmost Washington include a diverse range of volcanic and sedimentary assemblages whose age, paleotectonic setting, and relationship to each other and/or to the North American craton are poorly understood. We have dated detrital zircons (n=1410) from a total of 21 samples of clastic rocks from within most of the Paleozoic assemblages in this area to test possible relationships between these assemblages and the North American craton, and to provide constraints on possible depositional age(s). We also examined the lithogeochemistry of the mainly mafic volcanic rocks within each assemblage to assess the paleotectonic setting in which they formed. In addition we have obtained several new macro- and microfossil ages from some of the rock units. Our new data, together with results of recent studies by other workers, indicate that each of the basement assemblages range in age from Middle Devonian to Middle Permian. The oldest rocks (including the Knob Hill assemblage in the Greenwood area and probably the Palmer Mountain Greenstone near Loomis in Washington) were erupted in a magmatic arc setting. Younger volcanic rocks yield a mix of arc, N-MORB and E-MORB signatures. The detrital zircon signatures that we have obtained comprise variable proportions of middle and late Paleozoic (390-295 Ma), probably first cycle grains, that were likely derived from nearby active magmatic arcs. Most samples also contain abundant, mainly well rounded Precambrian grains, with major age peaks at 2800-2450 Ma and 2150-1600 Ma, with a minor peak at 2450-2150 Ma. These three older age peaks are consistent with derivation of zircons in the various assemblages from the northwestern part of the North American craton. There is also a scattering of Late Proterozoic to Early Paleozoic detrital zircon grains in many of the samples whose provenance is less certain. Some or perhaps all of these may be derived from scattered local sources that have been identified in the Cordillera. Our new results indicate that despite their lithologic diversity, the various assemblages share a common detrital zircon age signature, suggesting that they may have originally formed in proximity to one another. We also argue that on the basis of overall lithology, age and detrital zircon age signature, the typically deformed and metamorphosed Anarchist Group in southern British Columbia is likely correlative with the little deformed Late Devonian to Middle Permian Harper Ranch Group farther to the north.

SEISMIC INTERFEROMETRY BASED TOMOGRAPHIC IMAGING OF THE SAN ANDREAS FAULT NEAR PARKFIELD, CA

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High-resolution direct tomographic imaging of subsurface Earth structures is generally limited by the distribution of seismic sources necessary for such studies. However, seismic interferometry has the potential to significantly overcome this issue through the use of ambient seismic noise recordings. Whereas the recovery of

virtual surface-waves via seismic interferometry techniques are the most abundant results produced by this technique, it has recently been shown that virtual body waves can also be recovered under appropriate conditions. In this work, using ambient seismic noise recordings across a network of borehole stations near Parkfield, CA, we observe both virtual body waves and surface waves propagating among stations distributed around the San Andreas Fault. From these waves we propose a detailed velocity model of the San Andreas Fault, wherein virtual P waves are used to constrain velocities laterally and virtual surface waves to constrain velocities at depth. We further investigate the possibility of recovering body-wave scattering (P to S) from interactions with velocity discontinuities associated with the fault, which would provide a dramatic improvement in our ability to characterize seismic velocity structures. Finally, we examine the potential of seismic interferometry to produce time-lapse body-wave characterizations of the San Andreas Fault, in which properties of the fault can be seen to change in time.

CONTAMINATED GROUNDWATER DISCHARGE ON URBAN STREAM WATER QUALITY: SPATIAL ANALYSIS OF EIGHT STREAM CATCHMENTS IN EASTERN CANADA

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Urbanization is a prevalent concern for its impacts on water quality as it increases the presence of contaminants in parking lots, parks, lawns, and commercial areas. Eight urban stream catchments in eastern Canada have been analyzed for spatial trends of groundwater contamination upon entering the streams. Datasets for streams in Nova Scotia and Ontario, provided by the National Water Research Institute in Burlington, Ontario, Canada, are mined for spatial correlations in anticipation to raise cognizance for future contaminant projects. Insight into the associations between elements and compounds gives potential to use safer and more cost-efficient remediation and contamination-control techniques, rather than attempting to contain each variable. Contaminant groups within the study of urban streams include: petroleum compounds, chlorinated ethenes, solvent compounds, pesticides, metals, metalloids, chloride salt, nitrogen compounds, phosphorous, artificial sweeteners, and perchlorate. Federal or, where federal limits are not stated, provincial guidelines for each compound and element were reviewed and a risk assessment at each stream was conducted and compared against the guidelines. At every stream, potential risk of contamination of one or more of the contaminant groups ranged from 9% to 60%, while probable risk of contamination ranged from 40% to 88%. Trends of contamination were largely due to local geology, urbanization (commercial, residential, and military), wash-off from storm events, and by known chlorinated solvent plumes. Contaminants are transported by groundwater flow, putting the stream catchments in peril at discharge locations.

Correlations between contaminants and other associated base cations, inorganic anions, and trace elements, are examined using bi-variate and multi-variate relationships in statistical and geochemical modelling programs: iOGas and PHREEQC. Results in statistical analysis indicated that assigned guidelines were exceeded most commonly for metals with metals and metals with chlorinated solvents, along with base cation (sodium, magnesium, potassium, and calcium) associations with metals and chlorinated solvents. Correlations with a coefficient, 'r', of up to 1.0 were present; however, r-values between 0.70 to 1 and -0.70 to -1 are examined.

As urban settings continue to expand into untouched land, groundwater contamination will continue to transpire with unchanged environmental regulations. Awareness of federal and provincial guidelines to protect the health of humans, wildlife, and a flourishing ecosystem is essential. Knowing the correlations

between hazardous compounds and common elements is the key to the most efficient form of remediation of exceeded variables within groundwater and its at-risk discharge location(s).

ARE IOCG-TYPE ALTERATION AND MINERALIZATION FROM THE LABRADOR TROUGH SIMILAR TO THOSE OF THE GREAT BEAR MAGMATIC ZONE?

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Geological research conducted from 2005 to 2016 in the Great Bear magmatic zone (GBMZ) under the Geological Survey of Canada's Geo-mapping for Energy and Minerals (GEM) and Targeted Geoscience Initiative programs has significantly improved our understanding of the genetic linkages between iron-oxide-copper-gold (IOCG), iron oxide-apatite (IOA) and albitite-hosted uranium deposits within regional iron oxide alkali alteration systems. In parallel, recent work conducted in the Romanet Horst of the Labrador Trough by Honey Badger Exploration Inc., Energizer Resources Inc., the Geological Survey of Canada and a research group from the University of Ottawa suggested that the variety of hydrothermal alteration types and their metal associations are related to IOCG-type mineralization and albitite-hosted U-Au prospects. Similarities and contrasts in the chemical signatures of hydrothermal alteration types, magnetite, and the least-altered host rocks permit information to be gained about metal associations and alteration assemblages from IOCG-type environments from contrasting geological settings (i.e. intermediate to felsic volcanic sequences and siliciclastic-dominant sedimentary basins in the GBMZ versus mafic volcanic sequences and carbonate-dominant sedimentary basins in the Romanet Horst).

GEOCHEMISTRY, MINERALOGY AND GENESIS OF BANDE NARGES SKARN IRON ORE DEPOSIT, CENTRAL IRAN

Nazari, M. and Lotfi, M.

The Kouh-e Latif iron deposit is located approximately 205km NE of Isfhan and is a small area in the NE of Urumieh– Dokhtar Magmatic Arc, Iran. The skarn hosted in a Cretaceous limestone, intruded by granite and granodiorite. The calcic skarn has experienced two stages of metamorphism: 1) prograde stage, which include endoskarn and exoskarn facies with clinopyroxene, garnet, scapolite and albite mineralization, and 2) retrograde stage which produced actinolite, epidote, chlorite and apatite assemblage through retrograde alteration. The ore minerals in Bande Nargesskarn are magnetite, with minor chalcopyrite, pyrrhotite and pyrite. Gangue minerals are predominantly diopside, andradite, epidote, chlorite, quartz and calcite. Micro-thermometric measurements yield a homogenization temperature range for skarn alteration of 414 to 448°C, with a salinity of 11 to 13.186 wt.% NaCl equivalent. Fluid inclusions in calcite associated with mineralization generally consist of a vapor bubble and a liquid phase with a rare occurrence of three-phase inclusions. Homogenization temperatures for two phase inclusions vary from 168 °C to 203 °C with a salinity of 0.5 to 2 wt% NaCl equivalent. Homogenization of three phase inclusions was observed between 162 °C to 278 °C with salinity of 4 to 23 wt.% NaCl equivalent. The high-temperature and high-salinity of fluids indicate magmatic nature of the trapped fluids within progradeskarn mineral assemblages in contrast the fluids with lower temperature and lower salinity displaying a possible meteoric source within the retrograde skarn assemblages. Therefore moderate temperature and high-salinity fluids could infer to possible isothermal mixing between the fluids.

GEOCHEMISTRY, MINERALOGY AND GENESIS OF BAND-E NARGES SKARN IRON ORE DEPOSIT, CENTRAL IRAN

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The Band Narges iron deposit is located approximately 205 km NE of Isfahan and is a small area in the NE of Urumieh-Dokhtar Magmatic Arc, Iran. The skarn hosted in Cretaceous limestone, intruded by granite and granodiorite. The calcic skarn has been experienced two stages of metamorphism: 1) Prograde stage, which include endoskarn and exoskarn with clinopyroxene, garnet, scapolite and albite mineralization, and 2) retrograde stage include actinolite, epidote, and chlorite. The ore mineral in Band-e Narges skarn are magnetite with minor chalcopyrite and pyrite. Gangue minerals are predominantly diopside, andradite, epidote, chlorite, quartz and calcite. Micro-thermometric measurements yield a homogenization temperature range for skarn alteration of 414 to 448°C, with a salinity of 11 to 13.186 wt.% NaCl equivalent. Fluid inclusions in calcite associated with mineralization generally consist of a vapor bubble and a liquid phase with a rare occurrence of three-phase inclusions. Homogenization temperatures for two phase inclusions vary from 168°C to 203°C with a salinity of 0.5 to 2 wt.% NaCl equivalent. Homogenization of three phase inclusions was observed between 162°C to 278°C with salinity of 4 to 23 wt.% NaCl equivalent. The high-temperature and moderate salinity of fluids indicate magmatic nature of the trapped fluids within prograde skarn mineral assemblages, in contrast the fluids with lower temperature and low to moderate salinity displaying a possible meteoric source within the retrograde skarn assemblages. Therefore lower temperature and high-salinity fluids could infer to possible fluids dilution.

DETRITAL ZIRCON DATA FROM BASAL HAZELTON CLASTIC STRATA IN THE ISKUT REGION DOCUMENT THE END-TRIASSIC TECTONIC TRANSITION IN NORTHERN STIKINIA

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The Hazelton Group overlies the Stuhini Group on a diachronous Late Norian-Early Jurassic unconformity. Lowermost Hazelton units include well-sorted, clast-supported polymictic conglomerates with rounded clasts. Their sedimentary maturity contrasts with the volcanoclastic Stuhini Group. Clasts are of coarse-grained equigranular to porphyritic felsic intrusive rocks, radiolarian chert, and minor volcanic rocks. Clasts of Stuhini origin are rare. Conversely, no large Late Triassic plutonic bodies have been recognized in the region. The mismatch between local Stuhini basement and clasts in overlying Hazelton conglomerates indicates non-representational sedimentation: distant sources, deep erosion, and long surface residence time.

Detrital zircon populations: An uppermost Stuhini sample shows peaks at 212 Ma and 203 Ma, which is taken as the M.A.D. (maximum age of deposition). Above the unconformity, two Late Triassic conglomerates show peaks at 221 Ma, substantially older than that of the immediately underlying Stuhini Group. Late Triassic (222-225 Ma) peaks also occur in Early Jurassic samples. The sample taken near the top of the siliciclastic succession shows a subsidiary peak at 197 Ma (M.A.D.). Above a second, higher unconformity on Snippaker Ridge, the basal conglomerate contains a main 204 Ma peak and two subsidiary peaks at 216 and 198 Ma, the latter considered M.A.D. The older peaks correspond to local and regional Stuhini sources.

A pronounced shift to older detrital ages took place across the sub-Hazelton unconformity, from 212-203 Ma below to ca 220-225 Ma above. Penecontemporaneous arc-derived extrusive and

hypabyssal sources gave way to deep erosion of the Stuhini arc and its basement. Abundant plutonic clasts were derived from large surface exposures of ca 220 Ma granitoids. At present, extensive exposures are only seen in the Hotailuh, Hickman and associated batholiths of far northern Stikinia. Stuhini arc activity was abruptly terminated in the latest Triassic (ca 203-204 Ma), succeeded by the development of a broad tectonic highland that shed debris towards the south.

GEOCHEMICAL BEHAVIOUR OF VANADIUM AND NICKEL IN PETROLEUM COKE DEPOSITS AT AN OIL SANDS MINE IN NORTHERN ALBERTA, CANADA

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The geochemical characteristics of three petroleum coke deposits at an oil sands mine near Fort McMurray, Alberta were investigated. The coke being studied was generated in large volumes via fluidized-bed coking during the upgrading of oil sands bitumen, and was then slurried with process-affected water to deposits onsite. This research aimed to better understand how coke trace metal speciation and release varied with field conditions, in order to inform on coke storage. Continuous core sampling and multi-level well groundwater sampling were performed to 8 m depth throughout the deposits to acquire samples from differing storage and redox conditions. Bulk elemental analyses confirmed that this coke was composed mainly of C and S, with a secondary fraction of clays and oxides (Si, Al, Fe, Ti, Ca, K, Mg) and a suite of trace metals dominated by V (1280 ± 120 mg/kg) and Ni (230 ± 80 mg/kg). Synchrotron powder x-ray diffraction revealed the presence of quartz, rutile, and vanadyl porphyrins, and provided information about the amorphous asphaltenic carbon matrix of coke. Electron microprobe analyses and scanning electron microscopy revealed concentric rings within coke grains, defined by elevated concentration of clay micro-particulate, V, and Ni. Vanadium and Ni K-edge x-ray absorption spectroscopy (XAS) showed that these elements were hosted in porphyrins and similar organic complexes throughout coke grains. However, micro-focused XAS further showed that V is inorganically complexed along the aforementioned concentric rings, with coordination being consistent with substitution into the distorted octahedral site of phyllosilicates. Sulfur K-edge XAS confirmed that thiophenic coordination is predominant. Groundwater depth profiles of pH, Eh, electrical conductivity, major ions, and stable isotopes of water showed evidence of a mixing zone between the infiltrating, oxic, sub-neutral pH precipitation and the underlying, anoxic, alkaline pH process water. Data suggested that V and Ni are mobilized only at the top of the saturated zone due to ingress of oxygen and precipitation. Vanadium was found to undergo oxidative mobilization in the form of oxyanionic species whereas Ni mobilization occurred as pH decreased.

YUKON-NATIVE BACTERIA AND THEIR CAPACITY TO REMOVE METALS FROM MINE DRAINAGE IN COLD-CLIMATES

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Passive treatment, using sulfate-reducing bacteria, is a promising and is increasingly being used as an alternative for the treatment of mine drainage compared to conventional methods. However, several challenges remain concerning implementation in cold climates, where water temperature remains cold all-year round and bacterial growth is temperature limited.

The impact of cold temperature on sulphate-reducing bacteria activities and subsequent Cd and Zn removal was studied through static tests conducted, over 90 days, at 4.5°C. Mine water was

collected at Silver King adit, located in the Historic Keno Hill Silver District, Yukon. Cd and Zn concentrations in the water collected on site were above the discharge limits established for the Bellekeno mine in the district (0.5 mg Zn/L and 0.01 mg Cd/L).

The experimental design used in this study was based on the in-situ pool water treatment proposed as a closure option for this site. We used waste rock collected at Silver King and microbial inoculum collected from Crystal creek. Two different sources of carbon were tested to assess their ability to support bacterial growth: molasses (Mo), methanol (MeOH) and a mix of Mo/MeOH at a concentration based on molecular ratio with sulfate (76.9 mg C/L). The 1 L-capacity reactors were monitored biweekly and the residual concentration of Zn, Cd, sulfate, Total Organic Carbon, pH and oxydo-reduction potential were measured.

The initial control experiment with waste rock and deionised water revealed metal leaching up to 0.78 mg Zn/L and up to 0.022 mg Cd/L after 90 days. However, when adding a carbon source to the mine drainage and waste rocks, both Cd and Zn concentrations decreased significantly at 4.5°C. This reduction resulted from the microbial reduction of sulphate, boosted by carbon addition. The use of a liquid carbon substrate for the microbial community clearly improved the rate of metal removal and lowered the concentrations below discharge limits. Up to 94.8% of zinc and up to 99.4% of cadmium were removed after 90 days in the presence of liquid carbon. Molasses was found to be slightly more efficient but less predictable than methanol. These findings indicate that native sources of sulfate-reducing bacteria might be used successfully in the to the control metal concentrations in discharged water.

THE MINERALOGY AND PETROLOGY OF THE LAYERED SERIES NEPHELINE SYENITE WITHIN CENTER II OF THE COLDWELL COMPLEX, MARATHON, ON

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The Coldwell Alkaline Complex is the largest alkaline intrusion in North America, and was emplaced during initial magmatism of the Keweenaw Midcontinent Rift (MCR) at 1.1 Ga. This rift system forms an arcuate feature, which can be traced over 2000 km from Kansas to Michigan, and represents one of the largest known aborted continental rifts. Located on the north shore of Lake Superior, the Coldwell Complex was emplaced along the Thiel fault (the northern component of the Trans-Superior Tectonic Zone), and is host to rare earth elements (REE), Cu, Ni, PGE, and other high field element mineralization. Emplaced from east to west, the oldest – termed ‘Center I’ is host to gabbro and Fe-rich augite syenite; ‘Center II’ hosts biotite-gabbro and nepheline syenite; and ‘Center III’ is host to a variety of syenite. The focus of this study is to understand the magma systematics involved in the emplacement and crystallization of the different intrusive centers, specifically Center II. This involves field mapping, extensive sampling and mineralogical study of the complex syenites. There is an emphasis on identifying the REE minerals occurring in the nepheline syenites. This detailed assessment will help to understand the complex systematics of alkaline rocks in the Superior Province, and will assist with mineral exploration within the complex, which is currently underexplored for REEs.

Layered series nepheline syenite rocks display cumulus textured perthitic feldspar, with post cumulus amphibole and associated pyroxene, biotite, and zeolites. The feldspar exhibits secondary albitization of an earlier alkali feldspar which has produced lamellae of albite (An% 0-4.43). Amphiboles dominantly plot in the hastingsite range; with biotite classified as annite with rare siderophyllite; exhibiting a correlation in Mg# (Mg/ (Fe + Mg)) to the amphibole it altered from. Zoning compositions of amphiboles display a trend to Fe and Mn enrichment with Mg, Ca, Ti depletion. Samples from lower sections of the layered series rarely display amphibole zoning, indicating an equilibrium during crystallization with complete isolation from the fractionated magma

post-deposition. REE analysis of the layered series has displayed elevated levels of LREE in apatite (La, Ce, Nd) along with Th and Y, and titanite containing appreciable levels of Nb and Ta. The pegmatites associated with the layered series represent altered ‘normal’ syenites at higher structural levels in the Center II chamber. The pegmatites are host to many complex REE phases in Center II. Apatite has proven to be a viable mineral for tracer isotope analysis and will be used for future work to determine the mantle source of the parental magma.

FLUORAPATITE IN TILL AS AN INDICATOR MINERAL FOR IRON OXIDE ALKALI-ALTERATION SYSTEMS, GREAT BEAR MAGMATIC ZONE, NORTHWEST TERRITORIES, CANADA

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Fluorapatite-amphibole-magnetite assemblages are a signature alteration product in iron oxide alkali-alteration systems (IOAA) that can host iron oxide-copper-gold (IOCG) deposits. Major and trace element compositional zonation of fluorapatite ($\text{Ca}_5(\text{PO}_4)_3\text{F}$) within such ore systems is distinct from other settings and can indicate the presence of these ore systems in bedrock or surficial sediments. As part of the Geological Survey of Canada’s GEM-1 IOCG-Great Bear Project, fluorapatite recovered in the high-density (specific gravity >3.2) and mid-density (specific gravity 3.0-3.2) fractions of till and disaggregated bedrock samples from the Great Bear magmatic zone (GBMZ) and IOCG deposits within were examined to evaluate the mineral’s usefulness as an indicator mineral. The chemistry of fluorapatite was determined through EMPA and LA-ICP-MS in addition to SEM and cathodoluminescence (CL) characterization. Within IOAA systems, REE-rich fluorapatite forms during high temperature sodic-calcic-iron and calcic-iron metasomatism. As temperature declines and the fluid chemistry evolves, localized REE leaching within fluorapatite leads to irregular zonation and formation of secondary REE-bearing minerals. Inclusions of monazite and allanite are found in the fluorapatite from the GBMZ samples with allanite being the dominant REE-bearing phase where late, low temperature calcic alteration is evident. A blue CL response in fluorapatite grains reflects low Mn and high REE content and is common in fluorapatite from the GBMZ IOCG systems. This blue CL response was observed in 30 to 50 % of fluorapatite grains in 3 till samples down-ice of the Sue Dianne IOCG deposit and contrasts with the more common Mn-activated green to yellow CL responses of fluorapatite in till throughout the GBMZ. Grains with blue CL fluorapatite response occasionally display small orange and red CL spots that reflect the presence of calcite in polymineralic fluorapatite-calcite grains, and are indicative of calcic alteration within IOAA metasomatism. Zoning in the green to yellow CL response, metasomatic dissolution pits and REE-rich mineral inclusions can discriminate the regionally present GBMZ fluorapatite from those in the neighboring Wopmay metamorphic zone and Slave Craton. The 0.25 to 2 mm size range is adequate both for CL and SEM characterization of grains in bedrock and till samples. In till samples, metasomatic fluorapatite grains derived from IOAA systems can be mixed with fluorapatite from less altered host rocks of the GBMZ, therefore characterization of at least 50 grains per till sample is recommended to be able to detect the presence of the IOAA-derived fluorapatite.

CONSTRAINING THE GENETIC PROCESSES OF SUDBURY BRECCIA, ONTARIO, CANADA: IMPLICATIONS FOR EXPLORATION OF FOOTWALL Ni-Cu-PGE DEPOSITS

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The Sudbury breccia is a ubiquitous lithology in the footwall of the 1.85 Ga Sudbury Igneous Complex (SIC) in Ontario, Canada. The 30 × 60 km basin represents the remains of an impact crater with an estimated diameter of 200 km. The genetic processes that formed Sudbury breccia are not yet fully understood, with three competing theories: in-situ frictional melting; cataclasis or injection of allochthonous impact melt into the brecciated crater floor during the excavation; and/or modification of the crater.

Furthermore, the breccia acted as a pathway for the emplacement of evolved, Cu-Ni-PGE rich, sulphide melts derived from embayment structures at the basal contact of the impact melt. These footwall ore deposits were partially remobilised by post-impact hydrothermal systems active in the footwall of the crater. Previous work has identified significant variations in the metal content of the breccia away from ore zones that warrant further investigation as potential vectors towards mineralised zones.

This study utilises a mixing model to constrain the proportions of footwall and impact melt material contributing to the geochemical signature of the Sudbury breccia matrix. We use two localities in the Creighton Embayment to demonstrate that the breccia matrix can be constructed from local footwall lithologies with no requirement for a contribution from the impact melt sheet. Instead the data indicate a dynamic, parautochthonous in-situ melt, which was transported over tens of metres via thermal expansion or pressure-driven injection into low pressure, extensional fractures zones that developed adjacent to the zone of melting during uplift in the transient crater. The implication is that distal to ore bearing zones, the trace metal content within the breccia can be accounted for by assimilation of metal-bearing mafic units in the footwall and is not necessarily linked with the expulsion of metals from footwall deposits.

REGULATORY GEOSCIENCES IN THE CANADIAN OFFSHORE IN THE FLUCTUATING OIL PRICE ENVIRONMENT

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The oil and gas industry in Canada has had its challenges over the last few years with a decreasing oil price from a high \$140 a few years ago to recently below \$30 dollars a barrel.

Offshore oil and gas developments have their own unique challenges and issues which can test the regulatory regime legislated by governments and administered by the offshore boards such as the Canada Newfoundland and Labrador Offshore Petroleum Board (C-NLOPB).

As a regulator in the Newfoundland and Labrador offshore, 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 try to survive in less than \$30 dollar a barrel market.

Technical staff are an integral part of Resource Management department, especially its geoscientists. 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 ongoing training. In addition, staff must understand the legislation and its implementation.

Challenges for the department include: changing demographics, advances in technologies and changing government 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 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 their technical and careers 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 regulator 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.

These type of challenges are experienced by all professional geoscientists.

PETROLOGY, GEOCHEMISTRY, AND U-Pb GEOCHRONOLOGY OF THE LATE ARCHEAN PRESTIGE LEUCOGRANITE AND ASSOCIATED PEGMATITES, NWT

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The Yellowknife pegmatite field encompasses an area of 12,000 km² to the northeast of Yellowknife within the southern Slave Province. It is host to LCT-family rare-element pegmatites that are associated with Archean granitic magmatism. Studies of pegmatites in the district have found local occurrences of cassiterite associated with tantalum, beryllium, and lithium minerals. The large Prosperous Suite, a plutonic assemblage composed of muscovite-biotite S-type leucogranites, lies in the southwest quadrant of the pegmatite field. Numerous pegmatite dykes occur within the granite and the surrounding schist-hornfels of the Burwash Formation. The present study focuses on the Prestige pluton, where previous lithogeochemical results indicate high concentrations of Li (mean of 700 ppm); this result is significantly higher than the mean estimates for other plutons in the Prosperous suite. Barren quartz-feldspar pegmatite dykes intrude the pluton and the supracrustal rocks. Beryl-columbite subtype pegmatites are hosted primarily within the Burwash Formation. These dykes locally contain rare-element minerals, such as tourmaline, heliodore beryl, and uncommonly columbite-tantalite.

In the LCT pegmatite family, an increase in Li, Cs, Rb, Ta, and Sn with sequential decreases in ratios, such as K/Rb, K/Cs, and Sr/Rb in whole-rock and mineral data are typical as the degree of fractionation increases. The bulk rock geochemistry indicates it is a relatively evolved system. The K/Rb versus Cs plot shows that the interpluton pegmatites are the most fractionated. The pegmatites are enriched in incompatible elements, with averages of 22 ppm Sn, 9.5 ppm Ta, 19.6 ppm Nb, 21.0 ppm Cs, and 453 ppm Rb. Muscovite trace-element compositions, determined by LA ICP-MS analysis, report elevated levels of Rb, Cs, and Sn. Limited geochronology has been done on the plutons in the Prosperous Suite; the Sparrow Lake pluton has a known U-Pb age of 2.596 ± 0.002 Ga. This age will be compared to the U-Pb monazite ages determined by LA ICP-MS, which will indicate whether the Prestige pluton is coeval with the Prosperous Suite. This may alter the presumed tectonic exhumation and emplacement history of the region. The temporal relationship between the dykes and granites will be tested against the accepted simple cogenetic intrusion and dyking model. The geochronological results will be coupled with the geochemical data to determine if there is a correlation between the degree of fractionation and the timing of emplacement.

GENESIS OF SEDIMENT- AND VOLCANIC-HOSTED ZN-Pb DEPOSITS OF THE CANADIAN CORDILLERA – THE RESULT OF CONTINENT-SCALE TECTONISM

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Paleozoic-hosted stratabound base-metal sulphide deposits form a series of metallogenic belts in the Canadian Cordillera. The most outboard belt consists of Devonian-Mississippian (and older) volcanic-hosted massive sulphide (VHMS) Zn-Cu-Pb-Ag-Au deposits of the pericratonic terranes and outer continental margin. Clastic sediment-hosted (CSH) Zn-Pb (\pm Ag, \pm Ba) deposits, which have been traditionally referred to as sedimentary exhalative (SEDEX) deposits form a second, more inland belt, in carbonaceous marine sedimentary rocks of the Kechika Trough and Selwyn Basin. Farther east, in the Canadian Rocky Mountains, a series of Mississippi Valley-type (MVT) Zn-Pb deposits occurs within rocks that were originally part of the Silurian-Devonian shallow water carbonate platform. The Pine Point MVT Zn-Pb district and minor Zn and Pb sulphide occurrences westward of the Rocky Mountains coexist with coarse dolomite in petroleum reservoirs of the Western Canada Sedimentary Basin (WCSB).

The tectonic and coeval hydrothermal activity in the Canadian Cordillera during the Paleozoic time resulted in the formation of metallogenic belts (from west to east) consisting of primitive to continental arc-related VHMS deposits in the pericratonic terranes, CSH Zn-Pb (\pm Ag, \pm Ba) and alkalic-related VHMS deposits in continent-margin basins, and carbonate-hosted MVT Zn-Pb mineralization in the continental platforms. This metallogenic continuum is supported by (1) spatial deposit association; (2) similarity in the ages of the VHMS, CSH Zn-Pb (\pm Ag, \pm Ba), and MVT sulphide mineralization, and (3) similarity in the stable and radiogenic isotope signatures of sulphide and carbonate gangue minerals of these deposit-types. Dissimilarities between the main deposit types reside in their respective geologic environment of formation, host lithologies, deposit architecture and morphology, decrease in temperatures of deposit formation from west (westernmost VHMS) to east (Pine Point), and genetic model.

LOW-PRESSURE METAPELITIC PHASE EQUILIBRIA: APPLICATIONS AND CHALLENGES

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Metapelitic mineral assemblages underpin our characterization of low pressure (andalusite-sillimanite type) metamorphism. They provide a readily identifiable and, under optimal circumstances, remarkably sensitive measure of relatively small pressure differences at pressures below the Al_2SiO_5 triple point (~ 4.5 kbar). Mapped distributions of these mineral assemblages have allowed the identification of subtle differences in pressure amongst regional low-pressure terrains, in emplacement levels of intrusions, and in degree of post-emplacement tilting of intrusions. They provide more precise and robust estimates of P-T conditions than conventional or multi-equilibrium geothermobarometry, or, in the case of emplacement levels of intrusions, hornblende barometry. Examples of the above are discussed. Some aspects of low-pressure metapelitic phase equilibria remain poorly understood: the petrogenesis of rare, kyanite-andalusite-sillimanite assemblages in apparently non-polymetamorphic contact aureoles; the influence of kinetics on the development of Al_2SiO_5 minerals in staurolite-bearing sequences, with implications for pressure estimation using these assemblages; and incongruence between thermodynamic modelling of cordierite-bearing and staurolite-bearing phase equilibria and natural constraints.

