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Lake to Lake

D'un lac à l'autre

St. Catharines 2004

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GAC-MAC
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St. Catharines 2004
D'un lac à l'autre

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St. Catharines is the site of the 49th Annual Meeting of the Geological Association as well as the Mineralogical Association of Canada. The meeting is being hosted by the Department of Earth Sciences of Brock University. On behalf of the Niagara Region, the City of St. Catharines and Brock University, the local organizing committee extends a warm welcome to our meeting.

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SM-01

SEDIMENTOLOGY - PROGRESS, PROBLEMS AND FUTURE DIRECTIONS

PROGRÈS, PROBLÈMES ET ORIENTATIONS À VENIR EN SÉDIMENTOLOGIE

BRUCE HART (MCGILL UNIVERSITY)

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SM01-01 **HISTORY OF SEDIMENTOLOGY IN CANADIAN UNIVERSITIES: PERSONAL REFLECTIONS**

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In 1954, when I arrived in Canada, sedimentology was barely recognized as a discipline distinct from stratigraphy. Herb Armstrong had studied with Pettijohn and Krumbein in Chicago. Frank Beales taught at McMaster from 1947 to 1951 (before moving to Toronto, where he received his doctorate in 1952). “Sedimentology” appeared in the 1947 Calender: probably the first such course taught in Canada, though some sedimentology was certainly taught elsewhere as part of stratigraphy courses. Zbigniew Sujkowski was appointed as a sedimentologist in 1953; he was killed in a drowning accident in 1954, and I was hired the following year. Roger Walker was appointed in 1966 (replacing Vint Gwinn, 1962). Sedimentologists appointed in other universities before 1980 included: Lerbekmo (1956) at Alberta; Murray (1965) and Church (1969, geography) at UBC; Oliver (1959), Klovan (1970), Derald Smith (1971, geography) and Wardlaw (1974) at Calgary; Donaldson (1968) at Carleton; Stanley (1963), Swift (1963), Schenk (1963), Gees (1967), Piper (1972) and Bowen (1973?, oceanography) at Dalhousie; Martini (1969) and Brookfield (1969) at Guelph; Roussell (1964) Copper (1967), Wolf (1970), and Roe (1975) at Laurentian; Mountjoy (1963) and Hesse (1969) at McGill; Klovan (1966) and Teller (1970) at Manitoba; King (1967), Slatt (1970), and James (1974) at Memorial; Lajoie (1963) at Montreal; Laming (1959) and Van De Poll (1972) at UNB; Rust (1964) and Veizer (1973) at Ottawa; Wardlaw (1960) and Hendry (1971) at Saskatchewan; Jopling (1966) and Greenwood (1967) at Toronto; Lawson (1966) at Waterloo; Young (1963) at UWO; and Simpson (1974) at Windsor. At most universities, the first appointments came in the mid 60s to early 70s, a period not only of major university growth, but also of the near extinction of stratigraphy, in favour of sedimentology.

SM01-02 CARBONATE SEDIMENTOLOGY: BACK TO THE FUTURE, FORWARD TO THE PAST

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Carbonate sedimentology has already a strong foundation of innumerable case studies, modern analogues, excellent textbooks, plus a number of conceptual themes available to guide and be tested. Certain factors assert their influence on what is achieved, such as the setting and background understanding of target units, time span for accomplishing doctoral research, individual versus group efforts, publishing pressures and publication venues, along with personal experience and approach. Focused on elaborating past events, stratigraphers normally shy away from predicting the future, but...

Variably sophisticated documentation and basic environmental interpretation will continue to occupy most activity, thereby contributing to the factual database, solving specific problems, and acting as the training ground for students. Thus, textbook-style generalizations will keep their considerable influence, but should be considered open to question, refinement and even refutation. Differences are just as critical as similarities. Understanding the evolutionary vagaries and subtleties of the 'carbonate factory' will be an increasingly important goal, whereby the changing biota and its contribution must be integrated with past ecology, climate, oceanography, tectonics and other global considerations. Modern analogues will therefore be put into better perspective. Carbonate platform dynamics will be further fathomed, but the peculiarities of epeiric seas will attract renewed interest, having been somewhat neglected in the sequence stratigraphic paradigm. Incorporating geochemical proxies will reveal vital aspects more or less invisible via visual observation. The interfaces between pure carbonates and other lithologies should provide new insight into the workings of the carbonate factory and its stratigraphic response. Stratigraphic packaging, including cyclicity, will continue to be addressed within the framework of rate and time, but beyond Milankovitch explanations; determining the three-dimensional expression will be necessary. Unconformities will be better appreciated, not just as bounding and correlative surfaces, but also as tangible indicators of environmental conditions and underlying processes that shut down the carbonate factory and often led to erosion-reinforcing that property of geology to be concerned with things that are absent in addition to those that are present.

Carbonate sedimentology remains a highly fertile, field-based discipline involving many profound issues with far-reaching implications. Students need to be exposed to its uniquely integrative nature and its vast intellectual canvas by learning to make careful observations at a variety of scales then interpreting them imaginatively by asking pertinent questions. Every geology department should have a carbonate specialist teaching an advanced undergraduate course with field trips. Carbonate sedimentology is vital to the petroleum industry.

SM01-03

INVESTIGATIONS OF BURIAL DIAGENESIS WITH REFERENCE TO HYDROCARBON EXPLORATION AND EXPLOITATION

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The hydrocarbon reservoir properties of most sedimentary rocks are governed by diagenesis because they spent most of their lives at considerable burial depths. Hence, investigations of burial diagenesis are instrumental for hydrocarbon exploration and exploitation.

Diagenesis is governed by various intrinsic and extrinsic factors that include thermodynamic and kinetic constraints, as well as microstructural factors that may override the others. These factors govern diagenetic processes, such as cementation, dissolution, compaction, recrystallization, replacement, and sulfate-hydrocarbon redox-reactions. Cementation, dissolution, and dolomitization require significant flow of groundwater (of whatever type and/or salinity, ranging from fresh to hypersaline), driven by an externally imposed hydraulic gradient. Other processes, such as stylolitization and thermochemical sulfate reduction, commonly take place without significant groundwater flow in hydrologically nearly or completely stagnant systems that are geochemically closed.

Two major effects of mineral diagenesis are enhancement and/or reduction of porosity and permeability. However, these rock properties can also remain essentially unchanged through diagenesis at depths from near-zero to several kilometers. In extreme cases, an aquifer or hydrocarbon reservoir rock can have highly enhanced porosity and permeability due to extensive mineral dissolution, or it can be plugged up due to extensive mineral precipitation.

A proper investigation of diagenesis with the aim to assist in exploration for and exploitation of hydrocarbons should follow the "4(5)-step process". Step 1: facies analysis (including establishing the primary porosity and permeability distributions, and the primary aquastratigraphy); Step 2: petrographic analyses (paragenetic sequence, mapping amounts and spatial distribution of diagenetic phases); Step 3: geochemical analyses (isotopes, trace elements, fluid inclusions, etc.); Step 4: interpretation of diagenetic history (may require additional sedimentological and/or other data from surrounding rock units); Step 5 (not necessary, but desirable in at least some cases): modeling.

SM01-04 CLASTIC SEDIMENTOLOGY: PAST, PRESENT AND FUTURE

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Although it can be argued that clastic Sedimentology began when our Paleolithic ancestors started searching for clasts of chert, rhyolite and quartz-arenite to make tools over 50,000 years ago, the first surviving observations were by made by Greco-Roman philosophers including Herodotus, Plato and Homer. Despite comments by Leonardo da Vinci (1452-1519) on lithification and fossils in clastic deposits of the Arno River, and the recognition by Agricola in 1556 that fluvial processes were important in the localization of gold deposits, the serious study of the subject began only a few hundred years ago with the publication in 1830 of Lyell's Principals of Geology, and subsequent observations on the hydraulic significance of cross-stratification by Sowerby. Much of the early literature is concerned with nomenclature, stratigraphy and refuting evidence that the presence of exotic pebbles and boulders was evidence of a biblical flood. Major compilations by Twenhofel in 1925, Cayeux in 1931 and Pettijohn in 1949, provided a solid foundation for the rapid expansion of the science in the early sixties. Many studies at this time were centered on quantification of grain shape, size, populations and hydraulic significance often made within the framework of process-response models. Work on facies models, begun by Lyell and Sowerby flourished, with work on turbidites by Kunen, Bouma, and Walker, and fluvial deposits by Allen. This flourished in the 70's and 80's with a rapid expansion in the understanding of both modern and ancient facies. Concepts of global stratigraphy, initially introduced by Sloss and Wheeler in the 60's were later developed into models sequence stratigraphy by Vail, Posamentier, Van Wagoner, Miall, Embry and others into a variety of schemes which provide a framework for understanding the evolution of systems tracts within the framework of basin evolution. The most recent advances in understanding of clastic rocks have come as a direct result of the introduction and development of 3D facies architecture by Allen, Bridge, Fielding, Miall and others. With the progressive refinement of this approach, combined with GPR, LIDAR, 3D computer modeling, zircon and xenotime dating, it should be possible to refine clastic facies models to such an extent that the morphodynamics of ancient systems can be understood, and the physical properties of facies tracts be modeled with increasing certainty. The future of the field is up to you.

SM01-05 SEQUENCE STRATIGRAPHY - EARLY IDEAS, CURRENT CONFUSIONS, AND FUTURE DIRECTIONS

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Sequence stratigraphy provides the genetic framework for understanding the evolution and architecture of sedimentary basins. Unconformity-bounded sequences have been defined since the beginning of the past century as units reflecting cyclic changes in base level, which can be used for stratigraphic correlation and the subdivision of the rock record into genetically-related packages of strata. The limitation imposed by the lateral extent of sequence-bounding unconformities, potentially restricted to the basin margins, required a refinement of the early ideas by finding a way to extend sequence boundaries across an entire sedimentary basin. The definition of “correlative conformities”, which are extensions towards the basin center of basin-margin unconformities, marked the birth of modern seismic and sequence stratigraphy.

While the genesis and timing of unconformities are well understood and agreed upon, the nature and timing of their correlative conformities have been a source of contention ever since their conceptual birth in the 1970s. As a result, a number of different models are currently in use, each promoting a unique set of terms and bounding surfaces. This creates unnecessary jargon and confusion, and represents a barrier in the way of communication of ideas and results. A few reasons for this variety of approaches in sequence stratigraphy include: (1) the underlying assumptions regarding the primary controls on stratigraphic cyclicity; (2) the type of basin from which models were derived; and (3) the gradual conceptual advances that allowed for alternative models to be developed. Present-day sequence stratigraphy can thus be described as a still developing field that takes the science of Sedimentary Geology in an exciting new direction of conceptual and practical opportunities, even though along a bumpy road punctuated by disagreements and controversy.

Despite the lack of formal standardization of sequence stratigraphic concepts, a ground truth emerges in the sense that terminology is trivial and that the rocks remain the same regardless of the model used for their conceptual packaging. A bridge must therefore exist between all models. The “pulse” of sequence stratigraphy is fundamentally represented by shoreline shifts, whose nature and timing control the formation of all systems tracts and bounding surfaces. Beyond nomenclatural preferences, each stage of shoreline shift (normal regression, forced regression, transgression) corresponds to the formation of a systems tract. Surfaces that can serve at least in part as systems tract boundaries are sequence stratigraphic surfaces. These fundamental principles are common among all models, and allow for a unified sequence stratigraphic approach.

SM01-06 PETROLEUM GEOLOGY: CHALLENGES FOR THE 21ST CENTURY

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The petroleum industry, long one of the major employers of sedimentary geologists, is commonly viewed as a "sunset industry" by the public, politicians, university administrators and even many geoscientists. This negative perception is fueled by concerns for the environment (e.g., pollution, global warming) and/or much publicized impending shortages. The reality is that the next several decades will see a strong growth in demand for new petroleum geoscientists. Fossil fuels (primarily oil and gas, but also coal) satisfy approximately 80% of global primary energy demand, and growth forecasts suggest a 66% higher energy demand by the year 2030. Alternative energy sources (solar, nuclear, wind), or conservation, will not be able to fill these needs quickly and hydrocarbons will have to found and exploited until new sources of energy are readily (and cheaply) available. Two other trends strengthen the need for bright young minds to become petroleum geoscientists: a) hydrocarbons are becoming increasingly difficult to find, and b) demographics of the petroleum industry suggest that many current employees will be retiring within the next 5 to 10 years but there are very few young people entering the field to replace them.

Technology, in particular 3-D seismic technology, is increasingly being exploited to help reduce exploration risk (offshore exploration wells in deep water can cost many 10s of millions of dollars) and to maximize recovery from existing fields (some oil reservoirs may produce only 10% of the oil in place via "primary production"). This technology is erroneously viewed by some geoscientists as an end in itself, as a threat (more computers, fewer people) or as reducing the need for critical thought. In fact, 3-D seismic technology is best seen as a tool that can help geoscientists to understand sedimentary deposits. Limits on seismic resolution, non-unique seismic responses, processing and acquisition artifacts and other problems, demand that 3-D seismic data be integrated with other data types, such as core, wireline logs and other "geologic" data sets. A truly integrated project allows multiple scales of observation (grain scale to 3-D seismic) to be integrated, and the result typically is a more robust and deeper understanding of the stratigraphic units being studied. Appropriately armed, sedimentary geologists in the petroleum industry are addressing fundamental and applied problems that have hitherto been unimaginable.

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HUMMOCKY CROSS-STRATIFICATION AND OTHER SHALLOW-MARINE STRUCTURES: > 25 YEARS AND STILL THE DEBATE CONTINUES

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The fuel “crisis” of the mid to late 1970s instigated an explosion in research of the shallow marine. An early development of that work was the recognition of episodes of sand transport and deposition that interrupted otherwise quiet, suspension-dominant (mud) sedimentation. Within the interbedded sandstones was a style of cross-stratification termed hummocky cross-stratification, or simply HCS, by Harms et al. (1975). They attributed this new sedimentary structure to deposition during high-energy storm events, but provided no detailed discussion on the mechanisms of its origin. Since then the origin of HCS has been the subject of much debate, although the rigor of the debate has become somewhat more muted over the past several years. Nevertheless, the origin of HCS, and more profoundly sand transport on continental shelves, are still poorly understood, and hence a major impediment to accurately interpreting the shallow-marine sedimentary record.

And if that wasn’t enough, the recognition of combined flow and its influence on sedimentation patterns and characteristics in modern and ancient shallow-marine sedimentary environments has further complicated an already cloudy debate. Furthermore, the effect of bed aggradation rate has all but been ignored. Recently, however, important advances to these and many other questions have been made on a number of research fronts, including observations in the ancient and modern shallow marine records and flow-tunnel experimentation. Results from experiments suggest that the formative conditions for HCS and SCS are in fact rather restrictive: purely oscillatory or significantly oscillatory-dominant combined flows, and respectively, high versus low rates of bed aggradation. Combined-flows with moderate to strong unidirectional components, however, are rather common in modern shallow marine settings, suggesting that some, if not much (most?) of the shallow marine sedimentary record should consist of combined flow stratification. However, a perusal of the shallow-marine literature would suggest that combined flows are a geological rarity, rather than the norm, and that the shallow-marine sedimentary record was deposited almost entirely under purely oscillatory or significantly oscillatory-dominant combined flow conditions. An important question, therefore, is the cause for these apparently contradictory points of view, and therein a major direction for future sedimentological research.

SM01-08

SEDIMENTATION IN GLACIATED ESTUARINE VALLEYS AND APPLICATION TO ENVIRONMENTAL ASSESSMENT

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Glaciation resulted in the deposition of thick valley-fill sediments that now underlie many urban centres in Canada and the United States. Valleys that were inundated during deglaciation (estuaries, embayments), represent the thickest deposits and greatest stratigraphic complexity due to the interaction between glaciers and marine incursions. Interpretation of this sedimentary architecture often poses difficulty to engineers and planners responsible for acquiring and protecting potable municipal water sources and identifying other geotechnical or environmental constraints to urban development. Two common problems are, (1) the misinterpretation that the supply aquifer, overlying till or bedrock and in turn overlain by fine-grained sediments, is wholly confined and protected from surface contamination; and (2) the occurrence of sensitive sediments.

Studies at Fredericton and Sussex, New Brunswick, typify the sedimentology and environmental problems associated with estuarine valley sites. Here, surface water is linked to groundwater aquifers within a predictable sequence of deposits that can be delineated by three-dimensional mapping of the stratigraphic units. Both cities are located along rivers and overlie their supply aquifer, buried at some depth. Underlying sediments are more than 80m thick in the valley centre and include variable clay/silts (marine mud and laminated glacilacustrine clay-silt) intercalated with glacifluvial sand and gravel, underlain by a clayey lodgement till and capped by a post-glacial clay/silt and granular alluvium at surface. At both locations, late-glacial and Holocene fluvial scouring of the underlying fine-grained units created vertical pathways allowing contaminants to be transmitted into the aquifers.

At Sussex, New Brunswick, dissolved perchloroethylene (PCE) in concentrations to 1.6 μg/l were found in the aquifer that serves as the main source of municipal water supply. The PCE originated from a former laundry establishment near the urban centre. At Fredericton, minor petroleum contamination was found in near-surface sediments, mainly from residential oil tanks and infrequent gas station leaks. In addition, the marine clay/silt unit is highly sensitive to disturbance and vibration and represents a potential hazard to nearby structures from construction activities and seismic events.

These studies exemplify the growing demand for three-dimensional stratigraphic mapping as a precursor to land-use, groundwater supply, legislation or litigation. Computer technology can now facilitate large GIS and DTM data sets to produce striking graphic visualizations of subsurface data. However, an understanding of rudimentary sedimentology remains the fundamental tool for assessment of conductivity and contaminant pathways. This tool is often the missing link in the acquisition, analysis and interpretation of data for such assessments.

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SM01-10 OFFSET EARLY ORDOVICIAN DEPOSITIONAL CYCLES 1500 KM DISTANT ALONG THE LAURENTIAN MARGIN; EUSTASY WITH IMPRECISE BIOSTRATIGRAPHY OR TRUE REGIONAL VARIATION?

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An apparent slight temporal offset in Early Ordovician (Tremadoc, Arenig) depositional sequences of potential 3rd-order eustatic origin along the Laurentian margin, is used to underscore a continuing problem in sedimentary basin analysis: secure chronostratigraphic frameworks versus inferred correlation by sequence stratigraphy. Recent study of the Early Ordovician Theresa Formation in the Ottawa Embayment (inboard of the Quebec Reentrant) has revealed a T-R depositional cycle apparently spanning the Tremadoc-Arenig boundary. It overlies a regional unconformity that possesses evidence (grains of quartz with quartz cement overgrowth) of significant uplift and erosion of the underlying Potsdam Group sandstones within this craton interior region. A tripartite division of peritidal (siliciclastics), subtidal (normal marine dolostones), then peritidal (mixed siliciclastics-carbonates) characterizes the regional vertical facies distribution of the Theresa Formation. This division is traced seaward into the Quebec Laurentian platform. To the northeast, about 1500 km distant, previous work has defined two peritidal-subtidal-peritidal depositional sequences both thought to be of 3rd order eustatic origin. The first occurred wholly in the Tremadoc (with peak transgression during the middle Tremadoc), and the second occurred wholly in the early Arenig. A subaerial unconformity separates the two cycles.

A comparison of relative sea level curves from these two sites shows similarities in timing for parts of each individual sea level history, but peak trangression of the Theresa cycle appears to coincide with subaerial erosion on the Newfoundland platform. Does the temporal offset of peak trangression just reflect imprecise biostratigraphy? Or is there real regional variation in sea level along this platform segment of the Laurentian margin? The latter might be expected due to regional differences in subsidence/uplift patterns, interacting with eustasy, because of different tectonic settings; a continental reentrant (Quebec) versus promontory (Newfoundland). There is also growing evidence for Ordovician tectonism within the Ottawa Embayment that highlights a less than passive interior craton linked to tectonic development of the initial Iapetus Ocean basin. Both tectonic and eustatic signatures may be contained in the history of Ordovician sea level in the northern Appalachians.

SM01-11 EXPLORING IN UNEXPLORED BASINS - THE CANADIAN MARITIMES

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Exploration in areas of the Maritimes Basin which have not been drilled require several steps before drilling tests can be conducted. Surface geology combined with geochemical testing is the initial format CNR pursued in this endevor. Subsequent Aeromagnetics and Gravity data were acquired to characterize potential basin development with known basins in this geologic province. After developing analogus target areas confirmation via 2-D seismic reflection surveys were run to document the presence of sedimentary basins. Drill sites will be selected from the seismic to confirm the presence of suitable formations and traps to make way for successful hydrocarbon exploration in one of many untested basins in the Maritimes area of New Brunswick.

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SM01-12 LITHOFACIES RELATIONSHIPS AND STRATIGRAPHIC CORRELATIONS IN DEVONIAN BACKREEF SUCCESSIONS, CANNING BASIN, AUSTRALIA

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Upper Devonian reef complexes in the Canning Basin of northwestern Australia are world-class examples of paleoreef systems and they are well known for their excellent exposure of back-reef platform-to-basin relationships. However, stratigraphic correlation within and between platform successions has been hampered by the lack of continuous exposures of coeval platforms.

Frasnian back-reef platform successions in the Hull Range and Guppy Hills are the most northerly (landward) of the older platforms exposed in the southeastern Lennard Shelf of the northern Canning Basin. These successions exhibit considerable lateral facies variation and lack distinctive marker beds and stacking patterns, making facies and stratigraphic analysis a challenge. The integrated approach to this study, using lithofacies relationships, biostratigraphy and chemostratigraphy, has demonstrated the stratigraphic equivalence of these successions and their variable cyclicity. Four major facies associations have been recognized in the Hull Range and Guppy Hills successions: (1) deep subtidal, (2) shallow subtidal, (3) stromatoporoid bioherms-biostromes (shallow subtidal), and (4) peritidal. These facies associations are used to divide each succession into depositional units, 10-55 m thick, which in turn provide a preliminary basis for correlation. Metre-scale shallowing-upward cycles are variably developed, occurring in only some depositional units. A paleokarst surface in the Hull Range successions provides a key stratal marker for correlation. Two successions in Hull Range and Guppy Hills were used to test the viability of using isotopic carbon, oxygen and strontium data in correlating platform strata. Stratigraphic plots of $\delta^{13}C$ and delta;^{18}O values for the two successions show a similar pattern and the paleokarst surface in the Hull Range section shows a distinctive positive excursion. $^{87}Sr/^{86}Sr$ results appear to be unusable for correlation because of probable contamination from siliciclastic muds.

SM01-13 PARALLEL LAMINATION FORMED BY HIGH-DENSITY TURBIDITY CURRENTS

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Experiments were conducted in order to investigate processes of sediment transport and deposition from sustained turbidity currents with initial volume-fraction sediment concentration of 0.20, 0.25 and 0.35. Under such conditions most sedimentologists would not expect parallel lamination to form. However, parallel lamination was formed, and at bed-aggradation rates up to 4 mms^{-1} and bedload-layer sediment concentration up to 0.36. These results, therefore, contradict the generally held assumption that parallel lamination forms only from low-density flows and at low bed-aggradation rates. In addition, the results suggest that it is not possible to estimate flow concentration or aggradation rate based on the presence or absence of parallel lamination in the geological record, and the debate on the upward change from massive (Ta) to parallel laminated (Tb) sand in a Bouma-type turbidite remains unresolved. The experiments described here serve to illustrate our poor understanding of threshold values of grain-support mechanisms in the bedload layer, and in turn the boundary conditions for the formation of some sedimentary structures.

SM01-14 **DIAGENETIC HISTORY AND HYDROCARBAN MIGRATION IN FARAGHOON FORMATION, SOUTHEASTERN IRAN**

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A prominent feature of the Permian succession in southern Iran is the common occurrence of disconformable sandstone beds at the base. The Permian transgressive sea deposited the basinal clastic and shallow epicontinental carbonates. The Lower Permian Faraghoon Formation composed of thick silisiclastic units with minor carbonate content is 200 to 420 meters thick. Generally the formation is made up of braided plain, channel fill, and eolian sandstones and siltstones that were deposited in semi-arid condition. They are replaced basinward by braid plain deposits overlain by shallow-marine near-shore sediments to essentially shallow marine sands. The thickness of these clasics is variable due to onlap on the Hercynian structures.

The Faraghoon Formation in southeastern Iran represent a supratidal to lower shoreface facies and are considered a hydrocarbon carrier bed in the area containing numerous thin dolomitized carbonate horizons. Major oil reserves have been discovered in Central Arabia within Permian and carboniferous sequences.

Based on petrographic, cathodoluminescence and stable isotope investigations, quartz cementation and two types of dolomite have been identified in this formation:

a) Non-luminescent dolomite with $\delta^{13}C$ ranging from +1.6 to +2.6 ‰, and depleted ^{18}O ($\delta^{18}O$ = -3.6 to -7.3 ‰) indicating precipitation due to dissolution and recrystallization of fine-grained early diagenetic dolomite without a net supply of Mg. The observed geochemical and textural evidence confirms this.

b) Luminescent saddle dolomites, showing negative d13C (-5.0 to -4.3 ‰ PDB) and $\delta^{18}O$ (-5.3 to -1.4 ‰) indicating precipitation due to oxidation of organic matter under high temperatures regime, prior to hydrocarbon migration.

Illitization, which is pervasive in the underlying organic-rich Silurian shales, could have provided magnesium for dolomite precipitation. Hydrocarbons have altered kaolinite to illite at high temperatures with contemporaneous silica cementation of sandstones.

Formational fluids required for dolomite and quartz cementation of the Faraghoon Formation was introduced from underlying shales which are also considered the source rocks for hydrocarbon, due to compaction driven upwards-directed flow, causing cement precipitation and hydrocarbon migration. Diagenetic minerals formed under such geochemical conditions may prove to be extremely helpful in identifying potential reservoir formations.

SM-03

PAUL F. KARROW SYMPOSIUM – REVIEWS AND REFLECTIONS ON QUATERNARY SCIENCES

SYMPOSIUM PAUL F. KARROW: ÉTUDES CRITIQUES ET OBSERVATIONS SUR LES SCIENCES DU QUATERNAIRE

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SM03-01 FOSSIL INSECT RESEARCH IN CANADA, A WATERLOO PERSPECTIVE

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Fossil insect research in Canada goes back to the late 1800s when Samuel Scudder received materials sent by Colemen from the "Toronto interglacial" deposits. Modern research has determined that most of the names provided by Scudder for the "Scarboro' insect fauna" are invalid, and that the specimens submitted came from two different assemblages, one last interglacial and the second of early Wisconsin age.

P.F. Karrow was instrumentally responsible for renewing fossil insect research in the Toronto region and subsequently at many other deposits in southwestern Ontario and elsewhere. Fossil insect assemblages have assisted in the determination of past climates of both the Sangamon interglacial and, rather patchily, in various parts of the Wisconsin. The results of this research have thrown light on the migration and timing of the movement of the Canadian *Coleoptera* fauna through the last 120,000 years in various parts of Canada and the adjacent United States. Of particular importance has been the post-glacial colonisation of beetles across eastern North America. Beetle assemblages have elucidated the nature of the climate in the maximum Wisconsin advance regions of the United States and in the areas exposed as the ice retreated northward. Of special interest are the "earliest" beetle assemblages exposed at the base of kettle holes.

Many insect assemblages have been associated with sites that have revealed other mega-fossils such as the mammoths and mastodons, and these have helped add to the paleoenvironmental picture of the fossil sites. Modern ecological work has also been undertaken to determine where the fossil assemblages might best fit into today's climate in 9 different parts of northern Canada and Alaska or whether "non-anologue" conditions prevailed. Modern collecting has substantially modified known ranges of modern *Coleoptera* that are found in Quaternary deposits, thus refining paleotemperature and ecological information that can be applied to sites of Late Pleistocene age.

SM03-02

CARBON DATES ON HISTORICALLY COLLECTED QUATERNARY FOSSIL VERTEBRATES FROM THE DON VALLEY BRICKYARDS AND THE SHAW ST. PITS, TORONTO

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The classic late Quaternary deposits of the Don Valley Brickyards (DVB) were first made famous by pioneering glacial geologist A.P. Coleman. Subsequent studies over the last century, especially those of Karrow and his students, have continued to document the interglacial nature of the Don Formation. Organic materials in the Don Formation are beyond carbon date, so the age of this formation is unknown, but it is suspected to be around 125,000 years BP. Upwards of 500 species of fossils have now been identified from the DVB beds, mostly plants and microfossils, but the vertebrate remains from this site have received little attention. Karrow's 1990 summary paper lists only eight species, with another dozen or so fish taxa currently under study by Cumbaa, recovered through Kerr-Lawson's screenwashing efforts.

The historically collected larger vertebrate fossils from the DVB, many from Coleman's own collection and stated by him to be from the Don Formation, are in the Royal Ontario Museum collections. However, Coleman did not give actual stratigraphic level data for any of these specimens. Carbon dates on four of them range between 23,800 and 35,110 (+/- error) years BP, considerably younger than expected. This would suggest that these bones were not derived from the Don Formation, but from one of the younger overlying units. A fifth bone dates to 3,320 +/- 60, and therefore is probably from the Iroquois beach level, at the top of the sequence, or from another locality altogether.

Two additional bones were collected in 1967, one by Karrow himself, from another stratigraphically younger layer, later named by Karrow in 1974 as the Pottery Road Formation. Unlike the historically collected fossils, these two bones have a recorded stratigraphic level. The Pottery Road Formation, which cuts into the underlying Early Wisconsinan Scarborough Formation, is also thought to be Early Wisconsinan in age, perhaps dating to about 80,000 years BP. These two bones carbon date at 21,270 +/- 300 and 33,120 +/- 380 years BP, in the same range as the four historically collected bones, and again considerably younger than expected.

Finally, three historically collected bones from the Shaw St. pits (Bloor Street and Christie Street area) whose sediments have been correlated with the Pottery Road Formation by Karrow, carbon date between 27,620 and 33,060 (+/- error) years BP.

Although the congruence of these nine dates is striking, they are at odds with previous conclusions as to the ages of these units. New specimens with stratigraphic level data, from units above the Don Formation, need to be collected and dated before this dilemma can be resolved.

SM03-03 POSTGLACIAL ECOLOGY OF THE HAMILTON-CAMBRIDGE AREA: A TRIBUTE TO PAUL KARROW

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In his 1963 and 1987 publications on the Pleistocene - Quaternary Geology of the Hamilton-Galt/Cambridge Area, Karrow included four radiocarbon dated pollen diagrams; the three from bogs had pond mud beneath surficial peat. Radiocarbon dates near the bottoms of the cores provided minimum ages for local deglaciation.

Subsequent pollen studies have shown that: (1) proglacial Lake Whittlesey clay was dominated by recycled pollen and therefore was useless for paleoecological reconstruction; (2) postglacial pollen zones were dominated sequentially by spruce, jack pine, white pine, beech-maple-hemlock, oak-white pine and ragweed; (3) during the Early Holocene, a decline of the water table caused most bogs to cease accumulating peat and became dominated by white cedar; (4) pollen-climate transfer functions provide temperature and precipitation values for the postglacial; and (5) at Crawford Lake, pollen grains and other microfossils show that 15th century Iroquoian village farmers supplied nutrients that eutrophied the lake.

SM03-04 CONTINENTAL GLACIAL RUNOFF AND ABRUPT CLIMATE CHANGE

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The Younger Dryas (YD) North Atlantic cooling 11-10 ka, last of many ice-age millennial-scale high-amplitude climate oscillations with manifestations around the globe, has become a focus for understanding rapid oceanic and climatic change. Prevailing theory suggests these oscillations follow from fluctuations of northern Atlantic thermohaline circulation and deepwater production. Variation in this circulation is thought to modulate the transport of heat via surface currents to northern latitudes, and the export of deep water via subsurface currents. Increases in freshwater discharge to the North Atlantic may reduce surface salinity and density enough to curtail deepwater production and northerly surface current flow. Ongoing evaporation enhances surface salinity and density until thermohaline circulation and northward heat transport resume. Understanding this salinity oscillator is significant because global warming scenarios suggest greater future freshwater input to the North Atlantic basin than at present. Thus, it is prudent to know whether or when a similar, though probably non-glacial, oceanic and climatic shift should be expected. Knowledge of the magnitude and routing of runoff and outburst floods during a previous oscillation is thus critical to quantifying the thresholds of abrupt climate change for application to future scenarios.

The deglacial switching of drainage from giant proglacial Lake Agassiz to its lower eastern outlets is thought to be a critical forcing that slowed thermohaline circulation and rapidly induced cold conditions during the YD. Questions about the timing and routing of the Agassiz discharge have arisen with recent research results - no large freshwater impact in the Gulf of St. Lawrence at 11 ka, and the largest meltwater inflows, deciphered from evidence of the rate of sea level rise, occurred before and after, rather than during the YD. Possibilities that the 11 ka Agassiz discharge passed to the North Atlantic via the Hudson River valley, or by the northwest outlet to the Mackenzie River valley and Arctic Ocean are now being considered. A massive gray clay sediment unit, the Wilmette bed, beneath Lake Michigan and a possible correlative in the Huron basin do support Agassiz inflow about 11 ka. Much more evidence along downstream routes from Lake Agassiz should be obtained. Obvious targets for such constraining evidence are the sediment sequences of basins such as Lake Superior to test Agassiz eastern outflow, and Athabaska and Great Slave lakes, and Beaufort Sea in the western Arctic for Agassiz northwest outflow.

SM03-05 **LATE QUATERNARY HISTORY OF THE GEORGIAN BAY LAKE BASIN AS VIEWED FROM THE LAKEBED**

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Lake basin sediment and surficial bedrock stratigraphy of Georgian Bay are contributing new insights into the late Quaternary history of the Great Lakes region. Meltwater outbursts associated with the onset of late Wisconsinan deglaciation stripped the Georgian Bay basin of basal drift and generated S-form features and outwash channels in bedrock on the crest of the submerged Niagara Escarpment. Early to mid Holocene neotectonic activity in the basin is documented by pop-up ridges in bedrock outcrops and linear arrays of coalescing gas vents within glaciolacustrine and postglacial sediments. Evidence for post-Algonquin lake levels below outlet elevations includes eroded glaciolacustrine sediments, deep-water beaches, submerged waterfalls, relict drainage channels and in-situ tree stumps. Biostratigraphic evidence from a sediment core from the deepest sub-basin in Georgian Bay records low lake level conditions and evaporative conditions: total dissolved solids were higher than present and a more arid climate existed at 7.5ka. The above evidence suggests that lowstand Lake Hough levels were 30 to 50 m lower than previously thought between 9.5 and 7.5 ka allowing closed basin conditions to exist in Georgian Bay at intervals during this time period.

SM03-06 THE SEPARATION OF LAKE SUPERIOR FROM LAKE MICHIGAN/HURON

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The upper Great Lakes (Superior, Michigan, and Huron) were confluent during most of the late Holocene and their elevation was controlled by the Port Huron/Sarnia outlet. Following rebound of the bedrock surface near Sault Ste. Marie, the Sault outlet controlled water levels in Lake Superior. Farrand (1962) reported that this outlet change occurred about 2,200 calendar years B.P. Further work by Larsen (1999) suggested a similar time period. Preliminary results from our sedimentological analysis of continuous records of beach ridges in Lake Superior suggest the outlet change occurred between about 1,200 and 1,400 calendar years B.P.

Five different strandplains in Lake Superior embayments were investigated with 30 to 100 beach ridges in each. Over 300 vibracores were collected from individual beach ridges to determine elevations of the lake during the late Holocene. Over 150 ages were used to create age models for each site to determine a chronology of lake-level changes through time. Basal peat samples collected from swales between beach ridges were radiocarbon dated. Sand samples collected from inside beach ridges were dated using optically stimulated luminescence. Four of the five sites have a preserved record before and after the change in outlets. Subsurface elevations of basal foreshore deposits across each strandplain record a lowering of the long-term relative lake-level followed by a short-term rise or slower rate of fall. This aberration in the trend implies a change in the outlet from Port Huron/Sarnia to Sault Ste. Maire. Four of the study sites record water-level fluctuations after the outlet changed. All sites on the southern shore of Lake Superior have experienced a relative lake-level rise, or inundation of the shoreline, from about 1,200 - 1,400 calendar years B.P. to the present, with the Sault as the controlling outlet. One site on the eastern shore of Lake Superior has been experiencing a relative lake-level fall where the land is rising faster than the Sault outlet during the last 1,000 years. Understanding the relationship of water-level changes relative to rebound and the active outlet for Lake Superior is critical for addressing several important climate-related and regulatory issues at the forefront today.

SM03-07 ANATOMY OF A QUATERNARY ICE-MARGINAL DELTA, NORTH-CENTRAL ONTARIO, CANADA

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Field mapping, ground-penetrating radar profiling and architectural-element analysis of part of the Nakina moraine near Longlac, northern Ontario, indicate that the moraine is composed of numerous coalescing, extensive, high-energy, ice-marginal, shoal-water, deltaic systems.

Distributary channel deposits resemble channel elements of shallow, flashy, low-sinuosity braided rivers. Sediment transport and deposition under high-energy conditions is indicated by the presence of massive beds and sigmoidal to planar-laminated strata, formed in the transition zone between dune and upper stage flow-regime. Proximal to distal facies transition from sigmoidal to planar-strata reflects downcurrent bar evolution from simple compound-bars to plane-bedded simple-bars.

Assemblages of low-angle, trough and planar cross-stratified clastics have been interpreted as gently dipping deltaic foreset elements. These reflect rapid deposition from hyperconcentrated suspensions with minor redeposition by sediment gravity flows. Assemblages of silty, fine to medium sand with planar-laminae, sinusoidal drapes, and type A and B ripple-drift cross-lamination, are interpreted as interdeltaic deposits. Heterolithic pro-deltaic facies are characterized by well-sorted, fine to medium sand. Climbing ripple sequences, deposited primarily by bedload and suspension under lower-flow regime conditions are common within this facies and are interpreted as glaciolacustrine in origin.

Using architectural analysis of sand and gravel pits, combined with ground penetrating radar profiles it appears that the flat-topped body examined was initiated at the Nakina ice-front as a sub-aquatic fan. Due to the rapid supply of detritus from the esker-feeder tunnel, aggradation and progradation of sediment continued until the water-air interface was reached. Once this was accomplished, sediment prograded as a 'flash-flood-style' delta into a low-energy, protected, shallow receiving basin, which may represent an arm of a larger lake basin.

SM03-08 THE COCHRANE SURGES AND GLACIAL LAKE OJIBWAY IN NORTHEASTERN ONTARIO

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During the final 400 years of glacial lake Ojibway, the retreating Laurentide Ice Sheet margin surged southward into glacial Lake Ojibway forming the clay-rich Cochrane Till (North Driftwood Formation). Three of these surges are recognized in eastern James Bay, Quebec, and are informally referred to as Cochrane I, Cochrane II and Rupert ice surges. The Cochrane surge in northeastern Ontario correlates with the Cochrane I surge in James Bay. A second surge is documented in the Kapuskasing River area and is likely independent of the Cochrane II and Rupert surges.

A minimum of 209 varves were discovered overlying Cochrane Till near its southern limit in the Mattagami River lowlands and were undoubtedly deposited in post-Cochrane glacial Lake Ojibway following the rapid retreat of the Cochrane ice margin. Strandlines and wave-cut benches formed on Cochrane Till, providing elevations of late stage Lake Ojibway water levels. Varve chronology shows these sediments to be contemporaneous with the upper sequence of the Barlow Ojibway Formation (Connaught sequence) south of the Cochrane limit.

These new data provide minor refinement of Lake Ojibway water planes and defines more precicely the ages of the Cochrane surges in Ontario and the drainage of Lake Ojibway into the Tyrrell Sea. This information, in turn, has broader implications with respect to meltwater drainage induced climatic change and the nature of the rapidly wasting Laurentide Ice Sheet during the early Holocene. The established formal stratotypes, in particular the Barlow-Ojibway Formation and the glaciolacustrine sediments assigned to the North Driftwood Formation, will have to be reviewed and revised in the future.

SM03-09 CARBONATE DISPERSAL TRAINS AND ICE STREAMS, FOXE SECTOR, LAURENTIDE ICE

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Paul Karrow began a series of discussion papers on the identification and meaning of carbonate dispersal train in the southern Laurentide Ice sheet (LIS). This presentation focuses on carbonate dispersal in the NE sector of the LIS, on Melville Peninsula, Baffin Island, and Hudson Strait. The northern Melville dispersal train is distinctive in that there are sharply defined plumes within the main train. Carbonate dispersal trains are related to late-glacial calving sites at the ice front, with ice streaming characterized by intermittent gliding and deformation at the glacier bed. For the Foxe Ice Centre, the streaming events caused an abrupt collapse of the ice mass in Foxe Basin, about 6800 BP, and a shift to land-based flow centres on Baffin Island and Melville Peninsula.

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USE AND MISUSE OF DIGITAL ELEVATION MODELS IN TERRAIN ANALYSIS: EXAMPLES FROM NORTHWESTERN ONTARIO

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Digital Elevation Models (DEMs) have become a commonly used tool in geology and in particular landscape analysis and visualization. It is a fundamental component of predictive mapping for engineering geology terrain investigations in the boreal forest regions of the Canadian Shield. The use of DEMs and their derivatives, combined or fused with Satellite imagery (Landsat TM and ETM, RADARSAT) provide a first approximation of terrain conditions in this setting. A by-product of the predictive process, the “Satellite Image Map”, is an extremely useful and visual product that displays terrain conditions. Major landforms and landform relationships can be observed and a better understanding of the glacial history of this vast region can be obtained.

DEMs can also be misused or used beyond their limitations. The processes used in DEM construction can affect their uses. For example, drainage enforcement may not always produce a DEM true to the existing landscape. In addition, attempts to adjust DEMs to account for isostatic rebound are fraught with all nature of possible errors. When attempting this, extreme caution should be used and the limitations of the process and assumptions made, duly noted.

The characteristics and advantages of DEMs highlighted above can mask errors and assumptions made when using and interpreting DEMs. Field data should be an integral part of DEM use and in their interpretation for geological purposes.

SM03-11 **THE MECHANICAL NATURE OF LAKE AGASSIZ SEDIMENTS AS A FACTOR IN THE URBAN GEOLOGIC SETTING OF THE FARGO, NORTH DAKOTA, METROPOLITAN REGION**

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The Red River Valley of North Dakota/Minnesota is the youngest major land surface in the contiguous United States, having been subaerially exposed upon the final regional drainage of the waters of Glacial Lake Agassiz about 9,200 years ago. Underlying the Valley are soils that induce both great agricultural activity and challenging geotechnical conditions. These soils are developed on a wedge of smectitic clays and silty-clays derived predominantly from late-glacial meltwater erosion, which reworked Cretaceous shales (most notably the Pierre Shale) and dispersed the sediments in suspension into Lake Agassiz. This wedge thickens northward along the axis of the Valley toward Grand Forks, North Dakota. At Fargo, it is 32 m thick, with a predictable stratigraphy of ≈ 6 m of tan-buff laminated silty-clays of the Sherack Formation underlain by ≈ 26 m of gray, slickensided, fat clays of the Brenna/Argusville Formations. Typical soil engineering values for the Sherack Formation (depth: ≈ 1 – 6 m) are: PL = 30, LL = 85, N = 12, and Qu = 3000. For the uppermost Brenna Formation (depth ≈ 8 m), typical values are: PL = 31, LL = 113, N = 6, and Qu = 1370. The high shrink-swell properties of these clays induce foundation shifting, pavement failure, and utility line rupture. Where the sediments are unconfined, their high plasticity leads to slope instability; the valley and channel walls of the Red River and its tributaries are particularly prone to slope failure. Elsewhere, overloading of the lake clays has resulted in a notable history of structural failures; this history continues to develop despite precedent knowledge of the mechanical nature of the Lake Agassiz sediments from incidents such as the failure of the Stockwood Fill (northwestern Minnesota) in 1906 and the Transcona Elevator (near Winnipeg) in 1913.