STRUCTURAL CONTROLS OF INTRUSIVE ROCKS IN THE CANADIAN MALARTIC GOLD DEPOSIT

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The Canadian Malartic world-class gold deposit is the only known deposit of significant size located south of the Cadillac – Larder Lake fault zone in the Val d'Or-Malartic area. Understanding the structural controls and the alteration halo(s) of this deposit is of key importance for exploration for similar systems. Previous work demonstrated that gold mineralization is intimately associated with a second order fault zone (the Sladen Fault) which is located along the margins of large monzodioritic dykes within the Pontiac meta-sedimentary rocks. The diorite-monzodiorite-monzonite intrusive rocks appear to be critical controls on the distribution of the gold mineralization at Canadian Malartic. Other intrusive rocks in the area include meta-basic dykes and felsic dykes that crosscut the monzodioritic stock and that were also altered during mineralization event(s). In this work, we investigate the structural - metamorphic setting of the Canadian Malartic area using field observations, structural measurements and airborne magnetic data, and we discuss the possible control of the intrusive rock emplacement. Preliminary results show that three structural domains can be distinguished: 1) a domain, along the Cadillac – Larder Lake fault zone and in the vicinity of the Canadian Malartic deposit, that is characterized by variable (subhorizontal to subvertical) bedding orientation, by a strongly penetrative S_2 biotite foliation and by younging directions that are mostly toward the north. 2) An intermediate domain, south of the deposit, that is characterized by homogenous subvertical bedding orientation, a less penetrative S_2 foliation and younging directions that are mostly toward the south. 3) A south domain that is characterized by homogenous steeply dipping bedding orientation and a more subtle S_2 foliation. Monzodioritic dykes appear to be spatially associated with F_1 folds. However, their west-dipping geometry suggest a syn- D_2 opening, parallel to the east-dipping L_2 stretching lineation. It is therefore proposed that the first deformation event (D_1) built the overall architecture, including fold hinges that controlled the intrusion of later plutonic rocks and subsequent mineralization(s) during the second deformation event (D_2). A structural relationship between the intrusive rocks and the F_1 folds could be a critical parameter for exploration in the Canadian Malartic area.

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MAPPING TECTONO-MAGMATISM USING RHYOLITE GEOCHEMISTRY AND RADIOGENIC ISOTOPES: THE RECORD FROM PORPHYRIES FROM THE WOLVERINE VOLCANOGENIC MASSIVE SULFIDE (VMS) DEPOSIT, YUKON

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Porphyritic rhyolite intrusive rocks from the Wolverine volcanogenic massive sulfide (VMS) deposit, Finlayson Lake district, occur within the footwall to mineralization and record two episodes of magmatism at 352 Ma (quartz-feldspar porphyries) and at 347 Ma (feldspar porphyries), the latter coincident with VMS formation. These porphyritic rocks act a probes of magmatism, tectonic environment, and heat flow, and record episodic magmatism with in an evolving mid-Paleozoic continental back-arc rift along the western edge of North America. Lithogeochemical work has illustrated that the quartz-feldspar porphyries have lower high field strength element (HFSE) and rare earth element (REE) contents, and lower Nb/Ta ratios (~ 12) and zircon saturation temperatures, compared to feldspar porphyritic intrusive rocks, which contain higher HFSE, REE, and Nb/Ta ~ 17 and zircon saturation temperatures $> 900^\circ\text{C}$. New ϵNd_t results for the two populations ranges from -7.1

to -11.5 (average = -10.6) for the QFP suite and -7.8 to -8.1 (average = -8.0); both have Proterozoic depleted mantle model ages (TDM = 1.59-2.58 Ga). Whole rock ϵHf_t ranges from QFP = -12.2 to -20.8 (average = -16.5) FP -13.6 to -18.0 (average = -14.8). In situ U-Pb on zircons illustrate that while some ages are close to previously reported concordant TIMS ages, most ages have evidence of inheritance with ages ranging from 348-381.7 Ma for the QFP suite and 368.9-370.5 Ma for the FP suite. These same zircons yield in situ ϵHf_t values (calculated at 352 and 347 Ma for the QFP and FP, respectively) that range from -11.5 to -21.0 (average -15.3) and -11.6 to -26.0 (average = -18.7) for the QFP and FP, respectively. These integrated results are consistent with varying contributions of crust versus mantle in the genesis of the rhyolitic rocks with the FP suite containing a greater mantle component than the QFP suite, but both exhibiting significant input from Proterozoic continental crustal sources. These results can be accommodated within an evolving back-arc basin in which there was a progressive increase in mantle input as a result of upwelling of juvenile basaltic material beneath the back-arc basin as it opened. Notably, the upwelling of mafic magmatism and greater mantle components in the porphyries also coincided with higher temperature felsic magmatism and VMS deposit genesis; hence, more VMS prospective rhyolites have evidence of a greater mantle component. These results illustrate that tracer isotopes and in situ Hf isotopes of zircon are powerful tools for understanding crustal evolution, and petrogenetic and metallogenic processes in VMS associated felsic rocks and deposits.

STABLE ISOTOPIC INVESTIGATIONS OF GIANT BEAVER DIET AND ECONICHE – NOT ANOTHER DAM BEAVER

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The giant beaver (genus *Castoroides*) thrived in wetland habitats across North America – including Beringia – during the Pleistocene. Stable carbon and nitrogen isotopic analysis of bulk bone collagen has revealed that this 100 kg rodent consumed a diet of freshwater macrophytes, with an emphasis on submerged macrophytes. Regional differences in diet existed between Arctic and temperate latitude populations. The stable isotopic data for the giant beaver was compared with results for two modern semi-aquatic rodents with well-documented diets and ecologies (*Castor canadensis* and *Ondatra zibethicus*). This comparison shows that *Castor canadensis* is not an appropriate analog species to the giant beaver. We conclude from incisor morphology and stable isotopic reconstruction of palaeodiet that *Castoroides* neither harvested trees nor built dams. The stable isotopic dietary baseline and SIAR mixing models have been used to define the econiche of each rodent, and show that *Castoroides* and *Castor canadensis* occupied complementary dietary niches. This allowed them to co-exist in shared habitat space for much of the Pleistocene. However, the loss of optimal wetland habitat and a spread of environmental conditions that strongly favoured *Castor canadensis* occurred during the Pleistocene-Holocene transition. Increased competition for habitat space arising from shifting environmental conditions negatively impacted *Castoroides* populations and likely contributed to their extinction ~11,000 BP.

TILL MINERALOGY AND GEOCHEMISTRY IN THE HIGHLAND VALLEY CU-MO PORPHYRY DISTRICT, SOUTH-CENTRAL BRITISH COLUMBIA

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The Highland Valley district includes five economic Cu-Mo porphyry deposits hosted in the Guichon Creek batholith of south-central

British Columbia. Between 1962 and 2013, 1615 million tonnes of ore grading 0.4% Cu and 0.01% Mo have been processed at the Highland Valley Copper mine (HVC) representing one of the largest Cu deposits in Canada. The HVC region is characterized by an extensive cover of glacial sediments with a predominance of tills from the Late Wisconsinan Fraser Glaciation. Surface landforms include drumlins, flutings and crag-and-tails which indicate ice flow to the south to southeast. A total of 97 subglacial till samples were collected within a 1000 km² area centered on HVC with the objective of identifying the geochemical and mineralogical footprint of the porphyry mineralization in the surficial sediments. Samples were processed for indicator minerals in the medium to very coarse sand-sized fraction (0.25-2 mm) and for geochemical analyses of the silt plus clay (<0.063 mm) and clay-sized (<0.002 mm) fractions. Results show that geochemically, the Cu-Mo mineralization is well reflected in till with high Cu and Mo concentrations (e.g. >1500 ppm Cu and >20 ppm Mo in the silt plus clay) close to mineralized zones progressively decreasing to background concentrations (<200 ppm Cu and <1.5 ppm Mo in the silt plus clay) approximately 20 km to the southeast. Similarly, Al₂O₃ content of till varies from >17% near mineralized zones and drops to background concentrations <16% 10 km to the southeast. The high Al content of till near mineralization is interpreted to be derived from phyllosilicate alteration minerals associated with mineralization. Similar to the Cu concentrations, the number of chalcopyrite grains in till (0.25-0.5 mm; >3.2 specific gravity) is highest (>100 grains/10kg) near mineralized zones and decreases to <10 grains/10kg at about 10 km to the southeast. Scheelite and barite are more abundant in till near mineralization compared to background region and therefore, could be used as porphyry indicator minerals in the Highland Valley district. The regional geochemical and mineralogical footprint measured in till at Highland Valley is interpreted to result from glacial erosion of a cluster of economic and sub-economic mineralized zones and detrital glacial dispersal up to 20 km to the southeast.

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A GEOCHEMICAL STUDY OF DIAMOND INDICATOR MINERALS FROM THE NWT INTERIOR PLATFORM

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The NWT Interior Platform comprises a Phanerozoic sedimentary basin which is situated between the western margin of the Slave craton and the Cordillera. Although the region is considerably outside the bounds of the exposed Slave craton, both LITHOPROBE and more recent regional-scale surface-wave studies indicate the likely presence of lithospheric mantle extending into the diamond stability field.

Olivut Resources Ltd. discovered 29 kimberlites in this region. There is, however, a mismatch in the kimberlite indicator mineral (KIM) chemistry of the discovered kimberlites regional till and stream sediment samples taken by the Geologic Survey of Canada and Northwest Territories Geologic Survey between 2003-2006. We present new geochemical data on the regional KIMs with the aim of obtaining a geotherm, depth of mantle sampling constraints, as well as emplacement ages for those KIMs discovered to date. A statistical evaluation of the data will compare the similarities with available data from the surrounding cratons, to evaluate where these KIMs may ultimately be derived from.

In total, 3600 kimberlite indicator mineral grains were picked from the 0.25-2.0 mm size fractions. Peridotitic garnet grains dominate (46%), followed by microilmenite (26%), with decreasing individual proportions (all <15%) of chromite, low-chrome diopside, olivine,

chrome-diopside and eclogitic garnet. A sub-set of these grains (3143) were analysed by electron probe micro analyzer (EPMA). Garnet grains classify as to G9 (62.1%), G11 (16.5%), G10 (9.7%), G12 (6.3%), G1 (3.5%), and G0, G3, G4, and G5 (comprising 1.9% total). A sub-set of peridotitic garnet grains (~700) were selected for trace element analysis via laser-ablation inductively-coupled plasma mass spectrometry (LA-ICP-MS). Nickel concentrations for the selected grains were determined, with the majority (>80%) between 20-100 ppm, yielding TNi values between ~1000-1200°C. Extrapolating to a central Slave craton geothermal gradient, equilibration pressures for the majority of these grains are between 4-6 GPa (~120-185 km), showing dense sampling in the "diamond window". A total of 581 (81%) P-type garnet grains plot within the diamond stability field.

Careful analysis and compositional screening reveals that of the 128 clinopyroxene grains, only a few represent garnet peridotite source lithologies. Thermobarometry of these grains, assuming they were all derived from the same mantle section, yields P-T arrays consistent with a lithosphere at least 200 km thick at the time of eruption, consistent with the garnet results. Additionally, a sub-set of picroilmenite grains were analysed by MC-ICP-MS for Hf-isotopic compositions to constrain source kimberlite emplacement ages.

SHEELITE REVEALED BY CL IMAGING AND LA ICP-MS ELEMENTAL MAPPING AND ANALYSIS: NOT SO SIMPLE AFTER ALL

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Many minerals relevant to ore formation are either opaque to white light (e.g., pyrite, wolframite) or if transparent do not record the subtle chemical variations otherwise present in their structure. The latter is the case for scheelite, an important ore mineral for W, and for which there is little information currently available (e.g., isotopic, chemical, fluorescence, CL) that can be used to infer conditions of formation and hence constrain the deposit type (e.g., orogenic gold vs. skarn). This latter point is important given its high density, physical robustness and chemical resistance to breakdown during transport and hence its capacity to be used as a pathfinder mineral in exploration programs otherwise compromised by overburden. Here we present the results of an extensive, ongoing crystal-chemical study of 39 scheelite samples from 8 ore deposit settings (e.g., orogenic sediment- and greenstone hosted, greisen, porphyry, skarn, VMS, breccia, polymetallic) that provide for the first time an internally consistent database with which to interpret the formation of this ore phase. Methods used included standard optical petrography, SEM-EDS, cathodoluminescence (CL), and both point and raster LA ICP-MS, and oxygen isotopes. The scheelite data provide insight into two aspects of this phase, its growth history in hydrothermal ore systems and the chemical conditions during its growth. In terms of the former, high resolution CL maps reveal both simple and complex growth histories involving periods of uniform growth, dissolution events and late cross-cutting features. The latter information, in particular elemental mapping and point analyses, provides insight into the growth history: 1) progressive elemental changes, such as ΣREEs and $(\text{La}/\text{Sm})_{\text{N}}$, indicate gradual depletion of the fluid in a closed system, 2) uniform chemistry suggests replenishment of the ore fluid in an open system, and 3) drastic changes and discordant resorption features suggest extreme disequilibrium due changes in physio-chemical conditions. The $\delta^{18}\text{O}$ data show a large variation, -5 to +8‰, which, when combined with the chemical data would be consistent with closed system distillation or fractionation of the fluid reservoir. Lastly, the data suggests that the parameter Eu^*/Eu combined with other chemical indices (e.g., Mo content) may provide useful in distinguishing metamorphic from other types of scheelite.

POST-DEPOSITIONAL ALTERATION OF PHYTLITH SILICA: IMPLICATIONS FOR RECONSTRUCTION OF PALEOCLIMATE AND GEOCHEMICAL CYCLES

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The silicon and oxygen isotope composition of silica phytoliths precipitated in plants can be applied to paleoenvironmental reconstructions if their isotopic compositions are retained after deposition in soils. Partial dissolution of phytoliths can affect their isotopic compositions and physical characteristics (specific surface area, mean particle size), potentially causing problems with paleoclimate reconstructions. Phytolith dissolution experiments were conducted in batch reactors under a range of pH (4-10) and temperature (4-44°C) conditions. The oxygen and silicon isotope composition of phytoliths changed in a similar manner as dissolution progressed, with values increasing until the solutions were approximately 30-40% saturated with silicic acid. During this phase the isotopic composition of the remaining silica was primarily affected by dissolution reactions that preferentially removed the light isotopes. After ~30-40% saturation is reached, precipitation of new silica began to modify the silicon and oxygen isotope composition of remaining silica, trending towards lower values, despite a net dissolution. The silicon isotope composition of precipitated silica was determined by the silicon isotope composition of silicic acid previously released by dissolution. The oxygen isotope composition of precipitated silica was determined by the oxygen isotope composition of water and the temperature of the experiment. Silica precipitated in isotopic equilibrium with water caused a depletion of oxygen-18 in phytoliths as the solution approached saturation. In soil environments, such reactions may result in a silica coating on the phytolith that has an oxygen isotope composition that is in equilibrium with soil water, confounding paleoclimate estimates. This study demonstrates that assessment of the extent of post-depositional alteration of soil phytolith assemblages is essential prior to the use of their isotopic compositions in paleoclimate models.

TELESCOPING OF THE AG-Pb-Zn-Cu-Sn KEG DEPOSIT, CENTRAL YUKON: A PRODUCT OF DELAMINATION TRIGGERED REGIONAL EXHUMATION?

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Petrographic, fluid inclusions and stable isotope studies of mineralization from the 39.8 million tonne Ag-Pb-Zn-Cu-Sn Keg deposit, central Yukon, show juxtaposition of an early deep skarn and later, shallower, fracture hosted epithermal style of mineralization (telescoping). 3D modelling shows that the spatial distribution of the mineralization is controlled by a Jura-Triassic thrust fault. Re-Os dating of arsenopyrite in the epithermal mineralization gives a late Albian age ($101 \pm 0.5\text{Ma}$).

Telescoping of the Keg deposit is attributed to a rapid period of exhumation in the Albian and Cenomanian periods of around 10km in 10Ma as indicated by low temperature geochronology combined with pressure/time constraints from regional igneous bodies. The trigger for the exhumation is not certain. However, an isostatic calculation combined with a regional seismic survey of crustal thickness indicate the possibility of a 2500 m.a.s.l Cretaceous plateau in the area. Bulk rock geochemistry of igneous rocks in the region suggests the collapse of the plateau possibly occurred due to unstable lithospheric delamination and asthenospheric upwelling. This mechanism would also explain the anomalous regional crustal heat flow required to generate the Keg deposit mineralization.

The genesis of the Keg deposit therefore is intimately linked to Cordilleran structures, syn-mineralization tectonic events and igneous activity in this region of the Yukon.

FIRE AND ICE: REVEALING POTENTIAL HAZARDS AT GARIBALDI LAKE, B.C.

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Garibaldi Lake, a picturesque alpine lake located in Garibaldi Provincial Park, British Columbia would not exist without a series of seemingly conspiratorial geologic events that occurred approximately 11,000 years ago. During this time, the Cordilleran ice sheet was in rapid retreat, filling valleys in the area from sea level to 1220 metres above sea level (m.a.s.l.). In contrast, local mountain glaciers were stable only at relatively high elevations (~1500 m.a.s.l.). In this spatially and temporally limited, mid-elevation, ice free window (~1220 to 1500 m.a.s.l.), Clinker Peak (a part of the Garibaldi Volcanic Complex) erupted and a lava flow began its predictable down-valley journey. With the valley ice acting as a dam, the flow arrested, over-thickened and solidified. Subsequent melting of the valley filling glaciers left a 250 m high, unstable cliff called the Barrier (Mathews, 1952). The Barrier effectively dammed surface water outflow (mainly snowmelt and glacial runoff; Mathews, 1956) from the surrounding watershed and drowned the pre-existing mountain valley to a maximum depth of nearly 260 m, and created Garibaldi Lake. Significant rockslide events have occurred at this location in human history, including one large enough to dam the Cheakamus River. In 1981, the Government of British Columbia deemed habitation in the area unsafe resulting in relocation of the small village of Garibaldi outside the hazard zone. Further complicating the assessment of the hazards associated with the Barrier is the presence of Rubble Creek, which originates from the base of the Barrier. Rubble Creek is comprised of as a series of springs that flow at rates between 2 and 4 cubic meters per second. In order to better understand the formation and dynamics of Garibaldi Lake system, we mapped the bathymetry of the lake bottom using dual frequency single beam sonar and resolved primary lava flow textures beneath the lake surface via dual frequency and 3D interferometric side scan sonar. From these images, we mapped the paleo topography of the valley prior to Garibaldi Lake formation. Furthermore, we set up three water level monitoring stations for the lake level, overflow level and Rubble Creek to create a "water budget" for this intriguing system. Combining the paleo topography and water budget allows us to investigate the hydrodynamics of this system and better informs us regarding its seasonal and long term behavior leading to a better understanding of potential hazards.

APPLICATION OF LEAD ISOTOPES IN URANIUM EXPLORATION AT KIGGAVIK (NE THELON AREA, NUNAVUT)

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For quite some time, lead isotopes have been proposed as indicators of the fluid evolution of sedimentary basins and as guides for exploration of unconformity-type uranium deposits. In uranium exploration, the Pb isotope ratios provide information on timing of mineralization and element remobilization, and presence and timing of U and Pb migration on a regional basis and at drill hole scale. In sandstone, samples distal to known uranium mineralization dominantly show non-radiogenic Pb isotope ratios, while samples proximal to mineralization often display radiogenic Pb isotope ratios unsupported by the amount of U in the sandstone. However, the Kiggavik uranium deposits of the NE Thelon region, Nunavut, are all basement-hosted, within a completely different lithological environment: the metamorphic basement; typically the metasedimentary rocks of the Pipedream Assemblage (Mesoarchean Woodburn Lake Group), with the Thelon sandstone lying 2 to 15 km to the north. Many of the structurally-controlled deposits lie along the Kiggavik-Andrew Lake NE structural trend and mineralization is encompassed by clay mineral host-rock alteration haloes. Several generations of pitchblende mineralization are hosted by fault-related microfracture systems and foliation-parallel veinlets.

Earlier, plots using the $^{206}\text{Pb}/^{204}\text{Pb}$, $^{207}\text{Pb}/^{204}\text{Pb}$, $^{208}\text{Pb}/^{204}\text{Pb}$, and $^{207}\text{Pb}/^{206}\text{Pb}$ ratios have shown systematic trends in sandstone useful for vectoring in unconformity-type uranium exploration. In the basement rocks at Kiggavik, Pb-Pb model ages ($^{206}\text{Pb}/^{204}\text{Pb}$, $^{207}\text{Pb}/^{204}\text{Pb}$ relationships) relate to ages both of host rocks (Mesoarchean to Paleoproterozoic) and of mineralization/remobilization (Proterozoic) suggesting that radiogenic Pb was mobilized and thus inferring a positive potential for the presence of uranium mineralization. $^{206}\text{Pb}/^{204}\text{Pb}$ downhole plots, adjusted for U content, highlight those isotopic values that are unsupported by the amount of U in the rock, as do $^{206}\text{Pb}/^{204}\text{Pb}$ 'excess lead' plots. The isotopic data suggest that mineralization occurred post-Thelon (<~1500 Ma), that relatively late Pb mobilization has occurred, probably circa 300-100 Ma, and that many samples from the deposit areas display unsupported excess Pb (eg. Contact, Bong, End). $^{207}\text{Pb}/^{206}\text{Pb}$ and $^{207}\text{Pb}/^{204}\text{Pb}$ ratios show complementary trends downhole relative to location of uranium mineralization.

From these examples, in basement lithologies and not in the sandstone environment, it is evident that Pb isotopes can be useful for indicating elevated potential for presence of uranium mineralization and can provide vectoring information that will be useful for exploration within the Kiggavik region.

RECENT ADVANCES IN OUR UNDERSTANDING OF THE BROCK INLIER, NORTHWEST TERRITORIES

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Our studies of Brock Inlier comprise an activity within the GSC's GEM2 Mackenzie Shield to Selwyn geo-transect: studying the evolution of sedimentary rocks of the northern mainland NWT to improve exploration success. The Brock Inlier, an uplifted region of mostly early Neoproterozoic sedimentary rocks surrounded by lower Paleozoic and Cretaceous sedimentary rocks, is located just east of Darnley Bay, Northwest Territories. It overlies the eastern edge of the Darnley Bay anomaly, the largest gravity and magnetic anomaly measured in North America. Preliminary responses from 17 magneto-telluric survey stations along an E-W profile over the anomaly indicate that the overall thickness of the sedimentary succession above it is considerably greater along the western portion of the profile and suggest a conductive feature in the vicinity of the known anomaly. Our stratigraphic work has documented the first complete detailed record of the early Neoproterozoic Shaler Supergroup and Cambrian-Ordovician Mt Clark, Mt. Cap and Franklin Mountain formations; sandstone, shale and carbonate rocks exposed along the Hornaday River. Samples of these rocks have been collected for paleontological, geochronological and geochemical analysis. Preliminary analysis of shales from the Shaler Supergroup reveals a microfossil assemblage characteristic of other late Mesoproterozoic-early Neoproterozoic successions including: unambiguous eukaryotes (process-bearing acritarchs) *Trachyhystrichosphaera aimika* (~1.1 - 0.75 Ga) and *Dictyosphaera* sp. (~1.6 - 0.8 Ga; first reported occurrence in Canada). Stable C-O isotope values from the Mikkelsen Islands Formation offer stratigraphic variations that are consistent with possibly correlative carbonate-bearing successions in the northern Cordillera, > 500 km to the southwest. Samples of fluvial quartz arenite collected from the base and top of the Nelson Head Formation have almost identical detrital zircon U-Pb concordia age profiles with overwhelmingly Mesoproterozoic age sources, interpreted to have been mainly from the Grenville Province of eastern Laurentia. Helicopter-supported regional geological reconnaissance and selected ground traverses in key areas of NTS 97A (Erly Lake) and 97D (Brock River) are allowing us to build new and improved geological maps. This work is being aided by processing and analysis of newly acquired, high resolution remotely sensed and video imagery.

ZIRCON PROVENANCE DATA FROM THE AMUNDSEN AND MACKENZIE BASINS CORROBORATE LATERAL EXTENT AND DURATION OF A PAN-CONTINENTAL, EARLY NEOPROTEROZOIC RIVER SYSTEM

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In the mid-1990s, detrital zircon provenance studies of early Neoproterozoic fluvial sandstones from the Amundsen and Mackenzie basins of northwestern Canada were key to the development of a model linking supercontinents, orogenies and giant rivers. The early provenance studies were based on a few widely spaced samples and analysis of comparatively small numbers of zircon grains, but they suggested that fluvial detritus in northwestern Canada was derived mainly by erosion of the Grenville orogen, located 3000 kilometres to the southeast. Recent sedimentological studies also indicate that sediment was shed across the craton by braided rivers that occupied alluvial plains at times wider than 500 km and comparable to the largest modern fluvial systems on Earth. In this study, we present new data from exposures of these rocks in the Mackenzie Mountains, Yukon (5 samples) and the western Arctic, Northwest Territories (3 samples) and from several different stratigraphic levels to test up-section and regional variance in provenance.

Detrital zircon U-Pb age profiles highlight mainly Mesoproterozoic sources (prominent peaks at 1080 and 1460 Ma), which are consistent between basins and show very little stratigraphic variance. These results validate broad-scale correlation of the Katherine Group and underlying Tsezotene Formation of the Mackenzie Mountains (Mackenzie Basin) with the Nelson Head Formation of Brock Inlier and Minto Inlier (Amundsen Basin), over 800 km away, indicating that they were deposited by the same pan-continental river system at about the same time (maximum depositional age ~1.0 Ga in both basins).

THE FARO MINE COMPLEX: A CAUTIONARY MINING TALE

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Large scale open pit metal mining is a relatively recent phenomenon of industrialization, with a proliferation of open pit mine development arising in the latter half of the twentieth century. Open pit mining can continue for decades, resulting in massive earth-moving and processing operations that have turned mining into the largest waste producing industry on earth. Most of the waste materials are uneconomic rock (waste rock) and ground up materials (tailings) remaining after the metals of interest have been recovered. Some of these wastes contain sulphide minerals that may oxidize in the near-surface environment, and threaten the environment through the generation of acid rock drainage and the resultant leaching of potentially toxic heavy metals. Once a mine is exhausted, the resultant wastes will remain in perpetuity. Few large open pit metal mines have been adequately remediated to ensure long-term stability and protection of the environment. The largest liabilities, such as the abandoned Faro Mine Complex (FMC) in Yukon, are only in the earliest stages of a remediation process where no walk-away solution exists. In the 1970s, the FMC was Canada's largest lead-zinc-silver mine. Now, it is Canada's largest Acid Rock Drainage (ARD) contaminated mine site. Open pit mining of three separate pyritic, massive sulphide sedimentary exhalative (SEDEX) deposits occurred from 1969 through 1997, with some interruptions. Mining and on-site milling operations produced approximately 400 million tonnes of potentially acid-generating waste rock and tailings. The mine was abandoned in 1998 and is being jointly managed by Yukon Government and Indigenous and Northern Affairs Canada (INAC). Protecting the surrounding aquatic and terrestrial environment from these wastes and associated heavy metal-bearing seepage presents significant

challenges in a mountainous, northern environment. Current plans envisage decades of remedial works followed by long-term capture and treatment of mine-impacted waters. Modern mines have radically improved their environmental performance by learning from historical mining mistakes; Faro, unfortunately, will continue to burden Canadian taxpayers and the mining industry's reputation.

INTER-SITE ANALYSIS OF OBSIDIAN SOURCE MATERIAL AT THE LITTLE JOHN SITE (KdVo-6), YUKON TERRITORY

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In this paper we report on the results of spectral analysis of a large assemblage of obsidian artifacts from the Little John site (Borden Number KdVo-6), a multi-component site in southwestern Yukon with evidence of human occupation from the Late Pleistocene to contemporary times. Intra-site analysis of the distribution of obsidian source material and its use as formal and expedient lithic tools is examined through time and across the site, demonstrating both continuity and change in the technological organization of this lithic material. Following this we examine the inter-site comparison of obsidian source material at the Little John site with a selection of sites documented in the Alaskan Obsidian Database housed at the Museum of the North at the University of Alaska – Fairbanks, with a special focus on Late Pleistocene East Beringian sites of similar ages within the Tanana River Basin.

WHOLE ROCK $\delta^{18}\text{O}$ AND $\delta^2\text{H}$ FOOTPRINT TO THE CANADIAN MALARTIC GOLD DEPOSIT

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The Canadian Malartic Au deposit is the result of a hydrothermal system that has altered the host metasedimentary rocks of the Pontiac Group, metavolcanic rocks of the Piché Group, and late mafic dykes and porphyritic intrusions. Au mineralization formed by hydrothermal fluids flowing through these rocks which caused exchange reactions of O and H isotopes. These reactions are reflected in whole rock $\delta^{18}\text{O}$ and $\delta^2\text{H}$ values that can be used to trace the isotopic footprint of the mineralized system.

The isotopic footprint in Pontiac greywackes is marked by a decrease in $\delta^2\text{H}$ below -90‰ in the mineralization from background values of ca. 60‰, whereas $\delta^{18}\text{O}$ values remain relatively constant near 10‰. Mafic dykes in the area record an increase in $\delta^{18}\text{O}$ from background values of ca. 8‰ to values greater than 9‰ and a decrease in $\delta^2\text{H}$ from ca.-70‰ to ca. -80‰ in mineralization. The $\delta^{18}\text{O}$ and $\delta^2\text{H}$ values of biotite from auriferous veins indicate that the mineralizing fluid in equilibrium at 450°C would have had a $\delta^{18}\text{O}$ of 8.2-11.2‰ and a $\delta^2\text{H}$ of 6 to 1‰, compositions near those of metamorphic fluids at 450°C in equilibrium with average unmineralized greywacke.

Kriging of regional variations in O and H isotopic compositions show the $\delta^2\text{H}$ contour of -60‰ in greywackes encircles the mineralized domain and is elongated towards the NW and SE. In mafic dykes, the $\delta^2\text{H}$ contour of -72‰ marks both the mineralized domain as well as a large area towards the S and SE. The $\delta^{18}\text{O}$ isopleths from greywackes do not show a significant spatial association with mineralization. However, the $\delta^{18}\text{O}$ 8.3‰ isopleth from mafic dykes encircles the centre of the mineralized domain and is extended over an area towards the SE. In host rocks, decreasing $\delta^2\text{H}$ towards mineralization may be attributed to either a decrease in temperature towards mineralization or the infiltration of a later, low $\delta^2\text{H}$ fluid

in the fractured domain near mineralization. As this was a rock dominated system, $\delta^2\text{H}$ was preferentially exchanged while $\delta^{18}\text{O}$ of the greywackes remained largely unchanged. Modeling of O-H isotopic exchange would require the mineralized domain to be ca. 250°C and a temperature gradient extending to ca. 500°C 1–2 km south of the deposit. The increase in $\delta^{18}\text{O}$ observed in mafic dykes proximal to mineralization may be attributed to the carbonatization and silicification of these rocks by the mineralizing fluid. CMIC-NSERC Exploration Footprints Network Contribution 087.

GEOLOGY AND GEOCHRONOLOGY ACROSS THE SNOWBIRD TECTONIC ZONE, WESTERN CHURCHILL PROVINCE: IMPLICATIONS FOR THE RAE-HEARNE BOUNDARY

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The Snowbird Tectonic Zone (STZ), the ca. 2800 km-long boundary between Rae and Hearne domains of the western Canadian Shield, remains of uncertain tectonic significance. Structural and age compilations and new U-Th-Pb geochronology across the STZ indicate that the eastern Rae and western Hearne share a common history. The eastern Rae corresponds with a large tract of high-P granulites referred to as the Athabasca granulite terrane. Existing in-situ U-Th-Pb monazite geochronology suggests that the eastern Rae contains ca. 2.60 Ga arc rocks and widespread (high-P) structures, which formed at ca. 2.57 Ga (D_1) and 1.90 Ga (D_2 / M_2) and are well preserved in several subdomains. Starting at ca. 1.9 Ga, thick ductile shear zones juxtaposed disparate lithotectonic subdomains. At ca. 1.85 Ga, contractional uplift along the Legs Lake shear zone juxtaposed the high-P granulites of the eastern Rae above lower amphibolite- to greenschist-grade supracrustal gneisses of the Hearne domain. New U-Pb zircon data from a transect of the Hearne domain indicate that the structurally lowest plutonic rock crystallized at 2721 ± 6.1 Ma (MSWD: 1.8), with evidence of 2.90 to 2.77 Ga inheritance, and 2.55 and post-1.90 Ga metamorphic zircon growth. A syn-kinematic leucogranite that cuts supracrustal gneisses yielded a zircon U-Pb age of 2610 ± 5.6 Ma (MSWD: 2.7). These results suggest that ca. 2.6 Ga granites, once thought to be restricted to the Rae domain, are also in the western Hearne, and that rocks of the western Hearne were deformed at ca. 2.59–2.55 Ga, similar eastern Rae domain rocks. Based on these similarities, we suggest the STZ, on the ground, is not a Paleoproterozoic suture. Furthermore, based on the distribution and continuity of Rae and Hearne components seen along this transect, the two may have been together before 2.60 Ga. If present, a ca. 1.9 Ga suture is east of Charlebois Lake, SK. New U-Th-Pb zircon and ongoing in-situ monazite geochronology for rocks 400 km NE along the STZ, at Angikuni Lake (Nunavut), also record a history of Neoarchean assembly and Paleoproterozoic reactivation. Therefore, the STZ lineament may represent an intracontinental weakness within the western Churchill Province that was reactivated during the assembly of the Nuna supercontinent from 1.93 – 1.80 Ga rather than a suture.

APATITE IN CARBONATITES: TRACE-ELEMENT COMPOSITION, ZONING AND RARE-EARTH PARTITIONING

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Although apatite is the most abundant non-carbonate phase and an important host for rare-earth elements (REE) in intrusive and extrusive carbonatites, neither the extent of its compositional variation, nor trace-element partitioning between this mineral and carbonatitic magma, is well understood. We examined a large set of samples representing 50 localities worldwide to constrain the role of apatite

in carbonatite evolution. Igneous fluor- to hydroxylapatite is one of the earliest minerals to precipitate from carbonatitic magma, and form phenocrysts (\pm hopper-like groundmass crystals) in some extrusive and hypabyssal rocks, and cumulates in the plutonic environment (hydrothermal apatite is relatively uncommon). Our data indicate that apatite precipitation occurs well below the P_2O_5 saturation levels inferred from high-pressure experiments. The abundances of most minor substituent elements (in particular, Sr, REE, Th, Si, S and Cl) vary over two-three orders of magnitude among the examined samples and even within individual zoned crystals. Four major zoning patterns were identified in igneous apatite, which involve: rim-ward enrichment in REE (\pm Si, S, Na, Sr); REE (\pm Si, S, Na, Sr) enrichment in an intermediate zone followed by reversion to low values in the rim; loss of REE, Si, S and Sr along crystal edges and fractures; enrichment in Sr (\pm REE, Na) along crystal edges and fractures. The former two patterns are interpreted as igneous, whereas the latter two as generated by interaction of primary apatite with hydrothermal fluids. Apatites from structurally simple carbonatite complexes define compositional trends that may be interpreted from the standpoint of fractionation within the lanthanide series and differences in Sr partitioning between Mg-rich (i.e. dolomitic) and Mg-poor magmas. Structurally complex intrusions do not show such trends, implying that individual carbonatite units probably derive from discrete magma batches. In contrast to the previously published work, apatite-melt partition coefficients calculated in the present work (1) suggest that all REE are compatible with respect to fluorapatite irrespective of the composition of parental magma; (2) cannot be fitted to a single curve, but (3) peak close to the middle of the lanthanide series (Nd-Gd), and (4) reach maximum values ($D_{\text{La}} = 9$, $D_{\text{Gd}} = 14$, $D_{\text{Yb}} = 6$) in dolomite carbonatites. Igneous apatites lack Ce or Eu anomalies, but show slight depletion in Y (insufficient to affect the composition of magma undergoing fractionation). Hydrothermal apatite is relatively enriched in heavy REE ($\text{La}_{\text{cn}}/\text{Yb}_{\text{cn}} < 25$) and, in some cases, depleted in Ce (to $\delta\text{Ce} = 0.15$).

PETROGRAPHY AND GENESIS OF THE DEER HORN AU-AG-TE-W DEPOSIT, LINDQUIST PEAK, WEST-CENTRAL BRITISH COLUMBIA

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The Deer Horn property is located in west-central British Columbia, 150 km south of Smithers, extending over an area of 51 km². It is a relatively low-temperature, epithermal, polymetallic system enriched in Au-Ag-Te-W-Cu and lesser amounts of Pb-Zn-Mo, with the Au and Ag hosted in telluride minerals. The vein system containing the main zones of Au-Ag-Te mineralization formed 56 ± 2 Ma in the hangingwall of a local thrust fault. Observations by optical microscope and SEM-CL revealed at least three generations of quartz associated with sulfides (pyrite, pyrrhotite, sphalerite, chalcopyrite, galena), tellurides, gold (electrum), Fe-oxides (magnetite, hematite), and veinlets with minor amounts of alteration phases (chlorite, sericite, carbonate). Telluride minerals are 0.1–525 μm in size and most commonly form whole subhedral grains or composite grains of Ag, Bi, Pb, and Au-rich tellurides (e.g., hessite, tellurobismuthite, altaite, petzite, volynskite) that occur in following environments: (1) as clusters within fractures, interstices, or veinlets of quartz, typically very near sulphide grains and following distinct planes; (2) within all sulphides (most commonly pyrite and chalcopyrite, but also sphalerite, galena, and pyrrhotite) as inclusions, filling fractures, or at grain boundary contacts with quartz; (3) at grain boundary contacts between sulphides (commonly between pyrite + chalcopyrite or sphalerite + chalcopyrite); (4) very fine-grained inclusions in sulphides forming trails along crystallographic planes; (5) less frequently within and near alteration phases (sericite, chlorite). Chlorite + sericite + carbonate alteration post-dates

the main sulfide mineralization events; the mineral assemblage forms late veinlets crosscutting quartz and all sulfide minerals. Cathodoluminescence analysis performed on the largest quartz grains with undulose extinction revealed bright cores with remnant zoning, rimmed by homogeneous darker zones, representing primary hydrothermal quartz I, partially overprinted by plastic deformation and recrystallization (quartz II). Locally, oscillatory zoning observed in quartz II suggests participation of hydrothermal fluids. Quartz I and II are intersected by veinlets of fine-grained quartz III, which is very dark gray in SEM-CL. All quartz types are intersected by late veinlets of calcite which appear as thin, bright veinlets in SEM-CL; under the optical microscope, quartz I and II are difficult to distinguish, whereas quartz III has a distinct, fine-grained texture. This is evidence of at least two recrystallization and shearing events. Some samples contain very fine-grained quartz IV associated with quartz III and pyrite (and secondary magnetite); its border with quartz III is sharp. Its presence and association with quartz III may indicate fluid boiling.

RARE EARTHS, APATITES AND CARBONATITES: A TALE FROM MONTVIEL REE-Nb DEPOSIT, QUÉBEC, CANADA

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Montviel is a Paleoproterozoic (1.894 Ga) Alkaline-Carbonatite Complex located within the eastern section of the Superior Province, Quebec, Canada. The complex is dominantly composed of silica-undersaturated alkaline- and carbonatite intrusions. Based on previous work using ¹⁴³Nd/¹⁴⁴Nd, ⁸⁷Sr/⁸⁶Sr, $\delta^{13}\text{C}$, $\delta^{18}\text{O}$ and trace element geochemistry, the system was enriched in rare earth elements (REE) and Nb through three discrete magmatic-hydrothermal pulses originating from the depleted mantle. To date, Ressources Géoméga has undergone 36.3 km of drilling and provided a 43-101-compliant resource estimate of 266.6 Mt at approximately 1.5 % total rare earth oxides. Hydrometallurgical tests of the preliminary economic assessment process flow sheet reveal a recovery of more than 90 % of the REE using environmentally friendly hydrometallurgical processes. However, the resource estimate and the metallurgical tests were made without considering external zones enriched in apatite. The objective of this research is thus twofold: to evaluate potential new REE resources, and to study the hydrothermal system that has generated the deposit. Electron microprobe analyses returned apatite averaging approximately 2 wt.% total REE (n=53), and hosting up to 19 wt. % total REE. A few apatite crystals were strongly enriched in heavy REE, hosting up to 17.1 wt. % Dy and 2.1 wt. % Y. Rare earth element x-ray maps suggest that economically critical heavy REE-bearing hydrothermal events were distinct from the more generalized light REE-bearing hydrothermal fluids. Upcoming laser ablation ICP-MS should help unravel the hydrothermal evolution of the deposit and define new resources in critical REE from apatite.

TECTONIC EVOLUTION OF THE WESTERN GRENVILLE PROVINCE: A REFINED IMAGE FROM NEW U-Pb ID-TIMS AGE DATA

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During an ongoing project founded by the ministry of energy and natural resources (Ministère de l'Énergie et des Ressources naturelles) of Quebec, areas in the western Grenville province around Clova were investigated. Previous mapping, geochemical and geochronological work from that area answered questions about the magmatic evolution of the Grenville orogen throughout the Mesoproterozoic. Herein we present the second part of the project which addresses the remaining question marks in this

area. The goal is to develop a more refined picture of the geology and a deeper understanding of the tectonic evolution during the Grenvillian orogeny. We present new U-Pb ID-TIMS age data from structures of previously unknown age and unassigned tectonic position.

The sampling area can be divided in Allochthon and Parautochthon units. In general the Allochthon units reveal Palaeoproterozoic to Mesoproterozoic ages; units from the Parautochthon are Archean. The Grenville orogeny itself can be divided into two distinct phases: the Ottawa phase (1090-1020 Ma), primarily recorded in the Allochthon, and the Rigolet phase (1005-980 Ma), mainly seen in the Parautochthon. The border between Allochthon and Parautochthon is easily identifiable on the geophysical map, which is an important tool to illustrate general structures in this hard to access area. The Allochthon generally shows higher values, however a large structure with atypically high values surrounded by Parautochthon units remains ambiguous in terms of tectonic affiliation. A sample from a representative tonalitic gneiss reveals an intrusive age of 2654 ± 2 Ma and metamorphic overprint at 1054 ± 15 Ma. Despite the Ottawa metamorphic age the precisely constrained Archean intrusive age classifies the unit as Parautochthon, a member of the Grand Lac Victoria Complex. A BIF in the Lac Victoria Complex further north was injected by a quartz diorite at 1019 ± 1 Ma, but shows older, inherited zircons which may possibly indicate an Archean age for the BIF itself. A phlogopite from the Siscoe Mine related to the ultramafic Suzor intrusion gives a preliminary age of 1027 Ma. These and further data in process from tectonically questionable places will contribute to a refined model of the Grenville orogeny.

PHOSPHOROUS AND POTASSIUM ENRICHMENT IN THE MICHAEL-SHABOGAMO MAGMATIC EVENT OF EASTERN LAURENTIA; CAN INTENSE MANTLE METASOMATISM BE RESPONSIBLE?

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Traditionally, intrusions that outcrop in eastern Canada between Labrador City and Rigolet, Labrador, have been mapped as two groups: the Shabogamo Gabbros that outcrop west of Churchill Falls, and the Michael Gabbros that outcrop east of Churchill Falls. New U-Pb ages and detailed geochemical analysis of the Michael and Shabogamo events show that both are related, as others have previously proposed based on sparse U-Pb ages. Geochemically, most of the Michael and Shabogamo Gabbros are trachybasalt to basalt, and alkaline to sub-alkaline in composition with complicated evolutionary histories, involving: high P_2O_5 (~2 wt.%) and K_2O (~4.9%) values, evidence of cumulate ($1.1 < \text{Eu}/\text{Eu}^*$), residual ($0.9 > \text{Eu}/\text{Eu}^*$) and undifferentiated ($0.9 > \text{Eu}/\text{Eu}^* > 1.1$) subsets.

We define four geochemical groups on the basis of $[\text{P}_2\text{O}_5 \cdot 1000]/\text{Zr}$ ratios (P-Zr) that also correspond to the different ages of Michael-Shabogamo Gabbros: 1) 1450 Ma group - 6.19-2.77 P-Zr ratio; 2) 1430-1435 Ma group (preliminary ages) - 2.74-2.01 P-Zr ratio; 3) 1425 Ma group - 2.00-1.03 P-Zr ratio; and 4) an undated group - 1.08-0.45 P-Zr ratio. The positive slope of the P-Zr ratio indicates that apatite melting was a dominant process in the generation of the magmas for the Michael-Shabogamo Gabbros. For each of these groups, the P-Zr slope is inversely correlated with degree of partial melting, a lower degree of partial melt represents a higher P-Zr ratio. Additionally, plotting $(\text{P}_2\text{O}_5/\text{Nd})_{\text{PM}}$ and Nb/Y, the proxy for alkalinity in potentially altered rocks, further supports higher P_2O_5 values representing lower degrees of partial melt.

Enrichment of P_2O_5 and K_2O of the Michael-Shabogamo Gabbros indicate that the source of the magma was from metasomatized subcontinental lithospheric mantle, probably from a late Paleo- to early Mesoproterozoic phosphate-rich sedimentary source subducted by the closing of the basin that existed between the Molson Lake and Lac Joseph terrains at c. 1650 Ma. Mafic intrusions

of the 1647 ± 3 Ma Ossokmanuan event help constrain the timing of metasomatism of the mantle as the Ossokmanuan intrusions do not show similar P-Zr ratios, to the Michael-Shabogamo Gabbros, indicating that the proposed mantle metasomatism must have occurred after emplacement of the c. 1650 Ma dykes. On the other hand, the emplacement of the c. 1290-1280 Ma Nain HP and LP dykes show similar geochemical trends as the Michael-Shabogamo event. The c. 1100 Ma Aillik dykes (also in the area) do show enriched P-Zr ratios but the slopes of those ratios are negative indicating that apatite fractionation had a dominant role not mantle melting of apatite. The high P-Zr ratios indicate that a metasomatized mantle may have persisted beneath Eastern Laurentia for at least c. 350 Ma from <1650 Ma to at least c. 1300 Ma over multiple distinct melting events.

NEWLY RECOGNIZED 1550-1590 MA TOBACCO ROOT -WESTERN CHANNEL LIP, AND FURTHER EVIDENCE FOR BRINGING SOUTH AUSTRALIA BACK HOME TO WESTERN LAURENTIA

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Large Igneous Provinces (LIPs) have become increasingly important in both continental reconstructions and the understanding of continental breakup. Mafic dyke swarms, in particular, are proving valuable in providing geochronological and geochemical correlations between formerly adjacent crustal blocks. Recently we have identified multiple discrete geochemical signatures within a previously defined c. 1460 Ma Moyie-Purcell event along the western Laurentia margin using criteria including $(La/Sm)_{PM}$ and $(Gd/Yb)_{PM}$ ratios. Two of these distinct geochemical groups in the Tobacco Root mountains have been recently dated by baddeleyite U-Pb techniques and are termed the 1590 ± 3 Ma Mammoth and the 1552 ± 6 Ma Ramshorn events. These newly identified events have an intraplate geochemical signature. The expected felsic components of these events would provide a potential detrital zircon source to the Belt-Purcell basin, thus, ending the requirement of an off craton source for 1550-1590 Ma detrital zircons that lie within the age range of the formerly interpreted "North American Magmatic Gap".

Furthermore, the c. 1590 Ma Mammoth Group dykes in the Tobacco Root Mountains can be geochemically and geochronologically correlated with the c. 1590 Ma Western Channel Diabase (WCD) in northern Canada, and the c. 1550 Ma Ramshorn Creek dykes can be geochemically matched with an undated sill from the WCD. Based on these correlations, we postulate a 1550-1590 Ma Tobacco Root - Western Channel Diabase (TR-WCD) LIP that extends 2000 km along the western margin of Laurentia, from the Wyoming Craton in Montana, USA, to the Great Bear Lake region and Yukon Territory in Canada.

Furthermore, the 1590 Ma, bimodal Gawler Range magmatism of the South Australian craton matches in chemistry with the coeval 1590 Ma magmatism of western Laurentia. This combined with the previously established: 1) reconstruction (NW Laurentia – South Australian craton) based on paleomagnetism, and 2) the correlation of age-equivalent Wernecke breccias (Yukon), with Olympic Dam breccias in Gawler craton, extends the combined c. 1590-1550 Ma TR-WCD-Gawler Range LIP event to over 2500 km in length.

CONTROLS ON THE DISTRIBUTION OF PHANEROZOIC TIN, TUNGSTEN, AND TANTALUM MINERALIZATION

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The formation of tin, tungsten, and tantalum mineralization involves a sequence of processes that operate in different tectonic settings

and that may be widely separated in time, i.e., (i) source enrichment, (ii) source accumulation, and (iii) metal mobilization from the source. The sequence of these processes controls the large-scale distribution of mineralization in belts. In contrast, magma development and interaction with the wall rocks at emplacement level controls size, grade, shape, and kind (vein, greisen, skarn) of mineralization.

(i) Intense chemical weathering results in the preferential loss of most feldspar-bound elements (e.g., Na, Ca, Sr, and Pb) and the residual enrichment of elements incorporated in or adsorbed on clay minerals (e.g., Li, K, Rb, Cs, Sn, and W), i.e., produces some of the hallmark geochemical signatures of tin granites that are obtained by extreme magmatic fractionation of granitic melts. Intense chemical weathering occurs in tectonically stable areas with limited topography, as for instance in the interior of large continental masses.

(ii) Sedimentary accumulation occurs when these blankets of chemically intensely weathered sediments are redistributed from the continent interior to the margins of the continent during supercontinent fragmentation. Tectonic accumulation may occur when passive-margin sedimentary packages are reworked in an active margin setting.

(iii) The nature of heat source controls the type of melting of the crustal source rocks and the partitioning of metals between melt and restite. Sn and W are preferably bound to biotite and are distributed into the melt during biotite consumption at high melting temperatures, Ta is mainly hosted in muscovite, which melts at lower temperature. High melting temperature are only possible by heat input from the mantle by (a) mantle-derived melts in subduction settings, (b) emplacement of ultrahigh-temperature metamorphic rocks that had been subducted to mantle depth during continental collision, and (c) mantle-derived melts in extensional settings. Internal heating in orogenically thickened crust only generates minimum-temperature melts. The age of mineralization reflects the event of heat input.

The superposition of source enrichment (on supercontinent), source accumulation (at continent margin), and heat input (at plate boundary) explains both the distribution of Phanerozoic primary tin, tungsten, and tantalum mineralization and (i) their irregular distribution along these belts, (iii) their contrasting age within a particular belt, (iv) their contrasting tectonic settings, and (v) their presence on both sides of major sutures.

LANDSCAPE HAZARDS MAPPING FOR CLIMATE CHANGE ADAPTATION PLANNING IN THE YUKON

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Climate change represents a major challenge for northern regions, and its impacts are already being observed in many communities. In some areas, the thawing of permafrost caused by rising air temperature, and disturbance, can lead to ground subsidence, increased landslide risks and reduced bearing capacity of the soil. These effects increase considerably the complexity of community planning and are of particular concern in the Yukon, where there is a high prevalence of warm permafrost and permafrost degradation is already taking place. Risk assessments associated with permafrost degradation and its impact on contemporary landscapes have been performed in multiple Yukon communities for the past years by the Northern Climate ExChange (Yukon College, Canada), in order to help guide the planning efforts of the communities. The hazard mapping approach incorporated field investigations (soil and core samplings), geophysics (ground penetrating radar, electrical resistivity tomography) and geotechnical laboratory analyses (grain-size, ice content, thaw-settlement analyses, etc.) to assess the potential stability of landscape units. The data are integrated to produce ranked hazard risk maps of study communities. In turn, northern communities, First Nation governments, environmental

assessment boards and private consultants are using these maps to develop adaptation strategies and reduce and mitigate risk.

The resulting hazards maps created through these projects are therefore highly valuable tools used to identify and plan potential future trajectories of change, reduce risk, and increase the resilience of Yukon communities. Different case studies from six Yukon communities will demonstrate the use of hazard mapping and the importance of implementation measures to better adjust to the negative impact of climate change in northern communities.

SAGAR PROPERTY, ROMANET HORST, LABRADOR TROUGH, QUEBEC, CANADA: POTENTIAL FOR IRON-OXIDE-COPPER-GOLD-TYPE (IOCG) DEPOSITS?

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The Labrador Trough has been explored for natural resources since over a century and the 40 × 12 km Romanet Horst is one of twelve lithotectonic zones of the Trough which has been explored for precious and base metals such as gold, silver and copper for over 50 years. Recent geological work pursued on the Sagar property by Honey Badger Exploration Inc., Energizer Resources Inc., the Geological Survey of Canada and a research group from the University of Ottawa has shed light on the variety of hydrothermal alteration types and their metal associations, strongly suggesting the existence of iron oxide copper gold-type (IOCG-type) mineralization. Could geochemical characterization of iron alteration fingerprints the mineralization types to vector exploration? What is the source of the fluids and metals? To answer these questions, hematite and magnetite from a diversity of lithologies are being characterized using field relations, petrographic observations and chemical analyses. Iron oxides are analyzed for major, minor and trace elements using electron microprobe and laser ablation ICP-MS techniques. These results, combined with existing data and compared to that of other IOCG-type deposits, should help improved the understanding of the realm of mineralization types within the Horst. Longer term research may confirm (or infirm) that alteration and mineralization occurred between 1870 and 1820 Ma, and that ore fluid originated from the subduction zone associated to the De Pas Batholith.

TRACE-ELEMENT COMPOSITIONS OF IGNEOUS APATITE DISCRIMINATE TECTONIC SETTINGS

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Variations in relative abundances of halogens, OH, and trace elements in apatite, $\text{Ca}_5[\text{PO}_4]_3(\text{F}, \text{OH}, \text{Cl})$, are sensitive to fluid and melt compositions, oxidation state, and crystallization history of a magmatic-hydrothermal system. We use 537 analyses of igneous apatites by both electron probe and laser ablation ICP-MS (Mao et al., 2015. British Columbia Geological Survey GeoFile 2015-9) to test their chemistry as a proxy of tectonic setting. The examined apatites are from 29 intrusive carbonatite complexes (2691–95 Ma) from continental rifts worldwide and the ancestral North American passive margin; the Mid-Atlantic, Southwest Indian, and East Pacific ocean ridges (4 localities); the Bonanza, Quesnel and Stikine accreted island arcs (6 plutons, 209–183 Ma) and 4 post-accretionary intrusions (157–73 Ma), marking Cordilleran continental arc; and 5 late- to post-collisional (terminal) syenitic complexes (2714–2678 Ma) of the southern Abitibi belt, Canadian Shield. Apatite in silicic rocks has lower Sr and higher Mn contents and stronger negative Eu anomalies than those of apatite in intermediate and mafic rocks, consistent with fractionation of feldspar and Fe-Mg minerals during magmatic evolution. Apatite from carbonatites is distinguished by low Mn (<510 ppm) and high Sr (>1800 ppm)

contents, high (Ce/Yb)CN (35–872), a lack of Eu anomalies, and by weak positive Ce anomalies ($\text{Ce}/\text{Ce}^* = 1.0\text{--}1.7$). Apatite from mid-ocean ridge (MOR) gabbros has low Sr (<230 ppm) and Th (<20 ppm), high Mg (47–1327 ppm), Y (440–2025 ppm), and Zr (mostly 3–65 ppm) contents, and lower (Ce/Yb)CN (<6) than apatite in other rocks. Apatite in late- to post-collisional syenitic rocks from the southern Abitibi belt shows the highest Sr (up to 2.6 wt.%), Pb (6–114 ppm), and (La/Sm)CN (1.5–29), whereas apatite from arc rocks has the highest Mn (mostly 200–9350 ppm) and the widest range of Eu anomalies ($\text{Eu}/\text{Eu}^* = 0.08\text{--}1.36$) compared with those of other studied apatites. Similar to our discrimination of deposit types, we separated apatite trace-element compositions by tectonic setting using three discriminant-function diagrams. Six linear discriminant functions (DP) recast the apatite compositions as a sum of constant and log10-transformed concentrations of up to 10 elements (Mg, Mn, Sr, Y, La, Ce, Eu, Yb, Lu, Pb, Th, and U) in ppm, multiplied by a coefficient for each element for a given function. Our results suggest that trace-element chemistry of detrital apatite can discriminate tectonic settings of igneous rocks.

CARBONATITES, ISOTOPES AND EVOLUTION OF THE SUBCONTINENTAL MANTLE: AN OVERVIEW

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We examine mantle evolution using new Sr, Pb, Nd, and Hf isotopic data from 42 carbonatite complexes worldwide, spanning ages from 3.0 to 0.1 Ga, along with published global data (Rukhlov et al., 2015. British Columbia Geological Survey Paper 2015-3, 39–64). The Sr-Pb-Nd-Hf isotopic data from globally distributed carbonatites record the evolution of a primitive mantle source that has behaved as a relatively closed-system, at least during the last 3 Ga of Earth history, with the present-day, isotopic attributes similar to FOZO end-member. Solar-like noble gas (He, Ne, Ar, Kr, and Xe) and N isotopic signatures in carbonatites support the idea of a widespread source that may represent the deep, undegassed mantle. The Nd and Hf data from carbonatites and the oldest silicate rocks indicate a major depletion of chondritic Earth >3.0 Ga, perhaps during the Hadean (>4.0 Ga), and possibly a second, much later event at ~3 Ga, marked by a depleted mantle with low Rb/Sr and high U/Pb ratios. The ~3 Ga event could reflect a major change in the Earth's thermal regime marked by the onset of modern-style plate tectonics accompanied by the production of voluminous and more silica-rich juvenile, continental crust. It appears that over the last 3 Ga, HIMU- and EM-like mantle end-members, and rarely, a more exotic, high- $^{87}\text{Sr}/^{86}\text{Sr}$ component have been mixed in variable proportions with a depleted source (FOZO) accounting for the isotopic heterogeneity of carbonatitic melts. The interpretations that we favour is one in which these enriched mantle end-members represent complementary partial melt (EM1) and residual (HIMU) of the FOZO protolith, and the other the mixing of primordial materials, perhaps including recycled Hadean crust, sampled by deep mantle plumes originating from or near the D'' layer.

EXPLORATION FOR PORPHYRY DEPOSITS IN BRITISH COLUMBIA USING TRACE-ELEMENT CHEMISTRY OF DETRITAL APATITE

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Apatite grains from tills at the Highland Valley, Gibraltar, and Woodjam calc-alkaline porphyry Cu-Mo±Au and the Mount Polley alkalic porphyry Cu-Au deposits, and mineralized bedrock at the

Woodjam Southeast Zone were analyzed by electron microprobe and LA-ICP-MS. The molar Cl/F and Cl/OH ratios of these grains are similar to those of apatites from producing porphyry deposits elsewhere (e.g., Yerrington, Nevada; Bingham, Utah; Henderson, Colorado). Most apatite grains in till from Mount Polley have higher SO_3 , SiO_2 , Na_2O , Sr, Mg, V, Ba, Zr, Mo, Nb contents and (La/Sm) $_{\text{CN}}$ and lower Mn, Y, and ΣHREE contents relative to those from the Highland Valley, Gibraltar and Woodjam deposits. Apatite grains in till from Mount Polley also show weak negative Ce anomalies (Ce/Ce*; mostly 0.89–1.03) and moderate to weak negative Eu anomalies (Eu/Eu*; mostly 0.50–0.99). In contrast, those from the Highland Valley, Gibraltar and Woodjam deposits show weak positive Ce anomalies (Ce/Ce* mostly between 1.00 and 1.24) and strong negative Eu anomalies (Eu/Eu* mostly between 0.11 and 0.47). Most apatite grains from tills at Woodjam and a few from other deposits indicate variable degrees of depletion in minor and trace elements and LREEs, with highly variable (Ce/Yb) $_{\text{CN}}$ (<0.01–47), (La/Sm) $_{\text{CN}}$ (0.06–6.0), (Gd/Yb) $_{\text{CN}}$ (0.01–39), Ce/Ce* (0.23–3.8) and elevated Eu/Eu* (up to 1.5), probably reflecting metasomatic alteration of pristine apatite. The systematic differences in abundances of redox-sensitive SO_3 , Mn, V, As, Ce and Eu between apatite grains from Mount Polley and other porphyry deposits are consistent with a more oxidized alkalic porphyry Cu-Au compared to more reduced calc-alkaline porphyry Cu±Mo±Au systems. The strong negative Eu anomalies, coupled with higher Mn and lower Mg and Sr contents, of apatite grains at the Highland Valley, Gibraltar and Woodjam deposits also indicate more fractionated magmas, lacking significant Fe-Mg minerals, compared to the Mount Polley alkalic porphyry Cu-Au system. Classification of the analyzed apatite grains using discriminant functions correctly identifies the porphyry deposit-types at all four deposits. Unlike detrital apatite grains at other deposits, those from tills at Woodjam mostly show barren-rock affinity or evidence of metasomatic depletion in most minor and trace elements, perhaps indicating derivation mainly from a low-temperature alteration zone rather than from mineralized rocks such as at the Woodjam Southeast Zone. Our results show that apatite trace-element chemistry is diagnostic of specific porphyry deposit-types and thus can be used as an exploration tool for these deposits.