SM03-12 SAND AND GRAVEL IN SOUTHERN ONTARIO, 1963-2003

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Substantial changes have taken place in the aggregates industry since Don Hewitt and Paul Karrow published their review of the Sand and Gravel in Southern Ontario in 1963. Forty years have seen the depletion of many of the smaller aggregate sources in and around Toronto, and the gradual decline of sources in the Oak Ridges Moraine. The concentration of production with medium to small sized producers in 1963 has been replaced by an industry dominated by three major cement producers and the disappearance of many small producers. Production from bedrock sources is increasing steadily, and has eclipsed natural sand and gravel as the major source of aggregate. Significant advances in machinery, automation, and testing procedures have resulted in generally higher quality products and the ability to achieve greater improvements during the production process. Transportation of aggregates remains largely by truck. Marine transportation on the Great Lakes is a small, but growing, aspect of the industry, and rail transport has essentially disappeared. A series of regulations such as the Environmental Protection Act, the Planning Act, the Aggregate Resources Act, the Niagara Escarpment Planning and Development Act, and the Oak Ridges Moraine Conservation Act, now regulate the aggregates industry in Ontario, and the ability to secure land, meet regulatory requirements, and secure licenses has become a major challenge for the industry.

SM03-13 **QUATERNARY GEOLOGY, GEOHAZARDS, AND PIPELINING IN CANADA**

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The Quaternary history of particular areas in Canada has important impacts on pipeline design, construction and operation. Since almost all pipelines are buried below ground, the excavation of the pipe ditch is within Quaternary age sediments. These sediments will influence the types of equipment, and hence the cost, used to excavate the pipe ditch in addition to having important equipment trafficability considerations. The Quaternary history and soil types along a pipeline route also impact river crossing methodology, slope stability, groundwater and drainage considerations, and the availability of construction borrow. In northern Canada, the sediments were not only deposited during the Quaternary, but extensive and highly problematic ground ice was also formed.

Various geohazards, including landslides, river crossings, slope stability, erosion, debris flows and permafrost issues must be taken into account during pipeline design and operation. The presence and behaviour of these geohazards are usually the results of processes that occurred during the Quaternary period. Natural hazard and risk management (NHRM) can be considered a fiduciary responsibility of pipeline companies to their stakeholders. Financial institutions may require NHRM as a condition for stock exchange listing and insurance companies may assess the NHRM prior to setting premiums. NHRM is also a standard of care expectation in litigation or due diligence situations. Hazard evaluation is part of any pipeline integrity program.

NHRM involves identifying geotechnical and hydrotechnical hazards with potential to impact the pipe and/or pipeline facilities. These hazards are ranked to quantify the potential for service disruption. A Risk Management System has been developed that includes the determination of the risk factors, identification of the pertinent natural hazards, and a quantification of the attributes that affect each natural hazard. Case study examples illustrate a few of the pipeline geohazards that have been examined.

SM03-14

EVIDENCE TO SUPPORT PRE OR EARLY WISCONSINAN GENESIS OF A PRODUCTIVE KARST SYSTEM BENEATH THE CITY OF GUELPH

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This paper presents evidence to support a pre or early Wisconsinan genesis of a productive karst system beneath the City of Guelph. Guelph has a population of 110,000 and is located in south-western Ontario, approximately 60 kilometres west of Toronto. The majority of the water for the City is supplied from bedrock production wells in and around the City. The data from these wells provide interesting insights into the distribution of productive karst features in the local Silurian bedrock.

Available video log and flow velocity profiles from the City's bedrock production wells show the majority of groundwater entering the wells comes from one or more discrete solution enhanced features or caverns in the bedrock. However, while caverns and solution enhanced features are present in all of the bedrock production wells where quality data is available, there is a wide variation in the productive capacity of the wells. The commonly accepted theory for the cavern development is they are formed from dissolution of Silurian reef deposits, which suggests that the groundwater productivity of the caverns would be primarily a function of reef size. However, mapping of the productive capacity of the wells in three dimensions shows a strong correlation between the location of the higher capacity wells and the location of bedrock valleys. This correlation suggests while the caverns and solution features are widespread, only those located near the bedrock valleys are connected by a productive karst system.

The pre or early Wisconsinan age of the bedrock valleys indicates the karst system developed prior to the Wisconsinan glaciations. Furthermore the productivity of the wells completed near the bedrock valleys implies the karst system has remained at least partially intact since glaciers filled the valleys with till.

The mapping also shows there is significantly less correlation between well capacity and bedrock river valleys developed during the Holocene. This observation indicates there has been significantly less karst development in the area in the Holocene.

This presentation describes the evidence to support the above hypothesis. The determination of the age of the karst features beneath the City of Guelph may help other researchers examining karst at other localities in southwestern Ontario, such as the Elora Gorge. The recognition of the origin of the karst features also has important implications for those defining groundwater protection zones or looking for additional groundwater resources in the Guelph area.

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QUATERNARY GEOLOGY – FOUNDATION FOR ECONOMIC GROWTH AND ENVIRONMENTAL PLANNING IN ONTARIO, CANADA

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Systematic mapping of Quaternary deposits in Ontario has been an on-going activity of federal and provincial governments for over half a century. The mapping was initially focussed in southern Ontario but has more recently begun to cover regions in the northern part of the province. The majority of the mapping has been completed at a 1:50 K scale.

The completion of high quality mapping for large, contiguous areas has seen surficial information being used, either directly or indirectly, for a wide variety of applications. The mapping now plays a key role in three, broad and inter-related fields; environmental, land use and resource assessment. Tradition uses of the data, such as for the identification of surficial aggregate resources, have been expanded to include, for example, the development of ground and surface water protection areas, environmental assessments and municipal official plans. The development of economic strategies and public policy has benefited from a scientifically sound Quaternary geology database. The economic and social benefits of having Quaternary information are well documented and serve to justify government's investment in this type of geoscience program.

Demand for Quaternary information to assist in addressing current "public good" issues in Ontario has recently lead to development of a 3-dimensional mapping program. The primary driver for this subsurface mapping is the public's demand for safe and sustainable groundwater resources.

The wider use of Quaternary information, while serving to reinforce its value, has highlighted the need for products that are useable by multiple client groups, many of which do not have a geoscience background. This need has, in turn, necessitated the development of tailored and user friendly products by geoscientists.

SM-04

Late Cenozoic environmental change in the Arctic

Changement environnemental à la fin du Cénozoïque dans l'Arctique

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SM04-01 **GEOLOGY AND TECTONIC HISTORY OF SEDIMENTARY BEDROCK, ARCTIC ISLANDS, NUNAVUT**

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Unmetamorphosed sedimentary rocks of the Arctic Archipelago can be divided into Proterozoic, early - middle Paleozoic, and late Paleozoic - Tertiary strata. Tectonic events affecting the distribution, composition, physiography and resource potential of these rocks include extensional events (throughout Proterozoic, end Proterozoic, middle Carboniferous - late Cretaceous, early Tertiary), and at least three compressional intervals (late Silurian - early Devonian, late Devonian - early Carboniferous, early Tertiary).

Paleoproterozoic basin remnants in the islands are few and small. Mesoproterozoic basins are areally extensive; the largest is the Borden Basin, on northern Baffin Island. Neoproterozoic strata of the Amundsen Basin are present in western Nunavut.

Lower Paleozoic rocks underlie much of northern Nunavut. Latest Neoproterozoic to middle Cambrian shallow marine, terrigenous clastic rocks were followed by middle Cambrian to Ordovician carbonate and evaporite strata along a passive margin from northern Ellesmere Island to Victoria Island; deep-water terrigenous rocks were deposited outboard (north) of this. Silurian and Devonian shallow-water carbonate strata are areally extensive except in the vicinity of the Boothia Uplift, which emerged at the time of the late Silurian Caledonian Orogeny. Normal marine carbonate deposition was overtaken in middle Devonian - early Carboniferous time by southward-prograding terrigenous material derived from the developing Ellesmerian Orogen, a fold-thrust belt in the central and high Arctic.

The high Arctic Sverdrup Basin began subsiding in the Carboniferous. Late Paleozoic carbonate, terrigenous, and evaporite strata are overlain by up to 9 km of Mesozoic terrigenous rocks. In the early Tertiary, the Eurekan orogeny caused compression in the northernmost islands and extension in the south; rifting and seafloor spreading in Baffin Bay resulted in separation of Greenland and Arctic Canada.

The present-day physiography of the Arctic Islands reflects their tectonic and sedimentary history. In general, the region is uplifted and eroding. Mountains on northern Ellesmere and nearby islands are the result of compressional uplift during the Eurekan Orogeny. Highstanding Precambrian basement along eastern Ellesmere, Devon, and Baffin islands probably reflects residual thermal uplift from incipient rifting of Baffin Bay; other areas underlain by Precambrian basement have subdued topography. The low-lying southern islands are underlain by epicratonic lower Paleozoic rocks that have never been deformed. Continental-margin lower Paleozoic rocks in the central high Arctic, affected by Ellesmerian compression, still exhibit low hills. Areas underlain by undeformed post-Paleozoic strata are topographically low. Many large sounds and basins between islands are grabens that developed during Eurekan extension.

SM04-02 **A high-resolution stable isotope climate record from tree rings of Pliocene wood found on Ellesmere Island, Nunavut**

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WITHDRAWN

SM04-03 RELICT MIDDLE PLEISTOCENE PERMAFROST IN YUKON TERRITORY

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How long permafrost has persisted in Arctic regions is poorly known. This reflects the few truly old ice complex exposures known, and more likely, the difficulty in establishing reliable chronologies beyond the limit of the radiocarbon method ca. 40,000 yrs). However, understanding the future of permafrost in modern Arctic regions can be informed through documenting the responses of permafrost regions to the warming of past interglaciations. In northern Siberia, published estimates for the age of relict permafrost vary from 3 million years, based largely on the seeming survival of ancient bacteria in the ice, to as little as 200,000 years from U/Th dating of permafrost peats. The record in North America is even more poorly known and direct records of permafrost do not extend beyond the limit of the radiocarbon dating method (ca. 40,000 yrs). Here we report the occurrence of relict permafrost dating to the middle Pleistocene from the Discontinuous Permafrost Zone of central Yukon Territory. In the southern Klondike goldfields, Yukon Territory, large ice wedges, locally exceeding 10 m in depth, cross-cut underlying in-situ forest beds. The isotopic composition of the ice wedges is depleted in δD with values ranging from -230 to -233 ‰, while the underlying forest beds have δD values of -175 to -189 ‰, comparable to Holocene values in the region. Two tephra beds occur in association with the ice wedges. Sheep Creek tephra (190 ± 20 ka) is cross-cut by the ice wedges, but also occurs within the paleo-active layer above, and veins of the tephra occur along foliation cracks within an ice wedge indicating ice wedge formation was contemporaneous with tephra deposition. Dominion Creek tephra occurs on the surface of a paleosol 1 m above Sheep Creek tephra, and has an age of 170 ± 20 ka. Permafrost at the site is relict from the early part of marine isotope stage 6, while the underlying forest bed and associated aggradational ice is likely associated with marine isotope stage 7. These findings indicate that ground ice has persisted, at least in preferred locations in interior Yukon Territory through the last interglaciation. This finding provides the opportunity for paleoenvironmental reconstruction using permafrost pore-ice and permafrost-preserved fossils through at least the last two glacial cycles, and presumably much longer in large areas of northwestern North America.

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PLEISTOCENE STRATIGRAPHY OF THE BOREAL PLAINS IN NORTHEASTERN MOST BRITISH COLUMBIA

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Recent Quaternary geology investigations in the Boreal plains in northeastern most British Columbia have been initiated in response to the need for more information on the surficial geology of the region. The main demand has come from a rapidly expanding oil and gas road infrastructure and an accompanying critical need for the identification of aggregate deposits. Also, of interest is the discovery of natural gas in paleochannel sediments of inferred Quaternary age. Numerous wells, less than 300 m deep, have targeted these Quaternary reservoir units which are buried by thick Pleistocene, glaciolacustrine deposits and clay-rich tills which act as cap 'rocks'. In this paper we describe recent results of Pleistocene stratigraphic studies and their implications for these activities.

During the Pleistocene, glaciers advanced westward up the regional slope and dammed rivers draining eastward off the Rockies. This resulted in the widespread deposition of glacial lake sediments over pre-existing Quaternary deposits. In addition, the local bedrock is dominated by shales and, consequently, the derived glacial sediments are rich in clay. These fine grained Pleistocene deposits are common at the surface and are one reason why surficial aggregate deposits are relatively rare. During deglaciation, numerous meltwater channels were incised by streams generally flowing westerly from the retreating Laurentide ice sheet. Sands and gravels were locally deposited in association with meltwater channels but many appear to be entirely erosional and may have formed subglacially. Some recently discovered aggregate deposits, underlying stony diamicton along channel flanks, are interpreted to be subglacial channel deposits overlain by meltout till. Although, distinctive surficial deposits of aggregate are rare, one exceptionally large glaciofluvial fan-delta was discovered on the east side of the Fontas River map area (NTS 94I).

Dating of Pleistocene sediments in the area has been facilitated by the discovery of an interglacial peat underlying a thin diamicton and oxidized sandy unit. The peat contains abundant plant matter including many wood fragments, as well as numerous pelecypod and gastropod fossils. Radiocarbon analyses on two wood pieces yielded dates of > 38690 BP (Beta 183832) > 40590 BP (Beta 183831) radiocarbon years. Another fragment of wood recovered from gravels stratigraphically underlying till in the Elleh Creek area was dated at 24400 +/- 150 radiocarbon years BP (Beta 183598). Collectively, these dates and the associated stratigraphy provide new constraints on the Pleistocene history of the region and indicate that ice free conditions probably existed from before 40 ka until after ~24 ka BP.

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USING PERIGLACIAL PATTERNS TO MAP TERRAIN MATERIALS ON THE CANADIAN SHIELD NORTH OF THE TREELINE, WEST OF HUDSON BAY

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Northward from the treeline west of Hudson Bay to at least 66°N latitude, two broad classes of patterned ground provide unequivocal guidance for interpreting both terrain materials and terrain moisture/thermal conditions of the unconsolidated sediments on which they form. Except for bedrock outcrops, which are in some areas covered with felsenmeer, one or the other of these two classes of patterns can be found ubiquitously in this tundra terrain.

One class comprises extensive networks of circular, soft-sediment deformation features, ranging from 0.5m to over 2m in diameter, formed on well-drained surfaces underlain by poorly sorted sediment, such as till or marine/lacustrine silty clay. The bare or lichen-covered centres of the circles are surrounded by < 1 metre-high, vegetated ridges or by rings of boulders with little vegetation. At depths of less than 3m in the millions of lakes in this region, linear to sinuous, metre-wide by metres-long, parallel ridges, separated by metre-wide, boulder-filled troughs, extend offshore and merge into the circular patterns on shore where diamicton is the substrate. The circles are known by various names, mudboils (this author), frost boils, sorted or non-sorted circles, mud volcanoes, etc.; the subaqueous ridges are called rib-and-trough structures.

The other class comprises symmetrical, polygonal frost cracks, representing the surface expression of vertical ice wedges, that form patterns that range from one to many metres across and ornament the thick, non-plastic peat that builds up on poorly drained, flat surfaces, such as alluvial plains, regardless of the texture of mineral sediment that underlies the peat. Orthogonal frost cracks of similar scale develop on the well- sorted sediments of raised beaches, eskers, and other linear features composed of sand and gravel, whereas well-drained, non-linear accumulations of sand and gravel are cut by irregular, polygonal frost cracks.

In summary, mudboils and rib-and-trough patterns are found on sediment that is plastic or liquid and easily deformable under saturated or near saturated conditions. Polygonal or orthogonal frost cracks form on soils that are non-plastic or rigid, regardless of moisture content. Recognition of the simple relationship between periglacial ornamentation and unconsolidated sediment type has allowed very accurate surficial geology maps to be made in this region.

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POST-LGM GLACIAL HISTORY ALONG THE WEST COAST OF COMMITTEE BAY, CENTRAL MAINLAND NUNAVUT

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Extensive Quaternary field studies were undertaken in the vicinity of the Prince Albert group rocks (Committee Bay belt), approximately 150 km northwest of Repulse Bay, central mainland Nunavut during the 2002 field season. A rich assemblage of glaciomarine landforms and fauna has allowed the reconstruction of deglacial events within this extensively drift-covered region.

During the early deglaciation of the region, a marine inlet formed in the vicinity of the present-day Committee Bay. This marine incursion allowed the formation of a number of geomorphic features including ice-contact deltas, proglacial deltas, beaches, washed zones and nearshore sediments. The uppermost limit of these features occurs between 240 m and 255 m asl and hence, marks the absolute maximum marine transgression limit. Through association with similar marine limits at comparable elevations along the northeast coast of Committee Bay, this maximum marine limit is tentatively assigned an early deglacial age estimate between c. 9000 cal. yrs BP and c. 8600 cal. yrs BP.

Lower marine limits at ca. 220 m asl and ca. 180 m asl are associated with later phases of marine regression and southwestward retreat of the ice-sheet margin; the lowest observed limit likely formed during the early- to mid-Holocene based on the timing of early regional deglaciation and the minimum deglaciation ages (ca. 6800 cal. yrs BP) obtained from peat located 85 km southwest of that limit.

Offshore sediments that contain in situ, ice-proximal marine species (e.g., *Portlandia arctica*) are associated with early deglacial phases. Subsequent isostatic uplift resulted in a shallowing of these environments, depositing sandy substrates and allowing nearshore species such as *Mya truncata, Macoma calcarea* and *Clinocardium ciliatum* to inhabit the sites. Continued uplift resulted in emergence of sites exhibiting marine silt and clay; in some cases, these marine sediments were then eroded by meltwater systems and/or were buried by proglacial or modern alluvial sands.

Future work involves the evaluation of cosmogenic nuclide ages in addition to optical ages from deltas and nearshore sands. These quantitative age estimates will increase our ability to understand the relationships and chronology of events that gave rise to the present-day distribution of glacial and emerged-glaciomarine sediments.

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GENESIS OF HUMMOCKS IN GLACIOFLUVIAL CORRIDORS NEAR WALKER LAKE, CENTRAL MAINLAND, NUNAVUT

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As part of the Committee Bay Integrated Geoscience project (2000-2003), Quaternary field investigations were carried out within the Walker Lake map area (NTS 56J/9-16). A focus of these investigations is to examine hummocks found within glaciofluvial corridors. Morphologically similar hummocks in the Coppermine area (NWT), the Lac de Gras area (NWT), central Ontario and south central Michigan have been examined at varying detail resulting in a range of interpretations. In the study area, glaciofluvial corridors containing hummocks are spaced 5 to 10 km apart and are 100's of metres to several kilometres in width. They have undulating long profiles, abrupt material-boundaries with surrounding till, and occur in valleys and on the interfluves. Regionally, they occur within a belt ~120 km long (east-west) and ~60 km wide (north-south), located south of the Chantrey Moraines (formed at ca. 8 ka), and north of the Keewatin Ice Divide.

GPR was used on a hummock ~6 m wide, ~3 m high, ~50 m long, and spaced ~50 m apart. A 90 cm pit close to the crest of the hummock reveals a single lithofacies; a coarsely stratified, matrix supported gravely sand. This is similar to the "sliding bed facies" observed in esker sediments that have been attributed to high meltwater discharges in closed conduits. Longitudinal and perpendicular GPR surveys indicate a consistent texture of the sediment (i.e. without changes to finer (silt or clay) or coarser (boulder ~1 m in diameter) material) suggesting a composition of "sliding-bed-facies" throughout the thickness of the hummock, to a depth of ~10 m.

The resemblance of the deposits to the "sliding bed facies" indicates similarities to esker sedimentation, however, the variety of morphologic features (hummocks and some transverse ridges) and the width of the glaciofluvial corridors, indicates depositional conditions were different from those that formed eskers. We hypothesize that sedimentation occurred in cavities at the base of the ice sheet by a rapid influx of meltwater. The cavities formed possibly as a result of (1) pre-existing weaknesses in the ice (e.g. fractures), (2) meltwater flow variations that preferentially erode/melt some parts of the ice faster than others, or (3) substrate variations (either in the till or bedrock), that affect process 1 and/or 2. Once cavities were established further sediment accreted, likely from one continuous discharge, based on the lack of erosive surfaces observed in the GPR profiles.

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CONTRASTS IN DEGLACIATION: CANADA VERSUS GREENLAND ON THE ARCTIC CIRCLE. IMPLICATIONS FOR DRIFT PROSPECTING

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Late glacial to postglacial landforms near the Arctic Circle are compared in the Committee Bay area of Nunavut, and the Kangerlussuaq (Sondrestrom) area of Greenland. Our field observations appear to reflect different styles of deglaciation for the two areas. These differences may have important implications for mineral exploration, particularly drift prospecting.

Eskers, useful for diamond indicator mineral sampling, dominate the Committee Bay area, whereas none were found in the Kangerlussuaq area. Frostboils, useful in till sampling, are abundant in the Committee Bay area, but are scarce in the Kangerlussuaq area. The dearth of these two landforms in the Kangerlussuaq area may hinder the logistics of future drift prospecting programs.

Many small, closely grouped recessional moraines are well preserved within valley floors of the Kangerlussuaq area, reflecting pulsating lobes from the margin of the Greenland Ice Sheet. Such moraines were not found in the Committee Bay area, whereas large segments of the Chantrey Moraine system are found in the Committee Bay area which, in some cases, are kilometres long and reflect deposition at the retreating margin of the Laurentide Ice Sheet.

The extent of deglaciation appears to have been the controlling factor in these two contrasting areas: wholesale ice sheet decay many thousands of years ago in the Committee Bay area versus minor ice sheet fluctuations in the Kangerlussuaq area. For example, the Committee Bay area appears to have experienced larger volumes of meltwater than did the Kangerlussuaq area. Evidence for this includes the eskers mentioned above and numerous, large imbricated boulder channels found in the Committee Bay area, whereas nothing similar was found in the Kangerlussuaq area. Further evidence for meltwater floods in the Committee Bay area is the numerous Nye channels cut into the bedrock, whereas none were found in the Kangerlussuaq area.

Paleo ice-movement indicators such as glacial striae and crescentic gouges are abundant in both study areas and useful for determining ice-movements and for drift prospecting. However, these indicators are severely weathered or lichen covered in the Committee Bay area, whereas they are well preserved in the Kangerlussuaq area. This implies that deglaciation occurred much later in the Kangerlussuaq area.

In both study areas raised marine sediments contain abundant bivalves such as *Portlandia arctica*, and *Hiatella arctica*, representing marine incursions due to isostatic depression and rising sea levels.

Further work on these comparisons will improve our understanding of ice sheet dynamics and predictions of ice sheet behaviour.

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SM04-09

RECENT COASTAL DYNAMICS AND SEA LEVEL CHANGE ON MELVILLE ISLAND, WESTERN CANADIAN HIGH ARCTIC

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During the Last glacial maximum, Melville Island occupied the boundaries of the former Laurentide Ice Sheet to the south and the Innuitian Ice Sheet to the northeast. This glaciological setting generated glacioiostatic adjustments of the earth's crust that are still active today. After more than 10500 years of land emergence due to glacio-isostatic unloading, morpho-sedimentary evidence provided by field traverses and air-photo interpretation indicate that the coastline of the island is presently undergoing submergence. Recently activated coastal processes associated with submergence include beach retrogradation, drowning of coastal gullies and terrestrial vegetation, formation of lagoons, barrier reefs and islands as well as accelerated shoreline erosion. Direct evidence of such recent relative sea level rise (RSL) is also given by drowned vehicle tracks cut through terrestrial vegetation in the 1970s and 1980s during oil exploration. We estimate that regional submergence started on westernmost Prince Patrick Island sometime during the mid Holocene and has progressed eastward, recently reaching eastern Melville Island. This study suggests that the current zero isobase, the threshold between submergence and emergence, is located farther east than previously reported. Submergence on Melville Island is attributed to peripheral crustal forebulge migration towards both the loading centres of the former NW Laurentide and Innuitian ice sheets. Although glacio-isostasy is considered to be the main mechanism acting on the current crustal re-equilibrium in the region, other factors such as subsidence of the Sverdrup Basin, neotectonism (manifested by recent earthquakes in the Byam Martin Channel Zone) and modern eustatic sea level rise due to global may also be contributing to ongoing submergence on Melville Island. Recent climate warming may be playing a role in the intensification of shore-ice erosion, an increase in wave energy due to greater fetch during the summer, and the degradation of permafrost. These processes would have strong impacts on the fine-grained coastline of the northern sector of the island where modern submergence is apparent.

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OVERVIEW OF THE INNUITIAN ICE SHEET AND NEW PERSPECTIVES ON EPISODIC ICE SHELVES ON THE NW LAURENTIDE ICE SHEET

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At least three till sheets deposited by the NW Laurentide Ice Sheet (LIS) are recognized on Dundas Peninsula, SE Melville Island. The oldest till sheet crosses the peninsula, extending northward to Liddon Gulf. The absolute age of Dundas Till is unknown, but earlier work suggests that it likely pre-dates the Late Wisconsinan. When Laurentide ice lay grounded across Dundas Peninsula, trunk glaciers wrapped around the Melville Island coastline extending westward into M'Clure Strait and northward into Byam Martin Channel where they eventually floated, forming ice shelves. The next (younger) till sheet, also of unknown absolute age, lies inside the Dundas Till limit, overlapping the south coast of the peninsula, (~20 km inland). The upper limit of this till sheet (Bolduc Till) is horizontal and together with its silty and occasionally fossiliferous matrix appears to represent the grounded, inland margin of a former ice shelf (originating from the LIS). A likley counterpart to the Bolduc Till occupies the mouth of Liddon Gulf to the west, also forming a coastal apron (Liddon Till). The youngest till sheet (Winter Harbour Till) on Dundas Peninsula is confined to within 5 km of its south coast, well inside the Bolduc Till limit. Its upper limit is also horizontal and is ascribed to the Viscount-Melville Sound Ice Shelf that covered ~60,000 km^2, advancing >400 km to Melville Island after 10.4 ka BP and retreating ~9.6 ka BP.

We report new fieldwork on these respective till sheets, and especially the effort to establish their absolute ages based on the associated former relative sea levels recorded along their margins. Approximately 50 shell samples are currently submitted for AMS radiocarbon dating. At several localities, a previously unreported marine limit overlies the Bolduc Till and regression from this shoreline to a slightly lower elevation entrapped sediment recording the arrival of Winter Harbour ice. Both the post-Bolduc marine limit, and sediments from the Winter Harbour relative sea level are widespread in the interior of Dundas Peninsula. These shorelines rise southwestward along the Dundas Peninsula coast towards Viscount Melville Sound, indicating the glacioisostatic dominance of the NW Laurentide Ice Sheet. New evidence suggests that the final retreat of ice responsible for Dundas Till contacted the same relative sea level into which the Liddon Ice Shelf floated. If so, the three nested till sheets on Dundas Peninsula are all of Late Wisconsinan age.

New radiocarbon dates on ice-transported shells within Bolduc Till range from 25-28 ka BP, whereas two samples from the Dundas Till are 29 and 36 ka BP. Additional dates on both the arrival and departure of the Winter Harbour Till reinforce the previously reported chronology of 10.3 and 9.6 ka BP, respectively. This will be more rigorously tested by the pending AMS dates. The past history of episodic ice shelves (and the ice streams supplying them) is relevant to the mass flux of the former M'Clintock Ice Divide, to the sedimentary history of the adjacent Arctic Ocean Basin, and serve as analogues for modern ice shelves in Antarctica.

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GLACIAL EVENTS IN THE CENTRAL ARCTIC OCEAN: IMPLICATIONS FOR THE HISTORY OF THE LAURENTIDE ICE SHEET

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Sedimentary records from the western Arctic Ocean display cyclicity in lithology and microfaunal distribution, which reflects contrasting glacial/interglacial sedimentary patterns. It is inferred that during major glaciations extremely thick pack ice or ice shelves covered the western Arctic Ocean and its circulation was restricted in comparison with interglacial, modern-type conditions. Glacier collapse events are marked in sediment cores by increased contents of ice-rafted debris, notably by detrital carbonates from the Canadian Arctic. Composition of stable isotopes in foraminiferal calcite also shows cyclicity indicating changes in freshwater balance and/or ventillation rates of the Arctic Ocean. Light stable-isotopic spikes probably characterize deglacial events such as the last deglaciation at ca. 12 ka BP.

Further evidence of glacial impact on the Arctic Ocean emerges from geophysical sea-floor data. Sidescan and subbottom chirp sonar records depict numerous bedforms indicative of glacial scouring and/or molding of sea floor at water depths reaching 1000 m. These features are associated with extensive erosional surfaces that plane the tops of submarine ridges and plateaus. Sea-floor morphology in these areas includes random or subparallel scours, sets of parallel lineations (flutes), and transverse ridges. The combination of these features depicts a dramatic impact of grounded ice on the sea floor, both by icebergs and coherent sheets. These findings indicate that thick ice shelves once existed in the Arctic Ocean, rivaling or even exceeding in size the largest modern ice shelves of West Antarctica.

The prevailing orientation of flutes on the Chukchi Borderland and the Alaskan margin points at the northwestern sector of the Laurentide Ice Sheet as the major source of ice. The likely outlets were overdeepened troughs that dissect the Canadian arctic margin. This notion is consistent with orientation of major ice streams an the northen Laurentide margin as indicated by geomorphic and modeling data. However, distribution and trajectories of ice discharged into the Arctic Ocean could differ from one glaciation to another as depicted by several generation of flutes. Preliminary stratigraphic data of eroded sites indicate that the major ice-grounding event on Chukchi Borderland took place during OIS 6 or a substage of OIS 5, with another glacial erosion possibly occurring after OIS 5. For the LGM, existing stratigraphic data provide no evidence of ice grounding at large water depths, however the possibility of a thinner ice shelf over the Amerasia Basin is indicated by a halt in biological production and a hiatus in sedimentary records.

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SM04-12 DEGLACIAL HISTORY OF THE ICEBOUND LAKES (NTS 37G) REGION, NORTHERN BAFFIN ISLAND, NUNAVUT: DEVELOPMENT OF THE WESTERN MARGIN OF THE PALEO-BARNES ICE SHEET

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The C–NGO, in collaboration with the GSC and the PCSP, has begun a new geoscience initiative to evaluate the economic potential of northern Baffin Island, with the overall intent to reduce exploration risk in this remote region of Nunavut. The 2003 field season focused on the NTS 37G map sheet area, centred 170 km northwest of the Barnes Ice Cap. Specific objectives include the production of two 1:100 k-scale surficial geology maps (37G-east and west), a reconnaissance-scale till geochemical survey, and the evaluation of ice-movement chronology and glacial history of the region.

At this preliminary stage of research, four regional ice movement events and numerous local, late-deglacial flow events have been interpreted from 206 ice-movement indicators. The first event appears to be related to northward moving ice originating from the Foxe Basin prior to, or closely following the collapse of the Foxe Ice Dome. Regional deglacial phases included the retreat of the LIS margin southeastward from the Cockburn Moraines system, leaving a local remnant — the Baffin ice sheet — in place over the area (ca. ice-movement Event 2). Continued deglaciation within the study area resulted in the reduction of ice-sheet volume, modification of the ice-divide configuration, and the inception of the paleo-Barnes Ice Cap (i.e., an ice sheet more closely associated with the present-day Barnes, than the large ice sheets of the early-post LGM). Tentatively, this transition is associated with the southeastward shift in the paleo-Barnes ice divide (Event 3). During the last regional ice-movement recognized within the study area (Event 4), local ice caps would have become isolated in the Davis Highlands and the Baffin Upland north of the paleo-Barnes Ice Cap. Finally, late deglacial and neoglacial events occurred at a local scale and included ice streaming and small valley-glacier ice movement in the upland regions.

To further complicate the glacial history, many areas underwent overprinting from both warm- and cold-based thermal regimes at various stages of deglaciation. Current and future research focuses on the elucidation of basal thermal regimes, and further evaluation of the regional ice-movement event chronology.

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GLACIATION OF THE ASTON LOWLAND, BAFFIN ISLAND, NUNAVUT: IMPLICATIONS FOR GLACIAL CLIMATE AND LAURENTIDE ICE SHEET DYNAMICS

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The history of the Laurentide Ice Sheet (LIS) during the last glaciations of the eastern Canadian Arctic remains poorly understood despite over 40 years of field research. The Aston delta, a > 25 km^2, 80 m asl raised marine delta on the Aston Lowland of eastern Baffin Island, has frequently been cited as evidence of ice free conditions during the last glaciation. Nine non-finite radiocarbon dates confirm the pre-last glacial age (> 54,700 yr BP) of this delta and the associated 80 – 90 m asl shoreline; amino acid racemization of in situ marine molluscs suggests it to be ~95 ka. However, a new finite radiocarbon date of 36,490 yr BP on ice-transported molluscs on the Aston delta surface, and post-depositional lateral meltwater channels crossing the delta and lowland to the Holocene marine limit indicate the area was inundated by minimally erosive cold-based ice during the last glaciation.

During early Holocene retreat from the last glacial maximum, the marine limit was 23 m asl and dates to ~12 ka (cal). Eustatic sea level has risen ~60 m since 12 ka, combining for almost 85 m of post-glacial rebound since deglacierization. In contrast, the Aston delta formed in a relative sea level of 80 – 90 m asl, indicating at least this much total rebound without considering post-glacial eustatic sea level rise. Thus, the penultimate glacial loading of the Aston Lowland was greater than the last glacial loading of the area. This thicker ice sheet was also relatively non-erosive: amino acid racemization of in situ marine molluscs indicates undisturbed sediment > 260 ka is preserved adjacent to the fiords.

These new data indicate a relatively thin LIS covered most of the Aston Lowland during the last glaciation, terminating beyond the modern shoreline. However, preserved sediment and landform assemblages indicate the most distal portions of the LIS were composed of minimally erosive, cold-based ice during at least two glacial episodes. Undisturbed sediment > 260 ka adjacent to the fiords indicates fiord ice has not been sufficiently erosive to remove this sediment. Thus, rapidly moving, erosive, warm-based ice was probably restricted to the centres of the major fiord troughs during glaciations younger than > 260 ka. This suggests the eastern Baffin Island landscape is ancient in origin and has not been substantially modified during several glacial cycles. Late Quaternary glacial climate was probably too cold and dry to support large, warm-based ice sheets along the outer coast.

SM04-14 Late Quaternary history, central Baffin Island

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Early field work, recent cosmogenic dates and ice-mass models have suggested a major flow of glacier ice across Baffin Island from Foxe Basin before and during the last glacial maximum (LGM). An ice stream carried carbonate drift across the peninsula from Wordie Bay to Ekalugad Fiord across relatively low terrain, but limestone indicators relating to Foxe Ice do not extend far inland in other areas. It is possible that Foxe ice was cold-based for most of the LGM. Striations, indicator erratics, and landforms suggest later glacial flow from a Baffin ice centre. The prevalence of weathered rock, lack of ice-scoured lake basins, and absence of striations on the central plateau suggests that the island spine was a major ice divide, and that ice flowed out towards the two coasts. Baffin Ice may have been cold-based much of the time, producing rubble fields. Sharply defined swaths of eroded bedrock indicate that Baffin–centred ice was warm-based at some places and at some times, but cold-based at others. Crossing striations indicate that the ice-flow centre gradually shifted northwestwards towards the present Barnes Ice Cap, and that ice tongues located in valleys flowed towards both coasts during ice recession.

Deglaciation began more than 9200 years ago in the eastern outer fiords. Massive upland end moraines developed along the eastern part of the field area, crossing the heads of fiords about 8000 years ago when sea level was about 50-60 m above present. The Foxe Basin coast became ice-free about 6700 years ago when sea level stood at 110 m. Other large end moraines on the plateau, ice-dammed glacial lakes with sublacustrine moraines, and stacked sets of meltwater channels trace the pattern of ice recession towards and along the central plateau, and the recession of ice tongues from major valleys towards the Barnes Ice Cap.

Lichen-free zones on the east side of the field area and around the west side of the Barnes Ice Cap denote areas of snow and icefields during the Little Ice Age. Recent photography shows that there has been substantial ice recession on the western side of the Barnes Ice cap, but a stabilized front or advancing ice on the eastern side. Changes in ice-sheet profile are due in part to surges into proglacial lakes. Highland ice caps are generally receding.

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USING VARVES TO DOCUMENT RECENT CHANGES IN THE DIATOM ASSEMBLAGE OF A LARGE MIDDLE ARCTIC LAKE: SANAGAK LAKE, BOOTHIA PENINSULA, NUNAVUT

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A high-resolution chronology of the upper 20 cm of sediment from Sanagak Lake, a large arctic lake, was developed to investigate the timing of recent changes in the diatom stratigraphy. Agreement between ^{210}Pb, ^{137}Cs dating profiles and laminae counts suggest that the laminae represent annual deposits (varves). Results indicate a gradual decline in benthic relative to planktonic taxa since the late 1800s, and a sudden increase in the planktonics Asterionella formosa Hassal, Stephanodiscus minutulus (Kützing) Cleve & Möller, and Cyclotella atomus Hustedt beginning in the late 1980s. Species diversity also increases in the uppermost centimetre, corresponding to the mid-1980s, concurrent with a distinct change in the sedimentary structure. Comparison of these findings to other studies documenting similar changes in high latitude lakes and ponds shows a positive correlation between the timing of the change and lake size. Given the nature and geographical extent of recent shifts in diatom assemblages, such changes may be a reflection of recent trends in regional and global climate. Consistency between the timing of the shift in Sanagak Lake and the onset of unprecedented rates of warming, both regionally and globally, lend support to this hypothesis.

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LONG TERM HYDROCLIMATIC BEHAVIOUR IN THE CANADIAN MIDDLE ARCTIC RECORDED IN VARVED SEDIMENTS: HYDROLOGICAL OR CLIMATIC PROXY?

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A combination of hydrological monitoring, and detailed sedimentological and subfossil investigations were used to develop an understanding of the long term hydroclimatic behaviour on the central Boothia Peninsula, Nunavut (71°N, 95°W). Two years of sediment delivery observations in the Lord Lindsay River and two major tributaries indicate that sediment transport is primarily limited to the short period of peak discharge during spring snowmelt. During this time, suspended sediment loads reached 20-30 mg/L compared to 2-5 mg/L through the remainder of the season. Major summer rainfall events also increased discharge, but did not induce significant additional sediment delivery. Peak discharge in 2001 and 2002 were essentially identical (400 m^3/s) but peak discharge was prolonged by an additional five days due to the deeper snowpack in 2001. Hence, sediment transport to the lake in 2001 was nearly twice the amount observed in 2002, indicating a broad control on sediment delivery by snow water equivalence and the resultant hydrological response. The sediment delivery-snowpack relationship was proportional between years, but additional data is needed to quantify this relation, and comparison with weather station records of snowpack is complicated by highly variable and short records. Analysis of the long varve record from Sanagak Lake indicates periods of substantially higher sedimentation in the past and declining sedimentation in the 20th century. The decline since ca. 1900 AD is coincident with a decrease in lotic diatoms in the same sediment core. The change in diatom taxa suggests that the decline in sedimentation is not due to sediment exhaustion in the catchment, but represents a prominent shift towards shorter or less intense spring discharge peaks in these large rivers.

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HOLOCENE RECORDS OF CLIMATE CHANGE IN NORTHERN BAFFIN BAY: DECADAL-SCALE RECONSTRUCTIONS FROM DINOFLAGELLATE CYSTS

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Historical oceanographic measurements are presently used to constrain Global Climate Models (GCMs) of future climate change in the Canadian Arctic. However, these records cover < 200 years, a small part of the natural warm-cold cyclicity known from geological and archaeological records. Pleistocene microfossil records show millennial-scale glacial-interglacial oscillations with sea surface temperature (SST) changes of 4-8°C in Labrador Sea; centennial-scale palynological records from North Water Polynya (NOW) show cyclical changes of 2–4°C for the past 8,000 years. To increase our palaeoclimate database for the Eastern Canadian Arctic, an 11 m-long sediment core was collected from Coburg Polynya in Jones Sound (75°35 N, 78°41W, 561 m). Three mollusc ages show that sedimentation rates range from about 19 cm/century in the sandy mud unit deposited between ~7 and 3.3 ka to ~16 cm/century during the late Holocene. Large (~2 ‰) oscillations in $\delta^{18}O$ values occur at intervals of about 1000 years. Upward increase of sand and fine gravel in the trigger weight core indicates greater influx of ice-rafted detritus (IRD) over the past 2000 years, with reworked Ordovician acritarchs indicating local glacier calving and iceberg melting during the past ~100 years.

Decadal-scale quantitative records of changes in sea surface parameters (SST and SSS in summer and winter, and sea ice cover) have been obtained using dinoflagellate cyst assemblages as proxies. Dinocyst assemblages from the tops of box-core samples at 940 sites were calibrated against the oceanographic data to develop palaeoclimatic transfer functions. The paleoceanographic reconstructions show that from ~6500 to 1100 yr BP, there were large oscillations in summer SST from 4°C cooler than now to 6°C warmer, and that variations in sea ice cover (SIC) ranged from 2 months more of heavy (> 50%) SIC to a 5-month longer open water season compared to now. These results are important for the future of shipping in the eastern Canadian Arctic. The paleoceanographic data show that if the GCM predictions of +4°C are correct, then access to Grise Fjord and the entrance of the Northwest Passage by ships other than Class 8 ice-breakers will be extended from the present 1-2 summer months to 5-6 months/yr. However, our records show that the cold and warm intervals oscillate according to a period of ~450-550 years, which is comparable to the 550-yr oscillation of the thermohaline circulation pattern recorded in sediments cores from the North Atlantic Ocean.

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Trimlines and recently exposed terrain as indicators of Late Holocene climatic change in the Queen Elizabeth Islands, Arctic Canada

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Evidence for an expanded Neoglacial ice cover in the Queen Elizabeth Islands (QEI), Arctic Canada, is recorded by trimlines and newly exposed terrain, indicating the recent retreat of glaciers, small ice caps, and perennial snowfields following the Little Ice Age (LIA) (~1600 – 1900 AD). Classification methods were employed with high-resolution multispectral imagery (ASTER and Landsat 5 and 7) to map trimlines throughout the QEI. Results indicate a Neoglacial ice cover ranging from 27 - 84% greater than present on most of the QEI. Regional disparity of Neoglacial expansions suggests a strong topographic control and provides insight into the climatic processes involved in ice-sheet inception. In many cases, the mapped trimlines mark the former equilibrium-line altitude (ELA) of former ice masses, thereby, serving as a proxy for estimating late Holocene climatic change. Differences revealed between modern and former ELAs, as well as the removal and rapid retreat of former ice masses, serves to substantiate the impact of twentieth century warming in the QEI.