ANALYSIS OF SEISMICITY IN CHUGACH-ST.ELIAS REGION BASED ON DENSE NETWORK OF BROADBAND STATIONS

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The historical record of earthquakes in the St. Elias region is characterized by poor detection and location capabilities. Completeness down to M5 was only achieved in the mid-1960s. Detection improved with the expansion of the Alaskan and Canadian seismograph networks in the 1970s. Of the major earthquakes, only the 1979 M7.5 was well recorded instrumentally. Previous to 1979, no major earthquakes had occurred in the region since the 1899-1900 sequence.

In its transition zone from strike-slip of the Queen Charlotte Islands fault to the Aleutian megathrust, the Pacific-North American plate boundary is not identified with certainty. The Yakutat block, a border land terrane about 400 km long and 100-200 km wide, is wedged within this transition zone. It is bounded by the Transition fault in the south, the Fairweather fault in the north-east and the Pampalona zone in the west. At its northern end, near Yakutat Bay, the Fairweather fault appears to connect with the Chugach-St.Elias fault system, a series of seismically active E-W striking thrust faults that approximately follows the coastline from Yakutat bay to Prince William Sound. The underthrusting of the Yakutat block results in a crustal shortening and uplift of the Chugach-St.Elias range. The effects of this collision extend as far as 500 km inland and cause deformation along the Denali fault system. The eastern part of

the Denali Fault system consists of a series of faults with a varying degree of seismic activity. Based on tectonic and GPS models, the existence of a connecting fault from Totschunda to Fairweather has been proposed.

In 2005-2006 22 new broadband seismic stations were installed in the Chugach-St.Elias region as part of the STEEP project. In 2011-2012 remaining short period sites were upgraded to broadband instrumentation. In addition, 8 broadband stations were installed on the Canadian side at around the same time. As a result, a high quality earthquake catalog is available for the region for that past 10 years. It contains nearly 30,000 events including 12 events with magnitudes greater than 5 and 3 events with magnitude 6 or greater. The newly recorded earthquakes follow the pattern of the long term seismicity trend. They mostly cluster in the Yakutat Bay area, along the central part of the Chugach-St.Elias fault system, and near the Duke River fault. We will present results of the earthquake relocations and source analysis and tie it in with the existing tectonic models for the region.

TRIPLE OXYGEN ISOTOPES INDICATE ATMOSPHERIC CONTRIBUTION OF NITRATE TO SURFACE WATERS IN PINERY PROVINCIAL PARK, SOUTHERN ONTARIO, CANADA

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The Old Ausable River Channel (OARC) is located alongshore of Lake Huron between the towns of Grand Bend and Port Franks, Ontario, Canada. It traverses a major protected, recreational area, Pinery Provincial Park, en route to its outlet at the Ausable River Cut. Largely isolated from other water bodies, OARC water levels are mostly sustained by shallow groundwater. The OARC is periodically in a state of eutrophication, a condition commonly attributed to local anthropogenic nitrate loading. We have measured the spatial and temporal variations in dissolved nitrate isotopic compositions and concentrations within, and contributing to, the OARC watershed waters, including precipitation, surface water and shallow groundwater, during a multi-year monthly sampling campaign. We have used these data and Bayesian modeling techniques to quantify nitrate source contributions to the OARC and adjacent groundwater. Our results show that the northeastern portion of the OARC, outside of Pinery Provincial Park, is contaminated by septic effluent. Atmospheric nitrate is the single largest source of nitrate in the central portion of the OARC. The southwestern portion of the OARC exhibits elevated atmospheric nitrate loading likely arising from periodic back flooding from the Ausable River Cut, which is also contaminated by agricultural run-off. We also compared nitrate isotopes in precipitation between Pinery Provincial Park and London, Ontario, which is located approximately 70 km to the southeast. Dissolved nitrate nitrogen isotope compositions at both sites overlapped known ranges for vehicular-emitted NO_x . For London, oscillations in nitrate nitrogen isotope compositions reflect seasonal fluctuations in soil and anthropogenic emissions. At Pinery Provincial Park precipitation exhibits irregular nitrogen isotope oscillations that reflect its location distal from upwind anthropogenic emissions. The oxygen isotope compositions of nitrate in precipitation at both locations oscillate in a fashion that arises from seasonal variations in atmospheric oxidation pathways. Collectively, these results demonstrate the complexity that can be associated with nitrate loading of even a small waterway, and how such information can help to guide the best approach go watershed management. Most of all, these results highlight the contribution of regional-scale atmospheric transport of nitrate to local surface and shallow groundwater nitrogen budgets.

RECONSIDERATION OF CENOZOIC DRAINAGE EVOLUTION IN SOUTHERN YUKON, CANADA THROUGH DIGITAL TERRAIN MODEL RESTORATION OF THE TINTINA FAULT

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The northerly directed Yukon River basin, which captures drainage from across the Yukon Plateau, is characterized by reaches that are offset along the large strike length Tintina fault (TF). The drainages also feature cross-cutting valley systems with underfit streams or contemporary stream flow directions that are opposite from what would be expected from paleoflow indicators, such as descent directions interpreted from fluvial terrace deposits. Previous interpretations of the region's drainage history postulated rather convincingly that Miocene or older southward drainage of the paleo-Yukon River predominated prior to the onset of regional glaciation at ca. 2.6 Ma, wherein glacial damming was to have diverted much of the southerly drainage towards the northwest into the Bering Sea via the ancestral Kwikhpak River basin in Alaska. We explore the impact on regional drainage development imposed by the ~430 km of right lateral transcurrent movement along the TF much earlier in the Cenozoic Era.

While the Yukon Plateau is generally considered by many researchers to be a relatively young (e.g. Miocene) physiographic feature, the regionally widespread preservation of middle Cretaceous to Paleocene lithological successions demonstrate relatively low incision rates over the last 100 million years and indicate that it has been a stable feature since the late Mesozoic. We re-evaluate and reconstruct the Cenozoic drainage resulting from progressive displacement of digital terrain model data along the TF. Major physiographic elements (uplands and major valleys) were restored and the drainage modeled at specific TF offsets, wherein drainage was episodically diverted by the alignment of previously unconnected valleys. The models show the drainage of the Yukon River northwestward into Alaska via Yukon Flats has only been possible at TF displacements from 0 to about 50-55 km. The models suggest that at an offset of greater than approximately 55 km, an alignment of highlands precluded flow to the northwest, and drainage of the Yukon Plateau was southerly via the White River, then NW along the Shakwak Trench. At TF offsets of between 230 and 430 km, our models illustrate that a substantial amount of the paleo Yukon River drainage may have flowed eastward into the continental interior via an ancestral Liard River. We interpret the drainage reversals convincingly attributed to the effects of Pliocene glaciation as merely an overprint on far more ancient Yukon River reversals attributed tectonic displacements along the TF in the early Cenozoic.

THE LATE JURASSIC MCGREGOR PLUTON IN CENTRAL YUKON: A NEW INTRUSION-RELATED GOLD TARGET?

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The 700 km² McGregor pluton in central Yukon consists of a main body of coarse-grained, equigranular to porphyritic hornblende-biotite granodiorite with minor diorite, and a central, smaller body of fine to medium-grained, equigranular biotite-muscovite quartz monzodiorite. Both phases have low magnetic susceptibility, $<1.0 \times 10^{-3}$ SI units. A subtle semi-circular magnetic feature, $1-3 \times 10^{-3}$ SI units, in the center of the McGregor pluton likely represents a contact aureole imposed on the older granodiorite phase by intrusion of the central two-mica quartz monzodiorite. Three new U-Pb zircon CA-TIMS dates (161.17 ± 0.05 Ma, 161.20 ± 0.05 Ma, and 163.42 ± 0.05 Ma) indicate a Late Jurassic crystallization age for the main granodiorite body. These results are the first documentation of Late Jurassic magmatism in central Yukon. The McGregor pluton was previously considered as part of the Late Triassic-Early Jurassic Minto suite (204-196 Ma) based on compositional similarities with nearby dated plutons of that suite.

Precise dating of the central two-mica quartz monzodiorite phase of the McGregor pluton remains elusive, with poor quality zircons yielding a scatter of LA-ICPMS dates between 178 and 142 Ma, indicating a probable Cretaceous age for this body.

The main granodiorite body is metaluminous, alkalic to alkalic-calcic, and strongly enriched in light rare earth and large ion lithophile elements. These geochemical characteristics are consistent with the main body having undergone significant fractionation from its source magma, an interpretation supported by locally abundant pegmatite and aplite dikes. The central body is weakly peraluminous and calc-alkalic; the presence of muscovite suggests a crustal component in the genesis of that magma. The geochemistry of the main body is similar to that of the Mayo and Tungsten plutonic suites which are associated with gold and tungsten deposits.

Jurassic igneous rocks in the northern Cordillera are typically associated with copper-gold \pm molybdenum-silver deposits related to oxidized magma conditions, including the Minto and Carmacks Copper deposits in Yukon. The low magnetic character, geochemistry and mineralogy of the McGregor pluton is however more indicative of reduced magmatic conditions, suggesting that it may be more prospective for reduced intrusion-related gold systems or tungsten skarn. Although there are no significant mineral occurrences currently associated with the McGregor pluton, subdued stream sediment geochemical anomalies suggest that exploration for gold-tungsten mineralization is warranted.

UNRAVELLING THE STRUCTURAL AND LITHO-CHEMICAL HISTORY OF THE CANTUNG TUNGSTEN MINE, NORTHWEST TERRITORIES: AN EXAMINATION OF THE SWISS CHEESE LIMESTONE OF THE SEKWI FORMATION

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The tungsten endowment in the Cantung W-Cu-Au skarn is world renowned having been one of the most significant sources of the strategic metal in the Western world for over the past 50 years. Since the opening of the Cantung mine in 1962, an estimated total of 7.68 Mt of ore was extracted at an average grade of approximately 1.4 % WO₃. The mine is situated in the Selwyn basin of the Canadian Cordilleran approximately 400 km west of Fort Simpson, Northwest Territories. The deposit is associated with Mid-Cretaceous felsic plutonic suites that were emplaced near the transition between the shallower water carbonates of the Mackenzie Platform and siliciclastic rocks of the Selwyn Basin. The high-grade tungsten mineralization which made Cantung a world-class deposit is hosted in a pure, coarsely crystalline marble (Ore Limestone). However, in recent years a greater percentage of the ore reserve has incorporated a calc-silicate unit informally known as the Swiss Cheese limestone (SCL). Over the past half-century, there has been a lack of attention on the mineralization in this calc-silicate unit mainly due to its relatively lower tungsten grades. Consequently, the SCL represents a significant potential mining resource that remains virtually unexploited and under-explored. Mineralization in the SCL is concentrated in discrete lenses parallel to stratigraphic contacts with the overlying Ore Limestone and the underlying Older Argillite units, and along internal bedding horizons. Well-mineralized lenses of the SCL have a higher frequency of steep SE dipping tensile veins containing high tungsten grades. The mineralization also emanates out from these veins into the SCL along what may be more extensive secondary permeability in geochemically favourable zones. Where sufficient numbers of these veins concentrate, the tungsten grades are often elevated and form more pronounced mineralization. Understanding the structural history of the deposit, particularly the genesis and distribution of the steep NE-SW veins in the SCL, will provide more constraints on the distribution of mineralization with implications on future mining and exploration.

YUKON-TANANA REGION GRAVITY AND MAGNETIC BASEMENT TRENDS AND DOMAINS AND CONNECTIONS ACROSS THE TINTINA FAULT

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We map crustal magnetic domains based on analysis of the recently published joint US Geological Survey/Geological Survey of Canada aeromagnetic data compilation spanning the Alaska-Yukon border. The magnetic domains reflect the relative amounts of magnetic minerals within the middle (5 to 10 km) and lower crust (10 to 25 km). Our data analysis involves: (1) conversion of total-field magnetic anomalies to pseudogravity (magnetic potential) anomalies; (2) matched-filtering to produce depth slicing of magnetic sources; and (3) separate identification of discrete (4 tiers from low to high amplitude) source domains for the mid (5 to 10 km) and lower (10 to 25 km) crust.

First-order observations related to the magnetic crustal domains include: (1) strong correlation between mid and lower crustal domains; (2) primary association of geophysical domain boundaries with major transcurrent faults including the Denali, Tintina, and Shaw Creek faults; (3) secondary association of geophysical domain boundaries and trends with a number of NE-striking cross faults between the Denali and Tintina faults (e.g., the Black Mountain tectonic zone, the Mount Hayes fault, the Kechumstuk fault zone, and the Sixtymile lineament); (4) significant correlation with mapped geologic elements including (a) the mid-Cretaceous Dawson Range–Gardiner Creek batholith, (b) the Late Triassic Taylor Mtn batholith, and (c) the parautochthonous North American rocks along the Denali fault (White River - Totatlanika continental margin assemblage).

A recently published analysis of long-wavelength gravity anomalies (Hayward, 2015) showed a number of important lineaments within the regional gravity data of the YTT (especially when enhanced by gradient processing). These lineaments, when palinspastically shifted 430 km (to the southeast) along the Tintina fault, line up with well-known and established lineaments within the North American basement of Canada, including the Beaver River structure and the Liard Line. We employ the same palinspastic restoration of the depth-sliced pseudogravity data to examine the nature of cross-Tintina connections from a magnetic domain perspective. The 430 km palinspastic shift produces a number of intriguing cross-Tintina correlations of magnetic domain patterns. This supports the conclusion of Hayward (2015) that geophysical basement within the YTT preserves some record of prior crustal structure including structures that may have localized later tectonic events.

ANOMALOUS BIREFRINGENCE IN CUBIC UVAROVITE GARNET, IDEALLY $\text{Ca}_3\text{Cr}_2\text{Si}_3\text{O}_{12}$

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For over a century, the occurrence of anomalous birefringent garnet species has attracted the interest of many geoscientists. Past research has examined a number of potential causes concerning the origin of anisotropy including but not limited to, the distribution of hydrous components within the tetrahedral (Z) site, cation ordering on the dodecahedral [X] and octahedral [Y] sites, and strain derived from lattice mismatch at compositional boundaries. However, the origin still remains questionable. Uvarovite, a rare mantle-derived garnet, ideally $\text{Ca}_3\text{Cr}_2\text{Si}_3\text{O}_{12}$, is the least studied silicate end-member species. Under crossed-polarized light, the reported birefringence of this emerald-green mineral is 0.001-0.006 and some sections exhibit well-defined extinction positions displaying a sectorized 'bowtie' structure. This study focuses on the crystal structure and chemical analyses of birefringent uvarovite garnets from various localities using electron probe microanalysis

(EPMA) and synchrotron high-resolution powder X-ray diffraction (HRPXR) data. Our preliminary results indicate a consistency with other anisotropic garnet members analyzed with HRPXR and EPMA data, which further supports the origin of anomalous birefringence in uvarovite garnet, as arising from strain closely associated to crystals that contain additional cubic uvarovite phases revealing slightly different chemical compositions.

FIELD, PETROGRAPHICAL AND GEOCHEMICAL RELATIONSHIPS OF THE AXIS LAKE EAST ZONE NI-CU DEPOSIT, TANTATO DOMAIN, NORTHERN SASKATCHEWAN

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The southern portion of the Tantato Domain in the southern Rae Province (northern Saskatchewan) is dominated by mylonitized psammopelitic gneiss, garnet-bearing anatectic granite, and mafic granulite; the latter locally hosts Ni-Cu mineralization. The Axis Lake East Zone Ni-Cu deposit, which was discovered in 1929, is the largest known concentration of sulphides found within the mafic granulite intrusions, but its origin is poorly understood. The area around the deposit was the focus of detailed mapping and sampling in the summer of 2015. A layered diopside-bearing norite in the north of the mapping area appears to crosscut plagioclase-bearing pyroxenite, diopside-bearing norite and leuconorite to the south. The mineralization, which includes disseminated and net-textured sulphides, is found concentrated along this boundary. The dominant minerals are pyrite, chalcopyrite, pyrrhotite, magnetite and ilmenite, all of which appear to have been remobilized after the time of original deposition. Remobilization likely occurred during peak metamorphism at ca. 1.9 Ga and later brittle deformation events during which sphalerite-bearing, calcite and pyrite veins formed. Corona textures are common in the norite and leuconorite, and consist of orthopyroxene aggregates, which may have developed by reactions between diopside and plagioclase during retrograde metamorphism. Ongoing textural and lithogeochemical analyses will determine whether the mineralization is associated with the younger phase of the intrusions, namely the layered diopside-bearing norite. A sample of the net-textured mineralization yielded Ni, Cu, and Co concentrations of 5500, 8980, and 1230 ppm, respectively. Electron microprobe analyses of the sulphide minerals will be used to determine the host for the Ni in the deposit, although previous work has suggested that the pyrite is nickeliferous. The Axis Lake East Zone deposit likely formed by separation of an immiscible sulphide melt from the original mafic magma just before crystallization, followed by remobilization and possible redistribution of metals during later granulite grade metamorphism.

CHEMICAL COMPOSITION OF Fe-OXIDES IN BULK STREAM SEDIMENTS AND APPLICATION TO MINERAL EXPLORATION, FLAT RIVER AREA, NORTHWEST TERRITORIES (CANADA)

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The chemical composition of iron oxides is useful to fingerprint mineral deposit types. Coupled with the fact that these minerals are ubiquitous in various types of mineralization and are resistant to mechanical and chemical weathering, they have strong potential to be good indicator minerals in exploration. Bulk stream sediment samples were collected within the Flat River area, in the westernmost Mackenzie Mountains, as part of the Northwest Territories Geological Survey's drainage geochemistry program. In this study, the trace element content of magnetite and hematite from the 0.25 to 2.0 mm grain size ferromagnetic fraction of seventy of these samples was determined and used to detect the presence of a specific type of mineralization in the drainage basin bedrock.

Magnetite is the most common oxide in the ferromagnetic fraction, followed by goethite (that replaces Fe-bearing minerals), hematite, and rare ilmenite. Magnetite grains are rounded to angular, have locally porous habit, contain hematite or ilmenite exsolution, and show replacement by hematite. Hematite grains are rounded to sub-angular and, in a few cases, porous. They commonly host magnetite exsolutions. In the northwestern part of the study area, magnetite and hematite have mostly composition typical of skarn and, to a lesser extent, porphyry deposits in the Ca+Al+Mn versus Ti+V and Ni/(Cr+Mn) versus Ti+V discriminant diagrams. In the central part of the area, they show a dominant IOCG chemical signature. In the southeastern part of the area, magnetite and hematite composition is similar those of skarn deposits in the Ni/(Cr+Mn) versus Ti+V diagram and from Kiruna-type deposits in the Ca+Al+Mn versus Ti+V diagram. Overall, Fe-oxides do not show any Ni-Cu and VMS chemical signatures in the region, as suggested by the Ni+Cr versus Si+Mg and Al/(Zn+Ca) versus Cu/(Si+Ca) discriminant diagrams.

The Flat River area contains numerous skarn occurrences, polymetallic veins, lithium-bearing pegmatites, and Pb-Zn replacement in sedimentary host rocks. The occurrence in clastic sediments of Fe-oxides with a composition typical of skarn deposits is consistent with the presence of this type of mineralization in the region. In contrast, the IOCG, Kiruna-type, and porphyry signatures identified in magnetite and hematite suggest that this part of the Mackenzie Mountains should be further investigated for this type of mineralization currently unknown in the area of the study.

A RIVER RUNS THROUGH IT: CULTURAL DYNAMICS IN THE UPPER YUKON RIVER CANYON

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The Upper Yukon River canyon is a geographic corridor between the lowland river basins of Interior Alaska and the Northwest Coast. The summed probability of 50 radiocarbon dates on cultural components from sites located generally between Dawson City (Yukon) and Circle City (Alaska) offers a first-approximation chronology of the riparian zone in this borderlands region, and allows us to build a model of human adaptation to environmental changes over time. Temporal gaps during both White River ash events suggest periods of local abandonment. Obsidian toolstone in several components indicate trade through this interior waterway beginning with microblade-bearing peoples in the early Holocene. Radiocarbon and OSL dated terrace deposits in the riparian zone offer proxy records for the discovery of buried archaeological deposits in the topographically constrained channel of the Upper Yukon River.

ADVANCES ON THE Ni-Cu-PGE PROSPECTIVITY OF THE CANADIAN HALIP: TEMPORAL, SPATIAL & STRUCTURAL CONSTRAINTS

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Portions of the Cretaceous (~ 130-80 Ma) High Arctic Large Igneous Province (HALIP) of Canada's Arctic Archipelago may be prospective for magmatic Ni-Cu-PGE (platinum group element) mineralization, based on geochemical evidence and similarities to mining camps such as Noril'sk-Talnakh, Russia. Recent and ongoing research on the HALIP aims to identify and localize areas of enhanced prospectivity, as well as broadening our understanding of the petrogenesis and structural controls on magma emplacement.

Although extrusive basaltic lavas of the HALIP are limited to restricted exposures on Axel Heiberg Island and northwestern Ellesmere Island, the intrusive components of the HALIP (i.e., diabasic to gabbroic sills and dykes) are widespread and are 3-5 times more voluminous. A preliminary assessment of new and existing geochemical data indicates that there are spatial and temporal variations in HALIP Ni-Cu-PGE prospectivity. Alkaline components of the HALIP, exposed on northern Ellesmere Island, are younger than ~95 Ma are chalcophile poor and thus relatively unprospective. In contrast, on Axel Heiberg Island, tholeiitic units between 130-95 Ma are more prospective, except for 130-120 Ma tholeiitic intrusions exposed at the NW corner of the island. As coeval intrusions exposed in the E and NE portion of Axel Heiberg Island show evidence for prospectivity, this implies that there was a compartmentalization in magma delivery and/or sources. New sampling reveals the existence of tholeiitic and transitional alkaline magmas in Hare Fiord and the Blue Mountains of Ellesmere Island that are potentially prospective.

The prospectivity of the HALIP can also be constrained by considering its structure and the geometries of its intrusive igneous components. Economic Ni-Cu magmatic sulfide deposits are typically hosted within 1-10 km scale structurally complex feeder systems, which often exhibit irregular to tube-like geometries that are controlled by syn-emplacement structural processes (e.g., intermittent fault activity) or the amalgamation of dykes and sills. Such systems are ideal sites of Ni-Cu-PGE mineralization because they promote high magma fluxes and protracted magma flow-through, thereby favouring the interaction between metal-bearing mafic magmas and sulfide liquids that are progressively enriched in metals. Several 10 km-scale intrusive complexes of the HALIP, such as those exposed at Middle Fiord (W Axel Heiberg) and on Wootton Peninsula (N Ellesmere), show first-order architecture that are characteristic of systems with Ni-Cu-PGE potential. Moreover, the post-emplacement structure of the HALIP (i.e., the Eurekan Orogeny) strongly controls the uplift and preservation the feeder system of the province which, in turn, further spatially constrains mineral potential.

A MINERALOGICAL STUDY OF A DRAVIC TOURMALINE FROM THE GRENVILLE PROVINCE

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Tourmaline from a gem-quality deposit in the Grenville province has been studied with X-ray diffraction, visible-near infrared spectroscopy, scanning electron microscopy, thermogravimetric analysis, electron microprobe and optical measurements. The tourmaline is found within tremolite-rich calc-silicate pods hosted in marble of the Central Metasedimentary Belt. The crystals are greenish-greyish-brown and have yielded facetable material up to 2.09 carats in size.

Using the classification of Henry et al. 2011 the tourmaline is classified as a dravite tourmaline. Continuing microprobe work will further refine this classification. Rietveld analysis of powder diffraction data gives $a = 15.9436(8) \text{ \AA}$, $c = 7.2126(7) \text{ \AA}$ and a unit cell volume of 1587.8 \AA^3 .

A polished thin section was cut perpendicular to the c-axis of one tourmaline crystal, which showed zoning from a dark brown core into a lighter rim into a thin darker rim and back into lighter zonation. Scanning electron microscope traverses across this cross-section revealed that the increase in brown colouration is correlated with an increase in titanium content. Crystal inclusions in the tourmaline of chlor-apatite, and zircon were identified by petrographic analysis.

NATURE OF THE CANADIAN SHIELD-CORDILLERA TECTONIC TRANSITION AND ITS ROLE IN CONTROLLING DEFORMATION WITHIN WESTERN NORTH AMERICA

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Assembly of North America has been ongoing for more than 2 Ga, though geologically recent activity, over the last ~200 Ma, has been largely confined to the Cordillera, the westward margin of the continent. The Cordillera stretches from Alaska through to Mexico, and, unlike a typical plate boundary fault, is characterized by a broad zone of distributed deformation as much as 800 km in lateral extent. Here we focus specifically on the Canadian Cordillera, which is observed to have elevated heat flow, high topography, and a thin and weak lithosphere. Juxtaposed immediately to the east, and acting as a rigid backstop to deformation, is the cold, strong and thick Canadian Shield. Both the location and nature of the Cordillera-Craton transition have been a subject of much study and debate. Past results suggest that the Cordilleran Deformation Front—the surface trace of deformation—may mark the western extent of the cratonic lithosphere, whereas others indicate it extends further west, up to the Tintina Fault-Rocky Mountain Trench system. In the Mackenzie and Richardson Mountains of the northern Canadian Cordillera, this boundary likely becomes more complex and elusive due to the arcuate nature of the predominant tectonic structures.

Despite high levels of seismicity across much of the region, in particular the northern Canadian Cordillera, detailed study has been limited by insufficient coverage of seismological infrastructure, hindering resolution in past models. With the USArray Transportable Array now deployed in Alaska and northwestern Canada, combined with several active regional arrays (e.g. the Yukon-Northwest Seismic Network, Mackenzie Mountains Experiment, and Banks Island Seismic Network), national and regional networks, and past seismological datasets, new studies will now be able to achieve improved resolution across large regions of western Canada. Using the automated multimode waveform inversion of surface, S and multiple S waves, we present a vertically polarized shear speed model of the lithospheric mantle and crust across western North America. With this new model, we address key questions regarding the complex dynamics within the crust and lithosphere of western North America, including the location and nature of the Cordillera-Craton transition throughout the Cordillera, and what role the apparent step-change in lithospheric thickness has on the deformation, seismicity, and pattern of crustal fabrics around major faults.

REFRAMING THE MAMMOTH STEPPE: INSIGHTS FROM SIBER ANALYSIS OF ISOTOPIC NICHE

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Woolly mammoth (*Mammuthus primigenius*), horse (*Equus* sp.) and bison (*Bison priscus*) once coexisted with a variety of megaherbivores and megacarnivores across the Pleistocene mammoth steppe – an extinct megacontinental biome spanning northwestern Europe to northern Canada. Many aspects of this ecosystem are not fully understood, including partitioning of resources among megaherbivores, environmental variability across regions, and the ecosystem's response to climate change associated with the Last Glacial Maximum (LGM) and Holocene. We integrate published carbon and nitrogen isotopic compositions for mammoth steppe megaherbivores with new data and use SIBER (Stable Isotope Bayesian Ellipses in R) analysis: (i) to determine the carbon and nitrogen isotopic niche for individual species during each time period at several sites across the mammoth steppe and

(ii) to assess the overlap between individual isotopic niches. During the pre-LGM, species maintained relatively consistent carbon and nitrogen isotopic niche positions at different sites, suggesting diet and habitat niches were similar across the mammoth steppe. Bison-horse, bison-caribou, horse-woolly mammoth, horse-mastodon and bison-muskox isotopic niches overlapped at multiple sites. This implies that these species utilized similar ecological niches. Relative to woolly mammoth and mastodon, horse, muskox and caribou typically had larger isotopic niches, suggesting more generalist behaviour. During the pre-LGM, western Beringian sites generally had the lowest carbon isotopic compositions, implying they were the coldest, with higher values in eastern Beringia and still higher values in northwestern Europe and central Canada. Sites from western Beringia and Europe had higher nitrogen isotopic compositions than sites in eastern Beringia and were likely more arid. Pre-LGM patterns of species' isotopic niche positions and overlaps were not preserved during the LGM. Instead, individual species tended to have smaller isotopic niches and different isotopic positions, indicating more specialized diets and different habitat or forage than during the pre-LGM. These indicate a disruption of the pre-LGM ecosystem. Pre-LGM environmental and ecological conditions present were also not restored during the Terminal Pleistocene. This change in the mammoth steppe ecosystem may have caused increased vulnerability of species to extinction at the Pleistocene/Holocene transition.

TEXTURE, CATHODOLUMINESCENCE AND TRACE ELEMENT COMPOSITION OF SCHEELITE, INDICATOR MINERAL OF OROGENIC GOLD DEPOSITS

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A set of seven minerals were selected as indicator minerals for orogenic gold deposits for their ability to resist to chemical and physical erosion in till deposits and their potential to present a specific geochemical signature: arsenopyrite, galena, rutile, scheelite, tourmaline and Fe-oxides. The project aims at defining discriminant geochemical features in major, minor and trace elements in the mineral.

Typical samples of gold mineralization were collected from 84 world-class orogenic gold districts and deposits. Deposits were selected for the representativity of their hostrock composition and age, metamorphic facies (prehnite-pumpellyite to mid-amphibolite), and mineralization age (Archean to Cenozoic).