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S³: SULPHIDES, STRUCTURES AND SYNCHROTRON LIGHT - A SYMPOSIUM IN HONOUR OF MIKE FLEET

S³ : SULFURES, STRUCTURES ET RAYONNEMENT SYNCHROTRONIQUE – UN SYMPOSIUM EN L'HONNEUR DE MIKE FLEET

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SM05-01 **CORE ISSUES**

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Core/mantle layering of the Earth provides near-perfect mechanical sequestration for material of the core. Advective transfer and/or capillary-based percolative processes drive insignificant fluxes from core to mantle. Is the core's chemical isolation equally impressive? This is an important question for the balancing of the persistently enigmatic budgets of the highly siderophile elements and PGE to which Fleet's work has contributed so much. On redox criteria alone it is clear that the core and the mantle cannot be in bulk equilibrium, and therefore that there are chemical incentives for core/mantle exchange. Recent Os isotope evidence suggests that the core may indeed be leaking chemically [although some W isotope evidence does not encourage this view]. The high-T, fluid character of the outer core enforces chemical equilibrium with the immediately overlying mantle and with the surface of the inner core. Therefore core/mantle chemical transfer must not be by reaction. Instead three perturbed equilibria are considered. [Secular P changes at the CMB that could perturb equilibria are ignored.] (1) Cooling of the Earth provides a temperature perturbation that affects solubility balances. The balance between inner and outer core leads to light element accumulation in the outer core. The balance between the outer core and the oxides, sulfides, carbides, hydrides, and silicates with which inevitably the core becomes saturated is key. Cooling and buoyancy leads to a progressive transfer of liquid [or crystalline] precipitates to the mantle. Solubilities of nonmetals in the core need determination. (2) Electromagnetic forcing can also drive core/mantle transfer. Electrochemical transfers make dramatic trace PGE fractionations that do not occur in the absence of an electric potential. These transfers could be driven by the core's magnetic field. Interesting phase, electrowetting, and chemical fractionation effects are driven by ~1V potentials. The electronic character of, and voltages across, the CMB need determination. (3) Chemical transfers can be forced by emplacement of chemically incompatible assemblages into the CMB region. The redox imbalance between the core and oxidized slab material subducted to the CMB will certainly require chemical readjustments, most plausibly leading to core to mantle transfer of mass. The current debate about whether the chemical signature seen in some plumes is recycled crust or core need not have an exclusive either/or resolution. Recycled material could be key in refluxing core material into the mantle.

SM05-02 CHARACTERIZATION OF PLATINUM-GROUP MINERALS IN THE 21ST CENTURY

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Our understanding of platinum-group minerals (PGM) increased very rapidly from the 1960's with the application of the electron microprobe to analyses of minerals, increasing from about 20 known PGM (Cabri, 1972) to 109 by the beginning of the 21st Century (Cabri, 2002). However, in spite of the large numbers of accepted PGM, it was shown that the crystal structure of only six (5.5%) has been determined. Besides the relative rarity of PGM, they usually occur as very tiny inclusions. Hence, it is not easy to find the PGM, and, secondly, it is also difficult to extract good crystals for crystal structure determination.

The new technique of hydroseparation (Rudashevsky et al., 2002) was applied to several samples, ranging from gabbros to pyroxenites to layered intrusions to tailings, which has resulted in the concentration of several thousand PGM, including 14 potentially new minerals (9 PGM, 3 Au minerals and 2 sulftellurides), many rare PGM and some that are not well-known (e.g., "guanglinite" and mertieite II). Among the new and potentially new minerals are: cubic CuPd, orthorhombic Pd_2Sb, Cu_3Pd, Pd_4Sb_3, and $Rh(Te,Sb)_2$. The PGM were first identified by SEM-EDS, and full characterization of the "new" minerals has begun, with one so far having been accepted by the CNMMN-IMA. It is, therefore, predicted that this new technology will result in the availability of the required good crystals necessary for crystal structure determination, so that most of the current recognised PGM, as well as many more new ones, will be fully characterized by the middle of the 21st century.

SM05-03 Fractionation of the platinum group elements by olivine and chromite partitioning

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It is well established that the distribution of platinum group elements (PGEs) in igneous rocks may be controlled by metal or sulfide phases. However, the role of silicates and oxides in affecting PGE behaviour is less known. To better understand this aspect of PGE geochemistry, we have measured the chromian spinel- and olivine-silicate melt partitioning of the PGEs over a range of oxygen fugacity (fO_2; FMQ-0.5 to +5.5) at one atmosphere and 1300-1400°C. Samples consist of a natural basalt or synthetic basalt oxide mixture plus PGE metal added as a bead or powder, and the melt-metal mixture is held in open crucibles fabricated from San Carlos olivine or suspended as a bead. For experiments involving olivine, we employed a time-temperature history that resulted in the growth of a few, large (100+ micron) crystals. Spinel partitioning experiments equilibrated finely-powdered natural chromite during extensive isothermal soaking. Samples were analysed for PGEs in situ by LA-ICPMS, which combines high sensitivity with depth profiling, thus allowing analyses to be filtered for inclusions. Homogeneous major and trace element distribution, combined with reproducible partitioning from variable duration forward experiments and reversals involving glasses synthesized with different PGE contents, suggests mineral-melt equilibrium is achieved for Ru, Rh, Ir, Pd and Pt. In-situ analyses of olivine and glass revealed significant Os heterogeneity at the micron scale, however, which probably results from undissolved alloy inclusions, a hypothesis we are now testing using HRTEM. Results for chromian spinel indicate uniformly high mineral/melt partition coefficients (D) for Ru and Rh (>100), whereas Pd is excluded (D ~ 0.1). Preliminary data suggest that the substitution of Cr^{3+} for Fe^{+} in spinel results in a lowering of partition coefficients. With decreasing fO_2, Rh, Ru and Ir become more compatible in olivine, with maximum partition coefficients of 2-3. In contrast, Ds for Pd become smaller with decreasing fO_2, to a value of ~0.006. Pt was also found to be incompatible in olivine, with a D of less than 0.01. The relative partitioning of the PGEs observed in the lowest fO_2 runs indicates that olivine and chromite will play a role in producing the depletion in Ru, Rh and Ir relative to Pt and Pd observed in primitive mafic igneous rocks.

SM05-04 VESPERS: A NEW XRF-XRD-XAS BEAMLINE CAPABILITY FOR EARTH SCIENTISTS AT THE CANADIAN LIGHT SOURCE

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VESPERS (VEry Sensitive Elemental and Sructural Probe Employing Radation from a Synchrotron) is a new genre of synchrotron beamline that seems well suited for many of the microscopic analytical problems facing earth scientists. The recently-approved beamline for the Canadian Light Source will allow x-ray diffraction and fluorescence measurement to be conducted simultaneously, as well as providing for x-ray absorbtion spectroscopy to be done subsequently on sample areas as small as 1 um diameter. VESPERS will employ a focussed beam of x rays whose energy can be varied and whose band width can be changed to give either monochromatic radiation, "pink" radiation (15% bandpass) or white radiation (large bandpass). The pink radiation is sufficiently broad to allow Laue patterns to be collected in a few seconds on a large CCD camera. For fluorescence measurements, the exciting beam is expected to produce ppb sensitivities for some elements in a comparable period; better detection limits can be achieved by changing to monochromatic radiation. The scanning sample stage will allow mapping for XRF/XRD measurement modes.

The range of applications to earth science is seen to be enormous. For example, VESPERS will be able to address questions of precious element distribution in host minerals and their siting with regard to crystal phase and habit. Fluorescence will identify and map minor and trace elements and diffraction will map lattice spacings and orientation. Additional chemical information would result from XAFS and XANES measurments of the same areas.

SM05-05 ANOMALOUSLY HIGH δD VALUES WITHIN THE ARCHEAN BOSTON CREEK FERROPICRITE, ABITIBI BELT, ONTARIO: LINKAGE OF DEGASSING TO OXIDATION AND PGE MINERALISATION IN MAGNETITE GABBRO

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In-situ isotope analysis of hydrous igneous amphibole from the 2720 Ga Boston Creek ferropicrite, a 100 m thick peridotite-gabbro unit, provides insights into the mechanisms of PGE mineralization in magnetite gabbro. Ion microprobe analyses of amphibole (hastingsite) oikocrysts and rims from within the peridotite layer indicate a range of δD values from -46 ‰ to +51 ‰ at the 100-1000 ìm intra-grain scale. This range of values is higher than the bulk rock δD values of -50‰ for bulk rock samples, δD values of < 0 ‰ for amphibole (pargasite) from other Abitibi ultramafic units, and the generally acceptable δD range of -90 ‰ to -60 ‰ for mantle materials. The overlying PGE mineralization (1 ppm Pt+Pd+Au+Ag) is hosted in vari-textured zones of pegmatitic magnetite gabbro containing weakly disseminated chalcopyrite + pyrite, up to 20% interstitial (V-rich) ilmenite-magnetite, ferric/total iron = 25 %, and up to 25 % vesicles.

The wide range and anomalously high values of δD at the micrometre-scale cannot be attributed entirely to hydrogen loss during hydrothermal alteration and greenschist facies regional metamorphism. The uniform hastingsite composition of the amphibole precludes the possibility that the δD values reflect variable fluid/mineral fractionation. Consequently, the δD values represent the composition of the magma from which the amphiboles formed. The anomalously high äD values can be attributed to outward diffusion of hydrogen relative to deuterium during continuous disassociation of water and degassing of the ferropicrite magma. This mechanism would increase the oxygen concentration in the residual melt, which explains the (ferric iron-rich) hastingsite composition of the amphibole and the high modal abundance of ilmenite-magnetite and strongly elevated contents of ferric iron in the magnetite gabbro. The increase in oxidation state of the melt during the degassing led to the formation and concentration of Fe-Ti oxide and associated PGE-rich Fe-Cu sulphide. Exploration programs for PGE deposits in magnetite gabbro should consider evidence for progressive degassing and increased oxidation state.

SM05-06 **GOLD IN SULFIDE MINERALS AND ORE DEPOSITS**

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Sulfide minerals are the dominant host for gold in most ore deposits and can contain megascopic to nano-scale grains of gold and even so-called "invisible" gold. Porphyry copper and Carlin-type gold deposits provide examples of the range of gold behavior in sulfide deposits and share a common feature that enhances their gold contents.

Porphyry copper deposits account for most production of by-product gold, and have Cu:Au (atomic) ratios that form a continuous range from about 5,000 to 5,000,000 and a median near 40,000. Cu(-Fe)-sulfide minerals in the deposits have Au contents of 0.1 to 10 ppm that are strongly correlated with Cu content (Cu:Au ratios of 500,000 to 2,000,000). Sulfide minerals do not contain a significant proportion of Au in the deposits; most Au is present as native gold and electrum along margins of Cu-Fe sulfides. Experiments in the Cu-Fe-Au-S system show that bornite solid solution contains about one order of magnitude more Au than chalcopyrite solid solution (iss) at the same temperature. At temperatures of about 700°C, bornite contains as much as 1000 ppm Au.

Carlin-type gold deposits, in contrast, contain only arsenian pyrite and lack gold or electrum that can be seen even at highest SEM magnifications. SIMS and electron microprobe analyses show that this gold is hosted by arsenian pyrite (up to about 1(wt)% Au) and that the maximum gold content of pyrite is limited by its arsenic abundance [Au(wt%) = 0.0516*As(wt%)-0.0126]. Arsenian pyrite with Au contents above this limit contains nano-particles of gold (HRTEM) and Au(0) (XANES), whereas pyrite with Au contents below the limit lacks nano-particles of gold and contains largely Au(I), confirming that the line reflects a solubility limit.

On the basis of these relations, Cu-Fe sulfides and arsenian pyrite are not saturated with respect to gold in most porphyry copper and Carlin-type deposits, respectively. If this is so, Au in the sulfides was probably deposited from solutions that were not saturated with respect to native gold. Thus, the key factor in forming these deposits was stabilization of the host sulfide mineral. Once the sulfide mineral formed, its capacity to scavenge gold from even under-saturated solutions greatly increased the range of conditions under which gold was deposited. Computational models based on the occurrence of native gold that do not include this effect are likely to underestimate the nature and magnitude of gold concentrations in ore deposits.

SM05-07 VAPOUR TRANSPORT OF CU AND AU IN THE SUDBURY FOOTWALL

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The distribution of gold in footwall sulphide ore bodies of the North Range of the Sudbury Igneous Complex (SIC) is unpredictable and highly variable on a variety of scales. For example, in 15 samples of massive sulfide (chalcopyrite-cubanite) ore from a single vein (mean Cu = 30±4 wt%, 1s), the Cu/Pt ratio varies from 43 to 377 (mean Cu/Pt = 135), whereas the Cu/Au ratio varies more than 2 log units from 226 to 38226 (mean = 6418). Gold is often concentrated along the margins of massive sulphide veins or in volumetrically-insignificant accessory quartz-carbonate-sulphide assemblages, which occur in crack-seal type veins and tension gashes within brecciated gneisses. These assemblages usually show consistently high Cu/Au ratios (mean Cu/Au = 5350±2760; 1s, n=8). In this study, we present evidence for the remobilization of significant concentrations of Cu and Au by low salinity H_2O-CO_2 vapour during a hydrothermal event which post-dated the formation of the footwall deposits (Fraser Mine, Falconbridge, Ltd.). The vapour has been suggested to be the product of a late boiling event associated with shallowing of the North Range of the SIC during the Penokean Orogeny at ~1.7 Ga.

Single fluid inclusion LA-ICP-MS analyses (ETH Zurich, Switzerland) were obtained for secondary, vapour-rich inclusions hosted in a Au-rich (15 ppm whole rock) quartz-carbonate-chalcopyrite vein. The vapour-rich inclusions show high concentrations of Cu (up to 0.2 wt%) and very high, and variable Au contents (1.1 to 10.1 ppm), with low Cu/Au ratios between 15 and 440 (mean Cu/Au= 189±157; 1s, n=14). If this vapour communicated with local groundwaters in the surrounding country rocks, a significant amount of Au could have been removed from the massive sulphide veins and dispersed, thereby significantly lowering the concentrations of Au in the footwall ore zones being mined currently. This observation also suggests that distal Au (and Cu) anomalies in the surrounding country rocks may be applied as a pathfinder for massive sulphide veins (Au-depleted).

In contrast to the vapour-rich inclusions, secondary brine inclusions related to post-ore circulation of regional groundwaters contain no detectable Au, and low Cu (less than 100 ppm). These preliminary results suggests that removal of Au by vapour may account for the variable Au concentrations in footwall ores that are poorly correlated with Cu. Secondary brines, although spatially associated with (or hosted in) minor sulphide-bearing alteration veins, played a comparatively minor role in remobilizing some base and precious metals.

SM05-08 High pressure rheology and equation of state of core mimetic liquid Fe zlloys

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New developments in techniques to study high pressure liquid rheology and equation of state (EOS) in metallic melts have allowed the measurement of the viscosity and density of core-mimetic liquid alloys of Fe. We present technical details and results of high pressure - temperature viscosity and density measurements on Fe-FeS liquids using Stokes' method and a tailored density, composite probe sphere. The composite sphere is made of an inner, high density, metallic spherical core and an exterior, low density, refractory spherical shell or mantle. The structure of the composite sphere prevents reaction between metallic core and sample and the adjustment of core/mantle radii allows sphere density tailoring. Synchrotron X-ray radiographic experiments were carried out at high P,T at the Advanced Photon Source to image, in-situ, the motion of a probe sphere rising through the pressurized sample melt. Viscosity is calculated with a modified form of Stokes' equation using the terminal velocity of the probe sphere. The viscosity of Fe and Fe-8.5 wt% S liquids is constant along the pressure dependent melting boundary and is consistent with a prediction based on semi-empirical formalism. Further experimental verification of viscosity invariance along the high pressure melting boundary, especially where abrupt boundary slope changes occur as a result of different parent solid structures (i.e. at triple points), is required. The existing experimental evidence for pure Fe, particularly in other physical properties such as electrical resistivity and recent high pressure liquid structure studies, suggests that the preceding solid phase structure may play an important role in controlling property behavior along the melting boundary. EOS is calculated from density-pressure data from sink-float studies using composite spheres. The direct application of the EOS to Io and Ganymede and its extrapolation to the core of Mars and Earth suggests that Fe-10 wt% S is a candidate core composition for all of these planetary bodies.

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SM05-09

X-RAY ABSORPTION NEAR EDGE STRUCTURE (XANES) STUDIES OF METAL SULFIDES AND SULFATES FROM THE S K-EDGE AN AND L-EDGE USING SYNCHROTRON RADIATION

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Synchrotron radiation based X-ray absorption spectroscopy (XAS) has flourished in the last decades. The spectroscopy has been used as analytical and structural tools in many diverse areas of science and technology. In this presentation an overview of the applications S K-edge and L-edge (XANES) spectroscopy in mineralogy will be described. The emphasis will be on the qualitative interpretation of the near edge features of sulfide and sulfate mineral using simple multiple scattering and band structures theory [1-4].

[1] Sulphur K- and L-edge XANES of Zn, Cd and Hg monosulphides: A comparative study, D. Li, G.M. Bancroft, M. Kasrai, M.E. Fleet, X.H. Feng, K.H. Tan, B.X. Yang. J. Phys. Chem. Solids, 1994, 55, 535-543

[2] S K- and L-edge X-ray absorption spectroscopy of metal sulphides and Sulphates: Application in mineralogy and geochemistry, D. Li, G.M. Bancroft, M. Kasrai, M.E. Fleet, X.H. Feng, K.H. Tan, Canadian Mineralogist (1995) 33, 949-960.

[3] S K- and L-edge XANES and Electronic Structure of Some copper Sulfide Minerals, D. Li, G.M. Bancroft, M. Kasrai, M.E. Fleet, X.H. Feng, B.X. Yang and K.H. Tan, Phys. Chem. Minerals (1994) 21, 317-324

[4] Sulfur K-edge XANES study of local electronic structure in ternary monosulfide solid solution [(Fe, Co, Ni)0.923S] S. P. Farrell , M. E. Fleet Physics and Chemistry of Minerals (2001), 28, 17-27

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SM05-10 XAS study of the mine tailings associated with As enriched pore waters from a Gold/Silver mine

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The cyanidation process of gold ores can result in a variety of environmental contaminants, most notably Hg, As and cyanide release into adjacent aquifer systems. To assess the behaviour, stability and speciation of As in this type of tailings environment, the comprehension of the As mineralogy and aqueous geochemistry must be understood. In this study scanning electron microscopy, XRD (Rietveld) and X-ray absorption spectroscopy (includes X-ray absorption near edge structure (XANES) and X-ray absorption fine structure (XAFS)) were used to determine the speciation, structure and mineralogy of solid phase samples associated with pore waters containing high and low As concentrations from two adjacent tailings impoundments (A & B). Pore water geochemistry and solid phase samples were collected during the installation of two monitoring wells, one in each respective tailings impoundment (A & B). A comparison of the Arsenic pore water concentrations sampled at different depths, showed a range from 24.4 mg/L to 0.6 mg/L As in tailings A and 22.1 mg/L to 8.4 mg/L As in tailings B. As pore water concentrations showed large fluctuations in concentrations with depth. Correlations with the solid phase were performed using Rietveld refinement of X-ray powder diffraction patterns, scanning electron microscopy and XAS. Several arsenic containing mineral phases including scorodite, As-containing jarosite and As-containing hematite were identified at different depths. Bulk XAFS spectra were collected from four samples representing different depth locations to determine the arsenic speciation and structural associations within the A and B tailings impoundments. The XAS measurements show distinct differences in As speciation and molecular structure with depth for each respective tailings impoundment. Tailings-A impoundment is dominated by scorodite (e.g. As(V)) at deeper portions (37m, 43m and 61m) and As-containing iron oxides at shallower locations (27m). The 27m location also showed mixed speciation of As(III) and As(V). In tailings-B the As-containing phases change from a dominant phase represented by scorodite at 15m towards an As containing iron oxides (i.e. As-hematite) at 18 m, 21 m, 24 m and 27 m. Determination of the solid phase and correlation of these results with the aqueous geochemistry provides direct evidence for the speciation, distribution of As in the solid phase and insight into solubility controls on pore water concentrations from two adjacent tailings impoundments.

SM05-11 THE STRUCTURE OF LITHIUM CONTAINING SILICATE AND GERMANATE GLASSES

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The addition of alkali cations to silicate melts and glasses results in depolymerisation of the network, as non-bridging oxygens (NBOs) are generated. Recently, it has been observed that the Q species (Q_3, Q_2) distribution in silicate melts appears to have a dependence on the size of the alkali cation. Li-containing silicate glasses have a higher Q_2/Q_3 ratio than equivalent composition silicate glasses containing Na or K. This size dependence appears to be different in germanate melts/glasses. Lithium containing germanate glasses having lower Q_2/Q_3 ratios relative to equivalent Na and K containing composition glasses. We are currently investigating and comparing the Q species distribution in Li-containing silicate and germanate glasses. Silicate and germanate glasses containing from 5 to 30 mol% Li_2O have been prepared and examined using Si K-edge XANES/EXAFS, Si L-edge XANES, Raman spectroscopy and Li_7 NMR. Preliminary results will be presented and discussed with relevance to the Q_3 and Q_2 distributions in the two suites of glasses.

SM05-12 ADVANCES IN UNDERSTANDING OF THE CRYSTAL CHEMISTRY OF HEXAVALENT URANIUM

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Research concerning the crystal chemistry of hexavalent U by the Environmental Mineralogy and Crystal Structures research group at Notre Dame has resulted in the publication of more than 110 new structures of uranyl compounds (including 36 minerals). New insights into the crystal chemistry of U^{6+} will be presented, with emphasis on recently discovered novel structural connectivities. The structural hierarchy of uranyl minerals and compounds, which was first established for 180 structures in 1996, has been extended to include 145 new structures. The hierarchy is based upon polymerization of polyhedra containing higher-valence cations, and involves five distinct classes: structures containing isolated polyhedra (7), finite clusters of polyhedra (41), chains of polyhedra (52), sheets of polyhedra (184), and frameworks of polyhedra (41). The dominance of sheets in uranyl compounds (57% of known structures) arises from the unequal distribution of bond-valences within the uranyl polyhedra. Topological relations of the sheets in uranyl compounds are best understood by analysis of the topological distribution of anions within sheets in which sharing of polyhedral edges dominates, and by graphical representation of the connectivity of polyhedra in cases where sharing of vertices of polyhedra dominates the sheet.

SM05-13

SORPTION OF AQUEOUS U^{6+} ONTO NANO-SIZE SILICA-WATER INTERFACES: A ROUTE TO THE IMMOBILIZATION OF RADIOACTIVE NUCLIDES

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Sorption is a very important process that can immobilize toxic metal species in groundwater, which certainly has great significance in immobilization and remediation of nuclear wastes. Thus, understanding sorption of aqueous metal species onto mineral surface and microorganisms is extremely important, not only in modeling the transport and fate of toxic metal species in groundwater, but also in environmental assessment and remediation of nuclear wastes.

In this work, the sorption of aqueous U^{6+} species onto nano-size silica-water interfaces is investigated at different U concentration, different pH and a constant salt concentration that simulate typical brine conditions in geological repositories. The sorption species and mechanisms of U onto silica-water interfaces are characterized using several spectroscopic and structural methods. These methods include XRD, TEM, Raman, optical fluorescence, time-resolved laser-induced fluorescence, U L-edge XANES and EXAFS. The sorption of U species onto silica-water interfaces is minimal at pH < 1.5, and increases with increasing pH until they are completely up-taken by silica at pH > 5.0. At pH < 5, the dominant U species are mono-nuclear uranyl or hydrolyzed uranyl. These aqueous U species are sorbed onto silica-water interfaces as an inner sphere bidentate. The driving forces behind the sorption are two: (1) surface complexation, and (2) electrostatic attraction between U species of positive charge and silica surface of negative charge. However, at pH > 6, U may form precipitates, and precipitation is a dominant mechanism for the uptake of U.

SM05-14 SYNCHROTRON ANALYSES IN APPLIED MINERALOGY: DIAMOND, URANIUM MINERALS, AND CHLORITE

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Non-destructive synchrotron x-ray analyses, including x-ray absorption spectroscopy (XAS) and x-ray fluorescence spectroscopy (S-XRF), are used to analyze the chemical properties of minerals with high sensitivity and accuracy. The XAS-XANES technique is an element-sensitive probe for examination of the local chemistry of a given element and provides information on elemental oxidation states. The spectra obtained from S-XRF analyses provide direct elemental content information from the characteristic x-ray fluorescence emissions produced when the energy of incident synchrotron x-rays is used to excite the target.

Legal and socio-emotional issues associated with "conflict" diamonds prompted an investigation into characterization of diamond using synchrotron radiation for trace element chemical fingerprinting. S-XRF analyses were conducted on diamond specimens at the Advanced Photon Source with trace element data collected on the COM-CAT beamline using two incident photon energies to generate the fluorescence signatures. The trace element signatures from one diamond suite present dominant Fe and lesser Cr, Zn, and Zr trace element features, with some differences in Cu, Ni, Sr, Y, and Zr contents being observed between mine sites and between eclogitic and peridotitic parageneses.

Unconformity-type uranium deposits are exploited for nuclear power generation and studied for use as natural analogues of high-level nuclear waste repositories. U-Pb radiometric ages determined from uranium minerals are used as indicators of mineral closed system behavior, however, the geochronology of the uranium minerals is poorly understood because of varying chemical disequilibrium behavior of the U and Pb isotopes. Synchrotron analyses at the Advanced Photon Source PNC-CAT beamline are being used to improve our understanding of the geochemical behavior of U and Pb in uranium oxides (pitchblende, coffinite, uranophane) by examining the distribution of Pb, Ca, and Si, in parallel with U oxidation state (U^{4+}/U^{6+}), using S-XRF and micro-XANES techniques.

Fe K-edge x-ray absorption spectra in the XANES region was used to determine the ferrous (Fe^{2+}) to ferric (Fe^{3+}) proportions in chlorite specimens for use in a mineralogical uranium exploration tool. A suite of samples containing dominant chorite were selected to obtain several chlorite species covering a range of chlorite compositions (Al-Mg di,trioctahedral sudoite to Fe-Mg trioctahedral chlorite). The XANES results were collected at Daresbury and a calibration curve using standard data correlating Fe^{3+} proportion to absorption pre-edge position was used. From this curve, the analysed chlorites range in Fe3+ proportions from 34% to 87%, with several examples containing ~60% Fe^{3+}.

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SM05-15 **BULK STRUCTURAL AND ELECTRONEGATIVITY CONTROLS ON REACTIVITY OF FE SULFIDES AND ARSENIDES**

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Oxidative dissolution reactions between oxygenated fluids (e.g., the atmosphere or oxygenated aqueous solutions) and 3d metal sulfides and arsenides begin via adsorption of oxidants onto mineral surfaces, thus surface properties are integral to the understanding of reaction mechanism. Traditional leach rate studies focussed primarily on concentrations of dissolved oxidizing agents and soluble reaction products because these could be analysed; chemical state properties of the mineral surfaces were not obtained, because they were difficult or impossible to obtain. Recent utilization of STM/AFM and Synchrotron Radiation X-ray Photoelectron Spectroscopy (SRXPS) has allowed determination of properties of mineral surfaces before, during and after reaction, thus allowing determination of initial, intermediate and final reaction products at mineral surfaces.

SRXPS studies of minerals in the Fe-S-As system demonstrate the complexities of fracture surfaces. Fracture surfaces of pyrite (cubic system) are not reconstructed but an autoredox reaction stabilizes the reactive portions of the surface. Fracture surfaces of orthorhombic leollingite ($FeAs_2$) undergoes extensive reconstruction where surface and near-surface As atoms react to form surface polymeric species. The reaction decreases electron density on polymeric As atoms and enhances electron density on nearby Fe atoms. The similarity of Fe and As electronegativities diminishes the likelihood of surface auto-redox reactions and enhances the likelihood of As polymerization (homonuclear) reactions. SRXPS spectra of orthorhombic marcasite reveal surface S polymerization and evidence for an autoredox reaction.

Pyrite surfaces are least reactive toward atmospheric O_2 and initially S is less susceptible to oxidation than Fe. Marcasite is more reactive toward O_2 and Fe(sup>3+$_{aq}$ than pyrite, with Fe being more susceptible to oxidation than S. Loellingite is most reactive toward oxidation by O_2, with surface As being highly reactive. Many more kinetic studies are required of this mineral.

These results indicate that bulk structure (including metal-ligand organization and unit cell dimensions) and electronegativity considerations of 3d metal sulfides and arsenides are the major controls on surface reconstruction and reactivity and can be used to predict surface structures and reactivity. Chalcopyrite and sphalerite, for example, should display surface reconstruction on (111) surfaces where surface sulfur polymeric species are likely to form. These surfaces should be hydrophobic and should react differently from other autocompensated surfaces of these minerals.

SM05-16 Surface reconstruction of bornite (Cu_5FeS_4) fracture surfaces

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Synchrotron Radiation X-ray Photoelectron Spectroscopy (SRXPS) and conventional X-ray Photoelectron Spectroscopy (XPS) have been used to study a pristine fracture surface of Bornite (Cu_5FeS_4). Comparisons of these high-resolution spectra reveal for the first time, three distinct contributions to the S 2p spectra. The main symmetric peak of the S 2p spectra for bornite is located at about 163.51 eV and is likely derived bulk S atoms. The broad nature of the bulk contribution in comparison to other 3d transition metal sulfides, such as chalcopyrite, is consistent with the presence of both five fold and seven fold coordinated sulfur atoms in the bornite structure. A core level shifted peak was observed at 160.1 eV and has been attributed to a surface monomeric species (S^{2-}). The presence of a second broad contribution at 162.1 eV likely represents surface polymeric species (Sn^{2-}). The presence of surface sulfur polymers indicates surface reconstruction of bornite surface upon fracture. This data suggests that surface polymers form where polar surfaces are exposed during conchoidal fracture. Conventional XPS Cu 2p and Fe 2p spectra collected from a pristine fracture surface of bornite revealed a Cu(I)-S peak centered at about 932.2 eV and a high spin Fe(III)-S peak centered at 708 eV.

SM05-17 **CRYSTAL STRUCTURE DETERMINATION OF THE CALCIUM-SILICATE-CARBONATES, SPURRITE, TILLEYITE AND SCAWTITE AND THEIR RELATIONSHIP TO OTHER SPECIES IN THE SILICATE-CARBONATE CHEMICAL CLASS**

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Spurrite, $Ca_5(SiO_4)_2(CO_3)$, tilleyite, $Ca_5(Si_2O_7)(CO_3)_2$, and scawtite, $Ca_7(Si_6O_{18})(CO_3)•2H_2O$, are the only calcium-carbonate-silicate minerals known to date and all three form in high-temperature skarns. Crystals of spurrite and tilleyite from Coronet Hill, Metaliferi Massif, Apuseni Mountains, Romania and scawtite from the type locality in Scawt Hill, Ireland were used to refine the structures to R values of 0.036, 0.021 and 0.018 respectively. All three structures are monoclinic: spurrite, centrosymmetric space group $P2_1/a$, with a 10.484(1), b 6.712(1), c 14.156(2) Å, β 101.27(1)°, V 977,1(2) Å^3; tilleyite with centrosymmetric space group $P2_1/a$, a 15.082(3), b 10.236(2), c 7.572(1) Å, β 105.17°, V 1128.3(3) Å^3; and scawtite with non-centrosymmetric space group Im, a 6.631(1), b 15.195(3), c 10.121, β 100.59(3)°, V 1002.4(1) Å^3.

The calcium-silicate-carbonate structures are layered. The spurrite structure has two layers; [CaO_8] polyhedra adjoining [CO_3] groups in one layer while [CaO_7] polyhedra adjoin isolated [SiO_4] tetrahedra. The tilleyite structure has [CaO_8] polyhedra adjoining [CO_3] groups in one layer while [CaO_8] polyhedra intertwine [Si_2O_7] tetrahedral pairs in the other layer. The scawtite structure has [CO_3] triangles sharing a layer with [Si_6O_{18}] rings and a second layer with [CaO_n] polyhedra (n = 6 to 8). This layer has holes that accommodate the H atoms of the water molecule.

The Pauling bond strength received for each anion is high for the two anionic complexes (1.33 vu for the [CO_3] anionic group and 1.0 vu for the [SiO_4] anionic group). The high bond strength and rigid nature of the carbonate group prevents carbonate-carbonate bonds and carbonate-silicate bonds as the 'bridging oxygen' would be over-bonded. Silicate polyhedral polymerization is possible and the degree of polymerization depends on the cation to anion ratios and Lewis strengths of the silicate group. The alkali, alkaline earth and rare earth elements have low Lewis acid strengths thus forming large polyhedra that act as connectors between the carbonate and silicate groups. These principles are extended to include the 13 structures in the silicate-carbonate chemical class. As the degree of polymerization of the silicate groups increases the Lewis base strength (LBS) decreases from 0.33 vu for nesosilicates to 0.12 vu for a double sheet silicate. In general all these structures are layered with high coordination polyhedra and carbonate groups in one slab and the silicate groups with lower coordination polyhedra in the second layer. As the LBS decreases in the silicate layer there is an increase in the number of large cations within the layer.

SM05-18 MULTIFREQUENCY EPR STUDY OF RADIATION-INDUCED DEFECTS IN THE APATITE-GROUP MINERALS

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Radiation-induced defects in the apatite-group minerals [$Ca_{10}(PO_4)_6(F,OH,Cl)_2$] are of considerable interest not only within the geological sciences but also in optical and laser technologies, nuclear waste disposal and medical sciences. In this study, powder and single-crystal samples of synthetic fluorapatite, hydroxylapatite and chlorapatite have been treated by gamma or x-ray radiation, and were investigated by electron paramagnetic resonance (EPR) spectroscopy at X- and W- band frequencies. The defect centres after gamma-irradiation consist of various types of complex combinations of halogen-ion vacancies and substitutional O^{2-} ions, which may be classified as hole and electron centres. The hole centres are associated with oxygen ions substituted in the structural halogen chain, and the electron centres are formed by trapping electrons at halogen vacancies (or at O^{2-} - halogen-vacancy defects). Several centres of these types were observed. In particular, the high-resolution W-band EPR spectra made possible identification and characterization of several previously unobserved defects. Models of these centres will be discussed. In addition, radiation-induced centres in $Sr_{10}(PO_4)_6F_2$ and $Sr_{10}(PO_4)_6Cl_2$ have also been examined by EPR, and will be compared with their calcium analogs.

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Radiation-damage-induced cathodoluminescence in quartz from the Athabasca and Witwatersrand Basins: an integrated CL, EPR and Micro-Raman study

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Quartz grains in sandstones from the Athabasca (Saskatchewan) and Witwatersrand (South Africa) basins exhibit complex patterns and distributions of radiation-damage-induced cathodoluminescence (CL) colors. One type of CL occurs as ~50-μm-wide haloes around inclusions of U- and Th-rich accessory minerals (e.g., zircon, monazite, uraninite, fluorapatite and rutile) in the quartz grains. Another type of CL in patchy-to- continuous distribution along the rims or the fractures of quartz grains with or without any association of U- or Th-rich accessory minerals occurs locally and has the same width. The width of these two types of CL is consistent with the penetration distance of alpha particles in solids, suggesting that these types of CL are related to radiation-induced damage sites in quartz grains. At the McArthur River U deposit, Athabasca basin, the patchy and continuous CL rims are best developed in sandstones close to lithological boundaries, faults and the unconformity. Electron paramagnetic resonance (EPR) and micro-Raman spectroscopy revealed that the Athabasca and Witwatersrand quartz samples are characterized by a number of electron-like centres (E_1') and several hole-like centers. At the McArthur River deposit, the densities of those electron- and hole-like centres appear to increase with depth, being the highest approaching the unconformity. Moreover, the quartz grains in the sandstone samples close to the unconformity, which exhibit pervasive continuous CL rims, have not only the highest densities of the electron- and hole-like centres but also additional paramagnetic centres with effective g factors from 2.01 to 2.02. Further work is under way to: 1) better characterize the paramagnetic defects in quartz from Athabasca and Witwatersrand samples, and 2) establish relationships between the radiation-damage-induced CL and specific paramagnetic defects in quartz.

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SM05-P01 CHARACTERIZATION OF SULPHUR INTERACTIONS WITH HEMATITE MINERALS USING SYNCHROTRON X-RAY ABSORPTION SPECTROSCOPY

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Sulphur bearing hematite is a product of some novel hydrometallurgical sphalerite treatments. Leaching tests aimed at investigating the stability of the hematitic leach residue have shown that only a fraction of the sulphur present is removed. In this study sulphur bearing hematites were leached in a variety of media and examined using XANES Sulphur K-edge and L-edge spectroscopy at the Canadian Synchrotron Radiation Facility, SRC-Madison, WI, to address questions regarding the chemical environment, oxidation state and physical distribution (surficial versus intercrystalline) of the sulphur within the hematite minerals. XANES S K-edge FY and TEY and L-edge TEY spectra indicate that the sulphur predominantly occurs as sulphate having a formal oxidation state of S^{6+} and is largely distributed within the hematite matrix at concentrations between approximately 0.04 and 4.7 %. The XANES S K- and L-edge absorption spectra have also been used to assess the effectiveness of leach treatments employing HNO_3 and NH_4OH solutions for the removal of sulphate from the hematite minerals. Here, the spectra indicate that a 0.05M HNO_3 solution was largely ineffective at removal of surficial and intercrystalline sulphate whereas 1 to 4M NH_4OH leach solutions appear to have variably removed sulphate from the uppermost regions (5 to 30 nm depth) of the hematite minerals. Overall integration of the XANES S K-edge and L-edge TEY and FY spectra provides both unique information regarding the distribution of sulphate within the hematite matrix and a means to evaluate the effectiveness of leach processes used to remove sulphate from hematite minerals.

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SM05-P02 Mineral chemistry, Al/Si degree of order and formation temperature of alkali feldspar from Wulashan quartz-K feldspar and quartz vein gold deposit, Inner Mongolia, China

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The Wulashan gold deposit is situated along the northwestern margin of the North China craton, and hosted in ductile-brittle faults within Archean metamorphic volcano-sedimentary rocks of the Wulashan group. It is surrounded by a number of granitoid intrusions, pegmatite dikes and K-feldspar alteration belt including K-magma veins and magmatic hydrothermal vein (GPKA). The gold mineralization occurs in quartz-K feldspar and quartz veins, and is spatially associated with GPKA. Alkali feldspar is not only a major mineral in gold-bearing veins, but also widely exists in all varieties of geological bodies. The alkali feldspar from this area includes the whole series of sanidine (occurring in metamorphic rock), orthoclase (occurring in granite), intermediate to maximum microcline.

More than one hundred alkali feldspar samples were collected from various geological bodies and gold-bearing veins of two mineralization stages. The chemical compositions of the alkali feldspar samples are analyzed using electron microprobe analysis (EMPA). The powder X-ray diffraction (XRD) patterns were collected using Cu Ka source and used to calculate Si-Al degree of order (Z). The formation temperatures of the alkali feldspars are calculated using two-feldspar geothermometry. The results indicate that (1) the end member composition of feldspar (Or, Ab, An) in gold bearing veins is more similar to that in altered rock and magmatic hydrothermal vein than that in granite, pegmatite, K-magmatic rock, and regional metamorphic rock; (2) The Al/Si degree of order of alkali feldspar from gold-bearing veins is 0.89 ± 0.05, which, in combination with mineral chemistry, indicates a similarity to that of alkali feldspar from magmatic hydrothermal veins and altered granite; (3) the formation temperature of alkali feldspar in gold-bearing veins is lt; 400°C, which is close to that of alkali feldspar from altered rock, but apparently lower than that of alkali feldspar in granite and pegmatite.

SM05-P03 Experimental evidence for the formation of PGE alloy inclusions in chromite by local reduction

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The origin of PGE-enriched chromitites is not well understood. There is experimental evidence for solution of platinum group elements (PGEs) in spinel-structured minerals, but textural evidence from natural chromitites suggests that PGEs may be hosted by micro-inclusions of platinum group minerals (PGMs; including alloy, sulfide and arsenide), whose origin is unknown. In the process of conducting chromite-silicate melt partitioning experiments for the PGEs, we have observed the formation of PGE alloys along the margins of equilibrating chromite crystals, which may provide an analogy for the entrapment of at least part of the suite of PGMs in natural chromitites. Experiments were done at 1400°C and FMQ+3.6 and involved polished chromite slabs or a 40-70 micron seived powder, both immersed in a natural basalt. Samples were suspended in the furnace by wires of Pd or Pt/Rh alloy. Experiment durations ranged from 5 to 336 hours, and in all cases small (1-8 um) PGE alloy grains precipitated on the margins of crystals or slabs. Electron microprobe analysis of the chromite grains revealed core-to-rim zonation of iron and chromium, with a strong enrichment of ferric iron and depletion of chromian at the rim. Zonation is in response to the high fO_2 of the experiment, such that the original chromite is converted to a chromian magnetite. This conversion results in a preferred uptake of Fe^{3+} relative to Fe^{2+} from the melt, resulting in local reduction of the melt adjacent to the chromite. That this reduction zone exists is supported by local (fluorescence-corrected) enrichment of chromian in the melt adjacent to crystals, as chromite solubility increases with decreasing fO_2. Since the solubility of PGEs in silicate melts decreases substantially with fO_2, the local zone of reduction induces a chemical potential gradient within the experiment, causing dissolution of the wire hanger, and reprecipitation next to the chromite. At lower fO_2, chromite will incorporate Cr^{3+} to the complete exclusion of Cr^{2+} when crystallizing from a basaltic melt. The local reduction process may act to precipitate PGE alloys from a magma near PGE saturation, with further crystallization of chromite entraping these alloys.

SM05-P04 **INSIGHTS INTO THE ORIGIN AND ROLE OF CARBONACEOUS MATTER IN UNCONFORMITY-TYPE URANIUM DEPOSITS USING BULK C 1S XANES AND CAPERS X-PEEM**

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The origin and role of carbonaceous matter in the formation of unconformity-type uranium deposits remains an unresolved issue. In the eastern Athabasca Basin, many of the unconformity-type uranium deposits are located within or near reactivated high-strain zones hosted by graphitic pelitic gneisses and graphitic/carbonaceous fault zone rocks. Many types, habits, and generations of graphite and spatially associated carbonaceous matter are found in these high-strain zones. Since the early 1970s, several researchers have noted the presence of carbonaceous matter and solid bitumen within alteration and ore zones, leading to the hypothesis that the destruction of graphite and the formation of hydrocarbons were the main reducing agent in the genesis of unconformity-type uranium deposits. Other researchers have argued that this hypothesis should be rejected.