Scheelite is investigated in 25 of those deposits. Selected samples were disaggregated by Electric Pulse Disaggregation to recover scheelite which was easily recovered from heavy mineral concentrates using fluorescence under UV light (blue, yellow when high Mo concentration). Scheelite is anhedral to subhedral and is fine (20-500 µm) to coarse (cm) grained. It occurs disseminated in aggregates or veins and is commonly associated with native gold. Scheelite is typically homogeneous under cathodoluminescence with rare subgrain boundaries, local bright patches, cross-cutting veinlets, oscillatory zoning and breccia texture. Scheelite composition shows low variance in Ca and W (respectively averaging 14.11±0.89 wt% and 62.68±0.81 wt%), except scheelite from Crusader (Agnew district, Yilgarn) that contains an average of 54.26±0.80 wt% W and 8.70±1.08 wt% Mo. Scheelite from Crusader presents a well-defined oscillatory zoning. The chemical composition is explained by the high Mo content of the Lawlers batholith from which the fluids at the origin of the Crusader gold mineralization were derived. Additionally, the Crusader deposit is considered as an intrusion-derived type whereas other deposits are considered as orogenic gold mineralization. Laser Ablation-ICP-MS maps show that the trace elements composition is commonly homogeneous. Zonation in REE may occur and can be correlated with variation in the cathodoluminescence response. Preliminary results show that the REE+Y vs Sr+Ba diagram discriminates deposits formed under prehnite-pumpellyite to mid-greenschist facies from others formed under mid-greenschist facies to lower-amphibolite

facies. Rare earth elements display four patterns: 1) a bell-shaped curve centered at Eu; 2) a flat pattern; 3) a bell-shaped curve centered at Ho; and 4) a negative slope pattern. Patterns 1 and 2 constitute the two end-members of a series and both may be found in a single scheelite grain. Variation in composition within a single grain is interpreted to record changes in the chemical composition of the hydrothermal fluids.

THE ASH MOUNTAIN TIN-BEARING SKARN IN NORTHWESTERN BRITISH COLUMBIA

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The Ash Mountain tin-bearing skarn is located in northwestern British Columbia in the Tuya Range, which consists primarily of the Cretaceous Tuya and Parallel Creek Batholiths, separated by the Oblique Creek Formation (Carboniferous?). Most of the Oblique Creek Formation consists of thinly bedded micaceous quartzite and mica schist. Lenses of crystalline limestone or marble are interbedded with the quartzite in places. In several places adjacent to the plutons the lenses have been transformed to calc-silicate skarns. Mulligan and Jambor (1968) described Sn-bearing andradite and epidote (0.9% and 0.8 % SnO_2 , respectively) and a possible Sn-Ca silicate, and later Wilson and Robinson (1994) identified malayaite (CaSnSiO_5) in the skarns.

Fieldwork in 2015 found abundant tan, bladed malayaite crystals up to 3 cm in the green garnet and clinopyroxene skarns. The malayaite is weakly fluorescent greenish-yellow in UV light. The skarns also contain lesser amounts of calcite, quartz, clinozoisite, apatite, fluorite, graphite, amphibole, and minor amounts of pyrite and chalcopyrite. Garnet occurs both as large (ca. 0.5 cm), euhedral grains and as aggregates of smaller, subhedral grains. The larger grains are zoned and some of these zones, as well as many of the cores of grains, have been selectively replaced mainly by hedenbergite-diopside and calcite, but also by wollastonite and malayaite in lesser amounts. The vast majority of garnet is andradite with $\text{Fe}/(\text{Al} + \text{Fe})$ ranging from 0.67-0.94, however some smaller grains have cores of Al-rich grossular with $\text{Fe}/(\text{Al} + \text{Fe})$ down to 0.16. Andradite can contain trace Sn and Mg. The composition of clinopyroxene ranges from hedenbergite to diopside [$\text{Fe}/(\text{Mg} + \text{Fe}) = 0.95\text{-}0.20$], however the majority of clinopyroxene specimens are Fe-rich. Clinozoisite occurs as euhedral crystals in voids filled by calcite, and with hedenbergite-diopside and quartz radiating aggregates. Apatite and fluorite occur as small ($<200\text{ }\mu\text{m}$), anhedral inclusions in andradite.

Thus far, malayaite is the only mineral containing significant tin that has been identified in the skarns: no cassiterite has been found to date. Larger grains of malayaite can have patchy zonation due to minor substitution of Ti. The batholith associated with the skarns is a primitive, annite-bearing granite with minor clinocllore. Whole rock analysis of the skarns for major and minor elements indicated that they contain 0.037-0.936% Sn, 0.011-0.047% Ti, 35-72 ppm Zn, 2.5-6 ppm Ni, 1.85-7.24 ppm Cu, 1.8-2.4 ppm Co, and 0.8-7.8 ppm W. Efforts continue to completely characterize the skarn and constrain the conditions of formation.

PRE- AND LATE-VARISCAN PNEUMATOLYTIC AND HYDROTHERMAL SN MINERALIZATION STAGES OF THE ERZGEBIRGE-KRUŠNÉ HORY-VOGTLAND-SLAVKOVSKÝ LES METALLOGENIC PROVINCE (DE, CZ)

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The Erzgebirge-Krušné hory-Vogtland-Slavkovský les metallogenic province (EKVS) is a reference area for pre-, late- and post-Variscan mineralizations in the internal Mid-European Variscides. Tin mining

started at the end of the 13th Century for cassiterite placers followed by mining for Sn vein- and greisen-type deposits. 350 kt of Sn metal was produced until 1990. The oldest known Sn occurrences in the EKVS are pre-Variscan stratiform polymetallic ores in the former mining districts Johanngeorgenstadt and Schwarzenberg (discovered by U. Josiger). This stratiform pyrite-pyrrhotite-arsenopyrite-cassiterite-biotite-garnet-rutile mineralization is hosted by mica schists which show up to 80 m thick sulfide-impregnated areas. The cassiterite-bearing polymetallic sulfide ore bodies are interpreted as Cambro-Ordovician submarine-hydrothermal (SEDEX-type) mineralization associated with trough-related basaltic rift volcanism. The pre-Variscan Sn mineralization is extensively metamorphosed during the Variscan orogenic event (peak of regional metamorphism in Erzgebirge: 340 Ma) and recrystallized (\rightarrow new cassiterite generation and relict cassiterite with atoll type texture).

The Sn-polymetallic "Felsitzzone" mineralization in the northern Freiberg district was discovered during Ag-mining activity at the beginning of the 19th century. Different metallogenic models are discussed: A model in the 1970s favored a pre-Variscan age and postulated a syngenetic ore deposition linked to submarine exhalative hydrothermalism; Recent studies show an epigenetic model of structurally controlled late-Variscan hydrothermal Sn-enrichment. The Sn-bearing fluids migrated within shear zones and breccia zones that developed primarily at the contact between different lithotypes, especially between para-gneisses and mafic rocks. An enrichment of Sn, F, Li, Rb, Cs and W suggests a genetic link between the Sn-polymetallic "Felsitzzone" mineralization and the late-Variscan Sn-(Li)-F-polymetallic association.

An important part of the rare metal resources in the EKVS is related to the late-Variscan Sn-(Li)-F-polymetallic association (Ar-Ar ages: 315-307 Ma), especially to greisen-type mineralization. There are still about 150 million mt Sn-polymetallic ores at about 0.15-1 wt.% Sn with significant quantities of W, Mo, Bi, In, and Li as byproduct. The greisen-, stringer zone-, and vein-type Sn-polymetallic mineralization is characterized by cassiterite-(wolframite-sulfide)-quartz-topaz-fluorite paragenesis (with zinnwaldite/protolithionite: Altenberg, Zinnwald, Sadisdorf, Pobershau, Ehrenfriedersdorf-Geyer; with (Li)-muscovite: Gottesberg-Mühlleithen). The complex Fe-Sn-W-Cu-Zn-In-F mineralization in the Anthonsthal-Breitenbrunn-Pöhl-Tellerhäuser-Zlatý Kopec district is related to garnet-pyroxene-epidote-vesuvianite-skarn layers replaced by massive (amphibole-chlorite)-magnetite mineralization. Both are overprinted ("greisenized skarn") by pneumatolytic Sn-W-Cu-Zn-In mineralization (scheelite ore: 50 kt W; cassiterite ore: 200 kt Sn; Zn-As-Cu-In-Sn sulfide ore: 300 kt Zn, 2 kt In). The deposition of the Sn-polymetallic mineralization is spatially and temporally associated with post-collisional Li-F granite/rhyolitic and lamprophyric magmatic pulses (320-290 Ma).

THE SULFUR CYCLE IN THE PALAEOPROTEROZOIC EARTH

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The cycle of sulfur between the inner parts of our planet and the atmosphere in the Palaeoproterozoic remains poorly constrained. Sulfur is a critical element to the development of early life as well as to numerous other earth processes, including climate change, biological evolution and ore deposit genesis. What is known is that on modern Earth arcs are environments where sulfur is transported and recycled among different terrestrial reservoirs¹. However, up until now a clear understanding of the transport mechanisms of sulfur has been hindered by the lack of isotopic markers that could trace the source and map the path of this element through the uppermost layers of the mantle and crust (lithosphere). The discovery of the presence of anomalous mass-independent

fractionation of sulfur (MIF-S) signatures in Archaean (i.e. older than approximately 2.5 billion years ago) sedimentary rocks provides a revolutionary way to probe the global sulfur cycle. This study focuses on the Palaeoproterozoic Glenburgh sulfur-bearing gold deposit, which is a ca. 2 billion years old natural laboratory hosted in the Glenburgh arc of Western Australia. Because this arc developed at the margin of a subducting Archaean block, we applied multiple sulfur isotope analysis as a chemically conservative tracer to detect the presence of Archaean MIF-S signatures in the Glenburgh gold deposit. Results show that Archaean sulfur can be traced throughout the Glenburgh arc, supporting the hypothesis that a significant source of sulfur in arc magmas and associated mineral deposits is derived from the breakdown and release of sulfur from sedimentary pyrite in subducting slabs. These findings could revolutionise our understanding of the evolution of the sulfur cycle in the lithosphere and may result in a significant improvement in our understanding of the mobility of volatiles and metals in the outer parts of our planet.

THE PRE-ANDEAN ROOTS OF THE NORTH PATAGONIAN ANDES: EARLY PALEOZOIC LOW PRESSURE – HIGH TEMPERATURE METAMORPHISM OF THE COLOHUINCUL COMPLEX, ARGENTINA

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New mapping and petrological studies conducted on metamorphic rocks of the Colohuincul Complex near San Martín de los Andes (40°S - 71°W) result in the characterization of low pressure–high temperature metamorphism.

The metamorphic rocks are predominantly paragneisses and migmatites with minor schists and amphibolites. The migmatites are mainly diatexites with biotite rich schlieren and schollen of relictic migmatized paragneisses and schists. Leucosomes are equigranular, medium grained and composed of Qtz + Plg + Bt + K feldspar + Ms. Stromatolites are also recognized with leucosomes parallel to S_2 main foliation of paragneisses and schists.

Peak metamorphic assemblage of Qtz + Plg + Bt + Crd + Sill (fibrolite) + K-feldspar ± melt in paragneisses and schists is contained on the S_2 axial-plane foliation. A preliminary P-T pseudosection constructed with *Perple_X* in the NCKFMASH system allowed us to constrain the peak metamorphic conditions between 560° and 640°C, and below 0.36 GPa.

Field relations indicate that migmatization has occurred within the paragneisses and schists, and was followed by two generations of intrusive rocks: harmonic syn-kinematic leucogranites and discordant post-kinematic tonalitic plutons which cut the metamorphic fabric. The leucogranites are parallel to S_2 foliation and are most likely the result of melt accumulation derived from the anatexis of the local paragneisses and schists. U-Pb SHRIMP zircon crystallization ages of the post kinematic plutons are ca. 390 Ma. The high rheological contrast between this post-kinematic intrusives and their country rocks indicate that the metamorphic rocks were already deformed and metamorphosed at the time of the intrusion. Therefore the metamorphism occurred before 390 Ma.

We could identify at least two processes of melt generation. The first and the most important one, is the generation of melt produced by the prograde breakdown reaction of Ms + Qtz. The second one is the leucosome formation due to decompression. After these processes a re-hydration stage is suggested by post-kinematic muscovite porphyroblasts with reaction rims of Ms + Qtz symplectites which overprints the previous metamorphic fabric. Contact metamorphism produced by the intrusion of post-kinematic plutons cannot be completely ruled out as responsible of this porphyroblast.

On a regional context and considering the stratigraphic relations, the HT-LP metamorphism of the Colohuincul Complex on the Northpatagonian Andes seems to be related to an Early Paleozoic

subduction zone. In this geotectonic setting, the heat source could be related either to magma intrusions or to underplating of mafic magmas beneath the magmatic arc.

UNION ISLAND GROUP, EAST ARM BASIN: A RECORD OF CONTINENTAL RIFTING PRIOR TO 1.9 Ga

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The Neoproterozoic supercontinent Kenorland experienced widespread extension, continental rifting, and enhanced production of continental mafic magmatism in the Paleoproterozoic. During this time the East Arm basin of Great Slave Lake was formed and now preserves a protracted sedimentary and volcanic record along the southeastern margin of the Slave craton. Previous stratigraphic interpretations set the ~1.9 Ga Wilson Island Group as the base of the East Arm basin; however new field observations indicate that the Union Island Group (UIG) is the lowest stratigraphic succession. The UIG is a package of dominantly mafic volcanic and subordinate carbonate/shale sedimentary rocks that were deposited directly on Archean granitic basement, considered to be derived from the Slave craton. Within UIG, two stratigraphically and geochemically distinct volcanic units are recognized: an alkaline to subalkaline basaltic lower assemblage with associated gabbroic feeder sills and dikes, and a subalkaline basaltic upper assemblage. The lower assemblage basalts are geochemically more variable, characterized by high TiO_2 (2.2–3.4 wt%) and Nb (24–62 ppm) contents and more fractionated LREE-enrichment ($La/Lu_N=7.6$). In contrast, the upper assemblage basalts have a much more restricted composition characterized by lower TiO_2 (1.6–1.7 wt%) and Nb (<4 ppm) contents, with a significant negative Nb–Ta anomaly. The high TiO_2 and Nb contents and low Th/Nb ratio (<0.2) of the lower volcanic assemblage is consistent with an asthenospheric origin with minimal crustal contamination.

We interpret the UIG to represent a pre-1.9 Ga aborted rift sequence that formed under continental extension during the initial formation of the East Arm basin. The results of ongoing tracer isotope and magma evolution modeling investigations will be presented.

MUD LAKE DYKE (NORTHWEST TERRITORIES, CANADA) REVISITED: A MID-ORDOVICIAN OXIDIZED DOLOMITE KIMBERLITE

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The Mud Lake dyke located ~45 km SE of Yellowknife is a member of the little-studied group of diamondiferous kimberlites known as Domain I (Heaman et al., 2004, *Lithos*, 71, 153–184). Virtually nothing was known about the petrography and mineralogy of this dyke prior to the present work. The Mud Lake kimberlite is characterized by macrocrystic and segregation textures comprising macrocrysts of (in order of decreasing abundance): serpentinized olivine, phlogopite, ilmenite, spinel, garnet and zircon in a dolomite-serpentine matrix. In addition to primary dolomite laths, the rocks comprise a variety of secondary carbonates replacing olivine, ilmenite and filling fractures. Other late-stage minerals include serpentine (after olivine), chlorite (after phlogopite), rutile (after ilmenite) and baddeleyite (after zircon). Some samples bear resemblance to dolomite carbonatite from Wekusko Lake (Manitoba), which was initially misclassified as kimberlite. However, both phlogopite and zircon from Mud Lake are distinctly kimberlitic in their trace-element chemistry when compared to carbonatites; i.e. the phlogopite macrocrysts are enriched in Ti, Ni, Cr Co and Rb, but poor in Mn, Sr, Zr and Nb, whereas the zircon contains low levels of rare-earth elements, Th and U, has very low Nb/Ta ratios (1.1 ± 0.1) and shows a strong positive Ce anomaly atypical of carbonatitic zircon.

The high Zr/Nb values of the Mud Lake ilmenite macrocrysts (~0.7) plot in the high-diamond potential field of Carmody et al. (2014, *Economic Geology*, 109, 775-783). The *in-situ* U-Pb dating of zircon yielded an age of 469 ± 9.7 Ma, implying that the Mud Lake dyke is coeval with the Drybones Bay volcanoclastic kimberlite located 4 km away. The trace-element composition of zircon was used to estimate its crystallization temperature ($776 \pm 49^\circ\text{C}$) and oxygen fugacity [$\log(f_{\text{O}_2}) = -10 \pm 3$]. Attempts to estimate the temperature of ilmenite-to-rutile conversion were unsuccessful due to a heterogeneous distribution of Zr in rutile crystals (480-3280 ppm) implying disequilibrium. The whole-rock geochemistry of the Mud Lake dike is consistent with hypabyssal kimberlites elsewhere (e.g., Y/Ho = 27, Zr/Hf = 38, Sc/Cr = 0.009: Chakhmouradian et al., 2009, *Lithos*, 112S, 347-357), although its Zr/Nb ratios are skewed to higher values owing to the abundance of zircon macrocrysts. Our data indicate that the Mud Lake dyke is not a mere intrusive equivalent of the Drybones kimberlite, although their exact genetic relationship remains to be ascertained.

PROVENANCE OF THE PALEOPROTEROZOIC MURMAC BAY GROUP, SOUTHWEST RAE CRATON, SASKATCHEWAN FROM COUPLED U-Pb, Hf, AND O ISOTOPIC ANALYSIS OF DETRITAL ZIRCON

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The Murmac Bay Group (MBG) is a Paleoproterozoic sedimentary succession at the southwestern margin of the Rae craton in northern Saskatchewan. Although the approximate depositional age has been constrained by reconnaissance-style geochronological studies using zircon and monazite, the sedimentary provenance of the MBG is still poorly understood. As a result of at least three episodes of deformation affecting the MBG since deposition, sedimentary structures are preserved only locally, making traditional methods of determining stratigraphic relationships, thicknesses, depositional environment, paleocurrent direction, and provenance difficult. We utilize coupled U-Pb, Hf, and O isotope analysis of detrital zircon to further elucidate the depositional age and sedimentary provenance of the MBG. As the relative positions of cratons surrounding the Rae craton are poorly known during MBG deposition, provenance analysis is expanded to nearest neighbouring cratons to the Rae craton.

The MBG is broadly divided into a lower and upper succession separated by an unconformity. Previous detrital zircon studies determined a maximum depositional age of 2.32 Ga for the lower MBG. The upper MBG consists of quartzofeldspathic psammopelite to pelite, and is migmatitic at higher metamorphic grades, requiring careful *in situ* analysis of detrital zircon. The youngest detrital zircon identified in our new data for the upper MBG is 2.01 Ga. Younger zircon ages are interpreted as metamorphic. ϵHf (ranges -7.6 to 8.7) and $\delta^{18}\text{O}$ (ranges 2.9 to 10.7) isotope analysis of MBG detrital zircon show evidence of new crust generation circa 2.3 Ga and 2.1 Ga, and crustal reworking events circa 2.3 Ga, 2.1 Ga, and 1.93 Ga, coinciding with known metamorphic events.

In addition to the new U-Pb geochronological data, previously published MBG detrital zircon U-Pb age data were compiled, and age peaks were compared with igneous crystallization ages from neighbouring cratons using the DateView database to identify potential sources for MBG sediments. We identified potential provenance locations on the neighbouring Slave craton and Buffalo Head-Chinchaga terrane. The new ϵHf and $\delta^{18}\text{O}$ isotopic data presented for MBG detrital zircons are compared with available isotope data (including Nd isotopes) from potential source rocks to further narrow down potential provenance locations. While this method does not account for undiscovered, undated, buried, or eroded source rocks, it serves as a first step in identifying potential provenance locations for the MBG, where primary sedimentary structures have been largely erased by deformation.

DIAMOND AGES: WHAT DO THEY MEAN?

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In the 30 years since the landmark paper reporting the first Paleoproterozoic Sm-Nd ages on garnet inclusions in lithospheric diamonds (Richardson et al., 1984), debate has surfaced from time to time on their meaning. Complexities that apply to both the diamond and its inclusion(s) have been central to this debate: the formation of diamond along metasomatic pathways; the necessity to obtain ages on mineral inclusions (not the diamonds themselves), the need to understand the genetic relationship of each diamond relative to another when plotting isochrons; the often complicated, multistage history of the inclusion prior to encapsulation and its equilibration with the diamond-forming fluid; the reaction of the inclusion with the diamond-forming fluid; and the inability to retain the fluid in a gem diamond. At present, the simple textural classification of inclusions as protogenetic, syngenetic, or epigenetic fails to provide an adequate framework to handle this complexity as is evident from advances in X-ray crystallography, computer assisted tomography, stable isotope and trace element geochemistry, and single grain dating. All diamond inclusions are greatly diminished in size compared to normal mantle xenoliths, either due to dissolution, recrystallization, or both. Furthermore, texture alone usually does not discriminate recrystallization of a pre-existing mineral in the presence of a fluid versus simple growth around a pre-existing mineral. Isochron ages from multiple diamonds will record a valid and accurate age when the diamond-forming fluid promotes isotopic equilibrium across grain scales, even for pre-existing minerals -equilibrium being the gold standard condition of an isochron. This clearly can and does occur and has multiple analogues in the field of dating metamorphic rocks. In cases where an age is suspect, due to scatter about an isochron, an age may still be valid if its regression uncertainties can encompass a known and plausible geological event, especially if the age can establish an association between that event and the source of diamond-forming fluids. The occurrence of mineral precursors prior to diamond growth, the complexity of mineral inclusions, and the evident multistage relationship between the fluid and the forming diamond do not invalidate diamond ages. Rather, these features allow diamond ages to be interpreted using realistic diamond growth models that relate to actual geologic events, in the same way that we are able to date metamorphic events in earth's crust.

S.H. Richardson, J.J. Gurney, A. Erlank, J.W. Harris (1984) *Nature* **310** 198-202.

THE CA. 1800 MA PRUTIVKA-NOVOGOL LARGE IGNEOUS PROVINCE OF THE EAST EUROPEAN CRATON AND ITS POTENTIAL EXTENT WITHIN THE NUNA SUPERCONTINENT

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A number of mafic and ultramafic intrusions can be linked to the single Prutivka-Novogol Large Igneous Province (LIP), which is widespread throughout the Ukrainian Shield and Voronezh Crystalline Massif that together constitute the Sarmatia segment of the East European craton. These include numerous dolerite dykes and gabbroic layered intrusions of tholeiitic affinity, and dykes of subalkaline gabbro, picrite, and kimberlite compositions. Dykes are from few to 500 m in width, steep to subvertical in dip, and some of them can be traced along strike for tens of km, whereas thickness of the layered intrusions can reach up to 1200 m and more. Most of the tholeiitic dykes are Ni-rich (>100 ppm Ni) and comprise dolerite and gabbro. Layered intrusions contain

variably abundant sulphide Cu-Ni mineralization that may reach the scale of an economic deposit. Dykes are closely associated in time and space with anorthosite-mangerite-charnockite-granite (AMCG) intrusions and various metasomatic bodies (e.g., U-bearing albitites and Be-REE-bearing metasomatites). Several precise U-Pb ages for rocks of the Prutivka-Novogol LIP fall in the range 1810-1780 Ma. This time interval corresponds to the final stage in collision of Sarmatia and Fennoscandia segments of the East European craton, and to the earliest stage in emplacement of AMCG complexes.

A large set of Sr and Nd isotope data is available for rocks of the Prutivka-Novogol LIP. The Rb-Sr isotope system yielded an age of 1772 ± 39 Ma with rather uniform initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratios (0.70264 ± 0.00020). Sm-Nd regression line is less well-constrained and yielded an age of 1890 ± 190 Ma; the initial $^{143}\text{Nd}/^{144}\text{Nd}$ ratio according to the regression line is 0.51030 ± 0.00018 . ϵNd values of individual samples vary from ~ 0 to $\sim +2$, whereas ϵHf values for zircons vary from $+1.6 \pm 1.3$ to $+5.5 \pm 0.8$. Isotope data are thus consistent with the mantle derivation of magma and minor crustal contamination.

Dykes of this age are known on other cratons that could have been adjacent to Sarmatia in the Palaeoproterozoic supercontinent Nuna also known as Columbia. Some tectonic and paleomagnetic reconstructions place Sarmatia next to Amazonia and West Africa at ca. 1.8 Ga, while other models place North China craton in the vicinity of Baltica. Mafic magmatism (including dykes, sills and volcanic rocks) emplaced between ca. 1800 and 1750 Ma is abundant in Amazonia, West Africa, and North China cratons and suggesting the possibility that they are all linked to a single plume-related LIP.

FLUID PARAGENESIS AND ISOTOPIC EVOLUTION OF ANCIENT DEEP CRUSTAL FLUIDS USING FRACTURE-FILL QUARTZ CARBONATE VEINS IN THE PRECAMBRIAN SHIELD, ABITIBI GREENSTONE BELT

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Saline fluids in fractures from rocks 2.1 km to 3 km deep in the Kidd Creek Volcanogenic Massive Sulphide deposit, Timmins Ontario, present an opportunity to study the effects of water-rock interaction over geological time scales in the Precambrian Shield. The deep crustal fluids contain noble gas components with mean residence times of 1.5 billion years suggesting long term preservation of fluids in the deep continental crust. Noble gas data even suggests components of the groundwater fluids may be related to a regional metamorphic event 2.62 Ga. In this study fracture-fill vein samples from the Kidd Creek deposit are analyzed to understand the fluids that contributed to their formation. Fracture-fill carbonate and quartz geochemistry and mineralogy are analyzed using a combination of x-ray fluorescence, cathodoluminescence (CL), and carbon and oxygen stable isotopes to characterize formation temperatures, fluid paragenesis and isotopic evolution. Preliminary data suggests that the fracture-filling veins formed from a hydrothermal fluid during a late, post ore depositional, devolatilization and shearing event, associated with regional metamorphism. This research tests the potential for carbon isotopes to trace water – rock interactions in fracture minerals in the deep Precambrian crust to provide insight into the origin of deep crustal fluids.

SOURCES OF THE REE-RICH, STRANGE LAKE A-TYPE PERALKALINE GRANITE, REVEALED BY Nd- AND O-ISOTOPES

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Although it is well-known that peralkaline granites commonly form in anorogenic tectonic settings, the processes controlling their

concentration of the REE and HFSE to extremely high values are still debated. The 1240 Ma Strange Lake pluton in the Paleoproterozoic Churchill province of Québec-Labrador provides an extraordinary example of hyper-enrichment of the REE, Zr, and Nb in an A-type granite. Bulk rock samples and arfvedsonite (Na-amphibole) separates from the unaltered hypersolvus and transsolvus granites of the pluton, as well as bulk rock samples of the Napeu Kainiut quartz monzonite host, were analysed for their Nd-isotope composition. The age-corrected ϵNd values range from -0.34 to -5.32 for the arfvedsonite, from -0.62 to -5.67 for the Strange Lake bulk rock samples and from -9.60 to -8.57 for the host rock; the $^{143}\text{Nd}/^{144}\text{Nd}$ values range from 0.51191 to 0.51230, from 0.51179 to 0.51203 and from 0.51141 to 0.51153, respectively. The negative ϵNd and relatively low $^{143}\text{Nd}/^{144}\text{Nd}$ values indicate a significant crustal component in the Strange Lake granites, and an even larger crustal component in the host rock. This suggests that the granites and their host are not related by fractional crystallization. The similar ranges in ϵNd for the hypersolvus and transsolvus granites indicates consistent proportions of crustal and mantle components, and thus a common source for the corresponding magmas. These interpretations are supported by oxygen isotope data. Quartz separates from the unaltered granites and the host rock were analysed for their oxygen isotope composition. The $\delta^{18}\text{O}$ values range from +8.2 to +8.9 ‰ and from +8.9 to +9.1 ‰, respectively (relative to VSMOW), and are within the range typical of A-type granites. These values are considerably higher than the mantle value (5.7 ± 0.2 ‰) and therefore also indicate a substantial crustal component in the magma. The extent of crustal contamination can be estimated, if it is assumed that the contaminants are dominantly paragneisses of the Churchill province. These rocks generally have low ϵNd and high $\delta^{18}\text{O}$ values. For example, Kerr (2015) reported ϵNd values of -12.4 and -13.0 for garnet-bearing gneisses near Strange Lake, and Peck (2010) and Ripley et al., (2000) mean $\delta^{18}\text{O}$ of +9.5 and +10.9, respectively, for the Tasiuyak paragneiss occurring widespread in the Churchill province. Mixing of 25 – 30 % of these paragneisses with a mantle source ($\epsilon\text{Nd} = +5$, $\delta^{18}\text{O} = +5.7$) would result in values close to those obtained for the Strange Lake granites.

ON THE ORIGIN OF LARGE, GEM-QUALITY TYPE II DIAMONDS

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Nearly all famous and notable diamonds, like the Cullinan and the Hope, share a rare set of characteristics that have led many researchers to regard them as a distinct family. Although they are often simply termed Type II's, alluding to their low nitrogen contents, not all Type II diamonds necessarily belong to this family. There are additional characteristics to consider. Diamonds that are Cullinan-like tend to be large, inclusion poor, relatively pure, irregularly shaped, and highly resorbed. These diamonds are exceptionally valuable as gemstones and difficult to access for research. Even when made available, the inclusion-poor nature of these diamonds maintains a barrier to their study. The geological origin of large, gem-quality Type II diamonds remains unknown.

In order to investigate this long-standing problem, Type II diamonds from the day-to-day grading operations of the Gemological Institute of America's New York laboratory were systematically screened to find any diamonds with inclusions. This approach produced multiple examples of what are otherwise very rare diamonds. Non-destructive laser Raman spectroscopy was used to examine the inclusions.

After analysing more than fifty included diamonds, including many diamonds greater than 5 carats, a few recurring inclusion phases emerge and two in particular establish a prominence. The first is CaSiO_3 walstromite, interpreted as a retrograde product from calcium-silicate perovskite. Some diamonds with CaSiO_3 walstromite also contain orthopyroxene inclusions, interpreted as retrograded magnesium-silicate perovskite, together suggesting

a lower mantle origin. The second prominent inclusion type is a metallic phase, unidentifiable by Raman. Careful inspection reveals that the metallic inclusions are often elongate and occur in chains that trend along a direction. The chains are spatially associated with bright, curvilinear features in cathodoluminescence, which are interpreted as healed cracks of {110} orientation that intersect along the chain-defining vector. The features of these unusual metallic inclusions suggest their present distribution is the result of deformation of the host diamond. This mechanism of mobilizing inclusions offers a reminder that caution is required when inferring a proto- or syngenetic origin for inclusions. Overall, the inclusions portray a clear deviation from the more common mineral assemblages of lithospheric diamonds. Instead, many large, gem-quality Type II diamonds may originate from the sublithospheric mantle and constitute a genetically distinct diamond variety.