The authors have chosen the Spherical Grating Monochromator (SGM) at the Canadian Synchrotron Radiation Facility (CSRF) and the Canadian Photoemission electron Research Spectromicroscope (CaPeRS X-PEEM apparatus) for their ability to provide complimentary high-resolution analytical tools in identifying the speciation and location of carbonaceous matter in rocks. Bulk XANES spectroscopy at the C1s core edges on the SGM beamline was used for the initial spectroscopic research of analyzing and characterizing the different types of samples from various areas in the sub-Athabasca basement. Following these bulk XANES analyses, the X-PEEM apparatus was utilized for chemical imaging and analysis of carbon speciation within individual samples at the submicron/micron scale. The CAPERS X-PEEM apparatus was also used to determine nitrogen, oxygen, and transition metal speciation in other minerals associated with the carbonaceous matter.

Our bulk XANES analysis of ~75 samples indicates that the absorption spectra are very complicated and are composed of varying mixtures of graphitic (ordered and disordered: C1S ® II*Gr) and organic material (aliphatic and aromatic: C1S ® II* and C1S ® IIs). In all cases, the bands at 285.3 and 291.7 eV are due to ordered graphite within the analyzed samples. Overall, the graphitic samples are a mixture of graphitic and aliphatic/aromatic hydrocarbons with more ordered graphite in samples that are less altered. In carbonaceous fault zone rocks with no evidence of graphite, we only observe spectra for organic material (aliphatic and aromatic: C1S ® II* and C1S ® IIs). We conclude that additional studies of carbonaceous matter, from graphite to kerogen, will continue to yield valuable information on the origin and role of carbonaceous matter in the formation of unconformity-type uranium deposits within the Athabasca Basin.

SM05-P05 **Platinum-group element alloy inclusions in chromites from Archaean mafic-ultramafic units: evidence from the Abitibi and the Agnew-Wiluna Greenstone Belts**

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The composition of chromites and olivines in sulphur-poor (S < 0.6 wt%) komatiites from the Agnew-Wiluna Belt (Western Australia), and of chromite concentrated from komatiitic basalt, ferropicritic basalt and tholeiitic basalt from the Abitibi Belt (Canada) were analysed in order to investigate the role of primary magmatic phases in the behaviour of PGE. The results of laser ablation ICP-MS analyses show that PGE-bearing alloys are not stable in crystallising komatiite and that ruthenium is soluble in chromite during crystallisation. Conversely, analyses of chromites separated from Theo's Flow tholeiitic basalt indicate that Ir-Os- (±Pt) enrichments (> 200 ppb) reflect the presence of alloys within chromites. Platinum enrichments (>370 ppb) in Boston Creek ferropicritic basalt reflect the presence of Pt-rich compounds, whereas chromites from Fred's Flow komatiitic basalt contain Ir-rich compounds. The presence of PGE-bearing alloys in Theo's Flow and Fred's Flow is due to late S-supersaturation, whereas the presence of Pt-rich compounds in Boston Creek Flow reflects high state of melt oxidisation. The lack of PGE-bearing alloys in the olivines and chromites of komatiites can be explained by thermal instability of PGM, depletion in PGE at the mantle source, early S-supersaturation, the oxidisation conditions of the melt, or a combination of these factors.

SM-06

THE A, B, C'S OF CONODONTS (AUTECOLOGY, BIOSTRATIGRAPHY AND CONODONT PALAEOBIOLOGY)

L'ESSENTIEL SUR LES CONODONTES (AUTOÉCOLOGIE, BIOSTRATIGRAPHIE ET PALÉOBIOLOGIE DES CONODONTES)

PETER VON BITTER (ROYAL ONTARIO MUSEUM)

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SM06-01 **GEORGE JENNINGS HINDE'S TORONTO CONNECTION (1872-1879): EARLY AND IMPORTANT CONODONT STUDIES IN CANADA**

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George Jennings Hinde (1839-1918) came to Canada from England about 1872, after nearly ten years sheep-farming in Argentina; between 1873-75 he was enrolled as a non-matriculated student in University College in Toronto, initially studying under Professor Henry Alleyn Nicholson and then probably under Professor Robert Ramsey Wright, successively Professors of Natural History. Hinde published his first paper, a joint study on Silurian fossils of Ontario with Nicholson in 1875; he continued geological and palaeontological work in the region, publishing in 1877 the first detailed identification and description of interglacial deposits in Canada, based on his observations at Scarborough Bluffs. Contrary to previous reports, he did not return to England in 1874 but remained in Toronto until at least 1879, increasingly focusing and publishing on microfossils.

Hinde's 1879 publication on Ordovician and Devonian conodonts of southern Ontario, and western New York, respectively, was at the time, second in importance only to Christian Pander's 1856 groundbreaking publication. While in Toronto, Hinde discovered Late Ordovician conodonts on bedding-plane surfaces of the local Georgian Bay Formation; many years later, in the 1960s, several of Hinde's single element conodont species were grouped by S.M. Bergström and W.C. Sweet into multielement conodont species, when they and G.F. Webers established Ordovician multielement conodont taxonomy. Hinde's naming of Devonian faecal conodont assemblages on black shale from North Evans, N.Y., Polygnathus dubius, was "right for the wrong reasons"; nevertheless, it represented the first application of multielement taxonomy, using the concept that several different conodont elements existed simultaneously in any one animal. The conodont genus *Polygnathus*, erected by Hinde, are still used today; *Hindeodella* and *Hindeodus* among others, were named in honour of Hinde.

Hinde, although apparently a motivated and focused individual when he came to Canada in his early thirties, possessed only minimal academic credentials. Nevertheless, his formal and informal studies in Toronto were such that he was able, at the age of 40, to enter the University at Munich, Germany, for doctoral studies. By 1880 Hinde had completed and published his doctoral research on fossil sponge spicules, conducted under Prof. Karl von Zittel. Hinde returned to England, married, and continued with a successful scientific career, particularly as a student of fossil sponges.

SM06-02 **INTERPRETING LAURENTIAN-WIDE EARLY ORDOVICIAN SEA LEVEL AND TECTONIC EVENTS USING THE PATTERN OF CONODONT COMMUNITIES**

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The Newfoundland Appalachian and Canadian Cordilleran margins of Laurentia during Early Ordovician were tectonically controlled by paleo-northward active subduction of Iapetus with accretion of peri-Laurentia arc/back-arc system, and by phases of extension, respectively. Early Ordovician conodont community patterns established for each margin were synchronously affected by sea level and tectonic events. The community patterns are based on nine cluster analyses using 96,177 conodont specimens from 472 samples of nine sections representing platform and slope-to-basin environments in western Newfoundland, and another six cluster analyses employing 39,319 conodont specimens from 148 samples from six sections representing platform, shelfbreak and basin environments in northeastern BC. In total, 33 and 19 conodont communities are recognized from the latest Cambrian, Tremadocian and Arenigian intervals in western Newfoundland and northeastern British Columbia, respectively, and they reveal five principal phases of sea level events.

Transgressive Phase I (early-middle Tremadocian) had three transgressive sub-phases: 1) initial transgression in early *Iapetognathus fluctivagus* Zone time; 2) further transgression in early *Cordylodus angulatus* Zone time; 3) and highstand in late *C. angulatus* or early *Rossodus manitouensis* Zone time. Regressive Phase II occurred in late Tremadocian. Highstand Phase III (latest Tremadocian-Arenigian) experienced five fluctuations: 1) transgression for most of *Tetragraptus approximatus* Zone time; 2) two transgression-regression cycles in the Appalachians and a single regression in the Cordillera in late *T. approximatus* and *T. akzharensis* Zone time, respectively; 3) highstand for the entire *Pendeograptus fruticosus* Zone time; 4) major regression for most of *Didymograptus bifidus* Zone time; 5) frequent sea level fluctuations in the Appalachians and a single transgression in the Cordillera during late *Didymograptus bifidus* and *Isograptus victoriae lunatus* Zone time, respectively. Regressive Phase VI occurred in earliest *I. v. victoriae* Zone time. Prolonged Regressive Phase V started with brief transgression in early *I. v. victoriae* Zone time, followed by prolonged regression through late Arenigian-early Darriwilian.

The striking similarity of sea level history reflected by conodont community development between these widely separated margins during the Early Ordovician suggests a primary eustatic control and a secondary tectonic control. The former was presumably controlled by plate-scale mantle processes that synchronously affected all of northern Laurentia and the latter by regional tectonic processes on each margin.

SM06-03

WHERE CONODONTS GO WHEN SEA-LEVEL BECOMES LOW: A CASE STUDY OF REFUGIA AND EVOLUTION USING THE ORDOVICIAN GENUS *CAHABAGNATHUS*

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A common pattern in the evolution of Cambrian-Ordovician conodont lineages, especially those adapted to shallow marine facies, is the appearance of new species at sea-level rises and disappearances at sea-level drops. This simple picture can be complicated by intervals that consistently have no examples of a particular lineage, even after extensive sampling of the most complete sections. Presumably the lineages survived in refugia, but commonly these endemic taxa remain unknown. The distribution pattern of the endemic and more cosmopolitan species of *Cahabagnathus* demonstrates how collecting material in less favorable lithologies for conodont sample processing, which we interpret as refugia, can add to our understanding of the interplay between sea-level changes and evolutionary lineages.

There are eight species of *Cahabagnathus* in the published literature at the present time that range from the early *Pygodus serra* Zone through the *Baltoniodus gerdae* Subzone of the *Amorphognathus tvaerensis* Zone. Five of the species are named. We recognize two lineages for *Cahabagnathus*, and propose a connection between evolution within both lineages and sea-level changes. Lineage 1 is *C. friendsvillensis* - *C. chazyensis* - *C. sweeti* - *C. carnesi*. Three new species are proposed in lineage 2, which consists of *Cahabagnathus* n. sp. 1 - *Cahabagnathus directus* - *Cahabagnathus* n. sp. 2 and *Cahabagnathus* n. sp. 3. Lineage 1 shows this connection with the widespread distribution of *C. friendsvillensis* during the first transgression of the Chazyan, followed by local distribution of *C. chazyensis* during the first regression.

Cahabagnathus sweeti evolved and is widely distributed during the second transgression, and the local distribution of *C. carnesi* coincides with the second regression. In lineage 2, C. directus evolved during the first Chazyan transgression, and with the first regression the descendants of *C. directus* were apparently isolated on the west and the east sides of the Transcontinental arch giving rise to two new species, *Cahabagnathus* n. sp. 2 and *Cahabagnathus* n. sp. 3, which we recovered from less favorable lithologies for conodont sample processing. The direct ancestor of the genus *Cahabagnathus* is still missing, and its relationship to *Cahabagnathus* n. sp. 1 is unknown. We agree with previous authors that *Cahabagnathus* ancestry is likely within the *Eoplacognathus* lineage.

SM06-04

INTERPRETATION OF LATE ORDOVICIAN CONODONT BIOFACIES IN MIDCONTINENT NORTH AMERICA USING RELATIVE ABUNDANCE DATA COMBINED WITH ND ISOTOPES AND SM/ND

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Conodont biofacies have been well defined for Late Ordovician strata in North America. Recent research has shown that combining studies of conodont biofacies with Neodymium isotope data and Sm/Nd ratios enhances the interpretation of biofacies and depositional history. Work has focused on Upper Ordovician epeiric sea carbonates in Saskatchewan and Iowa. New data from Saskatchewan bring the total number of samples available for study to 147, which collectively yielded 10,300 conodont specimens. Four conodont biofacies, based on conodont genera believed to be benthic or nektobenthic, are recognized for the Late Ordovician of Saskatchewan. These are, from shallowest to deepest: 1) *Rhipidognathus* biofacies; 2) *Aphelognathus-Oulodus* biofacies; 3) *Plectodina* biofacies; and 4) *Phragmodus* biofacies. When relative abundance data, based on conodont genera, are combined with analyses of neodymium isotopes and samarium/neodymium ratios, several patterns emerge.

Values for ε_{Nd} show that Precambrian basement was essentially covered by epeiric sea sediments by the mid-Edenian and therefore most of the Late Ordovician is characterized by ε_{Nd} values in the range of -10.8 to -7.1 indicating that the Nd isotope balance in seawater was primarily controlled by the relative contributions of Nd weathered from the highlands of the Taconic Orogen and possibly the extension of the Appalachian-Caledonian Orogen in the Arctic. Sm/Nd ratios, lithological data and conodont biofacies appear to correlate well in the Late Ordovician of Saskatchewan. Increases in Sm/Nd ratios reflect increasing water depth, whereas decreases in Sm/Nd ratios indicate decreasing water depth. For example, in the Yeoman Formation there are several shifts in Sm/Nd values that are well correlated with conodont biofacies. Lower values are associated with the Aphelognathus-Oulodus biofacies and higher values are associated with the deeper Plectodina biofacies. In the evaporitic Lake Alma member of the Herald Formation, where conodont are rare, it appears that *Panderodus bergstroemi Sweet* may be an organism that tolerates high salinity. Sharp decreases in Sm/Nd ratios are commonly associated with the appearance of the *Rhipidognathus* biofacies at the top of the Redvers Unit of the Herald Formation. It is clear that a combination of chemical methods with lithofacies and biofacies studies provides the possibility of a clearer understanding of the principal influences on biofacies distribution.

SM06-05 ORDOVICIAN CONODONTS FROM AKPATOK ISLAND, NUNAVUT

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Akpatok Island in Ungava Bay is a remote Ordovician outlier on the Canadian Shield. The island is largely bounded by sea-cliffs with an elevation of nearly 280 m, representing the surface exposure of Ungava Basin strata. Subsurface rocks are known from the Premium Homestead Akpatok L-26 drillhole located on the west side of the island. This borehole penetrated over 300 m of Middle and Late Ordovician rocks. These strata are now regarded as Ungava Bay (roughly coeval with the Ship Point Formation of Foxe Basin) and Frobisher Bay and Amadjuak formations. Conodonts from these strata were described by Barnes and Bolton (in Workum et al., 1976). Conodonts and macrofossils from surface exposures corresponding to mid-Akpatok Formation were also reported.

On the surface, Unit 3 of the Amadjuak Formation is succeeded by the Boas River Formation. The remaining surface strata are assigned to the Akpatok Formation. The oldest fauna reported here is from Unit 3 of the Amadjuak Formation - this includes *Belodina confluens*, *Protopanderodus liripipus*, and species of *Panderodus, Periodon, Phragmodus, Plectodina*, and *Walliserodus*. The highest Unit 3 or Boas River fauna is much more abundant and include these plus *Belodina arca, Drepanoistodus suberectus, Plectodina florida, Oulodus, Panderodus breviusculus, Plegagnathus nelsoni, Pseudobelodina quadrata*, and a form similar to belodiniform element sensu Nowlan and McCracken. Boas River or lowest Akpatok strata includes many of these conodonts, plus *Coelocerodontus trigonius, Culumbodina occidentalis, Pseudobelodina dispansa, Paroistodus? nowlani*, and *Staufferella*. Higher strata of Akpatok Formation records the occurrences of *Columbodina penna, Belodina lillianae, Pseudobelodina aff. vulgaris, Pseuodooneotodus beckmanni*, and *Pseudooneotodus mitratus*.

The subsurface fauna reported previously from the drill core has some species in common to the Middle Ordovician (Whiterockian) Ship Point Formation on Melville Peninsula of the western Foxe Basin. Amadjuak, Boas and Akpatok faunas from the surface strata are comparable to those found in the Foxe Basin on Baffin Island. These are latest Edenian and younger. There are some differences, however. Periodon on Baffin Island is completely absent from Akpatok (or Foster Bay) strata but it occurs throughout the sampled Akpatok Formation on Akpatok Island. *Amorphognathus ordovicicus* occurs in Akaptok strata on Baffin, but is absent on Akpatok.

Strata assigned to the Boas River Formation on Akpatok Island are brown bituminous limestones, which contain conodont and macrofossils that are similar to those other Ordovician shales and limestones throughout eastern Canada - Amadjuak Unit 1 on Baffin Island, Boas Oil Shale on Southampton Island, and Collingwood (Whitby) shale and limestone of southern Ontario.

SM06-06 **BIOSTRATIGRAPHIC VALUE OF RE-DEPOSITED CONODONTS, MCLISH FORMATION, ORDOVICIAN, SOUTH-CENTRAL OKLAHOMA**

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The Simpson Group of south-central Oklahoma is composed of the Joins, Oil Creek, McLish, Tulip Creek, and Bromide formations (ascending order). The Simpson is an important biostratigraphic unit because it is one of the most complete and fossiliferous records of the Middle Ordovician (Whiterockian - early Mohawkian) in the southern Midcontinent region. Previous reports suggest that the only significant hiatus in Simpson sedimentation occurs at the boundary between the Oil Creek and McLish.

Samples collected from the lower McLish Formation yield a seemingly anomalous conodont fauna, which includes species of *Neomultioistodus, Paraprioniodus*, and *"Scandodus"*. This fauna is similar to that of the underlying Oil Creek Formation. Conodont elements are broken and abraded. Based on this evidence, the lower McLish fauna was originally considered to be re-deposited and of little or no biostratigraphic value.

Recently, the lower McLish was re-sampled using a finer sampling interval than that of previous collections. The fauna derived from these samples contains a species, *Plectodina tynerensis*, previously unknown from either the McLish or Oil Creek. *P. tynerensis* is represented in the Tyner Formation of northeastern Oklahoma where it co-occurs with *Phragmodus polystrophos*, a biostratigraphically valuable species. *P. polystrophos* occurs in McLish samples above the interval of "re-deposited" conodonts. The presence of *P. tynerensis* in lower McLish samples challenges the model of re-deposition and reinstates the biostratigraphic importance of the lower McLish fauna.

SM06-07 **ARTICULATED SKELETONS OF *CTENOGNATHODUS* (CONODONTA, VERTEBRATA) FROM THE ERAMOSA MEMBER OF THE GUELPH FORMATION (SILURIAN) AT HEPWORTH, ONTARIO, CANADA**

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Understanding the relationships between the morphologically complex conodonts that dominate post-Ordovican faunas is fundamental to unraveling the evolutionary history of this diverse group of jawless vertebrates, and this is a prerequisite if conodonts are to realize their full potential as a fossil database for investigating evolutionary patterns. For a long time, conodont workers have drawn an important distinction between complex conodonts bearing elements with robust, peglike, discrete denticulation (formally grouped as Order *Prioniodinida*, or Superfamily *Hibbardellacea*) and those bearing elements with generally finer, fused denticulation, with carminate and angulate morphologies in P positions (Order *Ozarkodinida*, or Superfamily *Polygnathacea*). These higher taxa, and hence these characters, have been thought to correspond to major clades of complex conodonts.

In this context, the Silurian genus *Ctenognathodus* is particularly interesting because it combines characteristic features of ozarkodinid conodonts (typical carminate and angulate P elements) with diagnostic features of prioniodinids (S elements have robust, peglike, discrete denticulation). As a consequence, accurate reconstruction of the apparatus of *Ctenognathodus* and the topological homologies of its elements is at the same time problematic, because of the difficulty in chosing appropriate comparative taxa, and important, because of the possible implications for understanding the relationship between prioniodinid and ozarkodinid clades.

In recent years, the apparatuses of several species of Ctenognathodus have been reconstructed from collections of discrete elements by Viive Viira and her students working in the Baltic area. The apparatus of the type species of the genus, *C. murchisoni*, has been characterized as bearing carminate (spathognathodiform) Pa elements, angulate (ozarkidiniform) Pb elements, digyrate (lonchodiniform) M elements, alate (trichonodelliform) Sa elements, digyrate Sb elements, and bipennate Sc elements. As with all reconstructions of skeletons from associations of discrete elements, however, it is a hypothesis awaiting a test.

The test is provided by the discovery of articulated skeletons of *Ctenognathodus* preserved as bedding-plane assemblages and fused 'clusters' in Silurian strata at Hepworth, Ontario. These skeletons are associated with much more abundant apparatuses of *Ozarkodina excavata*. Our new material indicates that *Ctenognathodus* bore a 15 elements apparatus comparable to that of other ozarkodinids and prioniodinids, with paired P_1, P_2, M, S_4, S_3, S_2, S_1 and an unpaired S_0 element. The material confirms that S elements were short and robust with peglike, discrete denticles. Based on this definitive evidence of element position, orientation and topological homology, we look forward to seeing where phylogenetic analysis places *Ctenognathodus* among complex conodonts.

SM06-08 THE SHAPE OF A SPECIES: MORPHOMETRIC ANALYSIS OF THE CONODONT APPARATUS

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Unravelling the evolutionary history of conodonts, whether for biostratigraphic or palaeobiological purposes, relies on a sound understanding of element morphology. Whilst traditional observation and description provide the foundation upon which current conodont taxonomy rests, there are many examples where the complexity and variability of element morphology confound attempts at analysis, leading to taxonomic confusion, and poor resolution of evolutionary pattern and stratigraphic distribution. In such cases, quantitative morphometric analysis may be the only means of rigorously evaluating element morphology.

The well-known Silurian species *Ozarkodina excavata* provides a good example of the uncertainties that can arise in traditional morphological analysis. The taxon displays both unusually large spatiotemporal range and morphological variability for a single species.

Morphometric analysis of the apparatus of *O. Excavata* will test the null hypothesis that all elements currently assigned to *O. excavata* belong to this one species. Intraspecific variation has been constrained through analysis of elements and articulated apparatuses of the Eramosa lagerst„tte (Ontario), considered to represent a single population of *O. excavata*. This range of variation is quantitatively compared with that of elements from other parts of the *O. excavata* geographic and temporal range to ascertain whether there is a significant difference between them. Ultimately this may allow a finer scale morphological division of the *O. excavata* lineage, considerably increasing the biostratigraphic utility of this apparently widespread taxon. When examined in an ecological context, refined characterization of element morphology in *O. excavata* will facilitate a better understanding of the palaeobiology of the species.

SM06-09

INWARDS, OUTWARDS, UP AND DOWN: DIFFERENT VIEWS OF THE SIGNIFICANCE OF CONODONT PALAEOBIOLOGY

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For most of the last century, most conodont research has been directed towards solving geological problems. Biostratigraphy, basin analysis, tectonic reconstruction, thermal maturation, the list could go on, much of the work underpinned by careful taxonomic study. The application of conodonts to biological and evolutionary problems stands in stark contrast, the potential contribution of conodonts being severely limited by the lack of a phylogenetic and anatomical context for the group. It did not seem to matter much, in biostratigraphy for example, that we didn't know what kind of organism elements came from, what their biological role was, or what they were related to. But from a biological perspective this missing information reduced conodonts to little more than infamous curiosities. "Fascinating little whazits".

Things have definitely changed: with the discovery of fossils preserving the remains of soft tissues the vertebrate credentials of conodonts have been firmly established; the structure and function of elements and the feeding apparatus of which they were part is now much better understood, and we are starting to get a clearer picture of the evolutionary relationships among conodonts based on rigorous phylogenetic analysis. In many ways, however, palaeobiological studies of conodonts are still in their infancy. Looking inwards, there are still many unanswered questions concerning the biology of conodonts. The implications of apparatus architecture and element development for hypotheses of homology, relationship, character evolution and taxonomy are yet to have a broad impact. Our understanding of the evolutionary history of the clade (if Conodonta as currently conceived is indeed a clade) is far from complete.

Looking outwards, the possibilities for using conodonts to answer broader evolutionary questions are still largely unexplored. We do not have a clear understanding of what the most plesiomorphic conodonts were like, and advances in this area would enhance understanding of character evolution in early vertebrates. The fossil record of conodonts is acknowledged to be among the finest of any group of animals and is certainly without rival among Palaeozoic vertebrates. Thanks to conodonts' biostratigraphic pedigree we have a vast database with huge potential for testing and constraining evolutionary hypotheses and models at the micro and macro level. This potential has yet to be fully realized.

SM06-10 **DIFFERENTIATING SEA LEVEL EVENTS ACROSS LAURENTIA IN THE EARLY SILURIAN USING THE PATTERN OF CONODONT COMMUNITIES**

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Early Silurian was a time of deglaciation, with three possible intervals of ice readvance, and closure of the Iapetus Ocean, which affected Early Silurian sea level fluctuations. This study establishes sea level events between the Appalachian and Innuitian margins of Laurentia based on the pattern of conodont communities, and proposes that sea level events were not synchronous on the two margins. Conodont data for the Canadian Appalachian margin were taken from Becscie, Merrimack, Gun River and Jupiter formations (Rhuddanian, Aeronian, and most of Telychian), Anticosti Island, Quebec, and those for Innuitian margin from Cape Philips Formation (Rhuddanian through lower Sheinwoodian), Cornwallis Island, Canadian Arctic Islands.

Anticosti was located at paleolatitude 15-20 degrees South, where Lower Silurian sediments were deposited in a shallow, open-marine sublittoral environment; most conodonts are robust pectiniform and ramiform elements. Cornwallis was situated at paleolatitude 18-20 degrees North, where Lower Silurian sediments were deposited in a slope/basin environment; most conodonts are slender ramiform and coniform elements.

Within the Llandovery, eleven and six conodont communities are recognized, respectively, based on the cluster analyses for 24,839 specimens representing 42 species from 123 samples on Anticosti, and 4967 specimens representing 54 species from 77 samples on Cornwallis. Overall, the sea level curves inferred from the distribution of the conodont communities from Anticosti and Cornwallis exhibit frequently and less frequently oscillating patterns, respectively. During earliest Rhuddanian, similar conodont communities were developed on both Anticosti and Cornwallis, but then were replaced by a shallower-water community on Anticosti and a deeper-water community on Cornwallis; a highstand occurred on Cornwallis in late Rhuddanian, but was delayed to the end of Rhuddanian on Anticosti; a lowstand interval is virtually devoid of conodonts from Anticosti in late Aeronian, whereas a deep conodont community remained unchanged on Cornwallis from middle Aeronian to early Telychian. The sea level history on both the southern and northern margins of Laurentia, reflected by conodont communities from Anticosti and Cornwallis, is supported by the studies on Quaternary glaciation/deglaciation events that conclude that the melting of an ice sheet will be accompanied by sea level change and regional isostatic effects that do not generate a uniform global eustatic change.

SM06-11 **CHARACTERIZATION OF THE SILURIAN/DEVONIAN BOUNDARY IN THE SOUTHERN UNITED STATES USING CONODONT BIOSTRATIGRAPHY AND CARBON ISOTOPE CHEMOSTRATIGRAPHY**

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Detailed sampling for conodonts and carbon isotopes at three sections in the southern United States provides a wealth of biostratigraphic and chemostratigraphic information through the Silurian/Devonian boundary interval. Two southern Oklahoma outcrop sections span the Henryhouse-Haragan formational boundary and comprise a succession of argillaceous carbonate mudstone and wackestone deposited in an outer carbonate ramp setting that grade upward into interbedded wackestone and packstone. A core of the upper Frame Formation from Andrews County, Texas, contains a succession of carbonate mudstone and wackestone deposited in a slope setting south of a shelf margin that grade up into interbedded wackestone and packstone.

Three conodont faunal units characterize the Silurian/Devonian boundary interval, which ranges from two to five meters thick: 1. A diverse late Pridoli conodont fauna characterized by Oulodus elegans detorta, Belodella coarctata, B. anfracta, Dapsilodus, and Dvorakia amsdeni extends below the boundary interval. 2. The abrupt disappearance of many Pridoli species results in a low diversity faunal unit in which O.e. detorta ranges slightly above the base, B. resima? and Dv. philipi? appear, and acmes of Decoriconus fragilis and Pseudooneotodus beckmanni occur near the top. 3. The appearance of the early Lochkovian species Icriodus postwoschmidti marks the base of the third unit, which lies near where coarser skeletal carbonates occur in the section. Carbon isotope ($\delta^{13}C$) values near the top of unit 1 fluctuate irregularly up to +/-1 per mil and show a small (+1 per mil) shift near the boundary between conodont fauna units 1 and 2. Through fauna unit 2, carbon isotope values remain remarkably consistent, varying less than 0.5 per mil. Near the base of faunal unit 3, carbon isotope values show another small shift (+1 per mil).

The base of the Devonian lies within conodont faunal unit 2, but precise placement is not possible because comparable biostratigraphic detail for conodonts from other boundary sections, such as Klonk, does not exist. The small shifts in carbon isotopes do not compare well with the more dramatic carbon isotope excursions reported near the Silurian/Devonian boundary at sections in Europe, Nevada, and the Appalachians, and cannot be used to correlate to those sections.

SM06-12 HOLOTYPE OF *PALMATOLEPIS PUNCTATA* (HINDE, 1879) IS FROM THE RHINESTREET SHALE

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Palmatolepis punctata was named by Hinde in his paper: "On conodonts from the Chazy and Cincinnati Group of the Cambro-Silurian, and from the Hamilton and Genesee-Shale divisions of the Devonian, in Canada and the United States;" notable as the first description of North American conodonts and assignment of elements to an assemblage. The type specimen consists of a P1 (Pa) element with the lower surface imbedded in a chip of dark shale. The type locality is "North Evans, New York: Genesee Shale," where Genesee Shale is the term used for all North American Devonian black shales above the Hamilton. The "Genesee Shale" on the Lake Erie shore line and Eighteenmile Creek near North Evans, NY consists of the West River, Middlesex, and Rhinestreet shales of current usage. *Palmatolepis punctata* is an important and widely distributed taxon, recognized as the earliest lobed specimen in its lineage, utilized as a zone indicator as well as to define the base of the Middle Devonian. The holotype was last reillustrated in 1934 by Branson and Mehl and determination of the type horizon is problematic.

Specimens of *P. punctata* from the Middlesex Shale (Sonyea Group) have a less well developed outer lobe with shallow sinuses typical of early forms. Specimens from the upper Cashaqua Shale (Sonyea Group) and lower Rhinestreet Shale (Westfalls Group) have a well developed outer lobe and are similar to the holotype. Overall chemical composition and diagenetic dolomite in the holotype matrix is similar to a conodont-rich horizon in the upper Middlesex as well as a conodont-rich horizon in the lower Rhinestreet – the Weyer Bed – that also yielded the holotype of Ancyrodella nodosa Ulrich and Bassler, 1926. Based on element morphology and lithology of the matrix the conodont-rich horizon of the lower Rhinestreet Shale on Eighteenmile Creek is a likely type stratum.

SM06-13 **EVOLUTIONARY PROCESSES IN PERMIAN GONDOLELLID TAXA: COMPARING SEA-LEVEL FLUCTUATIONS WITH THE SCALE AND TYPE OF MORPHOLOGIC CHANGE**

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Permian gondolellid taxa are largely discriminated by changes in the configuration of carinal denticles. The Wuchiapingian-Changhsingian boundary (Upper Permian) is defined by a distinct change in the configuration of the denticles between *Clarkina longicuspidata* and *C. wangi*. In *Clarkina longicuspidata* the cusp joins the lower, penultimate posterior denticle by a ridge that slopes gently down from the cusp forming a gap, the lowest and narrowest part of the carina. In *Clarkina wangi* the posterior denticles are not reduced and the cusp connects the carina with a high ridge with no clear separation from the remaining fused denticles; the resulting carina commonly looks laterally like a high wall. While it is true that the smallest juveniles of *Clarkina* species appear to be very similar, some hint of the evolutionary process is revealed by comparing juveniles of *C. longicuspidata* and *C. wangi*. Juvenile *C. longicuspidata* have relatively discrete denticles compared to the increasingly fused denticles of intermediate and larger mature forms. In contrast, denticles of juvenile *C. wangi* are already partially fused, and in adults closing the anterior gap adjacent to the cusp, forming the high wall-like carina, completes this fusion. This implies a heterochronic process involving acceleration of development or peramorphosis. This small-scale evolutionary event within an anagenetic series of *Clarkina* species is associated with a series of relatively minor flooding surfaces.

In contrast, the presence of discrete denticles typical of juvenile *Jinogondolella granti*, in adults of the descendant *Clarkina postbitteri* suggests a paedomorphic evolutionary process. This latter event is associated with a major sequence boundary and extinction event (Middle-Upper Permian boundary) and involved the evolution of a new gondolellid genus, *Clarkina*, defined by the lack of serration and major change in platform outline. The degree of evolutionary change involving these taxa appears to be comparable to the scale of sea-level change that influences sequence stratigraphy.

The mammal-like occlusion in ozarkodinid conodonts like *Streptognathodus*, which have a long anterior blade that constrains element motion to the transverse plane and maximizes food-processing efficiency may provide a paleobiologic basis for relating the evolutionary scale of morphologic variation used in Permian biostratigraphy. The high anterior (or ventral) blade in the ozarkodinid genus *Clarkina* may have served a similar function. The importance of the carinal shape in these taxa may be related to the parallel evolution or extinction of taxa representing potential food sources or to the availability of food sources along some environmental gradient.

SM06-14

TAXONOMY, NOMENCLATURE, AND ZONATION OF CARNIAN-NORIAN BOUNDARY (LATE TRIASSIC) CONODONTS

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The taxonomy of Late Triassic gondolelloidids has confused non-specialists because of the diversity of generic assignments and overlapping species concepts. The genera *Epigondolella, Metapolygnathus, Gondolella*, and *Paragondolella* have been used by different authors for the same species, and species have often been delineated in different ways. Multielement interpretations of both *Gondolella* and *Paragondolella* exclude them from use for the common Carnian species, which are generally associated with ramiform elements like those that belong to Ladinian *Neogondolella*. The genus *Metapolygnathus* is distinguishe4d from the latter on the basis of the anterior platform profile of the P1 element, The transition is seen between *N. inclinata* and the Early Carnian species *M. polygnathiformis*. The apparatus of Lower Norian *Epigondolella* differs from that of *Metapolygnathus* and the former genus is not yet clearly recorded from the Carnian. Abundant and diverse Carnian-Norian boundary conodont faunas occur in the transitional beds between the Carnian Ludington and Norian Pardonet formations in from northeast British Columbia. *Metapolygnathus* species are subdivided into five lineages on the basis of: 1) platform margin profile, 2) pit position, 3) blade length, 4) posterior carina development, 5) node distribution, and 6) platform shape. These lineages involve both new and known species and are characterized as the following: a) *carpathicus-nodosus-permicus*, b) *angustus-noah-communisti-parvus*, c) *pseudodiebeli-samueli-pseudoechinatus-echinatus*, d) *primitius-quadrata*, and e) a lineage of new *lanceolate* species. Choice of a conodont datum for C-N boundary definition can now be made within the framework of a refined conodont zonation.

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SM06-15 **CONSTRAINTS ON THE AFFINITY OF THE CONODONT ANIMAL AND THE FUNCTION OF THE FEEDING APPARATUS AS IMPOSED BY THE MORPHOLOGY AND STRUCTURE OF THE APPARATUS ELEMENTS**

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Recent discussion as to the placement of the conodont organism on the dendrogram of early chordate evolution has revolved around the interpretation of characters that are either speculative or subjective in their interpretation. The interpretation of the function of the best preserved portion of the conodont animal, its complex apparatus of phosphatic elements, has largely been neglected in these studies. This study accepts that the conodont animal is within the chordate evolutionary grade, but that it is not craniate. Characters that define craniate grade evolution, cannot be conclusively demonstrated in the preserved conodont animals. Thus there is no hard evidence that they are vertebrate, but there is suggestive evidence in the structure and interpreted function of the conodont elements and apparatus that they are close to the cephalochordata (Branchiostoma).

Analysis of the element components of the conodont apparatus suggest that, especially in the morphologically more complex ramiform-pectiniform apparatuses of the Ordovician through Triassic, they can be separated into two groups. These two subsets of the apparatus probably represent different functions performed by components of the apparatus and are associated with the ingestion of food particles. Thus the discernens elements (M, Sa, Sc, Sb, Sd) tend to be bar-like with numerous small denticles and the contundens elements (Pb, Pa) tend to be more robust with reduced denticles. Similar morphologic differentiation, if more subtle, can be recognised in Cambrian and Ordovician coniform-coniform and ramiform-ramiform apparatuses.

The contundens Pb and Pa elements can be classed into three groups, depending on the apparent surfaces that interact. *Peraios* elements, as in *Ozarkodina* or *Polygnathus*, are located in opposition with upper or lateral surfaces working in contact. *Hyalion* elements, like *Drepanodus* and *Oepikodus*, are oriented with cusp apices pointed in the same direction and have lateral faces interacting. *Likmas apparatuses*, like *Teridontus* and *Erraticodon*, are also oriented with cusp apices pointed in the same direction, but there is no indication of effective interaction of element surfaces. The elements orientation and apparent effective action strongly suggests that conodont animals can be separated into at least three major groups.

SM06-P01 **δ^{13}C STRATIGRAPHY OF THE CHATFIELDIAN (UPPER MIDDLE ORDOVICIAN) DOLLY RIDGE FORMATION, PENDLETON CO., WEST VIRGINIA: A COMPLETE RECORD OF THE GICE IN THE APPALACHIAN FORELAND BASIN**

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An exceptional record of the Guttenberg δ^{13}C excursion (GICE), a perturbation in the global carbon cycle, is documented from a section on Dolly Ridge, near Riverton, West Virginia, which exposes the Ordovician Nealmont and Dolly Ridge Formations along with the overlying Reedsville Shale. Carbon isotope (δ^{13}C) analyses of these Chatfieldian marine carbonates show a positive δ^{13}C shift of +3 ‰ in the expanded Middle Ordovician Dolly Ridge Formation. This carbonate succession was deposited in a shallow water, shelf-type setting. The shift begins with baseline values near 0‰ in the Nealmont Formation, with values becoming increasingly positive, reaching a maximum, 58.5 m above base of overlying Dolly Ridge Formation, of +3.1 ‰. δ^{13}C values begin to fall in the upper Dolly Ridge Formation and return to baseline values around 0 ‰ near the top of this unit. This is an important section in the Appalachian Foreland Basin because it records the complete δ^{13}C excursion, which is unique having not been recorded in previously studied sections from this region. Previously studied sections (Pennsylvania, Virginia) have documented similar baseline values, and a positive shift of up to +3.5 ‰ in some sections, but never the return to pre-excursion values. Carbonate platforms in the previously studied areas quickly became drowned by clastics from the Taconic Highlands (Reedsville and Antes Shales), and therefore the end of the excursion was not recorded in carbonate facies.

This section contains fourteen K-bentonite beds, among which the two lowest beds are likely to represent the widespread and well documented Deicke and Millbrig beds. Fourteen conodont samples were collected at 10 m intervals throughout the section. The conodonts found thus far place the section within the upper Midcontinent *P. undatus* Conodont Zone through *P. tenuis* Conodont Zone. This agrees with the previously established relations of the GICE to conodont zones. This positive (δ^{13}C) isotope excursion begins in the uppermost part of the Midcontinent *P. undatus* Conodont Zone, reaches its peak values in the *P. tenuis* Conodont Zone, and returns to pre-excursion values at and/or just before the *P. tenuis/B. confluens* Conodont Zonal boundary. The GICE, apart from the latest Ordovician (Hirnantian) positive excursion, is the most significant δ^{13}C excursion documented in the Ordovician, and is one of the most widely documented excursions in the Paleozoic. The GICE with its complete record at the Dolly Ridge section makes it a very important succession in the Appalachian Basin to investigate various aspects of the GICE.

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SM06-P02 *DISTOMODUS KENTUCKYENSIS*: ALTERNATIVE RECONSTRUCTIONS, A BEDDING PLANE ASSEMBLAGE, AND THE IMPLICATIONS FOR APPARATUS EVOLUTION IN COMPLEX CONODONTS

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Almost all aspects of modern conodont palaeontology, including systematics, taxonomy, palaeoecology and palaeobiology rely on an understanding of conodonts as skeletal apparatuses, not just as isolated elements. Unfortunately, the conodont fossil record consists almost entirely of disarticulated remains, and for the vast majority of taxa the skeletal apparatus must be reconstructed using indirect methods. The confidence that can be placed in these reconstructions varies, but even the best are nothing more than hypotheses, the ultimate test of which is the discovery of the constituent elements as an articulated skeleton.

Among conodonts with morphologically complex apparatuses, taxa currently assigned to the order Prioniodontida are particularly problematic because articulated skeletons are rare, and the two species that have been described, *Promissum pulchrum*, and *Phragmodus inflexus*, differ in the number of elements they possess (19 and 15 respectively). Consequently, the number of elements in prioniodontid apparatuses is uncertain, and this leads to difficulties in multielement reconstruction, hypotheses of homology, and phylogentic analysis. This is frustrating, because the prioniodontids are important in understanding the evolutionary history of complex conodonts. We report here the discovery of a partial skeleton of *Distomodus kentuckyensis*, only the third prioniodontid to be described from a natural assemblage.

Several reconstructions of *Distomodus* have been proposed, and the differences between them have a bearing on hypotheses of relationship among prioniodontid conodonts. Although incomplete, this assemblage allows testing of the alternative reconstructions. The specimen indicates that *Distomodus* bore a pair of strongly asymmetric molarized P elements (probably in P_1 positions). It also provides the first direct evidence of isolated denticles preserved in association with P and S elements, indicating that the conical "elements" and pairs of fused cones often found associated with *Distomodus* are non-contiguous parts of larger elements. In addition, the specimen preserves the elongate denticulate process of an S element. Isolated processes such as this ("*Johnognathus*" elements) have been linked with *D. staurognathoides*, but this confirms their presence in *D. kentuckyensis*.

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SM06-P03 THE FIRST DESCRIBED DIVERSE UPPER ORDOVICIAN (CINCINNATIAN) CONODONT FAUNA IN THE WORLD: NEW DATA BASED ON REDISCOVERY OF BRANSON AND MEHL'S (1933) LOCALITY AT OZORA, MISSOURI

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In four classical papers Branson and Mehl (1933) described numerous Ordovician conodonts from Missouri. One of their papers, which was based on collections of the Maquoketa-Thebes formations, is of special interest in being the first description of a diverse Upper Ordovician conodont fauna, not only from North America but from anywhere in the world. Their specimens came from three localities, the most important one by far being a small quarry along Little Saline Creek south of Ozora in Ste. Genevieve County. However, for more than 50 years, repeated attempts by conodont workers to find this section have been unsuccessful. In early 2003, we finally located the old, now partly overgrown, small quarry from which Branson and Mehl described 10 new species, including the zone index species *Amorphognathus ordovicicus*. They reported that their conodonts came from the very basalmost part of the Maquoketa Shale that largely consists of redeposited sandy material from the underlying Thebes Sandstone. The top 2-3 cm of the Thebes is a well-cemented hard sandstone containing dark organic and phosphatic(?) particles, many small ostracodes, and fragments of other shelly fossils. It appears to be a condensation deposit upon which the Maquoketa rests with a sharp contact suggesting a depositional break. Our collection from the basalmost sandy Maquoketa, which includes several hundred conodont elements of 14 multielement species representing 13 genera, includes topotypes of virtually all of Branson and Mehl's *Ozora* species. Numerous elements of *A. ordovicicus*, including several specimens of the diagnostic M element, which was previously not known from *Ozora*, show that most of the recent interpretations of the composition of the apparatus of this species are correct.