UPPER MANTLE ANISOTROPY IN THE NORTHERN CANADIAN CORDILLERA FROM TELESEISMIC SHEAR-WAVE SPLITTING ANALYSIS

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Upper mantle seismic anisotropy (the directional dependence of seismic wave propagation speed) is a useful measure of the coherent alignment of anisotropic olivine minerals and gives information on the pattern of active mantle flow or fossilized fabric from past tectonic events. Recent results of seismic anisotropy in the southern part of the northern Canadian Cordillera are generally correlated with surface and/or crustal tectonics, indicating a change in anisotropy across the Cordillera-Craton transition and upper mantle fabric associated with plate boundary deformation extending 200 km into the North American continent. Unfortunately, the Cordillera north of latitude 60 remains poorly sampled. Here we present preliminary results of upper mantle seismic anisotropy beneath the northern Canadian Cordillera using shear-wave splitting analysis of teleseismic SKS phases recorded by an expanded network of stations that spans the entire northern Cordillera. Preliminary results indicate that fast seismic velocities are oriented parallel to both the Tintia and Denali faults, suggesting fossilized fabric from transpression accommodated in wide (>50 km) shear zones. Alternatively, these results may reflect alignment of fabric due to mantle flow around the Yakutat collision and subduction at least 400 km from the slab edge, possibly confined by the presence of the thick lithosphere of the Canadian Shield ~200-400 km westward of the deformation front.

LONG-TERM STABILITY AT THE EDGE OF THE CANADIAN SHIELD: INSIGHTS FROM CALCITE-FILLED FRACTURES INHERITED FROM BASEMENT STRUCTURES, SOUTHERN ONTARIO, CANADA

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The long-term stability of southern Ontario is relevant for regions currently being proposed to host deep geological repositories (DGR) for radioactive waste from nuclear power plants. In this study, we are investigating regional structures that are candidates for fault reactivation as a result of ongoing intraplate seismic activity, using secondary mineral precipitates to study reactivation events. Paleozoic units (including the Ordovician limestone proposed as a DGR host rock) unconformably overlie the Mesoproterozoic crystalline Grenville Province basement. Paleozoic orogenesis and rifting along the east coast of North America reactivated basement seated structures that propagate into the overlying carbonate platform forming mesoscopic-scale brittle structures. Exposed along the shores of Lake Ontario, near Picton, are decameter-scale fracture zones, spaced at 0.5 - 10 meters. The dominant fracture

set trends E-W, and often forms conjugate sets with less prominent NNE-oriented fractures. An older NW-oriented fracture set is crosscut by E-W and NNE oriented fractures. Regionally, there have been six directions of maximum horizontal stress in southern Ontario since the Precambrian, with the current orientation of maximum stress oriented ENE as a consequence of far field Atlantic ridge-push forces generated at distant plate boundaries. Due to the proximity of the carbonate units to the crystalline basement, we expect calcitic veins to be enriched in rare earth elements and are presently conducting trace element geochemical analyses. Calcitic vein and surface thickensses vary from 2.5 cm to 1 mm. Some veins show minor displacement, with fractured and displaced fossil fragments at the mm-scale, and cm-scale offsets at the outcrop. Calcitic veins show evidence of low temperature deformation (~200°C) through undulous extinction, bulging grain boundaries, tension gash structures, and extensive lamellar twinning. Twinning can only accommodate a limited amount of strain such that calcite lamellar twins are often kinked, broken and offset, suggesting reactivation of the calcite-filled fractures. Published U-Pb ages of ~400 Ma and ~100-50 Ma obtained from vein calcite in Ordovician units and Devonian units at the edge of the Michigan Basin in southern Ontario are in agreement with new thermochronologic modelling along the St. Lawrence platform that indicate Cretaceous cooling. Geochronology on calcite in this study will help resolve the timing of fracture reactivation providing further information on the stability of this part of the world, where deep geological repository projects are proposed to safely isolate and contain radioactive waste for ~1 million years.

GOLD MINERALIZATION AT THE HEBERT-BRENT SHOWING IN THE YELLOWKNIFE GREENSTONE BELT, NWT: PRELIMINARY PETRO-GEOCHEMICAL RESULTS

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The Hebert-Brent showing occurs within TerraX Minerals' newly defined Barney Deformation Corridor. It is located <2 km northeast of the Crestaurum mine shaft within the Yellowknife greenstone belt. The belt is known for the high-grade Con and Giant gold mines, which have produced a total of 14.1 Moz Au at an average grade of 16.0 g/t. Despite its proximity to shear zone/quartz vein-hosted gold deposits, the Hebert-Brent showing consists of replacement-style mineralization. The showing consists of bleached mafic volcanics that are locally pillowed. The gold mineralization is associated with sericite dominated shear zones enriched in pyrite (Py) and arsenopyrite (Aspy). The sample is dominated by muscovite, quartz, Py, and Aspy. Accessory phases include rutile, biotite, apatite, chalcocopyrite, Sb-sulfosalts, yttrium-phosphates, barite, and sphalerite.

Three polished thin sections (PTS) were made from the showing, which were examined petrographically and then characterized using SEM-EDS followed by LA-ICP-MS analysis. The primary objectives of this limited study were to determine the distribution of gold in the sample and characterize mineralogical associations. LA-ICP-MS spot analyses of Py and Aspy grains have shown that Aspy contains a higher average concentration of Au (9.4 ppm) than Py (0.73 ppm). The rims of Aspy grains were found to have higher concentrations of gold than the cores; however, the opposite occurs within Py grains.

Overall, gold concentrations in both sulfides are heterogeneous and suggest the presence of gold micro- to nano-scale inclusions. LA-ICP-MS trace-element distribution maps will be used to determine the distribution of these gold inclusions. Understanding the mineralization in this sample will help characterize the Hebert-Brent showing, give context to the showing within the Yellowknife greenstone belt, and help develop future exploration targets.

GEOLOGICAL ORIGIN OF THE LAKES ON SALT SPRING ISLAND

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Among the 40+ Gulf Islands located in the Salish Sea between Vancouver Island and mainland BC, lakes are relatively scarce therefore groundwater represents a majority of the potable water used by residents. Due to the relatively high importance of groundwater versus surface water combined with low regional recharge rates and yields from bedrock aquifers, considerable effort has gone into investigation of local hydrogeology. Summarizing earlier work by Allen, Journey, Morrison, Mackie, Surette and others, Gulf island primary permeability is low (5%), local and regional faulting and fracturing is spatially and lithologically heterogeneous, and discrete faults appear to have little effect on local recharge. In contrast, regional-scale fault and fracture zones (which cross lithologies and are related to several different deformation events) appear to substantially affect groundwater flow with high yield wells located on major NE-SW trending faults.

Unlike most of the Gulf Islands, on Salt Spring Island (one of the largest and topographically highest of the Gulf islands) lakes contribute substantially to the water resource utilized by residents (approximately two thirds of the residents rely on surface water). Here, we combine details about the island's fracture-scape and bedrock geology (BC Geological Survey, Mines and Petroleum Resources Open file 2009-11) to suggest the probable origins of Salt Spring Island's main lakes.

First, overview of Salt Spring Island's geology reveals surprising bedrock diversity that ranges from relatively 'old' predominantly igneous rocks in the south to 'younger' sedimentary rocks in the north. Next, we suggest that the origins of lakes on Salt Spring Island may be as diverse as the island's geology. For example, at the north end of the island a large natural depression with numerous seeps and springs formed due to accelerated erosion at the intersection of a NW-trending fold and N-trending brittle faults, and due to fault-induced permeability, respectively. Taken together, the combination fracturing and faulting appear to explain the presence of St. Mary Lake that is large in both area and depth. At the south end of Salt Spring Island, lakes are much smaller and shallower due to the predominance of granitic and volcanic rocks that naturally resist erosion and limit the movement of groundwater.

PROTECTION OF AQUATIC ECOSYSTEMS AFFECTED BY MINE WATER EFFLUENT: NICE GOAL BUT IS IT ATTAINABLE?

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What is a lake? A lake's trophic status (or level of productivity) can be classified by counting organisms or by measuring the concentration of chemical constituents, and a lake's mixing regime can be categorized as stratified or fully mixing by measuring water temperature. But assessing a lake ecosystem requires understanding bio-physico-chemical interactions. It follows that measuring the impact of mine water effluent (due to toxins, or due to non-toxic shifts in physico-chemistry) on individual components of a lake (e.g. zooplankton and phytoplankton, fish and zoobenthos, and mixing regimes and nutrient levels) may not reveal impacts on the whole lake ecosystem. Further, given that the aquatic organisms the comprise lake food webs have generation times from hours (microbes) to years (fish) it can take decades for an aquatic ecosystem affected by point-source pollution to achieve a new steady state, and decades to return to a former state. Last, given the naturally high sensitivity of lake ecosystems to stochastic environmental change (for example, rainfall and runoff, sunlight and air temperature) and given no two lakes are identical, a lake may respond uniquely to natural and to anthropogenic disturbance.

Can a whole lake ecosystem be sampled? With budget constraints in addition to the lengthy period of time needed to test predictions about whole lake disturbance, how do we proceed? First, care must be taken to select variables that indicate whole lake function (for example, the prevalence of large zooplankton, the grazability of algal biomass, and variables that indicate the relative importance of N versus P in limiting algal growth). Second, monitoring needs to continue for as long as possible. Third, effort must be taken to sample frequently enough to characterize seasonal regimes and inter-annual variation, and frequently enough to meet pre-set statistical power requirements so that we are as confident in declaring 'no impact' as in declaring 'impact detected'.

What is the point? If the goal of the NWT's Aquatic Effects Monitoring (AEM) Guidelines is to protect lake ecosystems through adaptive management, then the guidelines could be better designed both in choice of what, and how frequently to sample. Second, there is a need to appreciate the potential for AEM in remote locations to contribute to long-term records of undisturbed and understudied lake ecosystems in a region that may increasingly see resource development.

MODES OF DIAMOND PRECIPITATION THROUGH TIME

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Depending on the substrate and the composition of the diamond forming fluid/melt, several modes of diamond formation may operate. For harzburgite, the principal diamond substrate, a limited redox buffering capacity makes diamond formation via redox reactions with infiltrating carbonate- or methane-bearing fluids inefficient. Supersaturation in diamond of CHO fluids during isobaric cooling or ascent along a geothermal gradient likely prevails. In fluids near the water maximum, this would correspond to the redox neutral reaction $\text{CO}_2 + \text{CH}_4 = 2\text{C} + 2\text{H}_2\text{O}$ and carbon isotopic effects could be considered as the average of $\delta^{13}\text{C}_{\text{diam}}\text{-CO}_2$ and $\delta^{13}\text{C}_{\text{diam}}\text{-CH}_4$. In more reducing fluids, equilibrium between CH_4 and diamond determines carbon isotopic fractionation. Eclogite, as the second important diamond substrate, has a high redox buffering capacity and hence diamond precipitation likely relates to redox reactions involving either carbonate-bearing melts or methane-bearing fluids.

On this background, the carbon isotopic effects of diamond precipitation through supersaturation in a fluid and through redox reactions between fluid/melt and substrate should be the same and depend only on the redox state, i.e. negative $\delta^{13}\text{C}_{\text{diam}}\text{-fluid}$ at $f\text{O}_2 \geq$ water maximum or positive $\delta^{13}\text{C}_{\text{diam}}\text{-fluid}$ for more reducing conditions. Intra-diamond evolutionary trends of $\Delta^{13}\text{C}$ (SIMS profiles) can thus be used to determine the redox character of diamond forming fluids. We are employing this approach to assess if a change in the redox character of diamond forming fluids occurred either through time or in dependence of diamond substrate. We selected a number of diamond occurrences where the formation age of specific parageneses had previously been dated. From these localities, fragments of inclusion-bearing diamonds are imaged with CL and analyzed along "core-rim" transects for variations in $\Delta^{13}\text{C}$ and N-content. Nitrogen, as a diamond compatible trace element, allows to assess if variations in $\Delta^{13}\text{C}$ relate to isotopic fractionation during diamond growth or to variable fluid/melt compositions. Our current data set reveals that $\Delta^{13}\text{C}$ overall is a fairly poor tracer of diamond forming processes: $\Delta^{13}\text{C}$ only shows significant evolution (beyond the analytical uncertainty of $\sim 0.2\text{‰}$) in very dilute (carbon poor) diamond-forming fluids or for large degrees of diamond crystallization in fluid-limited systems. For the bulk of the diamonds (N=50) on which analytical transects were conducted so far, systematic co-variations between $\Delta^{13}\text{C}$ and N-content are absent. The few examples (N=6) where a growth mode can be identified are equally split between methane- and carbonate-related diamond precipitation and occurred in diamonds of both lherzolitic and eclogitic paragenesis.

A PETROLOGICAL AND MODELLING STUDY OF THE METAMORPHIC DEVOLATILISATION OF METABASALTS ACROSS THE GREENSCHIST-AMPHIBOLITE TRANSITION ZONE

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The transition zone between greenschist and amphibolite facies assemblages is one of the most important metamorphic facies boundaries due to its widespread development, particularly in greenstone belts, and its association with a number of major devolatilisation reactions that are a possible source for fluids linked to orogenic gold deposits. This study focuses on a greenschist-amphibolite transition zone located in the Flin Flon greenstone belt in Manitoba and Saskatchewan, which contains metamorphosed basalts and basaltic andesites, and comprises one of the best exposed sequences of its kind in the world.

This research suggests that across the greenschist facies, there are very few changes in mineral modes and compositions related to grade and that the main control on assemblages is bulk composition. In particular, bulk compositional variations related to pre-metamorphic seafloor alteration have a large control on the mineral assemblage, the proportions of hydrous mineralogy and the nature of the major devolatilisation reactions. Accurate determination of the changes in modal proportions of the hydrous mineralogy, and important accessory minerals such as carbonates and sulphides, has provided important information regarding the composition of fluids derived from the devolatilisation of these metabasites.

The greenschist-amphibolite transition zone consists of a complex set of coupled reactions with multiple forms of different minerals coexisting across various postulated miscibility gaps. Large changes in modal mineralogy occur at two major isograds: hornblende-in and oligoclase-in, suggesting that the major reactions occur over very narrow discrete bands of P-T space, rather than as part of slower continuous equilibrium changes. There are a number of examples of disequilibrium relationships between different minerals, including between coexisting amphibole and epidote group minerals. This study has shown that whilst there is strong evidence that a miscibility gap between actinolite and hornblende does exist, the amphibole pairs in these sequences, particularly at higher temperature, represent disequilibrium pairs. Understanding whether equilibrium or disequilibrium relationships are prevalent is essential, not only to understanding the nature of the key devolatilisation reactions, but also in constructing thermodynamic activity-composition models, and interpreting the effectiveness of equilibrium phase diagram modelling.

NEW INSIGHTS INTO REGIONAL METAMORPHISM OF THE TEHERY-WAGER AREA, SOUTHWESTERN RAE CRATON, NUNAVUT, CANADA

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The Tehery-Wager area (western Hudson Bay, Nunavut) is underlain by Archean and Paleoproterozoic metamorphic rocks of the Rae craton that were involved in the 1.83-1.80 Ga Trans-Hudson Orogen. The area is thought to host the northern extension of the ca 1.9 Ga Snowbird Tectonic Zone, a major boundary between the Rae and Hearne cratons. Geologic mapping is limited and spatial, temporal, structural and metamorphic characteristics of these rocks are poorly constrained. To increase geoscience knowledge, this area is the focus of a two-year regional mapping project coled by the Geological Survey of Canada and the Canada-Nunavut Geoscience Office. A Ph.D. project is underway to document the area's tectonometamorphic history for the first time.

The Tehery-Wager area consists of felsic to intermediate orthogneiss with subordinate metamorphosed and deformed

supracrustal belts. Petrographic analysis of metasediments from the eastern half of the study area reveals amphibolite- to granulite-facies peak-temperature assemblages, and lower amphibolite-facies retrograde metamorphism. Meta-basic rocks within the supracrustal belts contain clinopyroxene, orthopyroxene, garnet, amphibole, biotite, plagioclase, quartz, ilmenite, and minor sulphide minerals. Assemblages containing metamorphic orthopyroxene, clinopyroxene and garnet suggest peak metamorphism at mid-pressure granulite facies conditions. Aluminous paragneiss contains garnet, sillimanite, biotite, cordierite, K-feldspar, plagioclase, and quartz. Rare orthopyroxene, probably generated from biotite-dehydration reactions, and spinel, probably a product of sillimanite breakdown in the presence of cordierite, were identified in samples that also preserve pseudomorphed melt films around garnet porphyroblasts, and biotite breaking down to form cordierite and K-feldspar symplectites. These features suggest decompression from peak conditions at temperatures in excess of 750°C.

Garnet and pyroxene in the meta-basic rocks are partially replaced by amphibole locally with biotite coronae. In Al-paragneisses, garnet and plagioclase grains display opposite Ca zonation, with the highest Ca contents observed in garnet cores and plagioclase rims. These features suggest retrogression through amphibolite-facies conditions, possibly enhanced by anatectic melt crystallisation.

The textural and petrochemical analyses presented here will be compared to phase equilibria modeling (P-T, P-X and T-X pseudosections). Future work will also include isotopic dating (in situ SHRIMP on zircon and monazite, and Sm-Nd and Lu-Hf on garnet) to constrain the timing and duration of distinct phases of metamorphism. These data will be compiled to construct a suite of P-T-t paths from which the tectonometamorphic history of the Tehery-Wager area can be interpreted.

THE COMPLEX MINERALOGY OF THE PRECIOUS METAL-RICH GREENS CREEK VMS DEPOSIT, ALEXANDER TERRANE, SOUTHEAST ALASKA

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The Late Triassic Greens Creek massive sulfide deposit, located in southeast Alaska within the allochthonous Alexander terrane, is one of the top ten global silver producers and one of the most significant, though atypical, massive sulfide deposits in the world. The deposit has a combined resource of approximately 24.2 Mt grading 13.9% Zn, 5.1% Pb, 658 g/t Ag and 5.1 g/t Au. Massive sulfide lenses occur along with black dolostone and rift-related conglomerate at the base of a thick sequence of Late Triassic graphitic argillite, and unconformably overlie a footwall of altered Carboniferous mafic metavolcanic rocks intruded by mafic-ultramafic rocks. The current genetic model is a hybrid VMS-SEDEX-style hydrothermal system driven by shallow mafic-ultramafic hypabyssal intrusions below a major seafloor detachment.

The paragenesis of Greens Creek is complicated by intense polyphase deformation of fine-grained rocks with a wide variety of ore-related minerals. Mineral and rock textures are highly variable due to rheological contrasts between ore and rock types and low temperatures of peak metamorphism. A combination of traditional ore microscopy, NaOCl etching of polished sections, MLA imaging, and EMP, EDS, and LA-ICP-MS analyses, are used to identify mineralogy and develop a paragenesis.

Common sulfide minerals are pyrite, sphalerite, galena, and tetrahedrite, with subordinate chalcopyrite and local arsenopyrite, and colusite. Silver-bearing minerals include Ag-tetrahedrite, stromeyerite-mckinstryite, electrum, proustite-pyrargyrite, bornite, and pearceite-polybasite. Gold commonly occurs as electrum. Common gangue minerals include barite, dolomite, norsethite-witherite, barytocalcite, quartz, calcite, apatite, muscovite, albite, and graphitic material.

Four pyrite phases are identified: Py1 includes primitive textures such as framboidal, colloform, radiating, lath-like, and spongy pyrite; Py2 includes small (5-20µm) euhedral, well-zoned, inclusion-poor crystals overgrowing or surrounding Py1; Py3 includes coarse-grained (>100µm) inclusion-poor crystals overgrowing Py1 and Py2; Py4 is characterized by sub- to euhedral pyrite with abundant caries-like inclusions of surrounding sphalerite, galena, and/or barite.

Local discordant concentrations and veins of stromeyerite-mckinstryite with covellite and chalcocite post-date pyrite and overprint recrystallized and remobilized galena and sphalerite within barite-, carbonate- or quartz-dominated ore. The preservation of delicate replacement and exsolution textures suggests that remobilization or addition of Cu and Ag is paragenetically late and post-dates the major metamorphic recrystallization and remobilization event. Local bornite, enargite-famatinite, and trace electrum occur together with this assemblage, though lack delicate textures. The paragenesis of the ore-related minerals at Greens Creek will help to determine an improved genetic model, controls on distribution of precious metals, and aid in geometallurgy.

PETROGRAPHY AND GEOCHEMISTRY OF EOCENE MAFIC SYENITE INTRUSIONS FROM THE SOUTHERN OMINECA BELT, BRITISH COLUMBIA: IMPLICATIONS FOR MANTLE SOURCE CHEMISTRY

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Field mapping and petrographic work were conducted on the alkalic, early Eocene-aged Salmo River and May Blossom intrusions, to obtain more information about their magmatic source(s). The intrusions are located approximately 30km south of Nelson, British Columbia, and lie within the southern portion of the Omineca belt. Both intrusions intrude the siltstones of the Ymir formation and greenschist facies meta-volcanics of the Elise formation. The Salmo River and May Blossom intrusions are oval-shaped and have a surface area of approximately 1.0 km by 0.5 km. Texturally, the intrusions are phaneritic, which indicates that they cooled slowly at depth. The main bodies of both intrusions are composed of orthoclase (35%), normally-zoned aluminian diopside (25%), normally-zoned olivine (15%), biotite (13%) and plagioclase (12%). Both intrusions are classified as syenites, and have mineralogical similarity to extrusive trachybasalts. Phenocrysts of diopside and olivine display normal zoning, whereby the cores of crystals are Mg-enriched, and the rims are Fe-enriched. In olivine, the cores have an average composition of Fo₆₅ and the rims Fo₆₂. There is a small circular leucocratic core, approximately 300 m in diameter, outcropping in the northeastern portion of the Salmo River intrusion. This core is dominated by perthitic orthoclase (60%), diopside (15%), biotite (15%), and plagioclase (10%). The core is also classified as a syenite. Whole-rock analyses of the Salmo River (excluding the core) and the May Blossom intrusions were conducted. Total alkali (Na₂O+K₂O) values are 7.01wt% and 7.44wt%, with SiO₂ contents of 50.51wt% and 51.49wt% for the Salmo River and May Blossom intrusions, respectively. CIPW norm calculations indicate that both intrusions are nepheline-normative, although no nepheline was observed in thin section or during microprobe analyses. Major and trace element analyses of the intrusions show enrichments in the LILEs and depletions in the HFSEs relative to the primitive mantle. Significant depletions in mantle-normalized Nb and Ti values suggest an upper mantle source modified by subduction-related processes. Chondrite-normalized REE diagrams show enrichment of the LREEs with respect to the HREEs, without an Eu anomaly. This implies that plagioclase was present during the cooling history of the intrusions without fractionating from the melts. This study considers the possibility of the Salmo River and May Blossom intrusions originating from an enriched lithospheric mantle source contaminated by a pre-Mesozoic subduction process, and the tectonic settings that could have caused such phenomena.

THE HYDROTHERMAL AND METAMORPHIC HISTORY OF THE PHOTO LAKE VMS DEPOSIT AS RECORDED IN THE TRACE ELEMENT COMPOSITION OF PYRITE

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The Cu-Zn-Au-Ag Photo Lake deposit (PLD) is one of six VMS deposits hosted within the Chisel sequence of the Snow Lake arc assemblage of the Paleoproterozoic Trans-Hudson Orogen. The VMS deposits and host rocks have undergone deformation and peak middle almandine-amphibolite facies (~5 kbar, 550-570°C) metamorphism. With average Au and Cu grades of 4.87 g/t and 4.58 g/t, respectively, the PLD is unique when compared to the other Chisel sequence VMS deposits, which are characterized by high average Zn grades (8.19-10.60 wt% Zn) and low Au and Cu grades (0.40-2.90 g/t Au; 0.15-1.34 wt% Cu). The PLD occurs along the same productive ore interval as the other Chisel sequence VMS deposits but its Cu and Au enrichment suggests that it formed under different conditions.

The PLD consists of a Cu-rich #1 lens (5.71 wt% Cu) and a Zn-rich #2 lens (10.98 wt% Zn). Petrographic and SEM analysis of pyrite from the two lenses identified 4 distinct textural varieties: 1) concentric (Py1); 2) spongy (Py2); 3) pitted (Py3); and 4) crystalline (Py4). These textures are interpreted to represent different generations of pyrite, which developed during formation of the PLD at the seafloor (Py1, Py2, Py3) and during later alteration and recrystallization associated with metamorphism and deformation (Py4). Element maps produced through LA-ICP-MS reveal distinct chemical differences between the textural varieties of pyrite. Py1 and Py2 are most notably enriched in Se. The trace element composition of Py3 is variable relative to Py1 and Py2, with both enrichments and depletions of Se. Py1 and Py3 contain Au as inclusions and up to several weight percent Cu. Py4 is depleted in all trace elements relative to Py1, Py2, and Py3 except for Co and As. These chemical differences are interpreted to reflect the composition of the VMS-forming hydrothermal fluids and the effects of later metamorphism. The Se enrichment in Py1, Py2, and Py3 is consistent with a magmatic input to the VMS-forming hydrothermal fluids. This is significant given that Au and Cu are associated with Py1 and Py3, and Se-bearing minerals are notably absent from other Chisel sequence VMS deposits. Recrystallization to form Py4 removed the majority of the trace elements, producing a relative enrichment in Co and As. In summary, the primary textures of pyrite have been preserved in spite of metamorphism, and a magmatic input to the PLD-forming hydrothermal system may have produced the Cu and Au enrichment.

GOLD MINERALIZATION, REMOBILIZATION, AND CONCENTRATION IN THE BORDEN GOLD DEPOSIT, CHAPLEAU, ONTARIO

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The Borden Gold project is located near Chapleau, Ontario in the Wawa-Abitibi terrane and Kapuskasing Structural Zone of the Superior Province. The 2014 indicated resources are 1.6 million ounces of gold and inferred resources of 0.4 million ounces of gold at a 2.5 g/t gold cut-off grade. The Borden Gold project is an outstanding example of gold mineralization that has persisted throughout high-temperature metamorphism and deformation. The host lithologies reached amphibolite to granulite facies, migmatized to metatexites and diatexites, underwent retrograde metamorphism, and host mineralization in ductile to brittle-ductile shear zones, sheath folds, and boudin necks. The regional ductile shear zones strike east-west with a near vertical to vertical dip, with smaller-scale deposit scale to outcrop scale brittle-ductile shear zones striking oblique to the regional foliation. Regional to microscopic scale pegmatite, quartz vein, and amphibolite boudin necks host gold mineralization in trends near east-west with moderate to gentle plunges east or west. The contact between host lithologies and

boudin necks host the greatest gold mineralization. The protoliths to the host lithologies are seafloor-altered mafic lithologies and sulphide and oxide facies banded iron formations which are classified as garnet-biotite schists and gneisses. Outside of the ore zones the sulphide facies banded iron formation host subeconomic gold mineralization and could have been the original source of gold and sulphide mineralization which then subsequently remobilized in regional to microscopic ductile shear zones to boudin necks. Mapping has extended the Borden Belt into the Wawa Gneiss Domain as a diatexite and into the Kapuskasing Structural Zone as metatexites and pyroxene-garnet gneisses. Gold deposits in the Wawa-Abitibi terrane are lower-metamorphic grades with lower-temperature structural equivalents to the Borden Gold deposit of the Chapleau Belt.

ORDOVICIAN–SILURIAN ARC MAGMATISM RECORDED IN THE APOON ASSEMBLAGE OF THE DOONERAK FENSTER, CENTRAL BROOKS RANGE, ALASKA: IMPLICATIONS FOR CIRCUM-ARCTIC TERRANE LINKAGES AND PALEOGEOGRAPHY

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The Doonerak fenster of the central Brooks Range, Alaska, exposes para-autochthonous volcanic and sedimentary basement rocks (Apoon assemblage) to the Mesozoic-Cenozoic Brookian fold-thrust belt. Recognition of a major pre-Mississippian unconformity within the fenster led to previous correlations between Doonerak and the North Slope subterrane of the composite Arctic Alaska Chukotka microplate (AACM); however, the presence of arc-affinity volcanic rocks and the apparent lack of pre-Mississippian deformation in the Apoon complicates tectonic reconstructions of the AACM. Previous age constraints on the Apoon assemblage are limited to a handful of Middle Cambrian–Silurian paleontological collections and five K-Ar and ⁴⁰Ar/³⁹Ar hornblende ages from mafic dikes ranging from ca. 380–520 Ma. We conducted U-Pb geochronological and Hf isotopic analyses on mafic rocks and associated volcanoclastic sedimentary units in the Apoon assemblage to test Paleozoic links with the North Slope and assess the tectonic and paleogeographic setting of the Apoon arc assemblage. A new U-Pb SHRIMP-RG age of 461.8 ± 4.5 Ma from leucogabbro in the Apoon assemblage confirms previous geochronological evidence for Middle Ordovician arc magmatism in the Doonerak fenster. Furthermore, U-Pb LA-ICP-MS analyses of detrital zircon in volcanoclastic and tuffaceous horizons of the Apoon assemblage yield a spectrum of unimodal and polymodal age populations, including prominent age groups of ca. 420–490, 520–540 Ma, 960–1250, 1380–1500, 1750–1945, and 2650–2830 Ma. Hf isotopic data from the ca. 420–490 Ma age population, including the Middle Ordovician leucogabbro, are highly juvenile (~7–10 εHf), implying a distinct lack of crustal assimilation during Ordovician–Silurian arc magmatism. These data indicate that the Doonerak arc complex marks a prominent tectonic boundary between Laurentian- and non-Laurentian affinity rocks in the AACM. The U-Pb geochronological and Hf isotopic data also highlight a potential link between Doonerak and the juvenile Prince of Wales arc complex of the Alexander terrane and imply a connection to Taconic–Caledonian arc magmatism along the fringes of the Iapetus Ocean.

SYNCHROTRON SPECTROSCOPY FOR ORE SYSTEMS: TYING TRACE ELEMENT GEOCHEMISTRY TO MINERALOGICAL CONTEXT IN THE ABIBITI GREENSTONE BELT

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Synchrotron X-ray spectroscopy is an incredibly powerful tool that is under utilized in studying ore systems. It provides unprecedented contextual trace element information which can be tied directly to

mineralogy; something lacking in conventional bulk rock analysis. Synchrotron micro X-ray fluorescence (uXRF) provides quick and effective micron scale trace element analysis and mapping of minerals with ppm detection limits. Additionally, speciation of trace elements and gold can be probed using X-ray absorption near-edge structure (XANES) spectroscopy. This provides critical insights into trace element associations within ore minerals, which complements classical ore microscopy. However, unlike most high resolution techniques which generally precede sample characterization by ore microscopy, samples do not always require extensive preparation or characterization prior to synchrotron analysis, only a good understanding of their geologic context, and a relatively smooth surface. This represents a paradigm shift in the application of high resolution analysis for ore systems.