SM06-P04 **CONODONTS, SCOLECODONTS AND OTHER MICROFOSSILS FROM THE UPPER SYLVAN SHALE AND KEEL FORMATION (LATE ORDOVICIAN), ARBUCKLE MOUNTAINS, OKLAHOMA, USA**

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A fresh exposure of the upper 30 meters of the Ordovician Sylvan Shale (Richmondian, Ashgill) was recently created by a small excavation at the US Highway 77 classical road cut about 0.3 km south of the intersection of I-35 and US Highway 77 in the Arbuckle Mountains of Central Oklahoma. Samples (3-4 kg each) for microfossils were collected at 3 meter intervals though the Upper Sylvan and into the overlying uppermost Ordovician (Hirnantian, late Ashgill) Keel Formation. The lower 15 meters were almost barren of fossils; no organic-walled microfossils were recovered and conodonts were only found in one sample from the lower part of the section. Eight elements of *Plectodina tenuis*, 2 elements of *Amorphognathus* sp., and 1 element of *Dapsilodus*? sp. were recovered. Unfortunately, the relatively few conodonts recovered do not provide much useful biostratigraphic or paleoenvironmental information.

The upper 15 meters of Sylvan Shale yielded scolecodonts (polychaete jaws) and chitinozoans but no conodonts. The chitinozoans are dominated by *Cyathochitina* sp. aff. *latipatagium*. One enigmatic type that is also relatively common has the silhouette of *Lagenochitina*, but the wall pattern is unusual for chitinozoans. Therefore it could be a blue-green algae colony. In the uppermost sample, an elongated form tentatively assigned to *Conochitina* is moderately common. In addition, some enigmatic organic, smoothly globular spherules with an aperture were recovered. The probable foraminiferan *Thuramminoides sphaeroides* were present in most samples. The jawed polychaete fauna includes members of six families; *Paulinitidae, Ramphoprionidae, Polychaetaspidae, Atraktoprionidae, Hadoprionidae*, and *Kalloprionidae*. One new paulinitid species, belonging to *Kettnerites* (*Aeolus*), dominates. The low abundance and relatively low diversity Sylvan Shale fauna differs from approximately coeval ones of both Laurentia and Baltica, particularly by its high relative frequency of paulinitids and hadoprionids.

One sample from the base of the overlying Keel Formation yielded 47 conodont elements from 3 kilograms of oolitic limestone. The fauna consists of 12 elements of *Noixodontus girardeauensis*, 9 elements of *Plectodina cf. tenuis*, 4 elements of *Drepanoistodus* sp., 2 fragmentary elements of *Amorphognathus*? sp., 12 elements of *Oistodus* sp., 2 elements of *Panderodus*? sp., 1 indeterminate oistodiform element, and 5 elements of *Eocarniodus*? sp. This assemblage compares well with previous studies of the Keel Formation conodonts.

SM06-P05 **CONODONTS AS USEFUL GUIDE FOSSILS IN THE CAMBRIAN: A CONODONT ZONAL SUCCESSION FROM THE MIDDLE CAMBRIAN TO THE LOWERMOST ORDOVICIAN IN HUNAN, CHINA**

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Some of the most remarkable Middle and Upper Cambrian successions in the world are located in the Hunan Province in southern China. This richly fossiliferous, stratigraphically continuous, sequence is several hundred meters thick. It consists mainly of carbonates deposited in a slope environment the Jiangnan slope belt) along the margin of the Yangtze Platform. Magnificent outcrops, such as those at Paibi, Wangcun and Wa'ergang, have produced very diverse trilobites (>150 species) and conodonts (>100 species). Recently, the Paibi section was ratified by the International Commission on Stratigraphy as the GSSP for the base of the global Upper Cambrian Series.

Since the mid-1980s more than 2400 samples with a total weight of about 12,000 kg have been collected from these sections and processed for conodonts. Many of the more than 100 species recovered have short vertical ranges, and marked changes in the conodont faunas at some horizons make it possible to recognize 13 conodont zones from the Middle Cambrian through the lowermost Ordovician. Middle and lower Upper Cambrian conodonts have been little used as index fossils in the past, particularly outside China, but the present study shows that also many paraconodonts are useful biostratigraphically for both local and long-range correlations. This is illustrated by the Baltic Upper Cambrian conodont faunas that differ in some respects from those of Hunan, but have enough species in common to make it possible to recognize the interval of Chinese zones in the Baltic succession. Because the Hunan and Baltic trilobite faunas in the Upper Cambrian have few zonal trilobites in common, the conodonts provide valuable assistance to the trilobite correlations between these regions. Unfortunately, conodonts from the Middle and much of the Upper Cambrian remain virtually unstudied in North America. This substantial stratigraphic interval represents the last remaining major gap in our knowledge about the Cambrian-Triassic conodont succession on this continent.

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SM06-P06 CONODONT-, GRAPTOLITE-, AND CHITINOZOA-BASED SILURIAN COMPOSITE DEVELOPED USING GRAPHIC CORRELATION AIDS NEW CALIBRATION OF CURRENT SILURIAN CHRONOSTRATIGRAPHY

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There is little agreement upon the dates for epoch and age boundaries for most Silurian time scales developed since 1989. Reasons for those differences are the use of newly determined isotopic dates for subsequently developed time scales, differences in results of the two radiometric dating methods most commonly used since 1990, Mass Spectromic Isotope Dilution (MSID) and Sensitive High Resolution Ion Micro-Probe (SHRIMP), the absence of any stratigraphic units with isotopic dates at/near the Global Boundary Stratotype Section and Point in any Silurian boundary stratotype section, and the need for interpolation to calibrate Silurian chronostratigraphy due to the relative scarcity of reliable geochronological dates for most stage boundaries. In order to develop a revised calibration of Silurian chronostratigraphy that addresses the reasons for those differences, since the limited choice of isotopic dates remains the same, the method of interpolation is changed. Standard Time Units (STUs), units that represent equal rock thickness and also equal time (at least conceptually), are used as chrons for interpolation instead of graptolite zones. The STUs are based on the composite standard units (CSUs) which comprise a Silurian composite standard (CS) previously developed using graphic correlation on range-data of more than 400 species of conodonts, graptolites, and chitinozoa in over 60 stratigraphic sections in North America and Europe. Since the Silurian CS is currently only comprised of Telychian through lower Devonian stratigraphic sections, calibration of the Ordovician/Silurian and Rhuddanian/Aeronian boundaries can only be tentatively approximated. Two new Silurian time scales are developed by calibrating Silurian chronostratigraphy using the method of interpolation just described. One uses isotopic dates for rocks obtained mainly by using MSID-dating methods, while the other uses isotopic dates for rocks obtained mainly by using SHRIMP-dating methods. The time scales developed using the two sets of dates result in the following boundary calibrations (MSID calibration / SHRIMP calibration): Ordovician / Silurian (443.0 / 438.0 Ma), Rhuddanian / Aeronian (438.6 / 435.7 Ma), Aeronian / Telychian (430.6 / 431.1 Ma), Llandovery / Wenlock (428.95 / 427.95 Ma), Sheinwoodian / Homerian (426.5 / 423.3 Ma), Whitwell / Gleedon (425.2 / 420.85 Ma), Wenlock/Ludlow (424.5 / 419.6 Ma), Gorstian / Ludfordian (422.5/416.3 Ma), Ludlow / Pridoli (420.85 / 414.0 Ma), and Silurian / Devonian (418.0 / 410.0 Ma). Since the calibration of the Ordovician / Silurian and Silurian / Devonian boundaries of the Silurian time scale developed with MSID-determined dates are most comparable to the contiguous portions of the currently most widely accepted Ordovician and Devonian time scales, the new Silurian time scale based on MSID-determined dates is considered to be the best calibration of Silurian chronostratigraphy.

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SM06-P07 DISRUPTED CONODONT BEDDING PLANE ASSEMBLAGES, UPPER BAKKEN FORMATION (LOWER MISSISSIPPIAN) FROM THE SUBSURFACE OF WESTERN CANADA

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Discrete conodonts processed from shales often appear less well preserved than those from limestones due to post-mortem compaction of mudstones and processing methods. Elements preserved intact on bedding plane surfaces provide valuable supplementary information about conodonts from these lithologies. In this presentation disrupted conodont bedding plane assemblages are described from two mudstone core samples from the Lower Mississippian upper shale member of the Bakken Formation in the subsurface of southeastern Alberta and southwestern Saskatchewan. Element clusters dominated by *Bispathodus* and *Polygnathus communis* occur on the bedding plane surfaces of the core sample from southeastern Alberta. *Bispathodus, Mehlina* and *Siphonodella* dominate conodont bedding plane assemblages on the core samples from southwestern Saskatchewan. Several of the *Siphonodella* Pa elements are paired. This genus is dominant compared with *Bispathodus* and *Mehlina* among the discrete elements in samples processed with Quaternary O. The age of the latter sample is confined between the sandbergi and isosticha-Upper crenulata zones based on the occurrences of *Bispathodus aculeatus, B. stabilis, Polygnathus cf. P. longiposticus* (or *P. inornatus*) and *Siphonodella quadruplicata* in the upper member of the Bakken.

The conodont core bedding plane assemblage from southeastern Alberta shows little evidence of winnowing as indicated by the excellent preservation of the conodont elements and by the enclosing lithology. Thus, this assemblage, along with collections of discrete conodont elements from these strata, is a reliable source of data for reconstructing paleoecology and taphonomy and for testing apparatus reconstructions. The assemblages from the southwestern Saskatchewan core, however, show a greater degree of breakage and winnowing of elements, making it less suitable as a source of interpretive data.

The bispathodid biofacies appears to be represented by the conodont core bedding plane assemblage from southeastern Alberta whereas the assemblages from southwestern Saskatchewan represent the siphonodellid biofacies. Evidence from our study suggests that these biofacies were laterally correlative without any apparent change in lithofacies.

An apparatus reconstruction is proposed for a species of *Prioniodina*. This reconstruction is in accordance with previous reconstructions, although differences were noted in the Pa and M elements. The Pa elements in our reconstruction are carminate as opposed to angulate as in other reconstructions and our M elements are dolabrate in contrast to S-type elements in one other reconstruction.

SS-01

ATOMIC ORDERING IN MINERALS AND IMPLICATIONS FOR MINERAL STABILITY

RELATIONS ENTRE L'AGENCEMENT ATOMIQUE DANS LES MINÉRAUX ET LA STABILITÉ MINÉRALE

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SS01-01 COMPUTER SIMULATIONS OF CATION ORDERING PROCESSES IN MINERALS

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WITHDRAWN

SS01-02 **A COMPARISON OF ^{29}SI AND ^{27}AL MAS NMR FOR STUDYING AL-SI ORDER IN ALUMINO-SILICATE MINERALS**

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The ability to use MAS NMR spectra of spin ½ nuclei, such as ^{29}Si, to study atomic ordering has been available since the mid 80's, when empirical methods of calculating chemical shift from atomic structure were devised. As the peak position in MAS NMR spectra of spin >½ nuclei, such as ^{27}Al, is a summation of quadrupolar and chemical shift, their use for studying atomic ordering was limited. The recent introduction of computer programs such as WIEN2K and Gaussian98W which were capable of calculating the Quadrupole coupling constant (CQ) and asymmetry parameter (eta) and hence quadrupolar shift has enabled these spectra to be interpreted and used for studying atomic ordering.

Zunyite ($Al_{13}Si_5O_{20}(OH,F)_{18}Cl$) has the possibility of Al/Si disorder in both the pentamer and Keggin structures as well as F/OH in the Keggin structure. This atomic ordering was investigated by comparing experimental data of a series of samples of zunytite with different Al:Si and F:OH ratios with calculations of ^{29}Si chemical shift using the correlation of Sherriff et al (1988). CQ and eta obtained from simulations of ^{27}Al MAS and MQMAS spectra, were compared with those derived from the electric field gradients (EFG), calculated from an *ab initio* cluster quantum model using the program Gaussian 98W. This allowed unequivocal assignments for ^{29}Si, ^{27}Al and ^{19}F MAS NMR peaks and showed that the number of Al substituting Si(1) in the pentamer increased with Al content.

SS01-03 ^{29}Si MAS NMR AS A WINDOW INTO THE OCTAHEDRAL ENVIRONMENT IN OMPHACITE

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In framework and sheet silicates, ^{29}Si MAS NMR has long been used to quantify the number of Al nearest neighbours in tetrahedral sites adjacent to Si. In chain silicates, however, such as pyroxene, ^{29}Si chemical shift is sensitive to Al substitution in both the octahedral and tetrahedral sites. Interpretation of ^{29}Si MAS NMR spectra of aluminous pyroxenes has been problematic because Al substitution at the tetrahedral site deshields Si (producing a less negative chemical shift), while Al substitution at the octahedral site shields Si (producing a more negative chemical shift), resulting in severe peak overlap. In omphacite, however, Al enters the octahedral site only, thus eliminating the peak overlap problem and clarifying the interpretation of ^{29}Si MAS NMR spectra of aluminous pyroxenes. Several 'omphacites' of various compositions across the diopside-jadeite solid solution have been synthesized (at 3.5 GPa and 1000°C for 3 hr) and characterized by powder X-ray diffraction (XRD), electron probe microanalysis (EPMA), and magic angle spinning nuclear magnetic resonance spectroscopy (MAS NMR). ^{29}Si MAS NMR spectra were acquired at 9.4 Tesla, using a 300 s relaxation delay between pulses (at 30° tip angle) to ensure quantitative peak intensities. ^{29}Si MAS NMR spectra of intermediate compositions exhibit two discernable peaks: The first peak, at –84 to –86 ppm, is attributed to the 'diopside' component (having only Mg octahedral nearest neighbours) and the second peak, at –90 to –92 ppm, is attributed to the 'jadeite' component (having both Mg and Al octahedral nearest neighbours). Chemical shifts for both peaks increase gradually with increasing jadeite content. Peak intensities are approximately proportional to jadeite content (X), according to general formula $\{Na_XCa_{1-X}\}[Al_XMg_{1-X}](Si)_2O_6$. There are three nearest neighbour octahedral M_1 sites around Si, yet only two peaks appear in the NMR spectrum at intermediate compositions. This suggests two possible explanations: Either the structure is highly ordered, with Mg and Al alternating on the octahedral chain (as previously proposed for natural omphacite at $Di_{50}Jd_{50}$), or Si is sensitive to Al substitution at only one of the three M_1 sites.

SS01-04 CHALCOPYRITE DISEASE IN SPHALERITE: AN ALTERNATE DIAGNOSIS

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The experimentally determined limited solubility of Cu in sphalerite (ZnS cubic structure) at temperatures less than 500°C (Cu-Fe-Zn-S system) is cited as evidence against the exsolution hypothesis for chalcopyrite disease. The regularity of the radial and concentric inclusion patterns of chalcopyrite ($CuFeS_2$) in sphalerite (£\ZnS) is particularly striking. This negative evidence for chalcopyrite exsolution lead to other hypotheses including the replacement, epitactic growth, coprecipitation, and diffusion-controlled growth models. Wurtzite (£\ZnS) is a very common low-temperature phase recognized by its hexaform nature; some of these natural hexagonal ZnS crystals have chalcopyrite disease as well. However, the solution characteristics of Cu in wurtzite have not been investigated. This empirical study of ZnS crystals from a seafloor hydrothermal vent (Axial Seamount) suggests that polymorphic transformation and ordering of wurtzite to sphalerite causes chalcopyrite exsolution.

Wurtzite crystals from the vent wall of a submarine sulphide spire from Axial Seamount, Juan de Fuca Ridge, Pacific Ocean (Canada) that were formed at temperatures of approximately 250°C were analysed in detail. The ZnS crystals were variably birefringent and translucent in the core, but were opaque to semi-opaque along the rims. Microprobe traverses across the rims (opaque) into the interiors (translucent) of several hexaform crystals show that Cu contents of the opaque ZnS rims are significantly greater (1 to 2 atomic prop. Cu) than the Cu solubility in sphalerite determined experimentally, whereas the translucent interiors (ZnS) that have chalcopyrite blebs (disease) have Cu contents consistent with the solubility studies on sphalerite (< 0.1 atomic prop. Cu). In several cases, the boundary between the opaque and translucent zone in sphalerite has textures that are reminiscent of exsolution. If this is indeed Cu substitution/solution in wurtzite, polytype and then polymorphic transformations toward the cubic sphalerite structure induced by decreasing temperatures could cause chalcopyrite exsolution. At present the Cu solution stoichiometry in wurtzite is only known to be similar to cubanite or intermediate solid solution with a 1:2 Cu-Fe atomic ratio.

There are numerous possible scenarios for the exsolution of chalcopyrite from wurtzite (ZnS), which differ mainly in the coordination of Cu within wurtzite and whether Cu or coupled Fe-Cu ions are diffusing in the ZnS crystal (equations 1 and 2).

$CuFe_2S_{3(wz)} \Rightarrow CuFeS_{2(cp)} + FeS_{(sp)}$ [1]

$CuS_{(wz)} + FeS_{(wz)} \Rightarrow CuFeS_{2(cp)}$ [2]

This communication suggests that at least some chalcopyrite disease originates from exsolution of chalcopyrite during the polymorphic transformation of Cu-bearing, Fe-rich wurtzite to sphalerite.

SS01-05 SHORT-RANGE ORDER IN MINERALS: THEORY AND EXPERIMENT

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Short-range order (SRO) is the tendency for local arrangements of atoms to occur more often that is in accord with a random local distribution of those atoms. Short-range order is a prominent feature of many rock-forming minerals [e.g., amphiboles, micas, staurolite, scapolite] and complex oxysalt minerals [e.g., jamesite, tienshanite]. SRO strongly affects the configurational entropy of solid solutions, and is important in the formation of activity models. The chemical composition of a mineral is the sum of all its short-range configurations; hence constraints on patterns of SRO can strongly affect chemical substitutions and solid-solution/immiscibility in minerals. When extended to deal with local atom arrangements in minerals, bond-valence theory indicates that SRO should be a prominent feature of solid solutions that involve heterovalent substitutions. Unfortunately, SRO is difficult to characterize in complex solid-solutions as diffraction is not sensitive to SRO, and those spectroscopic techniques that are sensitive [e.g., infrared spectroscopy in the principal OH-stretching region, MAS NMR] are not applicable to all minerals, and show compositional restrictions to their sensitivity. Nevertheless, IR has proved a powerful technique for characterizing SRO in OH-bearing minerals via the frequencies and intensities of fine-structure bands in the principal OH-stretching region. This has proved effective in amphibole and mica solid-solutions, when the patterns of LRO (long-range order) are well-characterized [e.g., richterite-pargasite, tremolite-pargasite], and the results are in accord with local arrangements predicted by bond-valence arguments. Calculation of all possible SRO patterns in solid solutions allows assessment of the stability of each of the local arrangements by bond-valence theory; those arrangements that are not stable may limit the extent of solid solution. For example, along the tremolite-tschermakite join, tschermakitic compositions are constrained to be dominated by local arrangements that are not stable from a bond-valence perspective, accounting for the fact that natural and synthetic compositions along this join do not extend significantly past hornblende. In many complex oxysalt minerals, there are solid solutions involving heterovalent cations and heterovalent anions, e.g., Ti + 2O <-> Mg + 2OH. Crystal-structure solution gives only the average electron density, but local bond-valence arguments are usually effective in deriving the local configurations. Generally, local bond-valence requirements are satisfied by local association of the substituents, coupled with significant positional disorder of both cations and anions.

SS01-06

THE ANALYSIS OF MG AND TI ORDER/DISORDER IN PSEUDOBROOKITE BY RAMAN SPECTROSCOPY: IMPLICATIONS FOR THE GEOLOGICAL EXPLORATION OF MARS

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NASA is planning to equip the 2009 Mars mission with a nuclear-powered rover that will conduct in situ Raman spectroscopic measurement. It is well established that the identity of a mineral may be determined by its Raman spectrum. In such a way it is hoped that the Raman spectrometer on Mars will be used to identify calcite, olivine, pyroxene, etc. Furthermore, it is becoming apparent that the chemistry of some minerals may be determined to near microprobe accuracy with Raman spectroscopy, if the mineral group and its solid solutions have been previously well characterized. Huang et al (2000) reported that they could determine the concentration of Fe with a precision of 3% in orthopyroxene and 6% in clinopyroxene, and Wang et al (2001) reported that they could determine the amounts of Mg and Ca to 0.01 atoms per formula unit in planetary quadrilateral pyroxenes, all with a well-calibrated Raman library. As such, it should be possible to use the chemistry of coexisting mineral phases (for instance: feldspar, olivine, spinel, garnet, orthopyroxene and clinopyroxene in basalt) determined by the Martian Raman system and compute the peak pressure and temperature conditions experienced during crystallization or metamorphism through the application of geothermometers and barometers.

In addition to chemistry, it is also well known that the order-disorder state of a mineral can be used to determine closure temperatures and thus provide a measure of the thermal history experienced by the sample. In this paper we investigate the ability to use Raman spectroscopy to characterize the order-disorder state of pseudobrookite-type $MgTi_2O_5$. Yang and Hazen (1998) produced a suite of well-characterized single crystals of synthetic pseudobrookite-type $MgTi_2O_5$ that were heated to temperatures ranging from 600 to 1400°C and then rapidly quenched. The crystal structures were determined by single crystal diffraction and the site occupancy of Ti in the M1 site varies from 0.070(5) (ordered) to 0.485(5) (disordered). The same samples were investigated in our study with Raman spectroscopy. Seventeen Raman active modes can be identified. Positions and peak-widths vary with the degree of disorder. We will report the results of our analysis to determine whether Raman spectroscopy can be used to determine the order/disorder states, and the functional form of the required analysis.

SS-03

ROCKY SHORELINES IN THE GEOLOGICAL RECORD - PALEOBIOLOGICAL AND SEDIMENTOLOGICAL SIGNATURES

LES LITTORAUX ROCHEUX DANS L'HISTOIRE GÉOLOGIQUE - SIGNATURES PALÉOBIOLOGIQUES ET SÉDIMENTOLOGIQUES

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SS03-01 **LIMITS OF UNIFORMITARIANISM AS A GUIDE TO ROCKY-SHORE ECOSYSTEMS IN THE GEOLOGICAL RECORD**

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The rocky-shore ecosystem has been studied extensively by marine ecologists interested in the phenomenon of intertidal zonation. Paleoecologists have not explored the geological record of this ecosystem to the extent it deserves due to a flawed perception that high-energy waves cause continuous degradation of biological fabric and net export of sediments from rocky shorelines. This review compares modern and Pleistocene-Pliocene rocky shores from a uniformitarian outlook in order to evaluate the fidelity of physical and biological information entrained in the record through present-day processes. Coverage by latitude includes tropical, warm-temperate, and cool-temperate shores. Examples from each climatic setting are cross-checked to illustrate physical variations in topography against unconformities marked by sedimentary accumulations against rocks of igneous and non-igneous origin. Studies from widespread localities in North America, Australia, and the Seychelles Islands feature: 1) spot localities, 2) embayments that show continuous transition from exposed outer to protected inner shores, and 3) entire islands with windward and leeward shores. Species with hard parts account for 50% to 80% of the modern rocky intertidal fauna on a regional basis at any given latitude. Fixed organisms with encrusting, wedging, or boring habits (calcareous algae, corals, barnacles, oysters and other bivalves) have strong potential for fossilization in situ. Mobile organisms that cling to rocks (gastropods, crabs, echinoids) suffer post-mortem transport but may be buried within neptunian dykes or interstices among locked cobbles and boulders. At best, localized fossil deposits from the Pleistocene reflect approximately 30% of the biodiversity of skeletonized organisms tabulated from modern rocky shores on a more regional basis. The highest recorded fossil count is 62 species. Representation on this level is more than adequate to show biological relationships and to determine rank within a variable energy regime. As a guide to ecosystems through deeper geologic time, however, the physical and biological aspects of uniformitarianism must be separated. Terrace deposits are well developed in the Pleistocene, but ramp deposits are more typical of Pliocene and older deposits. The role of wind, waves, and tides in the sculpture of rocky headlands and islands has remained nearly constant within a narrow range of variables. By contrast, changes in sea level differ through time with regard to rate and magnitude. On the biological side, uniformitarianism provides little insight into the diversity of soft-bodied organisms (excluding stromatolites) that joined the ecosystem in Precambrian times and the extent to which such organisms dominated shore life through later times.

SS03-02 ROCKY SHORELINES AS DEFINITIVE ARCHIVES OF HIGH-ENERGY COASTAL PROCESSES

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Shorelines vary in their response to high-energy coastal processes. The response of beaches to extreme wave events is predominantly erosional. In estuaries records may be equivocal, because sand layers may evince both land-derived flood waves and marine inundations. In contrast, rocky shorelines generate and retain coarse gravels that may be the only depositional records of extreme waves and other processes. Megaclasts (coarse boulders and blocks) found on modern rock platforms and cliff tops are evidence of rapid coastline changes, caused by high-energy, low-frequency events, such as tsunami, cyclone or storm waves. Modelling the wave power required to move the largest megaclasts can give reliable estimates of wave energies where wave records do not exist, and can be linked to specific tsunami and storms.

A major impediment to interpretations of coarse gravels associated with rocky shorelines, including megaclasts, has been the absence of sedimentary facies models that link rocky shoreline deposits, emplacement processes and depositional environments. Consequently, enigmatic coarse gravel deposits along oceanic island and continental rocky coasts have frequently been interpreted as products of “mega-tsunamis”. Our recent work on such deposits in the Hawaiian Islands and eastern Australia reveals a variety of distinctive coarse gravel sedimentary facies, occurring in specific geomorphic settings above and below sea level, that result from a range of high-energy coastal processes. Some deposits have a high degree of stratigraphic ordering, and record relative sea-level changes.

Clearly, patterns of subaerial, shoreline and shoreface sediment distribution, and the sedimentary facies present on modern and ancient rocky shorelines will depend critically on the range of grain sizes in available sediment, sediment supply rates, and on the overall oceanographic regime, including episodic large wave events. To fully evaluate rocky shoreline deposition in its broadest sense, sedimentary facies models are needed for rocky shorelines occurring in a range of settings.

Resolution of recurrent “mega-tsunami” hypotheses is crucial not only for natural hazard assessment, but also for correctly interpreting the geological history of oceanic and volcanic arc islands, for distinguishing between ancient tsunami and storm deposits, and for interpreting coarse-grained deposits on continental margins.

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SS03-03 **ROCKY, STORM-SWEPT SHORELINE OF THE BASAL NANAIMO GROUP (UPPER CRETACEOUS); SOUTHERN GULF ISLANDS, BRITISH COLUMBIA**

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The Turonian to Santonian Comox Formation comprises the basal unit of the Nanaimo Group. In the southern Gulf Islands of B.C., the Comox Formation nonconformably overlies Devonian metavolcanic and intrusive rocks, and is interpreted as a rocky foreshore reworked by waves and ultimately drowned during transgression. The nonconformity displays relief of metres to 10's of metres. Basal deposits are highly variable in thickness, and their facies character varies along the length of the approximately 50 km of paleo-shoreline studied. In most areas, the basal lithofacies ranges from breccia to clast-supported conglomerate, and comprises a poorly sorted mix of boulders to pebbles of subjacent basement compositions, in a medium to coarse-grained sandstone matrix that contains rare bivalve fragments. Locally, the unconformity surface is overlain by up to 30 m of stacked muddy to sandy, matrix-supported conglomerate beds, grading complexly into open-framework cobble conglomerates. All basal coarse clastics grade into crudely stratified pebbly sandstones and, in turn, into sandstone beds with isolated pebbles. The conglomerates and sandstones commonly contain dispersed bivalve, gastropod, and cephalopod fragments, carbonaceous detritus, small wood fragments, and glaucony. The sandstones display low-angle, undulatory parallel lamination in stacked, erosionally based beds 10-35 cm thick. Locally, low-relief scours form swales. The lamination is interpreted as swaley cross-stratification (SCS) and lesser hummocky cross-stratification (HCS). Bedsets are locally bioturbated (BI 1-3) near their upper margins with Ophiomorpha, Skolithos, Palaeophycus, and fugichnia reflecting the Skolithos ichnofacies, interpreted to represent post-storm opportunistic colonization of tempestites. These tempestites are interstratified with more pervasively bioturbated (BI 3-5) sandstones and muddy sandstones, reflecting fairweather suites of the Cruziana ichnofacies. These beds are less common overall, but occur with greater regularity upward. Stratified conglomerates represent small gravelly fans dominated by debris flow processes, building out from local coastal cliffs and gullies directly onto the rocky shoreline. The sandstone facies associations reflect storm-dominated shoreface environments. These successions comprise upper shoreface pebbly sandstones that pass upwards through middle shoreface erosionally amalgamated SCS sandstones, and into lower shoreface HCS sandstones. The unusual thickness and coarseness of these shoreface intervals suggest a combination of increasing accommodation space, proximal and high sediment supply, and high frequency and energy of storm activity. This, in turn, suggests that the shoreline was not sheltered, thus enduring the full effects of large, open-ocean storms. This interpretation differs from most previous models for the lower Nanaimo Group, which suggest that deposition occurred in more sheltered strait or bay environments.

SS03-04 Basement onlap by the Ordovician Trenton Group in the Quebec City area and by the Mississippian Windsor Group in the Halifax area; comparison between two contrasting transgressive marine successions

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Keywords:
marine transgressions; ancient rocky coasts; Ordovician; Mississippian; Trenton Group; Windsor Group

Limestones of the Ordovician Trenton and Mississippian Windsor Groups onlap Proterozoic Grenvillian gneisses and Cambrian Meguma Group metasediments near Quebec City (Quebec) and Halifax (Nova Scotia), respectively. Although both transgressive events occurred rapidly through tectonic forcing in sediment-starved areas, there are significant differences in the sedimentology of these cover sequences. The Ordovician transgression occurred on a steep and well-washed surface, with each flat-lying limestone layer gradually prograding onto the basement rocks. Micrite was apparently deposited in low-lying areas, leaving steeper areas denuded. In contrast, the equally steep, rocky shoreline of the Mississippian sea is marked by coarse patches of submarine scree-cones and beach gravels. The sedimentology of these rocks indicates that the steep dip of the sub-Mississippian unconformity is quite close to that of the original sedimentary dip in the basal Windsor Group. The steep Mississippian rocky shoreline was blanketed by bafflestone, which was deposited directly on slopes that can exceed 50°. The overall geometry of these Ordovician and Mississippian marine basins may explain the marked differences between the two transgressive successions. In particular, the Ordovician foreland basin was more open and prone to developing a high energy wave-dominated coast than the Mississippian sea, which invaded a complex network of narrow pull-apart basins that were less likely to develop a high-energy coastline. Whereas regolith on the Ordovician coast was thoroughly removed, allowing micrite to be deposited directly on bedrock, the Mississippian coast was sufficiently quiescent for algal mats to develop under shallow water conditions, blanketing moderately reworked regolith. In both cases, marine transgression was too rapid and the bedrock too competent for wave-cut platforms and receding coastal cliffs to develop.

SS03-05 **THE COVE BENEATH THE COVE: ORDOVICIAN-SILURIAN PALEOSHORELINES UNDERLYING A MODERN SHORE NEAR CHURCHILL AIRPORT, NORTHERN MANITOBA**

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Scattered outcrops of Upper Ordovician and Lower Silurian sedimentary rocks in the vicinity of Churchill, Manitoba, represent shallow marine deposition around tropical islands that were formed by ridges of Proterozoic Churchill Quartzite. The most complete set of surface exposures in this region is in quarries and along the shore in a semicircular cove north of Churchill Airport. These exposures, occurring over a distance of about one kilometre, provide the only known surface record of the Ordovician-Silurian boundary interval in the Hudson Bay Lowland. Field studies of this cove have been carried out over several field seasons; drilling in 2003 now allows a three-dimensional interpretation. Drillcores were extracted from three sites. Each of these extends from the surface, through the entire Paleozoic succession and into the underlying Churchill Quartzite. The drill holes were 41.45 to 102.70 m deep. This considerable depth to quartzite in close proximity to the ridge (100 to 340 m laterally) indicates that the flanks of the ridge continue to dip steeply in the subsurface.

The greatest thickness of rock in each drillcore is Upper Ordovician. At the base of the Ordovician are quartz sandstones, boulder-field deposits, and weathered quartzites. Although only a very small area of Ordovician paleoshore is seen in surface exposures, the cores indicate that boulder and sand beaches were widely distributed. The overlying Ordovician rocks include a wide range of lithologies: dolostones, sandstones, siltstones, and clays, representing deposition under varied environmental conditions. Quartzite clasts occur at some levels and fossils are locally abundant. Substantial Ordovician exposures along the modern shore exhibit some of the same lithologies and fossils. The core, however, indicates that these surface deposits are stratigraphically incomplete and provide only a partial picture of paleoshoreline development.

A 1.5 to 2.0 metre-thick claystone of undetermined age overlies the Ordovician rocks. Above this, in both surface deposits and core, are Lower Silurian (lower Llandovery) muddy dolostones that were probably deposited in restricted, shallow-water conditions. The highest known Silurian beds, exposed on the modern tidal flat, are fossiliferous coral-rich dolostones. The Silurian strata in this cove are assigned to the Severn River Formation.

The combined assessment of surface deposits and drillcores is allowing us to see the ancient tropical cove that sits beneath the modern subarctic one. Together, this information permits reconstruction in three dimensions of a locality that is essential to our understanding of Ordovician to Silurian events in the Hudson Bay Basin.

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Extending the search for lower Silurian shorelines: Severn River Formation, Sutton Ridges Region, Hudson Bay Lowlands, Ontario

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Recent fieldwork in the Sutton Ridges area of Ontario included a preliminary search for rocky shorelines developed along a regional unconformity between Precambrian basement highs and adjacent or overlying marine carbonates of the Lower Silurian (Rhuddanian-Aeronian) Severn River Formation. The Sutton Ridges form the only significant topography within a vast expanse of low, monotonous terrain of the Hudson Bay Lowlands, with local relief of up to 180 m. Paleogeographical overviews of the region have suggested that the Precambrian highs probably stood above sea level, forming islands or promontories during deposition of Lower Silurian (and possibly Upper Ordovician) sediments, similar to the setting that produced spectacular fossil shorelines now exhumed along the Hudson Bay coast near Churchill, Manitoba. We focused our Sutton Ridges shoreline search in those few localities where earlier mapping identified probable contacts between Precambrian and Silurian units, specifically at Hawley Lake close to Sutton Narrows, and near the confluence of the Winisk and Shamattawa rivers.

Our work confirms the presence of at least 0.5 m of thinly bedded, fossiliferous clastics immediately overlying jaspilites of the Proterozoic Sutton Ridges Formation at Hawley Lake. The younger rocks are lithologically distinct from typical Severn River Formation carbonates exposed elsewhere in the area, and range from siltstones to coarse sandstones containing scattered fragments of quartz and jaspilite. Previously unreported fossils include abundant valves of orthide brachiopods and ostracods, with rare proetid trilobite sclerites. The single outcrop is so poorly exposed that exact contact configuration, lateral relationships, and total thickness cannot be determined, and a rocky shoreline status cannot yet be confirmed.

A smaller Proterozoic inlier, exposing a 12 m section of Nowashe Formation metasediments cut by quartz veins, is located on the southeast shore of the Winisk River about 2 km southwest of the mouth of the Shamattawa River. Here, the Precambrian rocks stand in low relief within 300 m of well-bedded to massive, microbial mound-bearing dolostones of the Severn River Formation. Glacial drift and recent river deposits mantle the inlier margins, but float slabs of typical Sutton River lithology, containing abundant angular to sub-rounded clasts of quartz, and green argillite and dolostone derived from the Nowashe Formation, occur nearby. Unfortunately, we were unable to locate an outcrop exposing the contact.

Despite equivocal results to date, paleoenvironmental interpretations for the Severn River Formation along with highly irregular basement topography suggest that rocky shoreline facies should be locally developed, and the search continues.

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CONTROLS ON ANCIENT ROCKY SHORELINE DEVELOPMENT: EXAMPLES FROM THE LOWER SILURIAN CHICOTTE FORMATION, ANTICOSTI ISLAND; GULF OF ST. LAWRENCE

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The Lower Silurian (Telychian) Chicotte Formation is a regionally extensive crinoid-rich unit exposed in the south central part of Anticosti Island in the Gulf of St. Lawrence. Reefal limestones including mud-rich fenestrate bryozoan and coral-stromatoporoid buildups are also present. The Chicotte encrinites represent an inner ramp, crinoidal sand-shoal complex (about 80 m thick) prograding over deeper mid to outer ramp facies of the underlying Jupiter Formation in response to a long-term sea level fall. The typical depositional unit is a meter-scale subtidal cycle indicating that higher frequency sea level changes related likely to the O/S glacial episode were also present.

Metre-scale cycles are typically characterized by coarsening upward, locally cross-bedded encrinitic material capped by sharp erosive surfaces. These capping surfaces change progressively upward from simple planar or scalloped erosive surfaces to more complex polyphase surfaces. Scalloped erosive surfaces consist of smooth elongate, locally curved, basins (30-80 cm wide) separated by sharp ridges. Relief is 5-20 cm high. The scalloped surfaces pass laterally into planar erosional surfaces. These surfaces truncate both grains and cement including isopachous rinds of marine fibrous calcite crystals associated with internal micritic sediments. Surfaces are locally infected with simple borings (mainly Trypanites) and encrusted by bryozoan and crinoid holdfasts. The repetition of these metre-scale subtidal cycles is most likely driven by short-term sea level fluctuations with accumulation of encrinitic material above abrasion wave base during the highstand phases and with lithification, hardground development and erosion by lowering of the abrasion wave base during the lowstand phases.

Metre-scale cycles in the upper Chicotte encrinites are capped by more complex surfaces formed by distinct but superimposed erosive events. Erosional relief is locally greater than 25 m indicating a drop in erosive base of at least the same amount. 3-D paleomorphological features associated with these surfaces are exposed along coastal and river sections and partially exhumed by modern erosion along coastal exposures. They include large scale irregular sea stacks and shallow cliffs similar to those present along modern rocky shorelines. These surfaces also developed during short term sea level lowstands in association with a long term reduction in accommodation space. Reefal limestones consisting of abundant, scattered to closely spaced, low-profile stromatoporoids and tabulate corals to stromatoporoid-rich pebble to cobble rudstones are commonly present above these irregular surfaces. They represent fringing reefs developed above a resubmerged irregular rocky shoreline offering variable protection to the incoming storm waves.

SS03-08 REMOTE SENSING ROCKY SHORELINES

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Low-cost to no-cost Thematic Mapper (TM) images are now available for most of the North American continent and much of the world. The identification of geologic units by remote sensing is possible in areas where contrasts in rock types are high and where vegetation cover and atmospheric interference are low. Ancient rocky shorelines usually are represented by siliciclastic or mixed carbonate-siliciclastic sedimentary units that often stand out, relative to the local basement rocks, due to differences in their reflectivity.

Rocky shorelines provide a pinning point for sea level, which is extremely useful in the reconstruction of basin histories, particularly those with complex tectonic pasts. Depending on the size of the basin and the ruggedness of the terrain, mapping ancient shorelines can be difficult and/or expensive. Multi-spectral satellite data, comparable in quality to Landsat TM images, can be used as a reconnaissance tool to evaluate large areas for the presence of rocky shorelines and similar unconformities. However, the size of the outcrop that can be detected is limited by the resolution of the image, which in the case of a TM image is 28.5 m per pixel. Visual interference from plant growth can be minimized by using images taken early or late in the growing season.

Pliocene-age deposits on the coast of the Gulf of California, north of Loreto, Baja California Sur, Mexico have been used to test the capabilities of TM satellite imagery as a reconnaissance tool. It has also been used to evaluate previously mapped Pliocene ramps and basins at Santa Rosaliita, near the base of Concepcion Bay, and at Punta Chivato to the north of the Concepcion peninsula. As a further test of this technique, previously mapped Cretaceous age shorelines along the pacific coast of the Baja Peninsula, and Upper Ordovician/ Lower Silurian shorelines near Churchill, Manitoba were compared with the relevant TM images. The results suggest that TM satellite imagery can be a good reconnaissance tool for identifying potential ancient shorelines and particularly suitable for identifying carbonate-rich deposits. Generally, this technique should be useful for tracing similar deposits exposed in any arid low-latitude or low-vegetation, high-latitude region of the world. It is also a relatively low cost way to do reconnaissance work in regions where weather and support costs limit the field season.

SS03-09 **A Tethyan equatorial rocky shore Sclerobiont community from the Late Cretaceous (Maastrichtian) of the Oman Mountains, Arabia**

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The Qahlah Formation is a sequence of very coarse sandstones and gravels deposited along the shore where the Neotethys met the newly emergent Semail Ophiolite in the latest Cretaceous. This rocky shore was almost exactly along the equator at that time. The clasts in the Qahlah Formation range in size from sand grains to boulders over three meters in diameter. They are lithologically diverse, consisting of ophiolitic gabbros, basalts and cherts, as well as fragments of contemporaneous carbonate hardgrounds, robust mollusk and coral skeletons, older limestone fragments, and many pieces of wood. The tropical environment and numerous substrate types supported abundant rocky shore sclerobionts (organisms which lived on or in hard substrates). This diverse fauna provides important data for the environmental and latitudinal distribution of sclerobionts, and for their evolution prior to the Cretaceous Extinction.

The encrusters on the Qahlah clasts and intercalated hardgrounds were dominated by the oyster Acutostrea, which was most common on exposed surfaces. Other exposed encrusters included several robust scleractinian coral species, two crustose alga species, and numerous delicate foraminiferans (Placopsilina and Nubeculinella). At least a dozen bryozoan species and two serpulid worm species are found in cracks, crevices and other cryptic spaces on and among the clasts. The borings in the Qahlah clasts are not surprisingly distributed according to substrate types. Silicates (igneous and chert clasts) are not bored, of course, and the carbonate and wood substrates are highly excavated. Carbonates (hardgrounds, older limestones, and bioclasts) have borings of bivalves (Gastrochaenolites), clionid sponges (Entobia) and acrothoracican barnacles (Rogerella). Pieces of wood are bored by teredinid bivalves, producing Teredolites.

We can easily conclude that this tropical rocky shore community of the Late Cretaceous Qahlah was diverse, which is an important addition to our developing model for the evolutionary ecology of marine sclerobionts. We can also see general patterns of ecological partitioning (especially exposed vs. cryptic encrusters) and the effects particular substrates had on individual encrusting or boring species. Our paleoecological conclusions are constrained, however, by taphonomic loss, time-averaging, and clast transportation, which is always an important lesson for rocky shore paleontologists.

SS03-10 **DEVELOPMENT OF THE PLIO-PLEISTOCENE ARROYO BLANCO BASIN, BAJA CALIFORNIA SUR, MEXICO**

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Basin and ramp deposits of Pliocene age are exposed in many places along the southern Baja California coast of the Gulf of California. These deposits provide an important record of the transition from extensional to transtensional tectonics within the Gulf of California at about 3.5 mya. However, many of the basins record only part of the Pliocene record from within the gulf. In most cases, it is not clear how much uplift has occurred since deposition.

Rocky shorelines are an important component of these basin and ramp sequences as they provide a pinning point for sea level. Used in conjunction with sea-level curves and biostratigraphic zonation, rocky shorelines are critical for untangling the relationship between tectonics and eustacy during the development of the Gulf of California.

The Arroyo Blanco Basin is located on the eastern side of Carmen Island, offshore of Loreto, Baja California Sur, Mexico. Triangular in shape, the approximately 3.3 km^2 basin opens to the east. One of several sedimentological basins on the Island, Arroyo Blanco is unusual as it contains an almost complete Pliocene sequence for the Gulf of California. The base of the sequence exposed in the basin is a massive deposit primarily composed of rhodolith debris. The presence of Patinopecten bakeri indicates an early Pliocene age for this unit. The top of the section contains a fauna of gastropods, pelecepods and corals, which point to an early Pleistocene age. Unlike other Pliocene basins in the Gulf of California, the sequence at Arroyo Blanco passes from intertidal through offshore pecten beds to deepwater facies in about 0.8 km.

The entire sequence has been uplifted at least 170 m subsequent to deposition. The northwestern section of the basin abuts a prominent hill of Miocene Commondu Group volcanics that commonly form the basement on Carmen Island. Several carbonate ramp deposits that sit behind and to the side of this hill suggest that erosion has removed much of what was a much more extensive basin. This suggests that during the Pliocene this hill was a peninsula and may have been an island before being uplifted into its present position.

SS03-11 Precambrian rocky archipelago from the Smalfjord Formation of east Finnmark, Norway

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A cluster of five monadnocks occurs within a two-square-kilometer area at the western terminus of Varangerfjord near Karlebotn in East Finnmark, Norway. The monadnocks are composed of gneiss of granitic and tonalitic composition dating from 1800 to 3000 Ma. They are surrounded by bedded quartzites from the Smalfjord Formation, deposited immediately after the Maorian Glaciation at about 630 Ma. Quartzites from this part of the formation are 80 m thick, and display fining-upward cycles on the order of 3-10 m thick. The monadnocks formed elevations in a valley or fjord that roughly follows the outline of the present Varangerfjord but opened towards the WNW on the margin of Baltica. Detailed stratigraphic measurements and correlation of sections in the Smalfjord Formation were compiled to reconstruct conditions at the present level of exhumation around the monadnocks. Topographic relief of gneiss above the surrounding quartzites varies between 4 and 22 m. During onlap, the monadnocks were transformed into an archipelago in an estuary that was filling up with marine tidal deposits derived from the WNW. Fluvial deposits progressed from the ESE across the area after the islands were buried. The largest monadnock is elongate with a circumference of 1 km that preserves direct unconformable contacts in all but a short segment on the eastern side. Strata dip away from the monadnock in a uniformly symmetrical pattern with an average slope of 13 degrees. Grids were used to record clast size of conglomeratic material (quarter square-meter sample surface) and petrographic thin sections were studied for composition. These data confirm two distinct sedimentary facies on opposite sides of the paleoisland. Well sorted, fine-grained, quartz-dominated deposits prevail to the SE and S, while a coarse diamictite with high mud, feldspar, and mica content fringes the NW and N flanks of the island. Cobbles and pebbles of foreign origin from glacially deposited material are mixed with locally eroded gneiss. The till was slumped off the island where the terrain was steepest or channeled through a low drainage into a cove. It is concluded that the northern shore was in the sheltered lee of the island, or otherwise shielded from tidal currents by other islands further NW. On the southern side of the island, tidal currents were free to strip and carry away locally derived material, leaving a sandy beach composed 96% of pure quartz sand in direct contact with gneiss bedrock.

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Eustatic sea-level changes (the Devil's Point event) during the last interglacial (5e) recorded in fossil coral reefs

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Fossil coral reefs are well preserved and excellently exposed on the Bahamian islands of Great Inagua and San Salvador. Detailed field work and precise TIMS dating revealed that coral growth within the Last Interglacial was interrupted by a rapid sea-level regression (the Devil's Point Event = DPE). Extensive reefs grew 130,000 to 128,000 years ago when sea level reached at least 4 meters above present levels. During the DPE, sea level fell a minimum of 4 meters and fossil corals preserved in growth position were erosionally truncated and a wave-cut surface was produced. Trace fossils created by terrestrial plants are preserved directly on planed-off coral heads. Subsequently, sea level rose to approximately 6 meters above present levels and younger reefs grew disconformably on the older reef surfaces 124,000 to 119,000 years ago. Plant trace fossils that lie directly on the surface of older fossil corals are encrusted by corals of the younger fossil reef. Karstic caves and erosional channels, which formed during the DPE sea-level lowstand, were filled by subtidal sands following the subsequent sea-level rise. Lithophagid borings in the disconformity surface contain an internal stratigraphy of cemented marine sands overlain by a thin layer of reddened paleosol and capped by marine bivalves. This sequence encapsulates in miniature the regression-transgression pattern of the DPE. Some lithophagid and associated sponge borings are overlapped by encrusting corals belonging to the younger reef.

Descriptions of other Last Interglacial reefs from around the world show that the DPE was a global event. Changes in sea level in tectonically stable areas are best explained by fluctuations in terrestrial ice volume. This implies that there were rapid changes in global temperatures and/or snowfall accumulation rates during the Last Interglacial. Based on the record found in Last Interglacial coral reefs, there can be no assurance that dramatic climate changes and fluctuations in relative sea level will not occur during the remainder of the Holocene Interglacial.

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SS03-P01 When a movable object meets an immovable object: the Late Ordovician rocky shoreline and storm ridge at Sheguiandah, Manitoulin Island, and resource exploitation by the founding (Palaeoindian) peoples of Ontario 9500 years ago

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The spectacular Late Ordovician rocky shoreline and storm ridge at Sheguiandah, Manitoulin Island, Ontario, described by M.E. Johnson and J.-Y. Rong in the late 1980s has inspired generations of geologists. The Late Ordovician rocky shoreline consists of rounded erosional hills of steeply dipping, white Huronian (Late Precambrian) quartzite of the Bar River Formation, eroded and rounded in pre-Late Ordovician times. The Late Ordovician storm ridge is defined by the more or less horizontally-bedded Late Ordovician sands, breccias, and quartzite boulder conglomerates of the Lindsay Formation, by an underlying regolith of angular quartzite breccia, and by the sharp angular unconformity between the underlying Precambrian quartzite and the overlying Late Ordovician clastics. The coarse, quartzite conglomerate clasts are variably rounded, ranging from angular to completely rounded; both the Precambrian quartzite bedrock and the Palaeozoic clasts show crescent-shaped percussion marks. The quartzite clasts are cemented by dolomite containing moulds of Ordovician nautiloid cephalopods and abraded and broken conodonts; rare encrusting corals have also been found in the conglomerate. The palaeotopography, the large, rounded quartzite boulders, the presence of percussion marks, and broken and abraded conodonts, all support the interpretation of a high-energy, Late Ordovician rocky shoreline.

Archaeologists and geologists have, in recent years, determined that Ontario's first (Palaeoindian) inhabitants were excavating Precambrian quartzite for tool manufacture from the Late Ordovician rocky shoreline at Sheguiandah, nearly ten thousand years ago. The Late Ordovician storm ridge that girds the quartzite hill at Sheguiandah "like the remnant of hair around a bald man's head" is the 'Mystic Ridge' of the archaeologists who first excavated the significant and sometimes controversial quarrying and manufacturing site at Sheguiandah in the 1950s. 'Mystic Ridge' as a topographic feature likely protected the Palaeoindian band, living and working behind the ridge at the "Habitation Site", from the sometimes stormy waters of Lake Algonquin- the higher-water ancestor of todays Lake Huron; 'Mystic Ridge' may also have provided a ready source of 'pre-excavated' and 'pre-tested'quartzite boulders for quartzite tool manufacture. Finally, the Late Ordovician storm ridge probably supplied and modified the Pleistocene sediments that directly underlie the "Habitation Site"; understanding this Pleistocene sediment transfer and sediment modification from a Late Ordovician source proved to be key to re-interpreting when these founding peoples of Ontario lived and worked at Sheguiandah.

SS-04

INTERPRETING THE STRUCTURES IN PARTIALLY MELTED DEEP (>25KM) CONTINENTAL CRUST

L'INTERPRÉTATION DES STRUCTURES DE LA CROÛTE CONTINENTALE EN FUSION PARTIELLE (>25 KM)

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SS04-01 MELT LOSS FROM LOWER CONTINENTAL CRUST: OBSERVATIONS, MECHANISMS AND IMPLICATIONS

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There are two fundamental approaches to understanding melt loss from lower crust and transfer into middle/upper crustal plutons: using observations from the field; and, using modeling based on a set of reasonable (?) assumptions. Sometimes it is difficult to relate the results from these different approaches to each other, which leads to polarized views of the process.

In exposed crust of deeply-eroded orogens, where evidence of melting is preserved in residual migmatites and granulites, magma chambers related to an inferred melting event appear to be absent. Therefore, either melt must accumulate in a macroscopic storage network that feeds drainage channels, or there must be some mechanism by which melt batches aggregate to increase in size and ascend through crust, or the source must ascend en masse. In deep crustal rocks, detailed mapping of residual melt distribution at thin-section scale, inferred from melt pseudomorphs, and of flow networks at outcrop-scale, inferred from leucosome-filled structures, indicates that melt loss from lower crust is accomplished by segregation from grain boundaries into deformation band networks, and by migration through these networks to propagating ductile opening-mode fractures.

In contrast, numerical, analogue and physical modeling have led to the suggestion that melt expulsion/extraction is a self-organized critical (SOC) phenomenon. However, the underlying physical mechanism by which this is accomplished has not been adduced nor has the relationship to observed patterning of anatectic lower crust been addressed adequately. Nonetheless, the expectation that melt loss is a SOC phenomenon motivates more rigorous approaches to mapping anatectic terrains, requires patterning of anatectic lower crust be quantified and demands realistic models of magma ascent, which match theory and modeling with observations from nature, be developed.

Weak layers in continental crust are commonly attributed to presence of melt, which layers have been argued to be due to melt segregation in situ (without migration and expulsion/extraction) or due to melt expulsion/extraction and accumulation at some shallower level. Whatever the starting inference, the structural level of any deep weak zone may evolve with time, since the orogenic environment is dynamic, with crust deforming and melt fluxing through from 'source' to 'sink' to 'sink' at all length-scales. Residual mineralogy and cooling result in strong lower crust, and crystallization of middle/upper crustal plutons allows local weakening to decay. Thus, melt loss from lower crust and crystallization both involve strengthening that may partition strain away from the orogenic core and localize intracontinental deformation into shear zones.

SS04-02 INFLUENCE OF CRYSTALLIZED MELT MATERIAL ON THE RHEOLOGICAL RESPONSE OF CRUST

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The formation in or introduction to the middle and lower crust of melts has distinct influence on the subsequent rheological response of the crust, not only as a magmatic phase, but also through variations in subsolidus micromechanical behaviour after crystallization. The predominant influence of the introduction of new material is a bulk softening of the overall host-melt system that occurs in conjunction with localization of strain. Both strain softening and localization reflect conditions of state and material properties of the crystallized melt that were absence in host material. The latter include local temperature increases; relative defect-free material with lower grain-scale stored strain energy; and both increase and decrease in grain size relative to the host crustal material. Temperature increase relative to the host rock requires either large volumes of melt input, or a relatively high temperature in the melt that introduced into a deforming host. These conditions can enable subsolidus deformation of crystallized grains at initially greater than ambient temperatures. Cooling of the grains may be also suppressed by heat of crystallization effects that enable both crystals and adjacent host rock to have a longer high-temperature transient during which strain is accumulated. Examples of the latter behaviour occur as anomalously distorted large single crystals in syntectonic dykes and pegmatites. More thermally passive introduction of melt will have igneous or 'annealed' grain textures in which crystal plastic processes are enhanced because of their lower density of glide inhibiting defects. Observations of 'micro-melts' have grain sizes that orders of magnitude smaller than the host rock. The latter in turn localize strain accommodated by diffusional grain-size-sensitive processes. Pseuodtachylyte has the same post-crystallization behaviour. As well as enhancing ductile flow, coarse grained crystallized melts can also serve to strengthen crust if the ambient temperatures and stresses are insufficient to induce strain.

SS04-03 **RE-COUPLING THE DECOUPLED PARTIALLY MOLTEN CRUST: THE CHANNEL FLOW-DETACHMENT TRANSITION**

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Partial melting, channel flow, and upper crustal extension are fundamental processes shaping the evolution of orogens, from the growth of orogenic plateaux to their subsequent collapse. Geochronology and thermochronology from numerous orogens increasingly document a tight age grouping for extensional basin development, detachment faulting, partial melting, and the exhumation and cooling of migmatites, suggesting that upper crustal extension and deep crustal flow are nearly coeval. However, the extent to which these processes are coupled and the nature of these interactions in space and time is poorly understood.

A ~3 km thick structural section is exposed beneath the Okanogan detachment fault along the western margin of the Okanogan gneiss dome, Washington State. Gneissic foliation defines two broad subdomes (10-15 km across), the Stowe Mtn and Burge Mtn subdomes, elongated NW parallel to lineation and separated by broad synforms. Within the Stowe Mtn subdome, high-grade metamorphic assemblages, including gedrite-cordierite-sapphirine-corundum-anorthite amphibolite, indicate T > 700-800°C. The subdome is comprised of three distinct structural zones with similar foliation and lineation orientation in all three zones. From bottom to top these domains are a migmatite zone dominated by diatexite, a ~0.5 km thick transition zone, and a ~1.5 km thick detachment mylonite zone.

In the migmatite unit, field observations such as amphibolite boudins elongated parallel to lineation with abundant leucosome in interboudin regions indicate that deformation took place in the presence of melt. Across the Stowe Mtn subdome, isoclinal fold axes within the migmatite unit are oriented dominantly NW, parallel to lineation, with fold vergence direction dominantly NE on the NE flank and SW on the SW flank. These folds cascade down from the axis of the elongate subdome and emphasize a vertical flow component within the migmatite unit. Over a few hundred meters of structural thickness in the transition zone, rocks recognized as the migmatite unit but deformed in the solid state show a dramatic change in fold orientation and vergence direction. Hinges trend N-NE, fold the migmatitic lineation, and verge uniformly to the W-NW. Open asymmetric folds in the vicinity of the migmatite unit tighten progressively upward into isoclinal folds at the top of the transition zone. The transition zone grades upward into the ~1.5 km thick mylonite zone. The nearly continuous section from migmatites to the detachment zone records consistent deformation in all units, preserving the coupling between upper crustal extension and a partially molten channel undergoing lateral and vertical flow.

SS04-04 **A STRUCTURAL APPROACH TO THE STUDY AND MAPPING OF PARTIALLY MELTED TERRANES WITH EMPHASIS ON FABRIC/MELT/TIMING RELATIONSHIPS: AN EXAMPLE FROM THE MONASHEE COMPLEX OF SOUTHEASTERN BRITISH COLUMBIA**

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High-grade metamorphic terranes are almost ubiquitously associated with high strain at deep structural levels of orogens. This attracts geologists of many flavours: petrologists, tectonisist and structural geologists, among others. Many are concerned with the role of high-grade anatectic terranes in a specific orogen or orogenesis generally. Scientific approaches to assess this role vary widely. Our approach has been one of detailed mapping of geometry and lithological and mineralogical relationships at a variety of scales.

In this contribution, we address the question posed by the organizers: How can the mapping of deep-crustal, anatectic-terranes be improved to enable useful detail within weak layers to be identified? We suggest that basic structural mapping with emphasis on the relationships between various fabric elements is essential to understanding the role of partially-melted, deep, continental crust in orogens. Specifically, it is necessary to establish a deformational history to which other features can be related, to understand the relationship between fabrics and melt, and to constrain 3D geometry and kinematic interpretations. This groundwork is essential to deciphering 'useful detail'. It ensures more realistic answers to questions such as how much melt is present at any given time (?); how much melt does it take to make a weak layer (?) and are anatectic terranes weak?

Though this approach is not 'the crystal ball' of studying partially melted deep continental crust, we believe it is a necessary first step and one that should be revisited regularly.

We use the Mt. Thor – Mt. Odin area of the Monashee complex of southern BC as an example of an area, in which, this approach has yielded interesting and useful detail. It can be demonstrated that much of the melt present in the deep structural levels of the region predates the orogen. It is also demonstrable that the majority of apparent melt in the rocks predates late stage doming, suggesting that diapirism is not a significant factor contributing to large-scale geometry of the region. Further, the 3D geometry of the area suggests that large-scale structure was likely produced in a crustal-scale, non-coaxial, triclinic shear zone with a near horizontal shear plane coeval with the production of a granitic melt.

SS04-05 FIELD AND PETROLOGICAL OBSERVATION ON THE LOCATION OF MELT IN DEEP CRUSTAL ROCKS

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The presence of melt is one way of weakening the crust; the melt could be of anatectic origin, formed when layers of suitable composition partially melt, or it could be injected from a distant source. Migmatites are the best known example of regional-scale, melt-bearing rocks, and are characterized by the presence of leucosome arrays, typically linked, that represent the former channels that melt flowed along, or the places where it collected. Granulite facies migmatites provide a view of what the lower crust may look like. Petrological and geochemical studies show that most granulite terrains have depleted compositions resulting from the loss of between 30 and 60 % granitic melt. Significantly, leucosomes are not abundant (< 5 %) in many parts of these terrains, although the residual rocks do contain grain-scale microstructures that indicate a few percent melt existed along the grain boundaries and along the foliation planes. This suggests that such rocks never contained a large melt fraction, and that the melt was continually drained from then during partial melting. Consequently, rock rheology was maintained, but layers may have been weakened by enhanced diffusion through the film of melt located on the grain boundaries. These layers were not magmas and, therefore, very weak. Where did the partial melt go, and could it make very weak layers? Many orogenic belts contain plutons emplaced at depths of 10 to 15 km, the level at which a weak layer exists now in the Himalaya. During partial melting, the melt first migrates along the layers by porous flow, then flows within the layer in channels, it finally leaves its source layer along discordant dykes, or shear zones. Some deep, high-grade terrains contain levels where anatectic melt did accumulate; typically these are structurally controlled, but melt can also collect beneath infertile, competent barrier layers. Regions of melt/magma accumulation can be laterally very extensive and create very weak layers in the deep crust. They are also petrogenetically important; the anatectic magma collected there begins to crystallize and leaves a plagioclase-rich cumulate behind and produces a fractionated granite magma that feeds higher-level plutons.

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SS04-P01 **THE MORPHOLOGY OF MIGMATITES AS A FUNCTION OF MELT FRACTION AND SYN-MIGMATIZATION STRAIN: A NEW CLASSIFICATION AND AID TO MAPPING**

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The Mehnert nomenclature for migmatites was intended to be non-genetic, but a survey of the literature from the past two decades shows that almost all of the morphologies it describes for migmatites are exclusive to anatectic rocks. Recent work indicates that subsolidus segregations do not grow during migmatization but formed earlier at low and medium grade. It is implicit in many recent papers that their authors regard migmatites as formed only by partial melting. Consequently, a non-genetic terminology is nolonger useful and one that recognises migmatites rocks formed by partial melting, i.e. anatexis is now essential.

All migmatite (regional or contact) terrains that have reached temperatures of biotite dehydration melting contain two basic morphological types. At lower grades the migmatites retain their pre-migmatization structures, but in the higher grades the pre-migmatization structures are destroyed. This first order division is a function of melt fraction (not degree of melting) in the migmatite. In most terrains the passage from metatexite to diatexite morphology is abrupt, suggesting threshold behaviour. The change from metatexite to diatexite occurs at a melt fraction of about 0.25. However, in some terrains there is a zone transitional morphology between metatexite and diatexite migmatites. Second order morphological variation in migmatites is due to the effects of strain, particularly how strain was accomodated, during partial melting. Partial melting in very low strain environments produces patch metatexite migmatites at low degrees of partial melting and nebulitic diatexite migmatites at high. Within metatexite migmatites there is a progression from patch to dilatant to net to stromatic morphology with increasing strain and on how the protolith responds to strain; at high strains all metatexite migmatites become attenuated and develop stromatic morphologies. For diatexites migmatites melt fraction controls the basic morphology and strain the degree to, or intensity with, which planar flow structures are formed. The prefixes schollen and schleric are added to diatexite for those with the high and intermediate proportions of palaeosome respectively. No prefix is required for diatexites with the least palaeosome.

Migmatites with vein, folded or layer-confined morphologies are outside of this classification because their origin depends on other factors, not necessarily related to melt fraction.

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SS04-P02 **CUMULONIMBUS STRUCTURE: DESCRIPTION, MECHANISM OF FORMATION AND GEOLOGICAL SIGNIFICANCE**

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A structure observed in migmatitic gneiss at the boundary of two lithological layers is characterized by a granitic melt that has an aspect resembling Cumulonimbus clouds. Mafic and felsic components are well differentiated on a millimeter to centimeter scale within the mafic host, which easily facilitates identification. The structure is at the boundary of two units, occurs periodically, and commonly has a broad base, tapering away from the base of the structure to form a, generally, wedged shaped feature. In other specimens the structure continues across the host layer until both sides of the host layer are bridged by leucosome. In well-developed specimens, this feature produces a new layering that is at a high angle to the original lithological layering.

We consider this structure to be the result of fracturing of a competent layer adjacent to a second, less competent layer, in the presence of a granitic melt. This happens at metamorphic conditions that are consistent with continued anatexis. Locally, shear along the boundary of two units of contrasting competency causes the more competent layer to produce fractures or microfractures into which localized granitic melt flows. Continuing to open the fractures, possibly assisted by the melt, through corrosive action at fracture tips, cause further dilatency and further differentiation of melt and restite. This process may occur to varying degrees at different places along the boundary but continues as long as anatectic reactions produce melt and dilatent sites are propogated. The process is arrested when either of these requirements is not met or changes in the deformation path results in the deformation and destruction of the structures.

Cumulonimbus structure, and the process of its formation, are important to structural work in migmatitic rocks: It is a structure that indicates crustal anatexis; it postdates the ductile fabrics developed in the host gneiss; a new foliation is formed locally that is at a high angle to the lithological layering; it indicates the synchronous processes of fracturing and melt migration at high grade metamorphic conditions.

SS-05

High-strain Zones: from Structural Analysis and Theoretical Modeling to Tectonic and Economic Significance

Zones de roches fortement déformées : des analyses structurales et des modélisations à leurs implications tectoniques et économiques

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SS05-01 HIGH STRAIN ZONES: SOME OUTSTANDING PROBLEMS

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Deformation in high strain zones can be partitioned into a pure shear component orthogonal with the zone boundaries and a simple shear component parallel to the zone boundaries, in a direction that may or may not be parallel to one of the ISA of the pure shear component. The pure shear component has been invoked to explain steeply plunging “stretching” lineations in transpressive shear zones. However, it is likely that if confined to the zone, the pure shear component is generally too small to explain the observed obliquity of lineation and shear direction. The reason being that to maintain strain compatibility, the pure shear component must result in extrusion, which, to be mechanically feasible, is generally too limited to explain the observed strain magnitudes. Possible explanations of the obliquity include: (1) the pure shear component affects more than the zone, (2) the lineation does not represent the principal stretching direction, and (3) there is grain scale partitioning.

Research on high strain zones has largely concentrated on zones with a major transcurrent component. However, similar kinematics and magnitudes of strain seem to be the norm in rocks of amphibolite facies and higher, where evidence suggests that the shear plane was horizontal or shallowly dipping. A major difference between the two, is that the lineation is generally interpreted as parallel to the shear direction in the shallowly dipping zones, but approximately perpendicular to the shear direction in many transcurrent zones. In both situations, lineation-parallel sheath folds may be observed, leading to the following questions: How does this bear on the lineation problem? Are vertically plunging sheath folds possible in transcurrent zones or are the folds compelling evidence of dip-slip?

The commonplace re-activation of high strain zones leads to problems of analysis. Classical methods of structural analysis are inadequate, but no better alternatives have been proposed. Analysis of zones with definable boundaries is dificult, but in high grade rocks with similar kinematics, a general lack of recognisable boundaries greatly exacerbates the problem.

Many high strain zones are strongly curved and it is commonly assumed that that was their geometry at the time of development. It is suggested here that this is only possible if the zone is curviplanar, or the country rock undergoes considerable concomitant deformation. Alternatively it is possibile that curvature is due to later deformation affecting both high strain zone and the country rock.

SS05-02

STRETCHING LINEATIONS IN TRANSPRESSIONAL ZONES: THEORETICAL PREDICTIONS BASED ON ZONES WITH MIGRATING BOUNDARIES AND NATURAL OBSERVATIONS

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Studies of natural transpressional zones have shown repeatedly that foliations in these zones generally define simple and similar patterns but lineations are more variable. While triclinic deformation paths can account for some lineation patterns that are unexplained by monoclinic models, I show in this study that the whole spectrum of lineation patterns so far reported can be explained once the migration of zone boundaries through material during deformation is considered.

A transpressional motion cannot be sustained (unless the convergence direction is almost parallel to the zone) if the zone boundaries are fixed to material planes because the boundary-normal convergence between the bounding blocks acts to reduce the thickness of the deforming zone causing the pure shear strain rate in it to increase to implausibly high values soon after the onset of transpression. Conversely, if the pure shear strain rate in the zone is to be roughly constant the convergence velocity between bounding blocks must decrease to zero shortly. To sustain the transpressional motion, "widening", the migration of the zone boundaries through rock materials into wall rocks must be significant to counteract the convergence-induced zone "thinning" so that the deforming zone can maintain an approximately constant thickness. The evolution of finite strain field in transpressional zones under such boundary conditions is investigated by theoretical modeling. Although a very simple model conceptually, various finite strain geometries and geological complexity are predicted by it. Assuming that lineations and poles to foliations represent principal strain axes, the model explains why lineation patterns can be so variable among natural transpressional zones while the foliations define simple and similar patterns. The applicability of the model to natural transpressional zones and some general problems regarding forward modeling are discussed.

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SS05-03 **DEFORMATION-PATH PARTITIONING VS. SLIP PARTITIONING AND THE IMPORTANCE OF DIFFERENTIATING STRETCHING LINEATION FROM DUCTILE SLICKENSIDE STRIATION IN HIGH-STRAIN ZONES**

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Deformation-path partitioning and slip partitioning are two very different concepts and processes. Deformation-path partitioning refers to variation in simple shear/pure shear ratio across a high-strain zone, whereas slip partitioning refers to variation in strike slip/dip slip ratio across a high-strain zone or among different but kinematically-related high-strain zones. It is very important to differentiate the two processes in structural and tectonic interpretation of high-strain zones. In this respect, it is very useful to distinguish stretching lineations from ductile slickenside striations in field mapping. By definition, the stretching lineation is parallel to the maximum principal strain axis, whereas the striation is parallel to the shear direction. Although it is now widely accepted that the orientations of these two types of lineations can differ significantly in an individual high-strain zone of general shear, the two are not always differentiated in field mapping, either due to the difficulty in doing so and/or a lack of understanding of the importance of doing so. This presentation will (1) review the concepts of deformation-path partitioning and slip partitioning, (2) discuss how to differentiate stretching lineations from ductile striations in the field, and (3) review the possible causes for variation in plunge of stretching lineations and/or striations across a high-strain zone, using natural examples from various parts of the world. Variation in plunge of striations across a high-strain zone indicates slip-partitioning and that of a stretching lineation can be due to deformation-path partitioning and/or slip partitioning. Non-steady state deformation can also lead to such a variation.

SS05-04 ‘Flow Apophyses’ and fabric development in deforming rocks

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‘Flow apophyses’ have become a popular concept when describing strain in shear zones; they are presented as a graphic illustration of non-coaxial flow of rocks, and more generally of flow with internal vorticity. This communications will first review the related – but not coincident – concepts of internal vorticity and of shear sense indicators. Then, with examples limited to plane strain deformation, it will argue that for a finite strain such that its final axial ratio is less than approximately 3 (i.e. a ‘significant’ but not a very large strain), the fabric of a rock is unlikely to ‘know’, i.e. to record the difference between coaxial and non-coaxial strain. In other words, no shear sense indicators would be found if the rock had been initially isotropic. Flow apophyses are graphic illustrations of only one class of finite strain, a class that we may label as ‘constant strain’ and that can be described by a strain rate matrix with fixed component values. It will be suggested that, except for the limiting case of progressive simple shear, no ‘machine’ is likely to be found, either in a laboratory or in nature, that could apply a ‘significant’ finite strain described by such a constant strain-rate matrix over a domain of significant size. And a ‘machine’ that could apply a constant strain in 3 dimensions, when material is allowed to escape upward (transpression) or to lose volume, is even more difficult to conceive. Consequently, whenever a history of non-coaxial strain is documented in a rock, that progressive strain is extremely unlikely to be describable by a strain rate matrix with constant components. It is concluded that a finite ‘constant strain’ history, and the apophyses that come with it, have no realistic meaning in rocks. Trying to determine such a ‘constant strain’ from rocks in a shear zone is not a useful exercise.

SS05-05 **MONOCLINIC S/Z FOLDS AS SHEAR-SENSE INDICATORS WITHIN MAJOR HIGH-STRAIN ZONES**

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Many cylindrical buckle folds, also called active folds, have monoclinic symmetry and S/Z style. Such style is held to be generally indicative of the sense of local shear strain parallel to the fold-enveloping surfaces. Similarly, monoclinic sheath folds, thought to be invariably passive, have been widely used as indicators of shear-strain sense. It is not always realized, however, that the use of monoclinic S/Z folds is problematic unless (i) the mirror plane is perpendicular to a principal direction of fold-forming strain and (ii) the folds had orthorhombic symmetry at one stage of their growth. Condition (i) relates to the evolution of monoclinic folds, during general progressive deformation, and the associated strain-induced rotation of a family of unmarked oblique surfaces that parallels the mirror plane at the end of folding. Experimental results suggest that condition (ii) is satisfied for most buckle folds, but not necessarily for passive cylindrical folds and monoclinic sheath folds.

Precambrian shields and crystalline cores of modern mountain belts contain major (> 10 km long) high-strain zones that are replete with monoclinic S/Z folds in the gneissic or mylonitic layering. Geologists may wish to use these S/Z folds in determining the sense of shear strain parallel to the border surfaces of the high-strain zones, at least for the deformation increment responsible for the S/Z geometry. Suppose that conditions (i, ii) are actually satisfied, throughout major high-strain zones, but that the enveloping surfaces of the final S/Z folds are everywhere oblique to the border surfaces. Folding experiments illustrate that obliquity angles of a few degrees can be sufficient to cause a reversal in the sense of instantaneous and/or cumulative shear strain between coplanar borders and the fold-enveloping surfaces. The position and attitude of the border surfaces are difficult to estimate in practice, but many high-strain zones contain a deformed lithotectonic boundary (distorted thrust fault, stretched unconformity or major intrusive contact) that parallels the border surfaces. The lithotectonic boundary and parallel gneissic layering of the wall rocks may be thrown into S/Z folds whose enveloping surfaces are effectively parallel, on the kilometer scale, to the border surfaces of the high-strain zone. This holds true, for example, in the major high-strain zone that contains the deformed boundary between the Shawanaga and Parry Sound domains, Georgian Bay region, southwestern Grenville Province.

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SS05-06 LARGE-SCALE FOLD GEOMETRY AND FOLDING MECHANISMS FROM THE THOR-ODIN CULMINATION, MONASHEE COMPLEX, SOUTHEASTERN BRITISH COLUMBIA

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The Monashee complex in southeastern British Columbia is a transposed, amphibolite facies, structural culmination. The Thor-Odin dome is the southern of two subsidiary culminations, which comprise the Monashee complex. Isoclinal folding and transposition of stratigraphy suggests that the Monashee complex has undergone extensive high-strain deformation.

Detailed structural mapping in the northeastern quadrant of Thor-Odin, revealed large-scale fold overprinting relationships. Two early formed (f_1/f_2) isoclinal nappes are overprinted by obliquely oriented kilometre-scale, inclined f3 folds of regular wavelength, but varying tightness. Finally, large scale warping completes formation of the culmination. Meso-scale fold overprinting relationship mirrors the large-scale geometry. Folds tend to be asymmetric, have heterogeneously distributed parasitic folding and consistent vergence.

Transposition of stratigraphy is heterogeneous throughout the map area. Domains of regular stratigraphy and irregular stratigraphy are juxtaposed on a kilometre scale. Domain boundaries coincide with fold axial planes.

The association of $f_1/f_2/f_3$ folds with their characteristic style and heterogeneous transposition domains is interpreted to be the result of a progressive non-coaxial deformation history. In this model, folds were continuously produced, tightened, overturned and reoriented. Passage of the overturned limb through the shortening field of the non-coaxial flow resulted in preferential development of parasitic folds on that limb. This irregular distribution of parasitic folds is responsible for the heterogeneity of transposition.

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SS05-07 STRAIN FEATURES AND DEFORMATION MECHANISMS IN SYN-SEDIMENTARY HIGH-STRAIN ZONES

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A high-strain zone may be defined as a tabular to sheet-like, planar or curviplanar zone containing rocks that are more highly strained than rocks adjacent to the zone. Bedding-parallel syn-sedimentary high-strain zones in the unmetamorphosed, Tournaisian-age Albert Formation of New Brunswick display some analogous features to high-strain zones resulting from post-lithification deformation at higher metamorphic grades. The deformation zones consist of folded, faulted, brecciated and boudinaged sandstone, siltstone and shale in tabular zones both overlain and underlain by undeformed strata. Scours and erosional contacts at the base of some, and sand volcanoes and truncated folds at the top of other deformed beds, are further evidence that the deformation in the units is syn-sedimentary. Stereoplots of fold orientations from several of the deformed units show that fold plunges are subhorizontal and trend north-north-east or south-south-west, while axial planes plot on a great circle girdle. This pattern is thought to result from the slumping of Albert Formation sediment down east-south-east- or west-north-west-dipping slopes. Another deformed unit, possibly also slumped, contains brecciated mudstone and has sand volcanoes on its upper surface. This indicates that the sediment was susceptible to dewatering, possibly in association with slumping, or after liquidization.

The pattern of deformation in the slumps is complex, with tight to isoclinal folds, refolded folds and thrust faults all present. The slumps may be highly coherent, or may be chaotic, containing detached fold hinges and isolated knockers of siltstone and sandstone in a shale matrix. In many cases the slumps decrease in coherence from base to top. There are also significant lateral variations in fold complexity and thickness of slumps. Some of the slump units contain unusual boudin-like features. These features are up to 0.2 meters across, and at least several metres long, with their long direction parallel to the orientation of fold hinges in the slumps. They are composed of red siltstone or mudstone, and have a variety of cross-sectional shapes, including round, elliptical, aerofoil-shaped and complex examples. Polished slabs cut perpendicular to the long direction of the features show complex internal folding, including sheath folds parallel to the long axis of the boudins, while slabs cut parallel to the long direction show a planar lamination cut by cm-scale normal faults. These boudin-like features seem to have formed through detachment of fold hinges during slumping, followed by rolling and shearing of the detached hinges during continued slumping and compaction.

SS05-08 **DIFFERENT STYLES AND AGES OF DEFORMATION IN THE CABOT FAULT ZONE OF WESTERN NEWFOUNDLAND**

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The Cabot Fault Zone (CFZ) in western Newfoundland is a long-lived (> 150 million years) crustal-scale structure that separates the Laurentian margin (Humber Zone) from peri-Laurentian terrains (western Dunnage Zone). Three different styles of deformation have been identified in the CFZ. These are summarized below, together with data from on-going isotope geochronology.

(1) Locally in the Dashwoods Subzone along the trace of the CFZ, strongly deformed amphibolite facies tectonites have been observed. Deformation is characterized by a gneissic foliation, asymmetrical folds, and late to post-tectonic pegmatite veins, but kinematic indicators associated with NE striking foliations and predominantly down-dip lineations are ambiguous. The protolith of these tectonites is interpreted to be meta-sedimentary based on the presence of marble and conglomerate layers. The timing of this dynamothermal event is Late Ordovician, based on the presence of a ca. 456 Ma late-syntectonic pegmatite dyke (U-Pb on Zircon) and a ca. 461 Ma metamorphic age (U-Pb on Monazite) from a meta-granite. This event is contemporaneous with the west-directed emplacement of large allochtons onto the Humber Zone of the Newfoundland and Québec Appalachians.

(2) A penetrative greenschist facies deformation along the trace of the CFZ has affected rock units of both tectono-stratigraphic zones and most importantly it truncates the meta-sedimentary thrust stack in the internal Humber Zone. The mylonitic foliations are consistently NNE striking and lineations are shallowly (S) SW plunging. Kinematic indicators associated with these mylonites show a predominantly normal-dextral movement, suggesting that the Humber Zone moved up and northward with respect to the western Dunnage Zone. Early Devonian (418 – 417 Ma) 40Ar/39Ar Hbl and Mus cooling ages from within the CFZ postdate those from within the internal Humber Zone (437 – 424 Ma), suggesting that ductile deformation had largely ceased by the start of the Devonian period.

(3) High crustal level brittle faults and cataclasite zones are spatially associated with the greenschist mylonites of the CFZ. At the eastern margin of the Carboniferous Anguille Basin, steeply WNW dipping siliciclastic beds, large brittle normal faults and associated slickensides with down-slip striations, and minor strike-slip fractures indicate that the basin is extensional in nature.

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SS05-09 NEW U-PB AND ^{40}AR/^{39}AR TIMING CONSTRAINTS ON THE DUCTILE DEFORMATION OF THE SUDBURY IGNEOUS COMPLEX

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The present elliptical outcrop pattern of the 1850 Ma Sudbury Igneous Complex (SIC) is partially the result of NW-SE directed shortening along the ductile-brittle reverse-sense South Range Shear Zone (SRSZ). Higher order splays off of the SRSZ occur along the length of the South Range footwall contact of the SIC. Structural mapping and sampling for geochronology was conducted at the Thayer Lindsley Mine where these shear zones overprint the South Range norite of the SIC.

Syn-kinematic metamorphic mineral assemblages within these shear zones at TL mine include magnesio-hornblende, actinolitic hornblende, plagioclase, quartz, and epidote within moderately strained norite; and biotite, quartz, and epidote (±chlorite) within intensely strained norite. These assemblages, along with an abundance of kinematic indicators are consistent with deformation occurring during a single episode of reverse sense ductile shear that initiated at amphibolite facies metamorphism and remained active through to retrograde greenschist facies conditions.

Six titanite samples were collected for U-Pb dating and four biotite samples were collected for ^{40}Ar/^{39}Ar dating. In thin section, two phases of titanite crystals are surrounded by metamict haloes within syn-kinematic biotite crystals. Brown titanite crystals are least common and are usually mantled by overgrowths of clear titanite, which also form separate grains. Brown titanite crystals (n=2), containing U concentrations >30ppm and Th:U >0.5, yield an upper intercept age of 1798±21 Ma and a mean ^{207}Pb/^{206}Pb age of 1815±15 Ma. Clear titanite crystals (n=4), containing U concentrations <30 ppm and Th:U ratios <0.5, yield a mean ^{206}Pb/^{238}U age of 1600±100. Syn-kinematic biotite crystals (n=4) yield plateau ages consistent with cooling through closure (300-350°C) at 1477±8 Ma.

These data constrain the timing of deformation between 1700-1470 Ma. Although the South Range shear zones have been previously interpreted as ca. 1.8 Ga Penokean orogenic structures, this range in ages suggest that the shear zones are not Penokean in age. The shear zones may have formed during regional K-metasomatic and magmatic event that affected the Southern Province ca. 1700-1750 Ma ago. However, this event correlates with “anorogenic” granite and anorthosite magmatism in the Southern Lake Superior area, USA. Alternatively, the shear zones may have formed during the Pinwarian Orogeny, ca. 1400-1500 Ma episode of Andean Style convergent tectonics that extends along the SE margin of Laurentia from Labrador to New Mexico.

SS05-10 **Tectonic significance of geochronological and thermochronological constraints from the Walker Lake area, Committee Bay belt, Nunavut**

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SS05-11 **THE ASSEAN LAKE AND AIKEN RIVER DEFORMATION ZONES OF THE SUPERIOR BOUNDARY ZONE, NORTHERN MANITOBA**

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The Superior Boundary Zone, which separates the Archean Pikwitonei Granulite Domain (PGD) of the Superior Province to the southeast from the Paleoproterozoic Kisseynew Domain of the Trans-Hudson Orogen to the northwest. The Split Lake Block (SLB) is part of the PGD and is bounded by the Assean Lake and Aiken River deformation zones to the north and to the south, respectively.

The Assean Lake deformation zone was initially interpreted as being the Paleoproterozoic contact between the PGD and the Kisseynew Domain. Recent discovery of Mesoarchean (pre-3.0 Ga) crustal material north of the Assean Lake deformation zone, in the Assean Lake Crustal Complex (ALCC), however, indicates that the contact between Archean and Paleoproterozoic rocks lies further to the northwest. The Assean Lake deformation zone may be an older (Archean?) suture zone between the SLB and the ALCC.

Metamorphism reached granulite facies in the SLB and amphibolite facies in the ALCC. Metamorphism in the PGD reached granulite facies, except for the northern edge where only amphibolite-facies conditions were recognized. All three domains plus the Assean Lake and Aiken River deformation zones experienced retrograde greenschist-facies conditions.

The Assean Lake deformation zone records at least one generation of tight to isoclinal folding, including south-side-up sheath folding. Shear movement was south-side-up and dextral. The Aiken River deformation zone displays two generations of tight to isoclinal folding, followed by close to open east-trending folding and subsequent open north-trending folding. Shear movement was north-side-up and dextral.

Dextral, south-side-up shear on the Assean Lake deformation zone and dextral, north-side-up movement on the Aiken River deformation zone may have caused uplift of the SLB. Uplift would result in exposure of deeper structural levels, and therefore exposure of rocks with higher metamorphic grades, in the SLB. This is consistent with exposure of rocks that underwent granulite-facies metamorphism in the SLB and of amphibolite-facies rocks in the ALCC and at the northern edge of the PGD.

SS05-12

STRUCTURE OF THE WABIGOON – WINNIPEG RIVER SUBPROVINCE BOUNDARY IN THE KENORA AREA, CANADA

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The boundary between the metavolcanics-dominated Wabigoon and the granite-dominated Winnipeg River subprovinces has been studied in detail along eight transects. Quartz fabric studies, using the Rotating Polarizing Stage, supplement these observations.

As currently observed, this boundary is an intrusive contact between late felsic plutons and mostly mafic metavolcanics. In seven of the transects, the contact is affected by a still later, and relatively small, shear of variable intensity, dominantly north-side-up with a lesser dextral component.

The late processes recorded in this study overprint any evidence of the primary origin of this boundary. This study thus does not give any argument in support of any one of the competing models of Archean tectonics. In particular, the late shear along the boundary is not related to any accretionary origin of that boundary.