Conventional thin sections, their offcuts, as well as cut slabs from hand samples and core from the prolific Timmins and Kirkland Lake gold camps have mapped in their entirety at 20µm resolution. This provides contextual mineralogical information on key trace element associations with gold, and aided selection of grains and samples for higher resolution uXRF and XANES analysis (<5µm). At the Dome Mine in the Timmins camp, trace element mapping of pyrite grains from the early ankerite veins identified multiple generations of gold mineralization with variable trace element associations and gold content, representing at least 3 distinct fluid events. Gold is intimately associated with pyrite mineralization and is present both as inclusions and fills fractures in pyrite grains, as well as nanoparticles and/or in the pyrite crystal lattice; known as “invisible gold”. Bulk rock geochemical data from the Kirkland Lake camp has been correlated with micron scale trace element mapping to distinguish spatial changes in fluid composition, address questions regarding mineralization history, and to identify novel trace element exploration vectors. Additionally, using the fundamental parameters based spectral deconvolution (fitting) and dynamic analysis capabilities of GeoPIXETM, quantitative composition analysis for individual samples and mineral grains (including gold) has been ascertained. This provides a new framework for investigating fluid evolution, depositional mechanisms, and fluid-rock interactions in gold bearing ore systems. These examples illustrate how synchrotron X-ray spectroscopy can be a quick and effective high-resolution analytical tool for better understanding ore systems as well as addressing industry relevant questions, providing powerful answers to real world problems.

LITHOSTRATIGRAPHIC AND GEOCHEMICAL STUDY OF SUPRACRUSTAL ASSEMBLAGES OF THE PINE LAKE GREENSTONE BELT, NORTHEAST GLENNIE DOMAIN, TRANS-HUDSON OROGEN: PRELIMINARY RESULTS AND IMPLICATIONS FOR GOLD EXPLORATION

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The Pine Lake greenstone belt of the northeast Glennie domain is one of many deformed, elongate and arcuate belts of supracrustal rocks in the Reindeer zone of the Trans-Hudson orogen, and hosts several currently mined (Seabee, Santoy 8 and Gap) and extinguished (Santoy 7, Porky Main and West) mesothermal gold deposits. Previous work identified three main supracrustal assemblages within this belt: 1) ‘Assemblage A’ of ~1890 Ma mafic volcanic rocks; 2) ‘Assemblage B’ distinguished by a thick basal polymictic conglomerate unit and overlying ~1840 Ma intermediate-felsic volcanic and associated sedimentary rocks; and 3) the overlying ‘Porky Lake assemblage’, comprising dominantly continental-derived siliciclastic rocks. Assemblages “A” and “B” have historically been viewed as broadly correlative with the Amisk and Missi groups (respectively) of the Flin-Flon Belt, whereas the Porky Lake siliciclastics are considered correlative with the Ourum group. In order to better constrain lithostratigraphic and structural relationships, a property-wide geochemical study of Assemblages A and B was undertaken. Multi-element geochemical data reveal a

number of previously unrecognized relationships. In the broadest sense, Assemblage A is dominantly tholeiitic to transitional in magmatic affinity and is composed of basalt with minor basaltic andesite and andesite, whereas Assemblage B is exclusively calc-alkaline and is dominated by andesitic to rhyolitic compositions. Trace element data indicate that a package of rhyodacitic flows previously thought to belong in Assemblage B may belong to the Assemblage A, rectifying the occurrence of Assemblage B rocks that appear to be stratigraphically out of sequence. Additionally, REE and multi-element plots distinguish at least two distinct basaltic suites (or panels) within Assemblage A that are spatially correlative with previously mapped geological units. These new findings have important implications for the stratigraphic sequence of the Pine Lake greenstone belt and future exploration. For example, of the two Assemblage A basaltic suites, only one appears to host substantial gold mineralization. Furthermore, early folding and tectonic imbrication appears to have controlled the distribution of this basaltic unit, which, due to the relatively high level of strain and metamorphism, cannot be readily distinguished by field observation alone. Geochemistry is therefore an important tool for identifying stratigraphic and structural breaks, and hence for targeting both local- and regional-scale exploration. Collectively, this new data can be used to reconstruct the local deformational history and to strengthen potential correlations with other greenstone belts in the Glennie and Flin-Flon domains of the Reindeer Zone.

THE EASTERN BERINGIAN NITROGEN CYCLE BEFORE AND AFTER THE TERMINAL PLEISTOCENE

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Defining an appropriate C and N isotopic baseline is an essential prerequisite to paleodietary studies of megafauna in Beringia. We analyzed the carbon and nitrogen isotopic compositions of fossil plants and fossil bones recovered from fossil arctic ground squirrel nests collected from different placer goldmines in the Klondike area of west-central Yukon Territory (eastern Beringia). These data, together with changes observed in decomposition experiments, show that microbially mediated decay has caused minor changes in the original carbon isotope composition (by ~0.1 ‰) of fossil plants and major changes in their nitrogen isotope composition (by ~2-10 ‰). By (i) coupling isotopic data for fossil plants and rodent bones, (ii) measuring the modern nitrogen-15 and carbon-13 spacing between ground squirrel bone collagen and vegetation, and (iii) accounting for the Suess effect and microbially mediated changes, we have estimated the carbon and nitrogen isotopic compositions at the base of the food web in eastern Beringia. Late Pleistocene foodweb isotopic baselines for this region were ~1.6 ‰ higher for carbon isotopes and ~2.5 ‰ higher for nitrogen isotopes relative to the modern grassland in this area. The results suggest a possible change in the nature of N cycling in this region since the late Pleistocene.

DIAMONDS FROM THE KONAWARUK RIVER (GUYANA)

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The Konawaruk River in Guyana is best known for its alluvial gold content but the recovery of diamond as a by-product of gold mining operations has also sparked interest in local diamond exploration. Possible sources for the Guyanese diamonds are yet undiscovered kimberlites on the Guyana Shield, diamondiferous sediments of the Paleoproterozoic Roraima Supergroup, and the alluvial and kimberlite-hosted Guianamo diamond deposits of Western Venezuela.

Here we study 86 Guyanese diamonds from the Konawaruk River using a combination of light microscopy, SEM and

cathodoluminescence imagery, and Fourier Transform Infrared (FTIR) spectroscopy. The studied diamonds typically are 3 mm in size, have dodecahedral morphologies, and, apart from common green and brown radiation spots on crystal surfaces, are colourless. Percussion marks aside, there is an absence of surface features that are commonly associated with alluvial diamonds (edge abrasion, ground surfaces, network patterns). Percussion marks alone provide no unambiguous evidence for extended sedimentary transport but could have resulted during diamond recovery in sluice boxes. The Konawaruk River diamonds, however, show a previously undescribed surface feature consisting of a crystallographically controlled network of narrow and shallow channels. SEM images reveal that these features relate to etching, progressing from crystal edges onto dodecahedroid faces, i.e. these “channel networks” are of magmatic and not alluvial origin. That these features have not been previously recognized may indicate a “new” local source.

FTIR analysis of nitrogen contents and aggregation states for the diamond suite allows calculation of time-averaged mantle residence temperatures ranging from 1075 to 1275°C, with a mode of 1165°C. Based on projection to an average shield geotherm, this temperature mode implies a mantle origin at about 160km depth. Degradation of platelets (two-dimensional features in diamond relating to nitrogen aggregation) in some of the diamond samples indicates strain and/or occurrence of a short lived heating event during mantle residence. This feature may suggest an origin beneath a reworked zone in the interior of a craton or a craton edge.

Based on the combined results, in particular the absence of typical surface features indicative of prolonged alluvial transport and the presence of a unique magmatic etch feature, it is probable that a local diamond source exists in the Konawaruk River area. This local source could be a yet undiscovered kimberlite or diamondiferous Roraima Supergroup sediments outcropping along the Konawaruk River.

ARCHITECTURE OF THE CRUST AND UPPER MANTLE IN THE NORTHERN CANADIAN CORDILLERA FROM TELESEISMIC RECEIVER FUNCTIONS

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The northern Canadian Cordillera is one of the most seismically active regions in North America, yet the current tectonic models describing such deformation are poorly constrained. The current leading model (called the “orogenic float” model) proposes a thin rigid crustal layer, decoupled from the underlying weak lower crust and mantle due to elevated basal temperatures, which is pushed horizontally at the plate boundary to the west and transmits stresses throughout the Cordillera. However, testing this model requires detailed information on the structure and properties of the crust in relation to earthquake activity obtained from geophysical infrastructure, which has been historically deficient in this area. Increased coverage in broadband seismograph stations in the Yukon and western Northwest Territories in the past few years is now allowing detailed models of the crust and mantle using modern seismic imaging techniques. Here we analyse data from all available current and past broadband seismograph stations in northwestern Canada and investigate the structure and anisotropy of the crust and upper mantle using teleseismic receiver functions. These data are sensitive to contrasts in seismic velocity and anisotropy associated with major structural interfaces at length scales of 1 to 10 km. We process the receiver functions to obtain maps of crustal thickness and bulk crustal Vp/Vs values (sensitive to compositional changes), and to obtain estimates of crustal seismic anisotropy. Stations located on top of thick sedimentary sequences in the foreland basin show large reverberations from the sedimentary layer that bias the receiver function data and are excluded from the analysis. Our results show that crustal thickness within the Cordillera is tightly distributed around 32 ± 3 km, with

small lateral variations across some terrain boundaries (e.g., Tintina Fault). Crustal seismic anisotropy estimates obtained from receiver functions shows large lateral variations in the depth, amplitude and orientation of anisotropy. Although we cannot rule out the presence of a lower crustal shear zone, our results do not support the presence of a pervasive lower crustal shear zone across the entire width of the Cordillera separating a rigid upper crust from ductile deformation below. Furthermore, our results suggest the presence of a high velocity lid directly beneath the Moho that may be related to a restitic lower crust or depleted upper mantle. A downward velocity decrease at ~60 km depth is interpreted as the lithosphere-asthenosphere boundary. Finally, our results support the orogenic float model where thin crust of the Cordillera is supported by elevated mantle temperature, although the relation between crustal structure and stress transfer across the Cordillera remains unresolved.

ASSESSING THE VULNERABILITY TO CLIMATE CHANGE FOR THREE NORTHERN AIRPORTS

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Three northern airports, Inuvik, Northwest Territories, Churchill, Manitoba and Cambridge Bay, Nunavut, were chosen to assess potential vulnerability of the infrastructure to climate change. The importance of these locations is due to the sensitivity of the permafrost foundations of the airport infrastructure to changes in climate. The assessment followed Engineers Canada's protocol developed by the Public Infrastructure Engineering Vulnerability Committee (PIEVC). The protocol has been developed as a tool to standardize vulnerability assessments of infrastructure to climate change in a schematic way.

The relevant infrastructure components and climate events were determined in collaboration with local airport staff and representatives from the territorial Governments and Transport Canada. Climate trends were determined from historical climate data from local weather stations together with climate change projection models over a period of 30 years (2015 to 2045).

The assessment is carried out in the form of a risk matrix that evaluates the interactions between certain climate parameters and specific infrastructure components. A risk score is determined for each interacting pair and then each pair is categorized as low risk, no immediate action required; medium risk, action may be required; or high risk, requiring immediate action. For the Inuvik airport, for example, more than 400 combinations were identified, of which 90% resulted in a low risk. The remaining 10% were categorized as medium risk with no high risk identified. While climate change is expected to affect the airport infrastructure and maintenance practices, the current infrastructure resilience is sufficient so that no immediate action is required. However, measures will have to be implemented with time in order to prepare for the changing climatic conditions at these northern sites.

CONSTRAINING THE MAXIMUM AGE OF DEPOSITION OF THE AXIALLY-FED WINDERMERE SUPERGROUP, NORTHERN MONASHEE MOUNTAINS, SOUTHERN CANADIAN CORDILLERA

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U-Pb ages have been determined from detrital zircon samples from the Ruddock Creek property in the northern Monashee Mountains of British Columbia, within the southern Canadian Cordillera. Data was collected from sixteen samples using laser ablation inductively coupled mass spectrometry (LA-ICPMS). The ages determined in this study carry with them significant implications for the age of

stratigraphy in the region and allow for a comparison of stratigraphic ages previously determined. Most samples analyzed have age populations with strong North American basement signatures that ranges from Meso- and Paleoproterozoic to Neoproterozoic. Interestingly, four of the samples lack this signature; instead two of the samples have a prominent Grenville peak (ca. 1100 Ma), and all four samples have robust Neoproterozoic peaks at ca. 655 Ma, which is the youngest population of detrital zircon analyzed for all 16 samples. One other sample with a Paleoproterozoic peak at ca. 1800 Ma also has a prominent ca. 655 Ma peak. Herein, we focus on the five samples with probability peaks that occur at ca. 655 Ma, which provides the maximum age of deposition and when considered with the other age populations discussed above, supports previous interpretations that the metasedimentary sequence is, in fact, a southern continuation of the Mica Creek Succession of the Windermere Supergroup. Selected Neoproterozoic grains from three samples of the ca. 650 Ma population were further analyzed by isotope dilution thermal ionization mass spectrometry (ID-TIMS), providing ages from 682 ± 11 to 672.9 ± 3.8 and 663.4 ± 1.2 Ma. Trace element geochemistry (Nb/Th, Ti, Th/U, Eu/Eu* and Gd/Yb_{cn}) of these younger grains suggest they have been derived from rift-related magmatism. As such, the age and geochemistry for these zircon strongly suggest they were sourced from magmatic rocks associated with the Neoproterozoic rifting along the western Laurentian margin. However, there is no obvious regional source for the ca. 680-655 Ma zircon, nor is there in the Canadian Shield or from basement rocks beneath the Alberta basin. Comparison of the data from the current study and previous work done in Idaho suggest that the source of the Neoproterozoic detrital zircon is the Big Creek-Beaverhead belt, possibly including the Acorn Butte, Rush Creek Point and Ramey Ridge suites, as well as a tuff from Daugherty Gulch, all in central Idaho. We propose a model in which the sediments bearing these zircon were axially transported from southeast to northwest along the diachronously rifting margin of western Laurentia during the Neoproterozoic.

THE WHOLDIAIA LAKE SHEAR ZONE: TIMING CONSTRAINTS ON METAMORPHISM, DEFORMATION AND UPLIFT IN THE SOUTH RAE

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The Wholdiaia Lake shear zone (WLSz) is a newly recognized crustal-scale shear zone in the South Rae craton that parallels the northeast striking Snowbird Tectonic Zone (STZ) to the east. A distributed zone of mylonite (proto- to ultramylonite) ~3 to 10 km wide has been mapped along a ~200 km strike length and discontinuities in regional aeromagnetic maps clearly delineate this structure as occurring over 300 km long. The WLSz forms the boundary between two northeast trending lithotectonic crustal blocks, the Firedrake (west) and the Snowbird (east). Structural and petrologic characterization of these crustal blocks on a regional scale is being examined by a GEM-2 collaborative mapping campaign between the GSC and NTGS.

The Legs Lake-Chipman shear zone (LL-Csz) occurs ~100 km southeast of the WLSz and displays similar west over east oblique thrust-sense dextral kinematics. It defines a 500 km portion of the central STZ in North West Territories and northern Saskatchewan that bounds the Rae craton to the west and the Hearne craton to the east. This structure has been argued to be part of an intracontinental shear zone, as well as the site of Paleoproterozoic orogenic suture. Protracted deformation, retrogression and uplift along the LL-Csz at 1.85 to 1.80 Ga post-dates peak granulite-eclogite conditions at 1.9 Ga in the South Rae.

Strong similarities in length, kinematics and orientation of the LL-Csz and WLSz suggest there were at least two major crustal-scale structures in the South Rae facilitating uplift that was accompanied

by Paleoproterozoic exhumation. Detailed microstructural, thermobarometric and U-(Th)-Pb zircon and monazite analyses via SHRIMP are currently being conducted to elucidate the timing and duration of metamorphism and deformation related to the WLSz. The characterization of the WLSz will ultimately help decipher the complex tectonometamorphic history of the South Rae and shed light on the timing of exhumation of a large high grade metamorphic terrane.

THE COLOUR AND STEREO SURFACE IMAGING SYSTEM ONBOARD THE EXOMARS 2016 TRACE GAS ORBITER: INSTRUMENT OVERVIEW AND IMAGE SIMULATIONS USING MARS RECONNAISSANCE ORBITER (MRO) DATASETS

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The Colour and Stereo Surface Imaging System (CaSSIS) is an 11 μ rad/px imaging platform ready for launch on 14 March 2016 from Baikonur on the European Space Agency's (ESA) ExoMars Trace Gas Orbiter (TGO). CaSSIS is comprised of a telescope with an 880-mm focal length and a 135-mm primary mirror with a 10- μ m pixel pitch 2k \times 2k CMOS hybrid detector. From a 400-km circular orbit, CaSSIS will provide full-colour/stereo images \sim 9.5-km image swath up to \sim 47-km long and at \sim 4.6 m/px. The instrument is designed to operate as a "push-frame", collecting 2048 \times 256 images with a repetition rate matched to the ground-track velocity of the TGO (\sim 3 km/s) to facilitate co-registration of individual image strips into a final composite image.

CaSSIS points 10° off-nadir and will produce stereo images \sim 30 seconds apart by using a rotation mechanism. After the acquisition of the first image, the telescope rotates 180° to point in the opposite direction, and acquire the second image.

The filter strip assembly is mounted above the detector providing 4 wavelength-bands covering the visible-near infrared (VNIR) range. Prior to convolution with the instrument, the position of the first two bands are 480.5 nm and 676.5 nm, which correspond closely to the first two bands used by the HiRISE instrument on MRO; however, CaSSIS differs from HiRISE in that it has an additional NIR band (3 - 838 nm, and 4 - 985 nm) instead on one in this region (i.e., \sim 900 nm).

CaSSIS science objectives include: 1) characterization of potential source regions for trace gases by providing contemporaneous imaging with the other TGO instruments, 2) characterization of potential landing sites for future missions, and 3) investigating active and dynamic surface processes that may be linked to atmospheric gas inventories. Notably, the 74° orbital inclination of TGO is not Sun-synchronous; hence, imaging at different local times will be possible, facilitating the study of active diurnal processes on Mars (e.g., surface water activity, sublimation in the 55-75° latitudes, other transient weather phenomena, etc.).

CaSSIS colour/stereo images are anticipated to greatly complement previous and future datasets, and significantly improve upon surface colour-coverage and photometric constraints. This presentation will provide an overview of the instrument, science objectives and a summary of the work on simulating CaSSIS data using MRO datasets. Please see our two LPSC 2016 abstracts (led by N. Thomas and one led by L. Tornabene) for images and more details.

IDENTIFYING GEOLOGICALLY MEANINGFUL U-Pb AGE DATES IN FOSSIL TEETH

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Age dating attempts on fossil material have thus far yielded mixed results. While successes have been reported on single specimens, most fossils are thought to have experienced a complex history that obscures a simple determination of age. For this study, transects along the cross-section of 13 fossil alligatorid teeth from the Arroyo Chijiuilita Member (ACM) of the Nacimiento Formation, New Mexico, and tyrannosaur and crocodilian teeth from the Dinosaur Park Formation (DPF), Alberta were analysed for trace elements and U-Pb isotopes using laser ablation ICP-MS. The reliability of this method was supported by good agreement in the TIMS (61.5 ± 1.6 Ma) and laser ablation ICP-MS (64.9 ± 3.6 Ma) ages for a targeted tooth region.

The cross-sectional profile of Y in fossil teeth was found to be a good indicator of the extent of post-fossilization alteration. Four gradational Y patterns were identified; 1) Concentrations 2-3 orders of magnitude greater in the center of the sample than the edges, 2) Concentrations 2-3 orders of magnitude greater at the edges of the sample than the center, 3) Profile and concentrations intermediate between Pattern 1 or 2 and Pattern 4, 4) Flat Y profile at very low (DPF) or high (ACM) concentrations. Patterns 1 and 2 samples preserve fossilization-age signatures in some portions of the teeth, while Patterns 3 and 4 samples are associated with progressive disturbance of the fossilization-age signature and preservation of secondary age dates.

In the ACM, the U-Pb system preserved in the fossil teeth analyzed can be considered a mixing between the fossilization-age, low-Y center of a Pattern 2 sample (64.2 ± 5.4 Ma) and a Pattern 4 sample preserving an alteration age (25.7 ± 2.1 Ma) corresponding to the end of large-scale volcanic activity in the Four Corners region. In the DPF, the U-Pb data is defined by an age of 71.8 ± 9.4 Ma from a Pattern 1 sample at low $^{238}\text{U}/^{206}\text{Pb}$ and altered analyses skewing towards higher $^{238}\text{U}/^{206}\text{Pb}$ values. Alteration ages are \sim 49 Ma and \sim 33 Ma, but have not been tied to a known geological event. Presented here is a simple geochemical screen to determine the extent of post-fossilization alteration a fossil has experienced, such that samples most likely to preserve a fossilization U-Pb signature can be identified. Furthermore, teeth that do not preserve a fossilization-age signature are used to elucidate the nature and timing of post-fossilization alteration events.

EXPLORING THE BENEFITS AND BEST PRACTICES OF EMERGING STUDENT-LED, TECHNOLOGY-ASSISTED FIELD TRIPS

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The experiential learning opportunities inherent in field trips have long been recognized for giving students hands-on experience in applying concepts and building new skills. Unfortunately, the resource-intensive nature of field trips, in conjunction with growing operational and budgetary constraints among higher education institutions, has limited the time most students get to spend in the field. Even when traditional field trips are available, many disabled and distance education students are unable to participate, demonstrating that there is clearly a need for more flexible field experiences. One solution is to develop technology-assisted, virtual or augmented reality field trips that students can experience on

their own time and schedule. Examples of these ‘flexible’ field trips are being adopted by institutions across North America, leading to the innovation of new tools designed to simulate or enhance traditional field opportunities. While this generates new and exciting opportunities for engaging students, success in leveraging new or existing technologies, as measured by student learning, hinges on informed design and sound pedagogical practice. This presentation offers a preliminary assessment of the effectiveness of a joint collaboration of several institutions across BC to promote open access, virtual and augmented reality field trips for post-secondary environmental science and geoscience courses. It also provides evidence-based best practices for maximizing the pedagogical benefits for undergraduate students.

FOUR BILLION YEARS AND COUNTING: TEACHER-TESTED IDEAS FOR USING THE BOOK AND WEBSITE IMAGES IN MIDDLE AND HIGH SCHOOL CLASSROOMS

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A workshop focused on using the newly published 4 BY and Counting book and accompanying website was developed in response to a request from the Mitchell Odyssey Foundation (MOF) for a teacher professional development opportunity highlighting an innovation in Canadian Earth science. The MOF mission is to motivate and inspire grade 7 to 10 students to pursue careers in engineering and science, by providing resources, leadership and hands-on learning opportunities to enrich their educational journey in the world of science, technology and mathematics. The annual Wild About Science MOF Symposium reaches a group of highly motivated, MOF funded teachers from across British Columbia, and features keynote speakers and three choices of 45 minute long workshops. The 4BY workshop was held during the 2015 Symposium at Science World in Vancouver, and was attended by 21 teachers and educators.

The EdGEO funded workshop, “Four Billion Years and Counting - Canada’s Geological Heritage” shared teaching resources and hands-on activities to explore how Canada’s landscapes, fossils and rocks have changed and evolved over time. Following a brief introduction to the book and website, and discussion about the relationship between earth science and our lives, the workshop involved a series of hands-on activities using the 4 BY book and particularly images, which are available for free through the website www.fbycbook.com.

In activities developed to use the 4BY images, the goal was to pair images with a range of types of questions, first to solicit pre-existing knowledge and ideas, and then to build understanding. In many situations the former led to identification of misconceptions such as the difference between weathering and erosion, which could then be addressed. The activities explored topics such as the rock cycle, how rocks and fossils are used as evidence for paleogeographic reconstructions, and the relationship between landscape and geological heritage.

Teachers found the 4BY images and activities informative, engaging, inexpensive to recreate, and easily utilised /translated into the classroom. They liked the potential of the questions to get students thinking, analysing and looking at things in different ways. They appreciated the use of local and Canadian images; as one teacher commented “...so students can connect to where they live”.

Based on this experience, these activities will be tested more widely with the goal of making them accessible, together with other teaching resources being developed, to teachers to use with the book and website.

COMMUNICATING GORKHA-NEPAL GEOHAZARDS

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The April 2015 Gorkha-Nepal Earthquake provides an excellent case study to evaluate how geohazard risk specialists communicate the 2015 Gorkha-Nepal Earthquake Sequence geohazard risks. This research seeks to provide guidance for future initiatives that communicate geohazard risk for disaster relief and recovery efforts. This paper presents preliminary research results of innovative science data collection systems, new technological applications, information exchange platforms and information products utilized during the geoscience research response to the 2015 Gorkha-Nepal Earthquake Sequence.

MANAGING RADIOACTIVE MINERAL RISK: A MEDICAL GEOLOGY PERSPECTIVE

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To capture 20% of the global rare earth element (REE) market by 2018, Canadian REE mines will be brought into production. Radioactive minerals - a common co-occurrence of U and Th with REE mineralization - will be mined. To support the REE mineral exploration industry, First Nations, Mining Watch and others, this poster paper presentation introduces the results of our research to date, and suggestions for future research. Discussion focuses on how empirical evidence of geohazard risk may be framed as a human health risk assessment to manage the general public’s risk perceptions of radioactive minerals and potential proactive medical geology public engagement initiative models that may be utilized at the local, provincial and federal level.

UNTANGLING CONFLICT MINERALS IN THE GLOBAL MINERAL SUPPLY CHAIN: THE CONFLICT MINERAL CERTIFICATION PROCESS (2016-2020)

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This longitudinal project involved discovering how International and North American legislation support the global-local restructure of the Tantalum-Niobium (Ta/Nb) supply chain, and seeks to untangle mineral supply chains from violence, torture and war. Conflict mineral supply chain risk/reward researchers will find value in this study. Key topics investigated include: emerging tools, technological innovations (i.e. geochemical analytical tools) and best practices to establish global flows of Ta/Nb and standardize the Ta/Nb certification process. This work has been completed to support the sustainable development of African Great Lakes Area Ta/Nb industry supply chain in the forthcoming decade.

GROUNDWATER RESOURCES AND RISKS IN CANADA

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Municipalities and communities could have used geoscience information to reduce groundwater risk before the 2013 Calgary Floods and the 2015 drought conditions of British Columbia and Canadian Prairie Provinces. This poster paper presentation

acknowledges increased geoscience communication benefits those who wish to understand the relationship between Canadian groundwater resources and municipal and regional exploitation of groundwater. This poster paper will present several studies that detail how regional hydrogeologists communicate the anticipated impact of natural and anthropogenic influences to ground water protection and management agencies. In general, geoscience information and visualization platforms assist stakeholders to better understand interactions among geohazards, groundwater resources, and water quality/quantity issues.

DETRITAL ZIRCON FROM BONNETIA LINKS THE GAWLER CRATON OF AUSTRALIA TO NORTHWEST LAURENTIA AT 1.6 Ga

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The Wernecke Breccia is a set of 1.60 Ga hydrothermal breccia zones that crop out in northern Yukon, Canada. The host rock is the Wernecke Supergroup, a metasedimentary succession that was deposited on the Laurentian margin between 1.66 and 1.60 Ga. Clasts in the breccia zones were predominantly derived from the Wernecke Supergroup. However, a minority of the clasts were sourced from other units and have no affinity to local sources. These exotic clasts consist of plutonic, volcanic and sedimentary rock and are commonly tens to hundreds of metres across. The igneous clasts are interpreted to have come from Bonnetia, a non-Laurentian volcanic arc terrane that was thrust over the Wernecke Supergroup prior to 1.60 Ga.

Here, we focus on the exotic sedimentary clasts. They comprise red interbedded mudstone and sandstone, red conglomerate and green mudstone. Textures of the red clasts include contorted shapes and undulatory boundaries which we regard as products of soft-sediment deformation during Wernecke Breccia formation. The green mudstone occurs as streaks and patches among other clasts. The exotic sedimentary materials were sourced from unconsolidated to partly lithified sediments that overlay Bonnetia and foundered into the breccia zones as the breccia zones breached the surface.

Detrital zircon was extracted from the sedimentary clasts and analyzed via U-Pb LA-ICPMS and SHRIMP. Subangular zircon with ages from 1.78-1.68 Ga greatly predominate over less angular zircon with older Paleoproterozoic to Archean ages. This profile is unlike that of the Wernecke Supergroup and other units of northwest Laurentia. It is, however, similar to those of 1.76 – 1.67 Ga metasediments exposed on the Gawler Craton of South Australia. We speculate that Bonnetia was a source of zircon for the Gawler craton prior to 1.67 Ga and the source of juvenile sediment or tephra in Australian interior basins. Westward subduction beneath Bonnetia accommodated convergence between Bonnetia and Laurentia. After Bonnetia was thrust onto northwestern Laurentia between 1.65 and 1.60 Ga, it served as the main source of sediment for the unlithified red and green sedimentary units that subsequently foundered into zones of Wernecke Breccia at 1.60 Ga. The obduction of Bonnetia was broadly synchronous with the accretion of Australia to Laurentia, with the Gawler craton docking alongside northwest Laurentia. To accommodate this configuration at 1.60 Ga as well as a connection between northwest Laurentia and the North Australia craton at 1.5 Ga, we appeal to post-collisional sinistral displacement between the continents.

ION EXCHANGE REACTIONS IN RECLAMATION COVER MATERIALS FOR OIL SANDS MINE CLOSURE

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Transport of oil sands process affected water (OSPW) through reclamation cover materials could have impacts on aquatic and terrestrial environments being constructed in mine closure landscapes. Surface mining operations have to date disturbed more than 700 km² of boreal forest in the Athabasca Oil Sands Region of northern Alberta, Canada. Most of the tailings deposited within the post-mining landscape will be capped with reclamation covers constructed from surface soil materials including peat and till salvaged during mining. The chemical composition of pore waters within tailings is initially dominated by OSPW, which is characterized by elevated concentrations of sodium, chloride, and other constituents relative to the reclamation cover materials. During consolidation of underlying tailings – including composite tailings (CT) or centrifuge fine tailings (CFT) – pore water has the potential to migrate vertically through the reclamation covers. Exchange of sodium for calcium and other cations within these covers can degrade soil structure by causing clay dispersion and swelling, which in turn reduces infiltration capacity, hydraulic conductivity and plant available water. Increasing sodium concentrations in wetlands constructed on reclamation materials could also have elevated sodium concentrations can have detrimental impacts on the health of plants and aquatic organisms. The overall goal of this research is to quantify the cation exchange capacity and sodium attenuation under dynamic flow conditions within the individual reclamation cover materials. Laboratory column experiments were performed to examine sodium attenuation during OSPW migration through the reclamation cover materials. Field measurements were also performed at a reclamation wetland study site in the AOSR to examine these processes under field conditions. Integration of laboratory and field studies will provide important information on the capacity for reclamation covers to attenuate sodium derived from underlying tailings.