SS05-13 **GOLD MINERALIZATION DURING REGIONAL DEXTRAL TRANSPRESSION IN THE BEARDMORE-GERALDTON BELT, WABIGOON SUBPROVINCE, ONTARIO**

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The Beardmore-Geraldton Belt occurs along the southern margin of the Archean Wabigoon Subprovince, Superior Province, Ontario. The belt consists of interleaved metasedimentary and metavolcanic rock panels bounded by shear zones. The panels were imbricated from 2696 Ma to 2691 Ma during D_1 thrusting and accretion of the Wabigoon, Quetico, and Wawa subprovinces. Post-accretion D_2 deformation produced regional F_2 folds that transposed lithological units parallel to the axial plane S_2 cleavage of the folds. During D_3, the folds were overprinted by Z-shaped F_3 folds and by a regional S_3 cleavage oriented anticlockwise of F_2 axial planes. Lithological contacts and S_2 were reactivated as planes of shear within dextral regional shear zones that generally conform to the trend of the belt. The shear zones, the regional S_3 cleavage, and Z-shaped F_3 folds formed during a regional dextral transpression event that also affected the Quetico and Wawa subprovinces, south of the Beardmore-Geraldton Belt.

The Beardmore-Geraldton Belt has historically produced over 4 million ounces of gold. The Leitch and MacLeod-Cockshutt mines are the two richest past-producing gold mines in the Beardmore-Geraldton Belt. The MacLeod-Cockshutt Mine has an epigenetic iron formation-hosted style of gold mineralization. Gold is in magnetite-rich iron formation horizons that were replaced by massive pyrite and arsenopyrite lenses, bordering < 1 m thick quartz veins. The quartz veins and sulfide lenses occupy near-bedding parallel D_3 faults and shear zones that cut through the hinges and limbs of property scale F_3 and F_2 folds. At the Leitch Mine, gold is associated with folded quartz veins and D_3 shear-hosted quartz veins that can be traced over 1.2 km along strike. The veins occur within the hinge area of a property scale F_3 fold, which is defined by folded metaturbiditic sandstone and hematite-jasper iron formation. All auriferous quartz veins are hosted within metaturbiditic sandstone, indicating that the hematite-jasper iron formation did not act as a physical or chemical trap for gold mineralization. The plunge of ore zones at the Leitch and MacLeod-Cockshutt mines is parallel to F_3 fold axes and to the intersection of D_3 shear zones with either F_2 or F_3 folds. Thus, gold mineralization in the Beardmore-Geraldton Belt is directly controlled by structures that formed during post-2691 Ma regional dextral transpression across the belt. Mineral exploration programs in the belt are now focusing on regional and second-order D_3 shear zones along the contact between metavolcanic and metasedimentary units.

SS-06

GROUNDWATER RESOURCES I: REGIONAL HYDROGEOLOGY IN SOUTHERN ONTARIO

RESSOURCES HYDRIQUES SOUTERRAINES I : L'HYDROGÉOLOGIE RÉGIONALE DANS LE SUD DE L'ONTARIO

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SS06-01 **AN OVERVIEW OF THE PALEOZOIC GEOLOGY OF SOUTHERN ONTARIO AS CONTEXT FOR UNDERSTANDING REGIONAL BEDROCK GROUNDWATER RESOURCES**

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The Paleozoic bedrock succession of southern Ontario consists a variety of sedimentary rock types ranging from Cambrian to Mississippian in age. Key structural features which affected sedimentation in this region were the Michigan Basin, a carbonate-dominated intracratonic basin, centered to the west of Ontario and the Appalachian Basin, a siliciclastic-dominated foreland basin, located to the south and east. The southwestern Ontario peninsula straddles a broad NE-SW oriented basement high, the Algonquin Arch, situated between these 2 basins. The NW-SE oriented Frontenac Arch separates the Paleozoic strata of south-central Ontario from those of the Ottawa Embayment in eastern Ontario. The Paleozoic bedrock succession reflects the complex interplay of regional tectonic forces which caused vertical (and sometimes lateral) movements of these structural elements (e.g., basin subsidence and arch uplift), sedimentation associated with orogenic activity, and eustatic sea level fluctuations.

The Ottawa Embayment is cut by numerous high-angle faults of post-Ordovician (probably Cretaceous) age, although some researchers have suggested faulting may have also occurred during the Cambrian and Ordovician. Vertical displacements of up to 1000 m are reported for some faults in eastern Ontario. Faulting is less prevalent and intensive in the rest of southern Ontario. A few large faults with displacements of up to 100 m have been documented affecting strata as young as Silurian and possibly Devonian in the subsurface of southwestern Ontario. Numerous smaller scale faults are also known there and appear to be confined mainly to Cambrian and Ordovician strata and the underlying Precambrian basement. An extensive network of fractures and faults has been interpreted for the whole of the Paleozoic succession of southern Ontario. Faults and fractures acted as conduits for fluids responsible for dolomitizing carbonate strata and dissolving salt-bearing strata.

Paleozoic bedrock units of hydrogeological significance include the Cambrian and Ordovician siliciclastic and carbonate units of eastern Ontario, Ordovician carbonates of south-central Ontario and Silurian and Devonian carbonates of southwestern Ontario. In southern and southwestern Ontario petroleum wells which penetrate the Paleozoic strata frequently encounter water-bearing zones within the Devonian Dundee, Lucas and Amherstburg formations, the Silurian Bass Islands and Guelph formations, and Cambrian sandstones. These formation waters are highly mineralized, salty and sulfurous. Although the groundwater resource potential of bedrock units may initially be dependant on their primary and secondary porosity, the development and degree of fracturing appears to be more significant in terms of attaining high yields.

SS06-02

THE QUATERNARY GEOLOGY OF SOUTHERN ONTARIO: AN OVERVIEW AND IMPLICATIONS FOR GROUNDWATER RESOURCES

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A significant percentage of southern Ontario's population relies on groundwater for their supplies of potable water. Much of this groundwater is derived from aquifers situated within the surficial materials that were deposited largely by the glaciations that affected southern Ontario during the Quaternary Period. By understanding the glacial record and regional distribution and types of sediments deposited a better understanding of the physical characteristics of southern Ontario's aquifers can be developed.

The surficial sediments of southern Ontario lie on bedrock of Precambrian and Paleozoic age. Prior to the Quaternary, the bedrock surface was subjected to an extensive period of subaerial exposure and weathering. A series of erosional escarpments developed on the bedrock surface as did a number of river systems. The location and extent of the river channels is poorly understood as they were destroyed or buried by thick successions of sediment during glaciation. From a groundwater perspective some of these channels may provide favourable settings to host aquifers.

The multiple advances of the glaciers across southern Ontario deposited numerous till sheets. The broad topographic depressions of the Great Lakes basins influenced the direction of ice flow as glacial ice initially followed topographic lows and radiated outward at their distal ends creating a lobate margin. As the ice thickened more regional flow patterns developed. During deglaciation, ice flow was again controlled by topography and lobate ice margins developed. Tills deposited by lobate ice have distinct properties that reflect bedrock types, as well as underlying sediments within and up glacier of each particular basin. In the interbasin areas of southern Ontario, a complex stratigraphy developed as a result of oscillating ice lobe margins.

The melting of glaciers that occupied southern Ontario also generated large volumes of meltwater. This meltwater carried large amounts of sediment that were deposited as ice-contact features, glaciofluvial outwash, glaciolacustrine and glaciomarine deposits. Sediments deposited by meltwater are extensive and those of coarser texture and better-sorting serve as favourable aquifers.

By understanding the succession, regional distribution and characteristics of the deposits left behind by glaciation in southern Ontario a much better understanding of the regions aquifers and aquitards can be had. An improved knowledge of the provinces aquifers is critical for their wise use and protection.

SS06-03 GROUNDWATER IN SOUTHERN ONTARIO: A REVIEW AND UPDATE OF THE 1994 REPORT

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A review of the regional hydrogeology of southern Ontario as described in the 1994 Environment Canada report "Groundwater in Ontario: Hydrogeology, Quality Concerns, Management" is provided. Groundwater forms an important source of municipal, industrial, agricultural and residential water supply in southern Ontario. Groundwater is available from a number of extensive bedrock aquifers in the Great Lakes and the Ottawa/St. Lawrence Lowlands and from sand and gravel aquifers found within glacial deposits in most parts of the province. The major aquifer units are discussed in terms of occurrence, groundwater availability, yield and water quality. Groundwater quality is generally good in most aquifers in Ontario. However, many aquifers are poorly protected from near-surface contamination sources and as a result anthropogenic contamination has been found in several areas. An update of the locations of the hydrogeological investigations for groundwater protection strategies conducted since 1994 is provided. The history of groundwater protection in Ontario since 1994 and future directions for source protection are described.

SS06-04

LOCAL AND REGIONAL SOURCE PROTECTION IN ONTARIO: THE CONTRIBUTION OF THE PROVINCIAL GROUNDWATER STUDIES PROGRAM (1998-2004)

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Ontario is leading many jurisdictions with its support for community-based mapping of groundwater. The goal of the Provincial Groundwater Studies Program was to provide a sound technical basis for developing and implementing effective source protection strategies. The Provincial Groundwater Studies Program was first announced in August 1998 at an annual conference of muncipalities. Following direct mail-outs to all municipalities across Ontario and a screening process, a total 34 groundwater studies were approved with a Ministry funding commitment of $4.3 million dollars out of a total $6.6 million dollar investment.

In August, 2001 the Ministry of the Environment announced an additional $10 million in funding for groundwater studies, representing the largest single investment in groundwater source protection in the province's history. The Ministry of the Environment assessed priority candidates based readiness to commence work, groundwater dependency, previous studies, and groundwater
pressures.

In November 2001 the Ministry published Provincial Terms of Reference (TOR) for the studies. The TOR mandated project leadership by conservation authorities and regional municipalities and required steering committees with multi-stakeholder representation. Each study also required a plan for informing and involving the public.

The Provincial TOR prescribed the scope and methods to be applied for groundwater mapping. At the local scale, this includes municipal well capture zone delineation; an inventory of potential contaminant sources in identified capture zones; and analysis of potential pathways within identified capture zones through which contaminants could enter water supply sources. At the regional scale, studies were required to map groundwater recharge and discharge areas and classify areas as to their intrinsic susceptibility to contamination. Point sources of potential contamination were inventoried, as was groundwater use in the study area.

By March, 2002, an additional 31 studies received funding, based on adoption of a formal Resolution of Council to undertake the study, written confirmation of firm costs, and Ministry-approved Terms of Reference. In April, 2003, the Ministry announced a further investment of $5 million in 32 groundwater studies to address remaining study gaps. When all the studies are completed, approximately 95% of groundwater dependent communities in Ontario will have a common information base.

SS06-05

TOWARD ONTARIO'S GROUNDWATER MANAGEMENT – AMBIENT CHARACTERIZATION OF REGIONAL AQUIFERS IN SOUTHWESTERN AND CENTRAL ONTARIO

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Management of groundwater resources implies activities to understand and control three main characteristics: quantity, quality and protection. Recently, the Ministry of the Environment (MOE) has primarily focused on assessing future groundwater protection through local-scale GUDI, WHPA, and regional-scale aquifer delineation and vulnerability mapping studies. Groundwater quantity and quality have not been as adequately addressed. Responding to this need, a current MOE-funded groundwater study is attempting to improve our understanding of regional groundwater quality throughout Southwestern and Central Ontario.

The three primary objectives of this study include: 1) identification of potential groundwater quality data sources and their relative value; 2) coordination and assembly of data sources; and 3) demonstration of effective data analysis and mapping techniques.

Numerous levels of government, environmental organizations, institutions, and business associations have collected a wealth of water quality data over the past 40-50 years. This data represents an enormous investment of finances and can be useful in further understanding and managing groundwater resources at a regional scale. The resultant data represents a wealth of knowledge that is stored in disparate data systems. Unfortunately, this data is not well organized and is generally not available to decision-makers. This can result in expensive groundwater investigations that needlessly recollect existing data.

Recognizing the value of this information, the Ministry of the Environment is making efforts to harvest available data and instill a mechanism to capture new data as it is developed. Through the current study, Ontario has developed a water quality data model that is compatible with both the MOE's data standard (Environet) and the list of common water quality data elements defined by the USGS and USEPA. Future population of this standard data model will permit the exchange and combination of multiple water quality data sets to maximize understanding from available data.

Beyond the data itself, there is a need to develop standardized methodologies for the analysis and mapping of water quality data to provide groundwater stakeholders with a means of visualizing available water quality data and developing a better understanding of the state of water quality. Important aspects of the water quality mapping process include: filtering / scrubbing of available data to assess its value, assessing the scale appropriateness of various mapping techniques, dealing with multiple chemical constituents and extracting the implications for human consumption and other uses, and assessing spatial and temporal trends utilizing existing knowledge of the stratigraphy and groundwater flow system.

SS06-06

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INVESTIGATION OF KARST GEOLOGY AND IMPACTS ON GROUNDWATER QUALITY IN AN AGRICULTURAL AREA NEAR EXETER AND STAFFA IN HURON AND PERTH COUNTIES, ONTARIO

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Conservation Authorities, Municipalities, and the Ministry of Environment in Ontario have recently worked together to complete more than 65 regional groundwater studies to characterize aquifers and to evaluate groundwater resources in support of source water protection initiatives. In many cases, these regional studies identified conditions that require additional characterization at a local scale to assess potential groundwater management implications. Recent increased awareness of the linkages between surface water and groundwater, and sinkholes identified in Perth and Huron Counties during recent groundwater studies, provided the motivation for this study. The study included the development of a sinkhole information system, identification of the general extent of the karstic environment, drilling a long term monitoring well, evaluation of groundwater quality, assessment of potential sources of contamination and development of proposed draft policies for the protection of groundwater resources in the study area.

More than 50 sinkholes (within ~100 km^2) were identified during the sinkhole investigation and characterization study, primarily off the flanks of the Seaforth and Lucan Moraines. The land use of this area is intense agricultural, with cash crop farming and livestock operations. In many cases, surface runoff from agricultural lands drain directly to sinkholes, providing a link to the bedrock aquifer. Residents of the rural area and surrounding urban centres derive all of their water from groundwater sources.

Bedrock seldom outcrops in the study area, as it is buried beneath a thick layer of unconsolidated sediments. The bedrock geology and topography have been interpreted based on water well records and oil and gas wells that are completed in bedrock. A 100 m drop in bedrock groundwater levels was observed to coincide with the subcrop contact between the Dundee Formation and the underlying Lucas Formation. This anomalous drop in water levels corresponds to the area where sinkholes have been identified, and is currently understood as the upgradient limit defining the karstic environment. As described, the Devonian aged Dundee Formation is understood to be the uppermost bedrock unit, however groundwater levels reside in the older Lucas Formation, due to the large drop in groundwater levels associated with the karstic geology.

Sinkholes were identified in topographically low-lying areas that are covered with a thin veneer of glaciolacustrine sediments. Each cluster is located within a closed drainage system, which promotes the erosion and subsidence of overburden, the dissolution of the rock, and the subsequent surface expression of the sinkholes. Based on discussions with local landowners, sinkholes are not observed to be actively forming.

SS06-07 WATERSHED WATER BALANCE ANALYSIS AND MANAGEMENT

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Water quantity has become a major concern in many jurisdictions. The amount of water replenished on an annual and seasonal basis is critical to assessing the influence of the water taking process. The amount of water recharging a watershed must be understood from a watershed ecosystem perspective. The cumulative water taking from a watershed must be sustainable demonstrating little or no impact on the natural environment.

Durham Region has many rural communities that rely on groundwater resources for their fresh water supply. Existing permits and domestic water takings all contribute to the uptake of renewable water resources throughout the Region. Various watersheds experience different levels of stress due to these water takings. To manage water resources and assist in the permit to take water-issuing process, the amount of renewable water resources must be quantified.

This study developed a comprehensive approach to understanding the intricacies of a watershed's water balance from the following: (1) Natural Heritage Features and Function, (2) Fish Habitat, (3) Geology and Hydrogeology, (4) Climate, (5) Land Development, and (6) Water-taking.

Durham has 20 quaternary watersheds that lie within or intersect the municipal boundaries. The focus of this study was to determine the quantity of renewable groundwater resources for each watershed within the region. This would assist the region's planners in determining the amount of groundwater available for future water supply. Currently there is little information available that demonstrates the level of water usage compared to the amount of renewable groundwater resources available. This study has initiated the work necessary to determine the amount of renewable groundwater available, where that water is likely to occur, and the level of resource vulnerability.

The key to the hydrologic cycle in any terrestrial environment is the influx of water into the system. In this case the driving factor is the fraction of precipitation that infiltrates the ground surface and enters the groundwater system – known simply as recharge. In most environments the majority of the precipitation is lost through evapotranspiration, while the surplus is partitioned into surface run-off and infiltration. Climate (particularly temperature), surficial geology, vegetation and ground slope govern the relative amount contributed to evapotranspiration, run-off and infiltration. Water surplus calculations were completed using 38 climate stations distributed throughout the study area. Flow station data was crucial for determining the level of accuracy achieved with the surplus estimates and the renewable groundwater recharge calculations.

SS06-08 **AQUIFER CHARACTERIZATION AND SOURCE PROTECTION IN THE NORFOLK SAND PLAIN OF SOUTHWESTERN ONTARIO**

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Groundwater studies are being completed across the Province of Ontario to characterize aquifers and to delineate wellhead protection areas. In many cases, these studies are conducted at a watershed scale, crossing municipal government boundaries. These studies are providing the basis for recommended groundwater source protection and management strategies, best management practices, incentive programs, public education activities, and land-use planning policies. The Norfolk Municipal Groundwater Study was completed in May 2003 for Norfolk County, in partnership with the Long Point Region Conservation Authority, Haldimand-Norfolk Health Unit, and the Ontario Ministry of the Environment. The study area included the urban and rural areas of the 14 watersheds within the jurisdiction of the conservation authority, comprising a total area of about 2 900 sq. km. The Norfolk Sand Plain represents about 70 percent of the surficial Quaternary deposits across this area. Land use is predominantly agriculture, but also includes significant urban, wetland, and forested areas. One of the priorities identified in the final report was to develop municipal groundwater source protection policies. Such policies have implications for present and future land and groundwater use, in an area where the shallow sand and gravel aquifers are an important source of groundwater supplies. This paper highlights the results of the groundwater study, including aquifer characterization, groundwater susceptibility to contamination, and municipal wellhead protection areas, and outlines associated land use planning issues.

SS06-09 REGIONAL HYDROGEOLOGY STUDY OF THE QUINTE AREA, SOUTHEASTERN ONTARIO

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The Ontario Ministry of the Environment (MOE) is undertaking a series of regional groundwater mapping studies in Southern Ontario to assess the characteristics of the groundwater resource and the demands that are put upon it. Dillon Consulting undertook the regional groundwater study for the Quinte area in south-eastern Ontario, comprising the Counties of Prince Edward, Hastings and portions of Lennox and Addington. The study area spans the southern fringe of the Precambrian bedrock Frontenac Axis and is characterized by generally thin deposits of glacial drift over a bedrock aquifer. Fractured Precambrian igneous and metamorphic rocks form the aquifer in the north, while flat lying jointed Paleozoic limestones, shale and sandstones are the main source of potable water in the south. Overburden aquifers of local significance are present in some localities in the form of eskers, moraines, kames or glaciofluvial sands and gravels that have filled pre-glacial bedrock channels. The specific objectives of the hydrogeological investigation included: a) identifying regional aquifers and aquitards, b) mapping the direction and magnitude of groundwater flow, c) identifying areas of significant groundwater recharge and discharge, and d) mapping areas where the aquifer is most vulnerable to surface contamination. Assessment of these conditions was accomplished by the review of MOE water well records augmented by the analysis of other datasets including government geological mapping and reports, government water well records, MNR oil and gas records, and various provincial digital Geographic Information System (GIS) databases including topography and drainage. The challenge presented to the investigators was to develop an assessment approach that would recognize the limitations of each data source, but when used together, would provide a useable source of information to assess the regional hydrogeological regime.

SS06-10 MUNICIPAL GROUNDWATER STUDY, SIMCOE COUNTY, ONTARIO

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Dixon Hydrogeology and Golder Associates, in conjunction with project partners, conducted a municipal groundwater study of Simcoe County. The study area extended from Georgian Bay in the North to the north slope of the Oak Ridges Moraine, and comprised a wide range of Precambrian shield, Limestone Plain, and glaciated terrain providing a diverse geological and hydrogeological setting. The groundwater study involved an evaluation of geological conditions, an assessment of groundwater usage, an evaluation of the distribution of aquifers, contouring of regional groundwater levels and flow directions, a determination of aquifer vulnerability across the county, and an assessment of potential sources groundwater contamination. A regional scale correlation of the major aquifers was completed for the County.

The hydrogeological conditions and aquifer properties in Simcoe County were evaluated by completion of more than 70 municipal groundwater supply systems comprising more than 150 well head protection areas (WHPAs). The study identified four main aquifer units across the County, which are interpreted to be deposited in five main tunnel channels that cross the County. Channel aquifers are generally overlain by fine grained lacustrine deposits and recharge to the aquifers is derived from upland areas like the Oro Kame Moraine, Hillsdale uplands and Moonstone uplands. The distribution of the surficial aquifers and the recharge areas is of significance for future groundwater supply and aquifer protection within the County. Surface water drainage basins were identified and groundwater / surface water interaction was evaluated and incorporated into 3-D models.

Groundwater protection strategies have been developed for the protection of groundwater resources are being implemented at the Municipal and County level. In addition, the importance of upland recharge areas such as the Oro Kame Moraine and Moonstone uplands should be investgated further to determine their significance in source water protection strategies.

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3-D GEOLOGICAL MAPPING AND GROUNDWATER FLOW MODELING IN THE CITY OF PICKERING, ONTARIO; APPLICATION TO URBAN ENVIRONMENTAL ISSUES

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SS06-12 REGIONAL GROUNDWATER MODELLING OF THE OAK RIDGES MORAINE: AN INTEGRATED, DATA DRIVEN, GEOLOGY FOCUSSED APPROACH TO GROUNDWATER MODELLING

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The Oak Ridges Moraine has been a focus of intense hydrogeological analyses for the past two years. The project has been undertaken under the direction of a partnership of local government agencies (municipalities and conservation authorities) and has led to the development of an effective water management tool that is being used to assess the affects of land use changes (including water allocations) on the overall groundwater flow system.

The success of the modeling effort can be synthesized into four key strategic initiatives: (1)a focus on data; (2) the incorporation of geological interpretation (as well as hard data) into the geological analyses; (3) a strong emphasis on understanding the linkage between the groundwater and surface water systems; and (4) an effective blending of regional scale thinking with sufficient resolution and detail for local scale analyses.

The data model constructed for the project was designed to effectively accommodate all data required to adequately undertake water management on a watershed basis. This includes groundwater, surface water and climate data. A unique approach in building the data model involved the scanning of nearly 2,000 key reports as well as the digital photographing of all maps and sections tied to the reports. Ready access all of the data through a pass-worded web site, as well through appropriate software tools also proved critical.

Another key aspect of the project was a strong focus on understanding the geological processes and the depositional setting of the Quaternary deposits that make up the moraine. In addition to simply kriging hard geological data from well records to construct geological surfaces, an emphasis was placed on incorporating “expert knowledge” in the form of digitized interpretation lines into the kriging process. This ensured continuity of valley systems, and allowed for layer pinch-outs to be effectively represented.

The model, although regional in its geographical area (8,000 km^2), was developed on a 100 m mesh size. This ensured that a sufficient number of cells were present between headwater streams for a local groundwater flow systems to develop. Calibration of the model was partially tied to flux measurements taken in headwater streams in the form of low flow measurement surveys. This focus on stream systems allowed for these groundwater dependent, sensitive headwater streams to be evaluated against changes in land use or water allocation strategies.

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THE IMPACTS OF KARST TERRAIN ON SOURCE PROTECTION PLANNING ALONG THE NIAGARA ESCARPMENT IN SOUTHWESTERN ONTARIO

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One of the challenges in developing groundwater source protection programs for municipal supplies in Ontario is the calibration of groundwater models to delineate Wellhead Protection Areas (WHPAs). This requires integrating all geologic and hydrogeologic data in a GIS, which is used to assign model property values and boundary conditions. The Grey and Bruce Counties Groundwater Study, which was completed in July 2003, included the development of 22 MODFLOW models for WHPA delineation. The WHPA results were integrated with an Intrinsic Susceptiblity (ISI) analysis of the uppermost significant aquifer as a basis for developing a Municipal Action Plan for groundwater resource protection. The key components of the GIS that were used to develop the groundwater models and to complete ISI mapping included the water well database for Ontario, surficial Quaternary and bedrock geology mapping and information on karst terrain within the Counties. The WHPA modeling and ISI mapping are both impacted by the presence of karst terrain, which increases the variability in observed hydraulic head values that are used to calibrate the WHPA models, and can also influence the Intrinsic Susceptibility analysis because thin surficial geology may lead to high ISI values. A number of groundwater models were developed for areas along the Niagara Escarpment where surficial soils are thin and karst terrain is common. Karst features could not be explicitly represented in the MODFLOW models, but were addressed in the conductivity distribution developed during model calibration. This paper presents the methodology used to address the influence of karst terrain as part of the model calibration process and the impact on model results.

SS06-14 A SIMPLIFIED MODEL TO ESTIMATE HYDROGEOLOGICAL SENSITIVITY IN A GIS

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A GIS-based methodology was developed to assess the vulnerability of groundwater and surface water resources. The method is applied to a portion of Eastern Ontario, east of Ottawa between the Ottawa River and the St. Lawrence River. The approach is based on monthly water budget calculations on a three-layer-system conceptual model for Eastern Ontario, and it can be used to estimate groundwater vulnerability on a monthly basis, under the monthly prevailing conditions. Aquifer vulnerability to contamination is based on Surface to Aquifer Advective Times (SAAT); flood potential is assessed by the Monthly Excess Runoff (MER); and deep aquifer depletion is assessed by the Monthly Excess Demand (MED). The key GIS layers developed for each month are: potential evapotranspiration, net available water, transmisivity, estimated volumetric flow rate, variation in groundwater storage, percent of groundwater storage, estimate for groundwater consumption, water table elevation, surface runoff, infiltration, groundwater deficit and aquifer vulnerability.

The approach was applied to several climatic scenarios (including extreme ones), based on an analogue-to-historical-record approach to climate-change predictions. In this approach, broad predictions are based on global models but localized and short-term predictions are based on analogue years in the actual record, in this case, extracted from the Canadian climate data. To estimate vulnerability indices (and their spatial distribution), the water budget calculations are compared to identical calculations for the "normal" year scenario, hence the indices represent changes in vulnerability for a given scenario, compared to a normal. By visual and quantitative studying of these parameters within GIS for normal and extreme scenarios, it is possible to find geographical areas that are always hydrogeologically sensitive for each month of the year; and areas that are sensitive only during the extreme scenarios.

The results of this analysis show that the most plausible climate change scenarios for Eastern Ontario do not have a large impact on the groundwater resources. The scenario with most impact on a monthly basis was the driest year. It produced large vulnerabilities and large MED values at certain times of the year but the water budget deficits were replenished by the beginning of the following year. An extremely important result from this study is that vulnerability is extremely variable from one month to another and from one geographic location to another. The GIS environment was extremely powerful at identifying geographic locations that were particularly vulnerable. This can be an extremely valuable tool to the watershed managers.

SS06-15 **RELIABILITY OF GROUNDWATER INTRINSIC SUSCEPTIBILITY ANALYSIS**

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Maps highlighting areas that are relatively more susceptible to groundwater degradation than other areas can be used to protect groundwater resources. In Ontario, the Ministry of the Environment has developed an Intrinsic Susceptibility Index method that uses information on soil and rock conditions recorded in Water Well Records to calculate an susceptibility index factor for each well. An intrinsic susceptibility index map is then produced using a computer algorithm (e.g., Kriging) to interpolate index values between water well locations. Since these maps may be used by land use planners and others to regulate land uses and activities, an assessment of the reliability and suitability of the method is required so that the maps are used in an appropriate manner.

The geology of Middlesex and Elgin Counties in southwestern Ontario is dominated by glacial overburden varying from low permeability till plains to high permeability sand plains and glacial spillways. This area has a large number of suitable Water Well Records and was therefore used to evaluate the reliability of the intrinsic susceptibility method. Three specific aspects of the intrinsic susceptibility method are examined: i) the use of indexed or non-indexed scores, ii) the computer interpolative algorithm and iii) and the precision of the method by using a subset (80% of wells) of the water well data to develop the intrinsic susceptibility map (the calibration step) and using the remainder of suitable wells to assess the reliability of the maps (the validation step).

The results of the assessment indicate that the use of indexed scores slightly increases the areas designated as more susceptible. The use of two different computer algorithms (Kriging and Natural Neighbour) produced virtually the same results. The calibration/validation assessment indicated that only about 60% of the validation wells has calculated indexed values equal to the interpolated index value. Further, a significant proportion of the wells had calculated high values but were interpolated to be in a low susceptibility area. This assessment leads to the conclusion that aquifer susceptibility maps are best used as a guidance tool only, and cannot be used on their own to make site specific decisions. Their use as a coarse screening tool where the groundwater vulnerability is a factor in the planning decision making process should be made with caution.

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DEPTH TO BEDROCK: 3-DIMENSIONAL BEDROCK AND OVERBURDEN THICKNESS METHODOLOGY FOR MINERAL AGGREGATES AND GROUNDWATER GEOLOGY MAPPING IN ONTARIO

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The Ontario Geological Survey (OGS) has developed a methodology for determining an area's bedrock elevation and overburden thickness, that provides a valuable tool for carrying out groundwater geology mapping projects. OGS is also responsible for producing Aggregate Resources Inventory Papers (ARIPs), which are used in municipal planning to help assure future supplies of crushed stone, sand and gravel. A key component of each ARIP is a bedrock resource map that shows the distribution of suitable bedrock and thin-drift areas (generally < 8m overburden). Starting in 2004, the 3-dimensional bedrock and overburden thickness methodology will be used in creating the ARIP bedrock resource maps.

Data used in determining the bedrock surface and overburden thickness include: a provincially standard digital elevation model (DEM), provincial water well records, geotechnical boreholes, surficial and bedrock geology maps. Supplementary data include: topographic maps, air photos and Landsat imagery. Data sets are assessed and appropriately filtered.

Borehole layer information is translated to "bedrock" or "overburden" using an OGS translation table and database query. The depth to bedrock for each borehole is calculated. Bedrock elevation is calculated as DEM elevation minus depth to bedrock. Outcrops are assigned DEM elevation as bedrock elevation, and vertices of thin-drift areas are assigned DEM elevation minus 1 m.

Kriging is used to interpolate an initial bedrock elevation surface from all the bedrock elevation points. Overburden wells, that go deeper than the initial kriged surface, are assigned a bedrock elevation of DEM elevation minus well depth. These elevations are added to the interpolation set, which is kriged again to honour the deep overburden wells. This bedrock surface is carefully inspected in plan and perspective views, for evidence of problems in the dataset. Once the data problems are resolved, the bedrock elevation surface may be kriged again.

An overburden thickness surface is calculated as DEM minus bedrock elevation surface. The mineral aggregates geologist uses the overburden thickness information, bedrock geology and land use information to draw preliminary bedrock aggregate potential areas, which are checked during fieldwork. New information from fieldwork is used to re-krige the surfaces and finalise the Selected Bedrock Areas for ARIP mapping.

This approach is also used by OGS in 3-dimensional groundwater mapping projects and Groundwater Resource Inventory Papers (GRIPs). This methodology enables the production of bedrock topography maps, overburden thickness maps and 3-dimensional models of fundamental stratigraphic units. Stratigraphic "picks" are used to refine the continuity of key units.

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3-DIMENSIONAL MAPPING OF QUATERNARY DEPOSITS IN WATERLOO REGION, SOUTHWESTERN ONTARIO

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Pressures directed at protecting and preserving the quality and sustainability of groundwater resources within the province of Ontario have greatly increased over the past decade. Public awareness of these key issues has escalated with the release of the Walkerton Inquiry report that recommended the establishment and implementation of province-wide, watershed-based source protection plans.

In response to this directive, the Ontario Geological Survey, in cooperation with the Geological Survey of Canada, the Regional Municipality of Waterloo (RMOW), the Grand River Conservation Authority and the University of Waterloo, has embarked on a project of 3-dimensional geologic mapping of the Quaternary sediments that lie within the RMOW. The RMOW was chosen for study since it is the largest municipal user of groundwater in Canada and has a population growth rate of 1.5% per year. The main objectives of this project are to characterize the geometry and inherent properties of subsurface deposits to assist with the development of policies surrounding land use and nutrient management, to aid in studies involving groundwater protection and remediation and to better understand the interaction between ground and surface waters.

Three main areas of work are currently ongoing as part of this project. These can be summarized as: 1) data compilation and standardization; 2) acquisition of new geologic and geophysical data; and 3) data interpretation, synthesis and presentation. To date, our working database consists of in excess of 25 000 subsurface records derived from a variety of sources of varying data quality. The development of a conceptual geologic model for the interpretation of this data was undertaken by the examination of all available vertical exposures, relogging of selected archived core, acquisition of seismic reflection and ground penetrating radar data and continuous coring of strategically placed boreholes. There are currently, in excess of 450 geophysically logged boreholes within the RMOW. Geophysical logging of the newly cored holes will assist with the interpretation of logs from non-cored holes.

Data interpretation and synthesis is a labour intensive, iterative process that will require the use of high-powered GIS tools and 3-dimensional viewing software. To date, a number of software programs have been utilized in the interpretation and synthesis process. The 3-dimensional data is housed in an Access database where it can be easily queried and updated. Preliminary interpretations of the data have been undertaken using ESRI products such as ArcGIS and ArcScene as well as Viewlog and GoCAD. Following the construction of a 3-dimensional geologic model, activities will focus on the development of both technical and "user-friendly" derivative products.

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SS06-P03 RECONNAISSANCE GPR PROFILING OF NEAR SURFACE QUATERNARY DEPOSITS IN WATERLOO REGION, SOUTHWESTERN ONTARIO

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Ground penetrating radar (GPR) profiling was conducted at 14 sites throughout the Regional Municipality of Waterloo. Most test sites were situated within the Waterloo Moraine. One site was located in the Elmira Moraine at the north end of Woolwich Township and 2 sites were situated over glaciofluvial deposits within the Grand River valley. All GPR lines were surveyed twice using both 50 MHz and 100 MHz antennae. One short transect line was also surveyed with 200 MHz antennae. Over 16 kilometres of GPR profiles have been acquired to date. Additional profiling is planned for 2004. Most of the upcoming surveying will be conducted in sand and gravel pits where calibration of the GPR signature is possible by collecting data at the tops of well exposed vertical exposures and relating the responses observed to the "unknown" test sites.

The primary objective of the GPR profiling was to image the stratigraphy within the near surface deposits and infer their depositional environments. Sites were chosen on the basis of surface morphology and consisted of hummocky terrain, ridges, gently undulating terrain and plains. Profiles from areas of hummocky terrain and ridges generally displayed variably-scaled channelized systems indicative of deposition in a glaciofluvial and/or subaquatic fan environment. There is very little evidence from the GPR profiling to support an ice-contact depositional environment. Faults and chaotic bedding are infrequently observed in the profiles. Reflectors are generally flat-lying and commonly truncated along slopes and valley walls. Much of the apparent hummocky topography is therefore interpreted as erosional in origin. Channel-form reflector packages often lie at the bases of knolls and hummocks indicating incision of pre-existing deposits. Gently undulating terrain and plains generally display variable internal reflector structure. Flat-lying parallel reflectors are interpreted to represent deposition in a basinal glaciolacustrine setting. Channelized reflectors on flat plains indicate deposition in shallow braided streams or deltaic environments.

SS06-P04 **SUBSURFACE MAPPING AND CHARACTERIZATION OF QUATERNARY DEPOSITS IN WATERLOO REGION USING SEISMIC REFLECTION AND DOWNHOLE GEOPHYSICAL SURVEYS**

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As part of the establishment of province-wide, watershed-based source protection plans being developed in Ontario, a project aimed at 3-dimensional geological mapping of the Quaternary sediments that lie within the Regional Municipality of Waterloo has been initiated (Bajc et al., this session). Geophysics plays an important role in this effort, particularly due to the large study area, complex glacial stratigraphy, and thickness of overburden sediments (to > 100 m), which makes 3D mapping using point data (e.g. boreholes) a challenging task. This poster presents a sample of the seismic reflection and downhole geophysical data that have been collected in this area; the results of ground penetrating radar profiling are presented in an accompanying poster (Endres and Bajc, this session).

Shallow seismic reflection methods are being used in this project to investigate the subsurface architecture and stratigraphic relationships of the complete sequence of unconsolidated sediments as well as to delineate the topography of the underlying bedrock surface. Locations for detailed common-midpoint (CMP) reflection profiles were chosen from the results of an initial survey of 19 test sites, designed to evaluate the data quality and estimate the depth to bedrock in various locations and geological settings within the region. On the basis of the test results, 9 sites were chosen for followup profiles, and to date approximately 12 km of seismic reflection profiles (P-wave) have been obtained using either an in-hole shotgun or the MiniVib (TM) source. These surveys have identified strong reflections associated with sequences of thick, high-velocity tills, channel features within and on the surface of these units, and channels or valleys on the bedrock surface. Test shear wave surveys using the MiniVib (TM) in shear mode have also been obtained in areas where P-wave data are poor due to the presence of a thick, low-velocity surface layer. The seismic data provide information on the subsurface with vertical and horizontal resolution in the order of metres.

Downhole geophysical logs are currently being obtained in a series of overburden holes being drilled at strategic locations along seismic profiles as well as in areas lacking high quality subsurface information. These logs include natural gamma, conductivity, magnetic susceptibility, temperature, density, and seismic velocity (both compressional and shear). These logs provide detailed physical characterization of the subsurface at sub-metre scales, and are being evaluated for their potential role in identifying stratigraphic units and relationships, and in aiding regional correlation.

SS06-P05 **THE CHARACTER, SEDIMENTARY FILL AND HYDROGEOLOGICAL SETTING OF THE BURIED LAURENTIAN VALLEY, NOBLETON ONTARIO**

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Buried valleys have been an important element of the geology of the Great Lakes from the time Spencer in the 1890s inferred that an ancient Laurentian river network may have helped form these large lakes. More than 100 years later, we do not have a clear idea of the geometry, extent and the sedimentary fill in the Laurentian valley that connected Georgain Bay with Lake Ontario, and, of other buried valleys in southern Ontario. Similarly, the processes responsible for the formation of such valleys and their thick sedimentary fills are not well known. To date, critical data have not been collected to test the classic inference that the valleys represent an ancestral Tertiary drainage system.

The development of well-constrained erosional and depositional models for buried valleys is relevant to efforts to model regional groundwater fluxes in areas with thick (>100 m) sediment. Considering that the potential size of such valleys, ~ 20 km by 80 km with sediment thickness of 100-200 m, buried valleys are likely to be of considerable hydrogeological interest to regional flow systems. Current knowledge needs to be summarized so as to establish a geological-hydrogeological framework to identify data and knowledge gaps for upcoming research and assessment of buried valley aquifer systems.

We present high-resolution seismic, borehole and core-logging data from the Nobleton area of the buried Laurentian valley. These high-quality data illustrate the first architectural information on a cross-section of the Laurentian valley system and the thick overlying sediment fill. Integration of these data provides insights into complex history of infill of the valley. The data indicates a history of depositional and erosional episodes that have produced a complex sediment facies arrangement in nested bedrock and sediment hosted valleys. The nature of the compound fill may significantly affect both horizontal and vertical hydrogeological connectivity and continuity. The compound valley fill of the Laurentian valley is illustrative of the need for integrated geological and hydrogeological studies that collect, analyse and develop evolving conceptual models. Such models can guide and be updated by new geological and hydrogeological data collection and analysis, in this area and other areas of southern Ontario and the Great Lakes.

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SS06-P06

DURHAM REGION GROUNDWATER STUDIES – WELLHEAD PROTECTION, CONTAMINANT SOURCES INVENTORY, AND WATER USE ASSESSMENT

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Durham Region has undertaken groundwater studies in each of its rural communities that rely on groundwater as a potable source of drinking water. There are eight rural communities and several thousand people throughout the region that utilize groundwater for agricultural, commercial, industrial and domestic uses.

A component of these studies included delineation of Wellhead Protection Areas for each of the Region's municipal supply wells. The investigative work included analysis of existing data in addition to subsurface exploratory drilling to confirm and test the existing aquifer formations in which the respective supply wells were completed.

The primary objective of the study was to identify a zone of contribution for each municipal supply well through numerical modeling techniques and asses the level of vulnerability associated with the respective aquifers. A contaminant sources inventory was completed within each well capture area and in proximity to the delineated zone of influence. With this information the Region is able to identify various land uses that are compatible with the wellhead protection area as well as those land uses that are less desirable.

A water use assessment was initiated in this study in an attempt to identify the potential quantity of groundwater resources available for each quaternary watershed located within the municipal boundaries of Durham Region. This component of the study revealed intriguing results with respect to the amount of water consumed on a watershed by watershed basis and a comparison to the estimated renewable water resources for the respective watershed. Ultimately, the Region is in a better position to assess land development applications that require water taking in some form or will influence the recharge potential for the respective watershed and aquifer system.

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REGIONAL SCALE ASSESSMENT OF GROUNDWATER CONDITIONS IN SUPPORT OF THE CANADA – ONTARIO WATER USE AND SUPPLY PROJECT

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The Canada – Ontario Water Use and Supply Project (WUSP) is a multi-agency effort to determine water use and supply relative to ecological requirements within the Ontario portions of the watersheds of the Great Lakes and Ottawa and Upper St. Lawrence Rivers. Groundwater is an important water supply across this region and is also critical to the maintenance of in-stream conditions and aquatic habitat. Assessment of groundwater conditions at a regional scale is therefore a central component of the WUSP. The objective of this assessment is the creation of results that provide a summary indication of groundwater conditions in a manner that is both consistent and seamless across the varying physiography of the region. With these results rendered in a consistent and seamless manner, it is then possible to identify both the diversity and similarity of conditions and to use this information to examine the implications of water use and supply relative to ecological requirements. Two significant practicalities are inherent in the assessment. First, relatively modest and largely in-kind resources are available. Second, by definition, the assessment must be based on the very few data sets that are consistent across the region. The approach that is being implemented is an extension of methodologies developed for studies of climate and groundwater interaction in western southern Ontario and is based on the analysis and interpretation of archival data such as stream flow and climate monitoring information, water well construction records, and geological mapping in the context of hydrologic information such as surface water features and watersheds. The physiography of the region introduces several unique challenges relative to the studies completed in western southern Ontario and will require considerable additional development of the methodologies. It is probable that the two indicators of groundwater conditions that were determined in the previous studies will also be used in the context of the WUSP. These two indicators are base flow index, which is a measure of base flow due to groundwater discharge to surface water features relative to total stream flow, and base flow recession, which is a measure of the timing of groundwater discharge relative to recharge. It is also probable that the creation of seamless results will again require the interpretation of these indicators relative to geological factors such as Quaternary and bedrock geology.

SS06-P08

BURIED VALLEY AQUIFERS: SIGNIFICANCE FOR MUNICIPAL WATER SUPPLY AND WATERSHED MANAGEMENT, CREDIT VALLEY, ONTARIO

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Buried valley aquifers are an important source of water supply to many communities in Ontario. They are likely to be of increasing significance to water resource managers as interest grows in source water protection, security of supply and in constraining estimates of watershed-scale water balances. To date, prospecting methods for this aquifer type have seldom used modern exploration techniques to discover, target and assess their reservoir potential and flow-system properties. This work outlines the exploration strategy employed near Caledon East in the upper Credit Valley watershed, southern Ontario.