INITIATION OF ACCRETIONARY OROGENESIS AT PASSIVE MARGINS: IMPLICATION FOR CANADIAN OROGENS

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Many orogens, including those that frame northern Laurentia, have an early history as passive continental margins, but the related processes of subduction initiation and orogen initiation are poorly understood. One model, proposed early in the history of the “Wilson cycle” may be termed “inversion”: the spontaneous conversion of an extensional passive margin into an active margin by foundering of old, cold oceanic lithosphere; initial subduction is directed under the margin. An alternative process involves the collision with a passive margin of a pre-existing arc above a subduction zone directed away from the margin; subsequent reversal of subduction polarity produces an active margin.

The history of oceans formed since the breakup of Pangaea contains no clear examples of margin inversion, suggesting that spontaneous subduction initiation at passive margins is rare. In contrast, continent-arc collision appears common, and is occurring in at least two places (Taiwan and New Guinea) in the present-day tectonic system, in each case accompanied by ongoing reversal of arc polarity.

In the Appalachian-Caledonide system, rifting continued to at least ~550 Ma, producing an Iapetus ocean with numerous hyperextended passive margins and microcontinental blocks. Arcs were present in the developing Iapetus Ocean by 505 Ma as

recorded by ophiolites from New England to Scandinavia. Several arguments indicate that these arcs were not generated by passive margin inversion. Many show juvenile isotopic signatures. Also, the E. to M. Ordovician Taconian/Grampian orogens are interpreted as products of collision between arcs and the Laurentian passive margin, implying prior existence of subduction zones offshore. Approximately simultaneous collisions on the margin of Gondwana, leading to the Penobscot and Monian deformation events, is also hard to reconcile with coincidental margin inversion on SE side of Iapetus.

In an alternative hypothesis, we infer that subduction was initiated by incursion of arc systems from the external ocean into the young Iapetus, comparable to the recent migration of the Caribbean and Scotia arcs in the Atlantic. Almost simultaneous deformation on the Gondwanan and Laurentian margin of Iapetus can then be explained by interaction with a single, though complex and sinuous arc system. A parallel migration of arc systems across northern Canada (the Northwest Passage) has been proposed, introducing Caledonide elements into the Cordillera. It is therefore likely that orogen initiation in northern and western Canada was also a product of arc migration from adjacent oceans, and not spontaneous inversion of passive margins.

DELINEATING THE ALTERATION ZONE AT THE BIG EASY PROSPECT USING GEOPHYSICAL METHODS

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The Big Easy Prospect is a low-sulphidation (LS) style epithermal system located along the northern extension of the Burin Peninsula High Sulphidation Belt in Newfoundland. It is believed to have been formed during an extensional magmatic episode around the late Neoproterozoic. Despite its age, the Big Easy is well preserved which is likely due to rapid burial shortly after it was formed. Overlying sediments have since been eroded. Bladed textures and sinters observed at the Big Easy suggest that the present day surface is near that of the paleosurface. This is of interest since LS deposits are typically formed within the upper 250 m of the subsurface.

The property is covered extensively with overburden, including forests, bogs, and lakes and has limited outcrop exposure. Therefore, delineating the alteration zone has proved to be challenging. However, the physical property contrast between the silica altered zone and surrounding sedimentary units is significant enough to be detected using geophysical methods. Several surveys were conducted over the property, including magnetics, gravity, and ground penetrating radar (GPR) in an attempt to gain a better understanding of lateral and vertical extent of the alteration zone. These surveys were followed with 2 1/2 dimensional modelling and 3 dimensional inversion.

The magnetic susceptibility did not vary significantly between most units, except for mafic dykes which had much higher magnetic susceptibility than other units. The magnetic survey allowed identification of mafic dykes throughout the property. These dykes help in understanding the deformational processes that occurred after mineralization. Bathymetry maps of the bogs and lakes were created using data collected from the GPR survey. This allowed for proper corrections in the gravity data as well as more accurate modelling of the near subsurface. The gravity survey was the most effective for delineating the alteration zone since the altered material was slightly less dense than the surrounding units. The results of the gravity survey also provide a proposed depth of alteration but further drilling is required to confirm this conclusion.

GEOSCIENCE KNOWLEDGE AND EXPERIENCE REQUIREMENTS FOR PROFESSIONAL REGISTRATION IN CANADA

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A goal for many geoscience (geology, geophysics, physical geography, environmental geoscience) students in Canada is to become a Professional Geoscientist (PGeo) 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 (GC), 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 PGeo. This presentation outlines how regulators across Canada use this document, which will be of interest to students. In addition, information will be provided on a recent project undertaken by GC designed to outline the skills or competencies that a PGeo should have by the time of registration. This may include the completion of a particular course or set of courses during a B.Sc. program; others may be demonstrated via specific work experience.

The fundamental assumption in the GKE is that geoscience knowledge is gained through the equivalent of a 4-year BSc. degree in Canada, which includes 9 courses in "foundational" science (e.g. chemistry, physics, mathematics), and 18 courses in specific "foundational geoscience" subjects. In Quebec, the provincial regulators have accredited the programs at Laval, McGill, UQAC, and UQAM. Elsewhere, there is no formal accreditation process and so local regulators develop a list of courses that are available in their province that cover the required areas. This set of courses is used as a check list for each individual applicant. Students who might not have majored in geoscience, but who have taken the necessary courses can satisfy the requirements for registration. Also, part of the time in a graduate program may count towards the geosciences experience requirement for registration.

TIMING AND RATE OF DEGLACIATION OF THE MIS 2 CORDILLERAN ICE SHEET IN YUKON TERRITORY, CANADA

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The northern Cordilleran ice sheet (CIS) consisted of a series of quasi-independent ice lobes that coalesced during the last glacial maximum (LGM) to form a continuous carapace of precipitation limited ice over southern Yukon. Deglaciation of the northern margin of the CIS and its rate of recession from the LGM are poorly understood. We use cosmogenic nuclide exposure dating (¹⁰Be and ³⁶Cl) on groups of 3-4 glacial erratics to reconstruct the timing and rate of deglaciation. Our sampling concentrated on the St. Elias, Cassiar and Selwyn lobes, as well as an independent glacier from the Ogilvie Mountains.

Boulders sampled up-ice from terminal moraines show that the initiation of deglaciation varied regionally. ³⁶Cl ages from the Ogilvie Mountains indicate that deglaciation initiated by ca 23 ka. ¹⁰Be ages indicate deglaciation of the NCIS initiated first in the Coast Mountains and St. Elias lobes at 18.2 and 17.4 ka, respectively. Deglaciation of the Cassiar lobe initiated before 16.4 ka. For the Selwyn Lobe, two sites separated by ~150 km returned ages of 15.3 and 16.5 ka.

Rates of deglaciation are best constrained for the Cassiar Lobe with two transects along different flow lines. Multiple valley bottom samples in the mid-deglaciation setting at Whitehorse yielded ages of 13.7 ka, while one boulder from the adjacent ridge top 600 m above is 15.4 ka. In the accumulation zone, ice-free conditions occurred by 12.1 ka. The other transect has higher elevation samples in a mid-deglaciation setting in the Pelly Mountains that indicate deglaciation occurred by 13.7 ka. Samples taken from high elevation and valley bottom sites close to accumulation zones of the Cassiar Lobe yielded ages of 13.4 and 10.8 ka, respectively, indicating ice persisted in valley bottoms much longer than uplands.

These results provide a chronology for the style of deglaciation interpreted from regional mapping throughout Yukon: gradual initial retreat and thinning marked by moraines, followed by rapid downwasting and regional stagnation. Thinning of the ice to expose uplands in the Cassiar lobe was coincident with margin retreat. The increase in rates of deglaciation after 14 ka fits well with mapped evidence of regional stagnation. Early animal, and possibly, human migrants could have traveled along the uplands as these became ice free first. Early deglaciation of the Ogilvie Mountains may be a result of moisture starvation due to the Laurentide Ice Sheet reaching its all time maximum in the western NWT.

SUBDUCTION-RELATED MESOZOIC METASOMATISM AND DIAMOND FORMATION IN THE CONTINENTAL LITHOSPHERE UNDER THE NORTHWEST TERRITORIES, CANADA

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The Slave province in the Northwest Territories of the Canadian Shield has been intruded by over 300 known kimberlites. This allowed detailed studies of mantle-derived fragments (xenoliths and xenocrysts) from the continental lithospheric mantle (CLM) beneath the region. Many xenoliths originating from the Slave CLM reflect refertilisation and enrichment by mantle metasomatism, a key mechanism for controlling abrupt changes in the chemical and physical properties of the CLM globally. However, these deep lithospheric fragments are prone to chemical changes and overprinting by multiple enrichment/alteration events over time. In addition, the nature of the fluids involved can normally only be constrained indirectly from geochemical proxies or calculated using mineral/melt partition coefficients. Diamonds are different, as their physical strength and chemical inert nature allow pristine preservation of included minerals and fluids from the time of their diamond host formation. A fast growing form of diamond – ‘Fibrous’ diamonds – trap volatiles-rich high-density fluid (HDF) microinclusions, providing a unique opportunity for tracing deep fluid metasomatism.

We analyzed 11 microinclusion-bearing fibrous diamonds from the Fox kimberlite in the Ekati kimberlite cluster. Diamonds contain saline HDFs are solely associated with peridotite on the basis of their micro-mineral inclusions. Silicic fluid compositions are related exclusively to eclogitic inclusions. Striking differences between the two HDF compositions are the positive Eu and Sr anomalies within saline fluids versus no Eu anomaly and negative Sr anomalies in the silicic fluids. These characteristics are identical to previously studied HDFs in fibrous diamonds from neighbouring kimberlites in Ekati and Diavik, which also contains diamonds carrying high- and low-Mg carbonatitic HDFs. Combining the data, we show a clear chemical evolutionary trend, identifying for the first time saline fluids as parental to silicic and carbonatitic deep mantle melts, via fluid-rock interaction in the Slave CLM. Moreover, the trace-element and Sr isotopic fingerprints of subducting slabs and the timing of host diamond formation suggest that a subducting plate under western North America is the source of the saline fluids, which controlled metasomatism in the Slave CLM prior to Mesozoic kimberlite eruption.

COMBINING GEOLOGICAL AND GEOPHYSICAL DATASETS AT THE ACADIAN STRUCTURAL FRONT IN WESTERN NEWFOUNDLAND

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Major deep-seated basement faults were generated and reactivated during various phases of rifting and orogenesis associated with the building of the Appalachian orogen. Understanding the geometry and history of motion along these faults is vital in understanding their role in the petroleum system.

On the Port au Port Peninsula, these faults are interpreted to have a protracted history, starting during Proterozoic rifting, continuing during (Middle Ordovician) Taconian flexure, and undergoing later reactivation and inversion during Devonian Acadian deformation.

Petroleum interest farther north, in the Parsons Pond area of the Northern Peninsula, has warranted improved geologic mapping at large scale. In this region, the Acadian thrust front has traditionally been viewed as a narrow zone dominated by the Long Range thrust, along which the Long Range Inlier is interpreted to have been thrust over rocks of the platform and Humber Arm Allochthon.

Outcrop exposure along the Northern Peninsula is sparse, leading to difficulty in using only traditional geologic mapping for structural interpretations. Airborne geophysical data and 2D seismic profiles in the region are essential in interpreting the geologic data collected at the surface and extrapolating this information into 3D. The combination of available geophysical data with updated geologic mapping demonstrates that the region is more structurally complex than previous mapping has shown. Deep-seated thrust faults on the Northern Peninsula are structurally analogous to faults on the Port au Port Peninsula and may share a similar protracted history. The Parsons Pond thrust is a significant structural feature, juxtaposing rocks of contrasting tectonic environments. Current mapping suggests that the Parsons Pond thrust runs offshore at Green Point and its southern extent has not been previously defined. New aeromagnetic data and reconsideration of map relationships may give clues to a possible southern extension of this major thrust.

These new observations suggest a genetic linkage between deep-seated thrust faults in the southern and northern parts of the Newfoundland Appalachians. They suggest that the entire Acadian structural front, along the western margin of the Newfoundland Appalachians, may result from inversion of earlier normal faults. These new interpretations in turn may provide an improved foundation for oil and gas exploration in western Newfoundland.

CONTEXTUALIZED MULTILAYERED GEOSCIENCE LEARNING

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For the last 100 years K-12 education has been presented as decontextualized boxes of learning where topics are frequently only discussed once or twice over the twelve years of schooling. With the changes in education focussing on internet resources we need to be much more aware of the pervasiveness of this low-level learning in the broader context of educating about community. Recent curriculum revisions in British Columbia have resulted in learning outcomes focussed on “students will know .”. This is just as true about geoscience education as in the other academic areas. Students graduate with little or no understanding about mining, resource processing, climate change, or their environment for example. This session will introduce the complexity of geosciences understanding within these multiple contexts and suggest ways in which we can start to influence education at all levels in developing broader contextual understandings and move away from disconnected boxes of low-level memory work.

TEACHING PROJECT-BASED GEOARCHAEOLOGY – IN THE WINTER ... INDOORS

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Geoarchaeology involves applying many different geological techniques to the study of archaeological sites. In order to teach such techniques, I get my students to excavate a site of their own: but since it is a winter-term course, they excavate a fake site, which I have made in individual boxes, labelled according to a grid system, in the lab. Each student is responsible for excavating their individual box; together, all the boxes make up the site. The students are grouped into teams for the entire term, and each team is responsible for a certain section of the site, so they have to work in concert as they excavate. As they excavate, they set aside samples for dating, sediment analysis, etc. The dating samples, for instance, must be appropriately selected, properly obtained and handled, and sent to a “lab” (i.e., me) for analysis. They can also take samples to a chemist for analysis, e.g. of residues in a pot. They analyse the stone tools both as tools and as raw materials, and use geologic samples and a geologic map of the (fake) area to suggest provenance. They study the stratigraphy and reconstruct the environments of formation of the multi-layered site. And so on. At the end of the term each team describes their section of the site to the others, then they all work together and do a class presentation to invited guests, where they explain the complete site. Since there is no archaeology or geology degree programme on my campus of UNB, this course is an elective for all students, but it is at the 3rd-year level and has a prerequisite of one course in geology. Students come primarily from Science, but also Arts, Engineering, Nursing and Business. The course uses Team-Based Learning in a context where it makes sense to all involved that they should be in teams, but has enough of an individual component that students feel in control of their marks. There is also a peer assessment component on the final exam, for 10% of each student’s mark. The main benefit of this approach is the very stimulating level of engagement that the students demonstrate. They are figuring out their site, applying each technique as we learn it to their own samples, and working together towards a common goal. They take it all very seriously, and we have a lot of fun.

SHEETFLOOD DEPOSITS IN THE REVETT FORMATION, MIDDLE PROTEROZOIC BELT SUPERGROUP, MONTANA, USA

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The Middle Proterozoic Revett Formation in northwestern Montana, USA is a gray, fine-grained quartzite, siltite, and argillite lithosome that interfingers eastward into mudcracked purple argillite and coarse quartzite of the Grinnell Formation in Glacier National Park. Within the Revett lithosome are four, continuous, mostly argillitic, silty, and fine-sandy lithostrome units. Lithostromes 1,3,5, and 7 contain cycles about 10 m thick with purple, thin, mudcracked silt-to-clay couplets at their bases deposited by sheetfloods that crossed exposed playa lake flats and formed ephemeral lakes that spread from Glacier National Park westward across northwestern Montana and dried. Middle parts of the cycles contain sandy and muddy antidunes deposited by upper flow regime muddy sheetfloods with wavy surfaces that crossed the distal part of an eastward-advancing sand and mud plain. Tops of the cycles contain mostly tabular, flat-laminated sandy beds deposited in upper regime plane flow. Interstratified with the flat-laminated sand beds are trough crossbeds, climbing ripples, and muddy desiccation-cracked layers arranged in upward-fining and -thinning event beds. These kinds of tabular, flat-laminated, sandy event beds compose most of lithostromes 2, 4, 6, and 8.

Floods that deposited the Revett and Grinnell formations came from the west, south, and east sides of the basin, and, ponding of the floodwater shows that the basin within the Columbia (Nuna) supercontinent was internally drained. As sediments filled the playa lakes, base level rose, and rising base level projected across

the adjacent flat planes, limiting incision and the development of channels. Revett trough crossbeds occur in sheets, and no accretionary crossbeds of braided channels with nested trough crossbeds within them have been found.

IMAGING THE DEEP CRUST AND MANTLE ACROSS THE YUKON/NWT CORDILLERA – THE MACKENZIE MOUNTAINS EARTHSCOPE EXPERIMENT

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We are conducting a 5-year NSF-supported a field and analysis project within the northwestern North American plate boundary zone that transects its broadest region of deformation and which is integrated within EarthScope TA, PBO, and other historic community efforts now initiated in Alaska and Canada. The field project transects the Mackenzie Mountains (MM) region from near the plate boundary (where it is rooted within EarthScope Transportable Array and other instrumentation) to the Slave craton and Canadian Shield. The MM lie many hundreds of km inland from the plate boundary, but are presently deforming and seismogenic. The principal field effort of our proposal incorporates a transect of 40 broadband seismographs with a mean station spacing of approximately 20 km, coupled with an integrated program of campaign and continuous GPS studies. Although the region forms a key component of northwestern North American tectonics and deformation, most of the region is presently unsampled. We expect that these data will be broadly relevant to many groups, we are still be sharing our data and to pursuing relevant joint research elements with the EarthScope community, as well as Canadian and other international partners, throughout the project.

The MM are an active deforming zone far inboard from the main plate boundary (Yakutat terrane), while the region between the plate boundary and the mountains is relatively aseismic. Early uplift of the MM suggests that inherited lithosphere-scale terrane boundaries may also play a role in their location. A prevailing hypothesis (Mazzotti and Hyndman, 2002) to explain the anomalous characteristics of the MM is that lateral transport in the relatively aseismic zone occurs along a crustal or lithospheric-scale detachment, with little deformation between the Yakutat indenter and the eventual inboard collision with the craton. Constraining surface strain from GPS in association with seismic tomography and anisotropy studies will enable us to test/refine/refute this hypothesis for intraplate stress transfer and to understand the geometry and nature of interaction between mobile lithosphere and the craton in much more detail than has been previously possible in this remote area. We propose to query a number of testable predictions of this prevailing model, related to viscosity, lithosphere-scale structure, evidence for crustal/lithosphere scale detachment, the transition between mobile and cratonic lithosphere, the partitioning of strain between the mobile belt and craton, and the influences and depth extent of major faults (i.e., the Tintina fault), and the associations between high heat flow and volcanism and lithosphere through upper mantle structure.

EARTH SCIENCE BLOGGING: A PALEONTOLOGIST’S PERSPECTIVE

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Over the past six years I have produced two earth science blogs, one personal and the other hosted at the Manitoba Museum. This presentation will mostly consider my personal blog (www.ancientshore.com), because it has operated for many years and covered a variety of topics, and I have access to detailed statistics. In creating this blog, I did not worry overly about audience – if you write about things you find interesting, an audience will find you. Some pieces reach a broad age range, as indicated by many hundreds of comments and other correspondence. Comments

show that people are using the blog as a source of information, and correspondence comes from other scientists, interested amateurs, and schoolchildren.

Linkages are critical to blog traffic. I link to related blogs, and ensure that each new post is cross-posted to Twitter and Facebook. This increases the chance of re-posting outside the earth science world; many visits come via referrers and a science blogging “salon”. Considering impact, it is important to be based on a platform directly accessible to the outside web (e.g., WordPress); subscriptions are essential. A blog within an organization’s website reaches those who are already visiting that website and may be a useful marketing tool, but will receive little exposure. A compelling blog is in the voice of the individual creating it, with minimal control by organization or committee.

In a blog for a general audience, it is as important to be accessible as it is to be scientific. Material should be diverse since you want to be “refreshing” to return visitors, but at the same time it should be consistent. Always include photographs or illustrations. Some posts can be entirely photographic – these often get better visitation than the more scientific pieces (one photo post with over 100,000 views has greatly increasing the traffic to other posts). Ideas-driven pieces can get many views if they include unusual photographs, such as a post about graveyards as the basis for mortality curves.

Consider the “competition”: be aware of gaps in presentation of earth science on the web. Many of my most-read pieces are primary online sources for local or regional stories, topics like the sand in Lake Winnipeg beaches and the geology of Currie Mountain, NB. If you are a scientist, then share your own science in interesting ways – I have received good visits for posts on fossil jellyfish and on paleontological fieldwork in Manitoba.

THE GEOARCHAEOLOGY OF DEADMAN LAKE: LATE PLEISTOCENE LAKE LEVELS AND THE SEARCH FOR INITIAL HUMAN OCCUPATION

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Dineh lands (Northway Natives) surrounding Deadman Lake in the upper Tanana River region, Alaska, contain numerous archaeological sites reflecting a long history of occupation and use from the recent past to geological contexts of the early post-glacial period. Excavations at DML-9 in 2015 revealed lacustrine sediments below a loess stratum containing freshwater snail shells [of *Valvata sincera helicoides* (Dall, 1905) and *Stagnicola elodes* (Say, 1821)] dated to c. 15,000 cal bp (13.3 ka rybp), suggesting a high water stand c. 2.2 – 2.5 meters above the current lake level during the early post-glacial period, immediately preceding the Bolling-Allerød warm interval. Modelling this high stand over contemporary geography reveals additional lakeshore strands along which we might expect to find evidence of the initial human occupation of the region coeval with sites to the west (Swan Point) and east (Little John) in the Upper Tanana River basin c. 14,000 years ago.

STRUCTURE AND PRESERVATION OF OPHIOLITIC ROCKS IN OBDUCTED AND UNDERPLATED SETTINGS, AND THEIR ROLE IN CORDILLERAN OROGENESIS

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Ophiolitic rocks are a ubiquitous feature of collisional orogens, where they are commonly interpreted to mark suture zones along which major tracts of ocean and/or marginal basins have been subducted. Northern Appalachians preserve distinct ophiolite belts that were emplaced along the composite Laurentian in three different tectonic settings. The Bichy complex ophiolite formed during hyperextension of the Laurentian margin during opening of the Iapetus Ocean. This Ligurian-style ophiolite is characterised by poor preservation of crust, highly altered mantle and association with continentally-derived sedimentary rocks. The Baie Verte

oceanic tract supra-subduction zone (SSZ) ophiolites formed part of an outboard arc that collided with Laurentian margin resulting in emplacement of ophiolites onto the Laurentian margin. These structurally disrupted, Penrose-style ophiolites are characterised by exceptional preservation of mantle tectonites and lower crustal cumulates. In contrast, SSZ ophiolitic rocks in the Annieopsquotch accretionary tract were underplated beneath the composite Laurentian margin following initiation of subduction in the backarc. These Penrose-style ophiolites are characterised by excellent preservation of the upper and middle crust, but lack ultramafic cumulates and mantle tectonites which remained below the basal decollement and were subducted.

Northern Cordillera ophiolites are exposed in the Slide Mountain and Cache Creek terranes. Cache Creek terrane ophiolites are commonly interpreted to represent the subducting Panthalassa plate that was subsequently back-thrust over the arc. These ophiolitic rocks are characterized by SSZ chemistry and excellent preservation of mantle tectonite and intraoceanic ophiolitic structures, including Penrose-style pseudo-stratigraphy to the south and ocean core complex in the north. Comparison to the Appalachians indicates that preservation of extensive mantle is most consistent with obducted setting for the ophiolitic component of the Cache Creek terrane. This indicates that the Cache Creek terrane, as presently defined, combines unrelated elements of the overriding arc and subducting oceanic plate. The actual suture in this case is a shallowly dipping thrust fault located at the base of the ophiolite above blueschists and accreted Tethyan seamounts, rather than the younger steeply dipping Nahlin or King Salmon faults which are responsible for back-thrusting of Cache Creek terrane over Stikinia. Similar issues arise in the Slide Mountain terrane, where the low metamorphic grade ophiolitic rocks likely form part of the overriding arc.

LATE TRIASSIC TO EARLY JURASSIC MAGMATISM IN STIKINIA: IMPLICATIONS FOR PORPHYRY MINERALIZATION IN THE NORTH AND COMPARISON WITH THE NICOLA ARC

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Paleozoic to Mesozoic Stikinia is an abundantly mineralized arc terrane and the largest accreted crustal fragment in the Canadian Cordillera. Cu-Au porphyry deposits in Stikinia are important economic drivers; however, poor understanding of regional geologic setting and remoteness of terrain pose significant exploration challenges. Geomapping for Energy and Minerals (GEM) Cordillera project will help address these problems. Key GEM deliverables will synthesize existing regional geochronological and geochemical coverage and form a foundation for deciphering tectonic controls on magmatism, sedimentation and mineralization in the Late Triassic and Early Jurassic plutonic and supracrustal successions. GEM work in Yukon and northern British Columbia builds upon seminal studies by Woodsworth et al. (1991) and Anderson (1993) and comparisons with the relatively well-studied Nicola arc of the Quesnel terrane.

Triassic magmatism in northwestern Stikinia can be broadly subdivided into Stikine, Polaris and Copper Mountain plutonic suites. Prolific volcanic and coeval sedimentary rocks comprise the Late Triassic Stuhini and Lewes River groups. Stikine plutonic suite ranges from pyroxenite through monzogranite. The oldest phases of the Stikine plutonic suite, identified in the Sheslay area, yield ca. 229 Ma U-Pb crystallization ages and host coeval Cu porphyry mineralization (ca. 227 Ma Re-Os). The Stikine plutonic suite also comprises several petrographically distinct younger phases that yield U-Pb crystallization ages from ca. 225 to 215 Ma and host ca. 222 Ma Cu porphyry mineralization at Schaft Creek. Coeval Stuhini Group volcanism is characterized by eruption of voluminous augite and feldspar porphyritic basalt and andesite, and

rare dacite and picrite. The voluminous nature of magmatism and late, volumetrically small eruptions of ultramafic magmas suggest a thermal perturbation in the underlying lower crust and mantle.

The Copper Mountain plutonic suite is compositionally diverse, including distinctive silica-undersaturated plutons that host rich alkalic Cu-porphyry deposits, such as Galore Creek and range from ca. 215 to 200 Ma. The youngest members of this suite include the latest Triassic calc-alkaline plutons that host the Red Chris deposit. Alkaline rocks appear to form a north-trending belt, which is truncated or tectonically buried by the King Salmon Thrust to the north. The calc-alkaline rocks of this suite are generally restricted to a narrow corridor near Highway 37. On-going regional studies continue to test the age range and distribution of the Copper Mountain suite components. Comparison of Stikinia to the Nicola arc in southern British Columbia reveals significant similarities and differences.

THE EMERGING FOSSIL RECORD OF LAST INTERGLACIAL MAMMALS FROM EASTERN BERINGIA

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Much has been said about the Beringia as a refuge for arctic biota during the late Pleistocene. Rich fossil vertebrate records from Alaska and Yukon reveal the “mammoth fauna”, which was dominated by woolly mammoths (*Mammuthus primigenius*), bison (*Bison priscus*), and horses (*Equus* spp.) during the last glaciation. Large radiocarbon data sets have revealed detailed information on the paleoecology and demography for these mammals over the last 50,000 years. However, much less is known about the composition of mammal communities in Beringia prior that time, specifically for the relatively warm Last Interglacial period of Marine Isotope Stage 5 (~125,000 years ago). We have focused our attention to radiocarbon dating fossils from mammals which are rare in the regional faunas or ones that don’t seem to fit ecologically within the glacial “mammoth-fauna”, such as American mastodons (*Mammut americanum*), western camels (*Camelops hesternus*), flat-headed peccaries (*Platygonus compressus*), ground sloths (*Megalonyx jeffersonii*) and giant beavers (*Castoroides ohioensis*). Developing chronologies for these strange beasts has been a methodological challenge, but our results seemingly suggest they only inhabited eastern Beringia prior to 50,000 years ago and mostly likely during the last interglacial. But, new questions are emerging. If these mammals were so well-adapted to interglacial conditions, why did they not survive the last glacial-interglacial transition at the end of the Pleistocene? Or, what happened to the high-latitude glacial “mammoth fauna” during the last interglacial?

COMPARING AND CONTRASTING W-MO MINERALIZATION FROM THE SISSON BROOK, MOUNT PLEASANT, LAKE GEORGE, AND BURNTHILL DEPOSITS, NEW BRUNSWICK, CANADA

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The Sisson Brook (W-Mo-Cu, ca. 378 Ma, Re-Os molybdenite, unpublished), Mount Pleasant (W-Mo-Bi and Sn-Zn-In, ca. 363 Ma, U-Pb zircon), Burnthill (W-Mo-Sn) and Lake George (Sb-Au and W-Mo, ca. 412 Ma, U-Pb zircon) deposits are related to metaluminous to peraluminous granitoids, which exhibit transitional I-type to A-type granite signatures. They are generally evolved (> 65% SiO₂) and enriched in incompatible elements. The anomalous behavior of these elements was caused by a combination of crystal fractionation followed by aqueous phase saturation and separation, a process whose activity is corroborated by field and petrographic evidence (e.g., miarolitic cavities, myrmekite).

The faults and fractures, in both endo- and exo-granitic settings, offer conduits for hydrothermal ore fluid flow and deposition of mineralization. The contact metasomatic rocks vary considerably and control the proportion of wolframite and scheelite in stockwork veins and replacement zones. The skarn-like alteration at Lake George promoted scheelite deposition, whereas the decrease of the aFe/aCa in the Sisson Brook deposit produced scheelite rims on wolframite in some vein systems.

At the Lake George deposit, the scheelite and molybdenite deposition were controlled by decreasing temperature (a function of distance from cupola) and increasing pH (H metasomatism and CO₂ effervescence). For the Sisson Brook deposit, the consumption of K⁺ in the fluids during alteration destabilized the hydrothermal HKWO₃ and liberated Ca²⁺ ions to form scheelite. The formation of the porphyry W-Mo orebodies at Mount Pleasant were related to high fluid pressures caused by crystallization of the underlying granitic magma that led to fracturing and breccia formation.

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