Sparse archival borehole data were used to target a poorly-defined ~E-W trending bedrock valley, which appears to connect eastward with the larger Laurentian valley. High-resolution geophysical and geological data were collected to investigate the extent, depth and architecture of the suspected bedrock valley and its sedimentary fill. This work included ~10 line-kms of reflection seismic data in 3 profiles spaced at intervals of 4-6 km, downhole geophysics, and, detailed sediment logging data from an ~180 m-deep, continuously cored borehole. Several cored boreholes from a nearby landfill investigation provide additional detailed geological context.

Resuls of this work confirm the presence of and delineate the suspected bedrock valley that is ~100 m deep and ~2-4 km wide. The valley appears to trend and widen to the northeast. Seismic reflector patterns tied to borehole data show 3 main elements. A basal, semi-continuous, high-amplitude reflector, seismic facies (A), is interpreted as shale and limey bedrock of the Georgian Bay Formation. An overlying ~10-100 m thick package of high-amplitude, less continuous, truncated and inclined reflectors of seismic facies (B), interpreted as stacked sand and gravel sets with cut-and-fill and cross-bedding structures. This gravel facies is inferred to represent high-energy deposition from a subglacial fluvial system. An upper 80-170 m thick, low-amplitude, weakly-planar seismic facies (C) is interpreted as sand and silt. Borehole data indicate increasing mud content upward in the top 100 m of facies C. This succession is interpreted to correlate with the regional Oak Ridges Moraine and Halton Till stratigraphic units. Similar structures and coarse sediments have been interpreted from seismic facies and confirmed with continuous core in the region. Coarse sediment of unit B provides an ~100 m thick and ~2 km-wide target for hydraulic testing. Estimates of depositional flow directions will aid in the monitoring and assessment of this potentially significant aquifer.

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AQUIFER VULNERABILITY MAPPING AND GROUNDWATER PROTECTION STRATEGIES – AN EXAMPLE FROM SOUTHWESTERN ONTARIO

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Oxford County, in southwestern Ontario, provides an excellent setting to test different approaches for mapping the vulnerability of aquifers to surface contamination. Local aquifers are present in unconsolidated glacial overburden as well as fractured Palaeozoic bedrock. Some of these aquifers have already been impacted by surface contaminants, particularly nitrate and road salt.

In an effort to protect vulnerable aquifers and municipal supply wells, aquifer vulnerability maps are being incorporated into the Official Plans of many Ontario municipalities, including Oxford County. Within highly vulnerable areas, planning controls typically include land use restrictions, zoning changes, nutrient management requirements and additional site-specific investigation prior to development. Such measures affect existing and planned land use to the extent that land values may be affected and municipalities may need to modify or reconsider their economic development strategies. The methodology for calculating and mapping aquifer vulnerability must therefore be both rational and defensible if challenged.

Several variations of the Groundwater Intrinsic Susceptibility Index (GwISI) method prescribed by the Ontario Ministry of Environment, as well as the Aquifer Vulnerability Index (AVI) methodology developed previously by Golder Associates, were used and the results compared with each other and with independent (direct) evidence of aquifer vulnerability. Both of the methods tested rely to varying degrees on water level data and subsurface materials descriptions contained in the digital MOE water well records. A raw vulnerability score is calculated for each well from the record of subsurface geology, and classed as high, medium or low vulnerability. The results are then interpolated to create a continuous vulnerability surface and colour coded according to vulnerability class.

The GwISI method was found to be less conservative than the AVI method in assessing aquifer vulnerability, in that the GwISI method predicts fewer areas of high aquifer vulnerability. Different interpolation methods produced similar vulnerability maps, although interpolation should be done on classed vulnerability scores rather than raw scores. A notable difference between the aquifer vulnerability maps based on the GwISI and AVI methodologies results from the different approach to identifying the data to be used in the gridding process. The GwISI methodology relies on the accuracy of the individual point data (i.e., geologic descriptions) contained in the MOE water well database and grids all wells together. Conversely, the AVI methodology employed for Oxford County incorporates a regional understanding of the subsurface geology to produce separate grids for each individual aquifer unit.

SS-07

GROUNDWATER RESOURCES II: WATER QUALITY AND HUMAN HEALTH

RESSOURCES SOUTERRAINES II : LA QUALITÉ DES EAUX ET LA SANTÉ HUMAINE

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GROUNDWATER RESOURCES II: WATER QUALITY AND HUMAN HEALTH
RESSOURCES SOUTERRAINES II : LA QUALITÉ DES EAUX ET LA SANTÉ HUMAINE

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SS07-01 **DETERMINING THE LONG-TERM PERSISTENCE OF HG RELEASES TO THE ENVIRONMENT FROM CYANIDE RICH GOLD-MINE TAILINGS**

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Mining operations that utilize cyanide (CN) for the recovery of gold may mobilize mercury (Hg) from natural sources in the gold ore. Residual CN in mine tailings may result in the formation of soluble Hg-CN aqueous complexes in the pore water that leach from the tailings and are transported to the surrounding environment. The Murray Brook gold mine, located in Northern New Brunswick, represents an example of this type of Hg contamination.

Quantification of the initial total mercury (HgT) and total cyanide (CNT) concentrations in the tailings solids indicates heterogeneous concentration profiles versus depth, with peak values of 39.5 mg Hg/kg and 9.5 mg CN/kg. In this case, Hg mobility is intimately linked to the presence of CN. We are assessing the long-term persistence of Hg releases by studying the controls on CN losses from the tailings with a series of in-situ and laboratory-based investigations.

Cyanide may degrade oxidatively through reaction with O_2 in the pore gas, and Hg may escape from the tailings in the volatile Hg0 state. Therefore, a monitoring program for tailings pore-gas concentrations was implemented to investigate the flux of O_2 into the pile and Hg0 from the pile. Measurements were made near the centre of the pile at 1 m intervals to a depth of 15 metres. Consistent trends are observed through time over a period of 1 year for both O_2 and Hg0. Contradicting the initial hypothesis that downward diffusion of O_2 from the atmosphere replenishes O_2 consumed by CN degradation, the profiles display relatively high O_2 concentrations at depth, suggesting that downward diffusion is not the controlling mechanism of O_2 transport. The Hg0 pore-gas concentration profiles are erratic versus depth, and do not provide strong support for the hypothesis that Hg0 diffuses outward from the pile to the atmosphere.

Loss of Hg and CN from the pile may also occur through leaching with infiltrating meteoric water. Laboratory-based column experiments were designed to quantify the amount of HgT and CNT that could potentially be leached. Initial aqueous effluent concentrations from the columns reached maximum values of 12,900 ìg Hg/L and 16,000 ìg CN/L. The concentration versus time profiles display an initial rapid decline, followed by a prolonged period of asymptotic concentration decrease. In order to assess the longevity of Hg and CN leaching from the tailings pile, numerical modelling will be conducted to scale the experimental results to the field scale.

SS07-02 LONG TERM RELEASE OF METALS FROM AN OLD TAILINGS IMPOUNDMENT, SHERRIDON, MANITOBA

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The oxidation of sulfide minerals from mine wastes results in the release of oxidation products to groundwater and surface waters. Hydrogeological and geochemical studies of an abandoned high-sulfide tailings impoundment were conducted in Sherridon, Manitoba. The Sherridon tailings have undergone oxidation for over 70 years. Mineralogical analysis indicates that the unoxidized tailings contain nearly equal proportions of pyrite and pyrrhotite, up to 60 % wt. of the total tailings, along with minor amounts of chalcopyrite, sphalerite, galena, and traces of arsenopyrite. Extensive oxidation in the upper 50 cm of the tailings has resulted in extremely high concentrations of dissolved SO4 and metals in the tailings pore water (pH<1, 129,000 mg/L Fe, 280,000 mg/L SO4, 55,000 mg/L Zn, 7,200 mg/L Al, 1,620 mg/L Cu, 230 mg/L Mn, 105 mg/L Co, 97 mg/L Cd, 55 mg/L As, 15.3 mg/L Ni, 5.9 mg/L Pb, and 3.14 mg/L Cr). The acid released from sulfide oxidation has been extensive enough to deplete carbonate minerals to a 6 m depth and partially deplete aluminum silicate minerals to a depth of 1 m. Below 1 m, sulfide oxidation processes have resulted in the formation of a continuous hardpan layer (7gt;1m thick). Geochemical modeling and mineralogical analysis indicate the hardpan layer consists of secondary minerals, melanterite, rozenite, gypsum, jarosite, and goethite, all of which control the solubility of dissolved SO_4 and metals. The highest concentrations of dissolved metals are observed directly above and within the massive hardpan layer. Near the water-table at a depth of 4 m, most metals and sulfate show a sharp decline in concentration. These results suggest that the oxidation products have migrated downward through the unsaturated zone to a 4 m depth over the last 70 years. Although dissolved concentrations of metals and sulfate decrease below the water table, these concentrations remain elevated throughout the Camp Tailings, with up to 60,600 mg/L Fe and 91,600 mg/L SO_4 observed in the deeper groundwater. A number of lakes in the area have been severely impact with elevated concentrations of Zn, Al, Cu, Pb, and other metals as a result of groundwater discharge from the tailings. Although the tailings have oxidized for over 70 years, a significant mass of unoxidized sulfide minerals remain in the 4 m of unsaturated tailings, suggesting metals and acid will continue to be released for decades to centuries.

SS07-03 **SULFIDE OXIDATION AND METAL RELEASE IN TAILINGS DEPOSITED VIA A CYCLONE PROCESS, LYNN LAKE, MANITOBA**

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Information on the fate and transport of heavy metals liberated by means of sulfide oxidation is important for developing appropriate remediation strategies and for preventing the degradation of adjacent water resources. Traditional tailings-management methods commonly result in the oxidation of sulfide minerals, generating low-pH conditions and high concentrations of heavy metals such as Fe, Ni, Al, Zn and Pb. Investigations were carried out on the East Tailings Management Area (ETMA) at Lynn Lake, Manitoba to evaluate the extent of sulfide oxidation and the resultant pore water quality. Mining operations of the Farley Ni/Cu mine began in 1952 and were terminated in 1976. Over the period of active mining operations approximately 21.8 million tonnes of tailings waste were deposited in the ETMA. Unweathered tailings contain approximately 20 to 30 % sulfide minerals, primarily pyrrhotite, with lesser amounts of pentlandite and chalcopyrite, and trace amounts of pyrite and sphalerite. Mineralogical and total-sulfur analyses both indicate that oxidation reactions have depleted the sulfide minerals in the upper 0.5 to 1.0 m in the shallow tailings. High concentrations of SO4 (max. 9760 mg/L), Fe (max. 4220 mg/L), Ni (3870 mg/L), Al (max. 2390 mg/L), Cu (max. 270 mg/L), Zn (max. 226 mg/L), Co (max. 156 mg/L), Pb (max. 4.75 mg/L), Cr (max. 0.85 mg/L) and Cd (max. 0.54 mg/L) are present in the tailings pore waters. Distinct pH plateaus are evident at most locations throughout the ETMA. The inference from geochemical modeling and profiles of total acid-leachable carbonates is that the acidic pore waters are undergoing buffering reactions involving carbonate minerals (pH = 5.7) and aluminum-hydroxide solids (pH = 4.0). Pore water chemistry infers that very low pH values are likely depleting the aluminosilicate minerals in the shallow zone of the tailings. An extensive hardpan has developed as a result of sulfide oxidation. Mineralogical analysis and geochemical modeling suggests that the hardpan layer consists mostly of ferric oxyhydroxides and hydroxysulfate solids, mainly goethite and minor amounts of K-jarosite and lepidocrocite. Although sulfide oxidation is nearing completion in the upper 0.5 to 1.0 m of the tailings, unweathered tailings are present throughout the vadose zone at greater depths. The extensive vadose zone present at the west end of the tailings, approximately 3.8 m thick, will allow oxidation processes to continue into the foreseeable future.

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SS07-04 **ZERO-VALENT IRON AND ORGANIC CARBON FOR USE IN PERMEABLE REACTIVE BARRIERS: ACID MINE DRAINAGE REMEDIATION**

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Permeable reactive barriers for remediation of mine drainage impacted groundwater generally contain mixtures of materials which promote sulfate-reduction, acid neutralization, and precipitation of metal-sulfides. Zero-valent iron increases pH and rapidly generates conditions favorable for sulfate-reduction. However, organic carbon bearing materials support bacterial sulfate reduction, generate alkalinity, and increase concentrations of dissolved organic carbon. Laboratory batch experiments were conducted using simulated mine-drainage water to evaluate sulfate reduction and metal removal rates associated with varying mixtures of organic carbon and zero-valent iron. Each reactive mixture had constant total proportions of reactive materials (58 dry wt%), porous support (25 dry wt%), and neutralizing agent (15 dry wt%). The reactive component was comprised of varying proportions of organic-carbon materials (58-0 dry wt%) amended by zero-valent iron (0-58 dry wt%). A bacterial source (2 dry wt%) was added to all mixtures containing organic-carbon materials. Conditions favorable to nitrate and sulfate reduction, indicated by Eh values of < 200 mV, developed within days to weeks. Nitrate concentrations decreased from approximately 150 mg/L to < 1 mg/L within 7-15 days. Increases in NH_3 concentrations from < 0.03 mg/L to > 200 mg/L were observed within this period for all mixtures containing organic carbon. Ammonia concentrations did not exceed 50 mg/L for mixtures containing only zero-valent iron. Concentrations of Ni and Zn decreased from 50-200 mg/L to < 50 mg/L within 15-30 days. Cadmium concentrations decreased from 3-10 mg/L to < 1 mg/L and concentrations of Pb decreased from 1-2 mg/L to < 0.2 mg/L over the same period. Increases in pH from initial values of 4.5-5.0 to > 6.0 were observed within hours to days. Greater increases in pH were associated with mixtures containing higher proportions of zero-valent iron. Alkalinity increased from initial values of < 60 mg/L (as $CaCO_3$) to > 1500 mg/L (as $CaCO_3$) within 20-40 days. Increases in DOC from < 2 mg/L to > 1000 mg/L were observed over the same period for all mixtures containing organic carbon. Results from this study will be used to determine optimum mixtures of zero-valent iron and organic carbon for acid mine drainage remediation using permeable reactive barriers.

SS07-05 MOBILITY OF CAFFEINE, CLOFIBRIC ACID AND IBUPROFEN IN OXIDIZING AND REDUCING AQUIFERS

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Recent studies by various researchers have shown that surface water and groundwater around the world may be impacted by a variety of pharmaceuticals. Research into the fate and transport of pharmaceuticals in different geochemical environments is limited. As part of a larger geochemical study, groundwater samples were collected from two shallow aquifers which exhibited different geochemical properties. One aquifer was reducing in nature with elevated concentrations of ammonia and iron whereas the second aquifer was oxidizing with nitrate and sulphate being dominant. The aquifers were sampled for caffeine, clofibric acid and ibuprofen to estimate the mobility of each pharmaceutical in oxidizing and reducing conditions. The two aquifers were located immediately below and down-gradient of active septic systems. Concentrations of the pharmaceuticals were typically in the ng/L range immediately below the septic system. Analysis of the geochemistry and hydrogeology suggests that the clofibric acid and caffeine appear to be conservative with respect to groundwater flow whereas ibuprofen appeared to be retarded in both aerobic and anaerobic conditions. The results of the study suggest that caffeine and clofibric acid may have the potential to migrate to receptors via groundwater or surface water whereas ibuprofen appears to be susceptible to natural attenuation processes such as adsorption and biological degradation. The possible uses of this information include the application of pharmaceuticals as tracers as well as quantifying inputs from septic systems to the groundwater as well as quantifying groundwater and surface water interactions.

SS-08

ENHANCING EARTH SCIENCE AWARENESS AND EDUCATION

REHAUSSER LE NIVEAU DE SENSIBILISATION ET L'ÉDUCATION EN SCIENCES DE LA TERRE

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DINOSAURS, ROCKS, MINERALS AND MORE. THE NEW MARCH NETWORKS EXHIBIT ATRIUM AT THE UNIVERSITY OF WATERLOO

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In the summer of 2003 the Earth Sciences Museum moved from the top floor of the Biology Building to the new March Networks Exhibit Atrium in the Centre for Environmental and Information Technology, a more visible part of campus. The March Networks Atrium is along the main traffic corridor from north to south, from the Davis Building to the pathway to the west of the Physics Building. As you walk through the atrium towards Physics, to your left is a water feature, "The Great Lakes," each carved into a slab of granite gneiss with water flowing from Lake Superior through to the St. Lawrence. To the right, a sliding door gives access to the museum. This is open during normal working hours, and exhibits may be seen through a window in the door after hours.

The museum houses *Albertosaurus* and, in the future a new acquisition, a mastodon. Visitors sit on steps, which lead into the Learning Centre for presentations. Paleontology exhibits fill the remaining area in the Learning Centre. Another door opens to the south making this room part of the main traffic flow through the atrium. On the wall past the Great Lakes water feature, display cases built into the wall highlight minerals. Some of the "view window" cases are at the level of children. Lighting for the atrium is provided by the showcases; lights above staircases, and shafts of light from skylights. Under the stairs a small viewing window show fluorescent minerals. Look over the mineral showcase down the stairs to the basement. Touchable specimens will be arranged down the staircase. The stairway from the first floor to second floor is a Paleozoic time-line. The stair treds are dolostone from Wiarton. Note the bronze time-line plaques on the wall. Don't forget to take the elevator to the basement, step out and look up. Drill bits piercing the floor above decorate the ceiling. Just ahead, a gneiss monolith from Allstone Quarry, Bigwood Township near Sudbury, rises up 8.5 metres from the basement to the second floor. The new location has made many more people aware of Earth sciences and makes it possible for casual visitors to visit seven days a week. Before moving to this new location we had between 100 and 120 group visits and about 10,000 visitors per year. We expect this number to increase because of the new dynamic display space.

SS08-02 BENEFITS OF PARTNERSHIPS IN THE OUTREACH EDUCATION COMMUNITY

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Those wishing to develop partnerships could learn a few things from the Canadian geoscience outreach community. Across Canada, individuals and local groups have fostered, nurtured and successfully maintained many collaborative activities and programs. Partnerships exist with museums, science centres, publishers, visual artists, entreprenuers, teachers, geoscience and teacher societies and associations, and departments of education. Our country has a proven track record in outreach that is envied by others. Dare we ask whether there is room for improvement? How do we take an already high-performing community to the next level? We suggest the strengthening of partnerships between existing outreach programs.

We already know the benefits of partnerships with groups outside the geoscience outreach community. How would this look in the proposed scenario? Here are some examples. EarthNet would post hands-on activities and field guides developed for EdGEO workshops and would promote local workshops. EdGEO workshops could hold sessions on the Geoscapes posters. EarthNet and Wat on Earth websites addresses would be included on Geoscape products. Other outreach programs would be encouraged to contribute and benefit from these collaborations.

Yes, some of the proposed partnerships are already active. Workshops on Geoscape posters have taken place. EarthNet has posted workshop activities and made links with Wat on Earth and Geoscapes. But we can strengthen these connections. As one example, EarthNet has a long way to go to fully represent all provinces and territories in Canada. EarthNet needs more partners in all regions of Canada to reach its potential. Once we establish ways that others can contribute easily and confidently to the site, outreach activists will feel comfortable using and promoting the resource.

As always, the primary goal remains the delivery of quality and low cost education materials to the schools and the public. The proposed partnerships would strengthen an active network and would enhance the awareness of reputable outreach programs and expertise in Canada.

SS08-04 ORGANISING YOUR OWN GROUNDWATER OR CLEAN WATER FESTIVAL

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Starting 10 years ago water awareness events have been presented in southern Ontario as partnerships between water professionals, researchers, industry, municipalities, volunteers and donors. The first Ontario event was held at the Ontario Agricultural Museum, May 28th through June 2nd 1995. Children from Waterloo and Wellington Counties, and Peel Region participated in this event. Since then, water festivals have been multiplying throughout Ontario. Waterloo-Wellington Children's Groundwater Festival is held yearly at Doon Heritage Crossroads Museum and caters to over 4,000 children. Other events are now held annually in 10 Ontario centres. The Children's Water Education Council is working to encourage more events hosted by local communities. They provide advice on starting a festival, a teacher resource website and an activity trailer, which can be brought to an area for an event.

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SS08-05 **GEOSCIENCE EXPERIENCE FOR NORTHERN COMMUNITIES (GENCOM): A PROJECT TO ENHANCE GEOSCIENCE KNOWLEDGE, ESPECIALLY IN THE COMMUNITIES OF NORTHERN CANADA**

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It is a basic truth that communities in Canada's north rely on natural resources for their economic well being and that the key to increased prosperity lies in building capacity so that the communities can participate meaningfully in resource-based development. The Northern Resources Development (NRD) Program of the Geological Survey of Canada launched a new project in 2003-2004 to enhance the understanding of geoscience in Canada's northern communities. The project, entitled Geoscience Experience for Northern Communities (GENCOM), is active across northern Canada, working in cooperation with other NRD projects to assist communities in developing the geoscience knowledge necessary to make informed decisions on resource development and land-use planning. The project is providing readily understandable geoscience information to northern communities through community and school-based programs and is engaged with literally dozens of partners in developing science outreach materials of general and local interest. Several Geoscape-style projects are under way, but the poster concept is being expanded into a more broadly educational tool. For example, a poster explaining the energy resources of northern British Columbia is being prepared in association with The Exploration Place, a science centre in Prince George, B.C. The poster will be integrated with educational materials that will travel to schools in a "Science-in-a-Box" program, with community-based field guides and also with exhibits at the science centre. A Geoscape poster with similar linkages is being developed for Dawson, Yukon and for diamond exploration in northern Alberta. The project is also developing attractive fact sheets that deal with Canadian resources. The sheets are developed in a hierarchy with a long-term view to establishing them on a web site. At the high end of the hierarchy are sheets that deal with topics like mineral resources, energy resources, industrial minerals and gemstones. The middle of the hierarchy has more detailed topics such as base-metals, coal, carving stone, and diamonds, while the bottom of the hierarchy is populated with northern-based stories like the Polaris mine, northern pipelines and Yellowknife gold. Another feature of the project is the development of focused workshops for teachers in northern communities and visits to schools in the same communities. The long-term goals of the project are northern communities with better geoscience knowledge and more individual residents of northern communities who feel inspired to pursue geoscience-related careers.

SS08-06 INCREASING PUBLIC AWARENESS OF ROCKS AND RESOURCES IN THE EDMONTON AREA, ALBERTA

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Although Alberta generates more than 50% of Canada's mineral production every year, this huge economic payoff has not meant that Albertans understand how essential minerals are in everyday life nor has it ensured that teachers have resources to develop a high level of geoscience literacy. If we want Albertans to understand mineral value and uses geologists must tell them. Alberta Geological Survey (AGS) and other Edmonton area geologists are doing just that. The AGS is producing people-friendly geological materials (geoscape poster, rock walk guidebooks and EUB KIDZONE web page) and geologists are engaged in activities for educators (urban fieldtrips, class visits, workshops for teachers, input into educational resource development, and presentations at education conferences). We expect these initiatives to create a greater awareness of minerals in Alberta, increase the level of geological understanding and also raise the profile of our organization. The outreach information developed in Edmonton has a long shelf life and a significant value-added component. For example: The Geoscape Edmonton poster (AGS report INF 126, 2004) focuses on Edmonton's key geological features and resources: the formation of the North Saskatchewan River valley; past, current and future mineral resources (gold, petroleum, clay, coal, salt and diamonds); geohazards; and the surficial and bedrock geology of the region. Concepts and material for the poster benefited from Edmonton Beneath Our Feet, a best-selling geology book developed by the Edmonton Geological Society (1993) and still very popular. In turn the geoscape poster was used in a teacher workshop that is leading to the development of a rock and mineral resource unit for Edmonton Catholic Schools. That unit will probably recommend the Geoscape Edmonton poster as a required resource.

SS08-07 THE USE OF WEBCT IN FIRST YEAR UNDERGRADUATE EARTH SCIENCE LABS

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The use of web based learning environments in post-secondary education has become an increasingly popular educational tool in recent years. The department of Earth Sciences at Brock University (St. Catharine's, Ontario, Canada) offers a first year undergraduate introductory Earth Sciences course for non-science majors. With increased enrollment (~500 students) in 2003-2004, and limited lab space the decision was made to reduce the number of time students spent in labs. In order to continue to provide students with a quality educational experience the decision was made to convert six of the past in-lab assignments to web based assignments offered using the WebCT system.

The WebCT assignments that were developed can be classified into three basic formats. The first format makes use of pre-developed freeware obtained through the Internet from the Virtual Courseware site. Instructions and descriptions of activities given at the site are detailed and easy to follow. Difficulties encountered in managing a large enrollment class through this site were mainly from a technical standpoint and dealt with computer connection problems. The second format used was a research based assignment that accessed the resources available via the Internet regarding volcanos and plate tectonics. Marking and grading time for this type of assignment was longer than for other assignments, due to the larger amount of data recorded and presented by students. The third type of assignment involved a direct conversion of traditional "in-lab" assignments to the WebCT environment. Students were provided with descriptive text, a variety of visuals aids, links to applets and/or short animation files in order to convey key concepts required for completion of the tasks assigned. This learning format proved to be the most difficult for students to grasp on their own. Laboratory demonstrators noticed a significant increase in students requesting extra help and clarification on assignments. Future modifications and versions of the WebCT assignments could include activation of the WebCT discussion group feature to facilitate small group tutorial settings.

SS08-08

THE CANADIAN GEOSCIENCE EDUCATION NETWORK: A RESOURCE FOR TEACHERS OF EARTH SCIENCES

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The Canadian Geoscience Education Network is a Standing Committee of the Canadian Geoscience Council, and the President of CGEN is an ex-officio member of CGC. CGEN was established over a decade ago on the recommendation of the Education Director. Since then CGEN has grown to over 100 individuals interested in the promotion of the geosciences across Canada. Most are from academia but many of the most active are from government (both Federal and Provincial), from museums, industry and consulting and a small number are very active retirees who still maintain a strong interest in their discipline.

CGEN supports four ongoing national initiatives, and one international activity which has just been completed and another national thrust which is just commencing. The ongoing activities include EdGEO that commenced in 1972 and continues with teacher education workshops and field trips. EarthNet, operating out of Halifax, is a web-based resource with teaching resources and a multitude of web-links for geoscience. Geoscape Canada is a federal initiative that has raised awareness about the role of geoscience in major population centres and different regions across Canada. What On Earth is a print and web-based geoscience newsletter that is striving to increase awareness of geoscience, ongoing geoscience activities, and serves as a low-level resource for Earth Science teachers and students.

On the international scene CGEN has just hosted an extremely successful, August 2003, meeting in Calgary hosting slightly over 250 delegates of whom 123 were Canadians and many were teachers, most of whom received subsidies for attending. Field trips were conducted in the vicinity of Calgary as well as into the mountains and into the "badlands" east of Calgary. Workshops and technical sessions covered many areas of teaching. A new venture for CGEN is a proposed "geoheritage" initiative that will serve to increase local geoscience awareness at communities across Canada.

In the past CGC (CGEN) has been responsible for creating "Careers" booklets. Initially aimed at Grade 12 and university students these are now being re-prepared for Grade 7 students. This activity will be web-based. This presentation will briefly address each of these initiatives and provide methods for interested teachers to become active participants in this national geoscience venture.

SS08-09 OGRENET: AN INFORMATION GATEWAY FOR ONTARIO GEOSCIENCE EDUCATORS

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Since its inception in 1996, the Earth Sciences Outreach Program at the University of Western Ontario has reached, on average, well over 1500 members of the public (principally K-12 students) annually through special workshops, departmental tours, and public outreach events. As a logical extension of our program, the Ontario Geoscience Resource Network (OGReNet) was constructed to provide our services to educators beyond our local community.

OGReNet is a web-based resource gateway designed to provide K-12 teachers resources for the effective communication of geoscience-related concepts to their students, with special emphasis on topics specified in the Earth and Space Science units of Ontario Teaching Curriculum. Our main objectives are: (1) to reduce the hassles so often experienced by teachers in accessing teaching resources; and (2) to provide teachers an outlet to discuss effective methods of teaching geoscience-related topics with other parties involved in geoscience education.

The OGReNet website includes lesson plans for Ontario K-12 teachers, some designed especially for OGReNet (following guidelines of the Ontario Teaching Curriculum) and others linked from websites of other organizations. Also included are interactive maps featuring localities in all major counties and regional municipalities in Ontario, interactive stratigraphic columns outlining major events in the geological history of Ontario, a 500+ term glossary of geological terms, "at a glance" primers on basic geological concepts, and links to other providers of geoscience education resources.

It is emphasized that the primary purpose of the OGReNet website is not to "reinvent the outreach wheel," but rather, to consolidate the existing resources offered through the many institutions involved in geoscience outreach and to fill in the information gaps that remain. OGReNet is but an initial step toward the creation of a virtual Ontario geoscience community that will connect geoscience educators at all levels. It is hoped that this provincial-level approach will provide an effective bridge between existing local- and national-level outreach programs.

The OGReNet project is currently funded by NSERC (PromoScience Program) and the Government of Ontario (Youth Science and Technology Program, Ministry of Economic Development and Trade). Visit us at www.ontarigeoscience.net

SS08-10 **GEOSCAPE TORONTO – A TOOLKIT FOR LEARNING ABOUT AND PLANNING FOR GREAT CHANGES IN THE GREATER TORONTO AREA**

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There have been great changes in the Greater Toronto Area (GTA)! Imagine standing in downtown Toronto between 420 million years ago and 12,000 years ago. At various times you would have found yourself in a tropical sea, standing on dry land, overrun by a glacier four times as high as the CN Tower and swimming in an ice-cold lake! The geological processes, deposits and landforms resulting from these events has been a major contributor to our geoscape. With a population of approximately 5 million people and another 2.5 million expected to call the GTA home by the year 2031, it is critical we understand our geoscape to aid in making informed decisions about land-use and resource management.

The Geoscape Toronto poster, web site and curriculum-correlated student lessons provide a set of educational tools to raise awareness of the significance of Earth Science in the GTA. Learn about the Geoscape of the GTA utilizing these resources. Relevant issues faced by a major urban centre, such as water supply, transportation, land use, access to building materials and natural hazards are examined. All elements are suitable for students, teachers, land-use planners, naturalists, and the general public.

The graphics-rich Geoscape Toronto poster contains informative text designed to engage and educate. It depicts the GTA's geologic past through five theme panels: The Niagara Escarpment; Past and Present Lakeshores; The Oak Ridges Moraine; Rivers and Valley Lands; and The Agricultural Plains. Panels outline interactions of the feature's form, resources and processes with human activities. Central to the poster is an enhanced satellite image of the GTA superimposing landscape and land-use information.

The Geoscape Toronto Web site (www.toronto.geoscape.nrcan.gc.ca) delivers ongoing and new support and reference materials. Teaching lessons are accessible free of charge in a downloadable format. Links from the site allow visitors to discover Geoscape Canada and numerous other geoscape projects across the country.

To enhance the effectiveness of the Geoscape Toronto poster in classrooms, curriculum-linked lessons have been designed to build on the theme panels. The lessons support Grades 7 to 9 teachers in delivering Earth Science and Geography curriculum expectations, while challenging students to relate the knowledge they have acquired to the world outside their classroom.

The Geoscape Toronto project is a co-operative effort of geoscience, planning and other professionals. It has been developed through the participation and support of the government, industry, and education partners.

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SS08-11

ENHANSING THE GEOLOGICAL FIELD TRIP EXPERIENCE FOR SECONDARY STUDENTS: A MULTIMEDIA APPROACH

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This presentation will serve as a model as to how a teacher may use the Internet and other multimedia to guide students on a self-directed path of discovery and to enhance field trip experience. Students are given the task of working out for themselves the story of a significant local geological event. The problem is put to the class in the form of a question such as the one discussed in this presentation: "Did continental glaciation occur in the Marathon area of Ontario?" The Marathon area is replete with glacial features. Clean, wave-washed outcrops along the shores of Lake Superior provide a suite of prominent, well-exposed erosional features from striations to potholes. Inland, along river valleys may be seen numerous glacial deposits from kames to kettle lakes. To answer the question, a 4-phased project is assigned. The phases incorporate both concrete and abstract cognitive processes: exploration and consolidation (concrete), observation and integration (abstract). The process crudely follows the Scientific Method and offers students the preferred opportunity to practice science rather than learn about it. The steps are outlined below.

EXPLORATION AND FAMILIARIZATION
Using the Internet, students are asked to research and document the physical attributes of a glaciated terrain. A key component of this phase of the project is the accumulation of images that illustrate glacial features. The task is to explore for the variety of features found in glaciated terrains and to learn to recognize them. This will help them answer the question once they go into the field.

CONSOLIDATION
With the information gathered, students are asked to assemble a field guide of glacial features. The guide will be used in the field to confirm any features students might encounter.

OBSERVATION
With a field guide complete, the class is now ready to answer the question. Students are taken to the field where their task is to use their own observation skills to document the evidence of past glaciations. The field guide provides them with a ready source of images with which to compare what they see with what they know. This becomes an act of discovery through a collaborative approach in which the individuals of a group work together to learn about and identify geological phenomena in the field. The evidence that supports or refutes the question is in front of the class, on the ground.

INTEGRATION
The final phase requires students to assemble their evidence into a presentation – a map, a poster display, a power point presentation, an essay or any other means that communicates the conclusion to a general audience – a panel of teachers, peers or invited guests. Many geological events are of direct or indirect benefit to society. In the integration phase of the project, the class is asked not only to demonstrate the occurrence of a geological event, but also to discuss the impact such an event has had on society – economically, socially and environmentally. In doing so, the important link between the Earth Sciences and society is forged.

SS08-12 DEMONSTRATION OF GROUNDWATER CONTAMINATION USING HELE-SHAW CELLS

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The Hele-Shaw cell is a useful tool for the study of the behavior and movement of fluids in aquifers. It is, relatively, simple to construct and can be used in the classroom for demonstrating confined and unconfined aquifer systems. The models are suitable for grades 8 and up.

An aquifer is a water-bearing body of soil or rock. The water that flows through an aquifer is groundwater. There are different kinds of aquifers. Unconfined aquifers are bodies of groundwater that are found within unconsolidated materials, like soil, gravel, sand, silt, clay, and the fragments of shells of marine organisms. Water flows through these materials through the natural openings between particles.

In a confined aquifer, the groundwater is confined from the top and bottom by consolidated rocks, like sandstone, limestone, granite, or lava. These rocks are formed of rock and mineral particles of different sizes and shapes that have been welded together by heat and pressure, or chemical reactions, into a rock mass. Water flows through them through fractures, gas pores, and other openings in the rock. The groundwater in confined aquifers is under pressure greater than the atmosphere.

Students can construct Hele-Shaw cells to study the behaviour of these kinds of aquifers. Different materials can be used to represent the kinds of aquifers, dyes can be applied to illustrate the spread of pollution and pipettes can be used to demonstrate wells. From a demonstration of the cell, students can learn that an unconfined aquifer is much more vulnerable to contaminations that originate from the surface than a confined aquifer. As a result the water that comes from a confined aquifer is more reliable, except in some special situations, like if the water goes through formations that add heavy metals or other kind of pollution. A confined aquifer is often only semi confined, or the confining layer changes in some places, thus making it semi confined. So, in these semi confined places, it is more vulnerable to pollution.

SS08-13 EARTH AND SPACE SCIENCE RESOURCES FOR THE GRADE 12 ONTARIO SCIENCE CURRICULUM

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Over the last two years a new discipline has been introduced into the Ontario secondary science curriculum: Earth and Space Science. From experience teaching this course last year, four key areas were identified from the curriculum areas that were lacking in high quality resources as well as accessibility for teachers and students. As well as this course lacking in resources, there is also a lack of knowledge of the subject material within the teaching profession due to the lack of qualified Earth Science teachers. One of the goals of the developed resources is to provide prospective and experienced educators, with minimal experience in this subject matter, background information to help them to augment and develop their own program. The resources developed include: mineral identification, fossil identification, identifying images from space and mass extinctions/geologic time scale with examples of each presented. With the continued encouragement of the use of technology in the classroom by the Ministry of Education, each of the resources has been designed with a tutorial and activity component that can be accessed via the internet. To augment the online resources class sets of representative, minerals and fossils have been prepared that correspond to the online tutorials and activities and serve to address the course expectations, contained within the Ontario Secondary School Science Curriculum. These kits are available for loan to teachers to have access through Brock University by contacting earth@craton.geol.brocku.ca.

SS08-14 EDUCATION/BUSINESS PARTNERSHIP INSPIRES TEACHERS TO BRING EARTH SCIENCE TO LIFE

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Established in 1997, Prospectors and Developers Association of Canada Mining Matters (PDACMM) is a charitable organization that provides teachers across Ontario with information and resources that inspire students to unearth the importance of rocks, minerals, metals and mining and the roles they play in their everyday lives. This unique collaboration between teachers, minerals' industry professionals and Ontario government geologists has lead to the development of a series of educational resources to fulfill the challenging curriculum requirements in Ontario.

Building on the success of the original Mining Matters unit, PDACMM has developed subsequent bilingual units for Grade 4, Deeper and Deeper, and Grade 7, Mining Matters II – The Earth's Crust, to meet 100% of the Ontario Science and Technology Curriculum Expectations for the topics "Rocks, Minerals and Erosion" and "The Earth's Crust". Both units bring Earth Science to life by engaging students with hands-on learning opportunities. Deeper and Deeper encourages students to investigate the importance of rocks, minerals and soil in their lives and discover how humans can both minimize changes to the landscape and adapt to these changes. Mining Matters II – The Earth's Crust enables students to explore the theory of plate tectonics, earthquakes, volcanoes, geothermal energy, rocks and minerals, Earth's resources, soils and Ontario's geology. The units contain lesson plans, activities, transparencies, rock and mineral samples, mineral testing equipment, videos, maps, posters and books. To date, over 6,000 teaching units for use in Ontario's Grades 4 and 7 classrooms have been produced and implemented. The 2003-2004 academic year will see the implementation of 400 additional units.

Teachers obtain the units by participating in a workshop that demonstrates how to best implement the unit in their classroom. This is an integral part of the program as it inspires and motivates teachers while enhancing their understanding of Earth Science. PDACMM also operates an Educator Support Program, which was established to provide teaching tips and resources through informative newsletters. Assistance for teachers is also available through the Telephone Information Line and PDACMM Web site (www.pdac.ca/miningmatters), which provides teachers with direct access to the program's project coordinator. The support provided to teachers by all components of the program is essential as it helps them deliver the Ontario Earth Science curriculum with confidence, drives enthusiasm year after year and provides students with a fascinating means to investigate Earth Science.

The presentation will describe in greater detail the subject matter covered in the units, identify the key elements of success and highlight new initiatives planned by the organization.

SS08-P01 EXPANDING GEOSCIENCE AWARENESS THROUGH FRIENDS OF CANADIAN GEOHERITAGE

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To promote greater public awareness and appreciation of the geoheritage of the National Capital Region, and to foster protection of classic geologic sites, a group of geoscientists launched the Ottawa-Gatineau Geoheritage Project (OGGP) in February, 2003. Since then, representations have been made to municipal, provincial and federal governments, with encouraging results at all levels.

When discussions with members of the public revealed considerable interest in OGGP, the Ottawa-Gatineau Geoheritage Committee (OGGC) took steps to tap this apparent widespread support, by creating a free-membership organization, Friends of Canadian Geoheritage. Membership in this group is now approaching 1000 (attained primarily through informal contacts), demonstrating the potential for rousing public interest and support. Good will towards the Geoheritage Project has been expressed by geoscientists across the country; and possibile adoption of the geoheritage initiative is now under consideration by both the Geological Association of Canada and the Canadian Geoscience Education Network, offering potential for the original Ottawa-Gatineau Geoheritage Project to evolve into a pan-Canadian enterprise.

Recent accomplishments of OGGC illustrate the potential for this initiative. For example, negotiation with Ontario Ministry of Transportation has allowed preservation of a portion of a significant Cambrian site that was scheduled for demolition related to highway expansion. As a result of discussions with the National Capital Commission, that organization is now planning to create signage for a spectacular but previously overlooked geological site on the shore of the Ottawa River. Concurrent contacts with officials of Ontario Parks has led to the initiation of procedures for updating brochures and signage to provide greater recognition of geological features in three Ontario Parks near Ottawa. At the invitation of the Mayor of Ottawa, one member of OGGC is now a member of the Ottawa Heritage Advisory Board.

A linkage has been established with Ottawa Riverkeeper, an environmental group concerned with sustaining the natural features of this magnificent landmark, now under consideration for designation as a Canadian Heritage River. OGGC has been invited to contribute geological information for the formal proposal required to attain this status. Museums and geoscience centres have indicated support, and we are now encouraging ecotour groups to include geoheritage components in their programs.

To maintain momentum, we hope that other geoscientists across Canada will rally to promote our initiative, thereby helping to increase public awareness, understanding and appreciation of the many impressive, but frequently neglected, aspects of our Canadian geoheritage.

SS08-P02 NOVA SCOTIA: A SUPERB GEOLOGICAL HERITAGE

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Provinces are becoming increasingly interested in promoting ecotourism and natural scenic areas, which invariably reflect the geology. The literature readily obtained by the ecotourist usually has information on the wildlife but contains minimal geology. In large part this is the fault of the geological community, which often stays divorced from promotional efforts. But this is changing. For example in Nova Scotia, a renewed interest in the earth sciences has been fostered by the geological highway map, now in its second revision, and the book, "The Last Billion Years". There are also other encouraging signs. The Atlantic Geoscience Society, the motivator behind the map and the book, recently discovered that the Province of Nova Scotia awards grants towards the production costs of flyers or brochures that highlight features of special interest. Two such are lighthouses and railway museums, which are now featured in two attractive brochures that are mailed out to potential visitors to the province. Last fall, on behalf of AGS we submitted a proposal for a geological brochure, and were delighted when it was accepted for funding support.

On the front of the two-sided brochure will be a geological map identifying 40 to 50 selected sites of geological interest. Examples are Joggins, Arisaig, the Cobequid-Chedabucto Fault System, and Sydney Mines. One or more photographs is included for each sight, with several insets showing details - such as minerals, fossils or close-ups of rocks - made at that locality. The photographs include some stunning views, some of which are aerial. For each site, we provide a write-up describing the geological features. Some of the write-ups serve as reference points with extended discussions of such features as transform faults, glacial features, and granites. On the same side, we include a general write-up of the rock cycle and a time line, with each site identified by a number. On the obverse side is the tourist map of Nova Scotia, with museums, rock shops and ecotour operators highlighted in boxes. This side will also have a section on safety and a list of useful references, such as the geological highway map, The Last Billion Years, and websites.

The deadline for the project is scary. AGS has promised, in writing, to print 30,000 copies of the brochure by 31st March, with 20,000 going to the Province. We started the project in late November and gave our compilations to the graphic designer in mid February. She did a beautiful job of putting it all together, in time to be sent to the printer in March. The exercise has been invaluable in spotlighting the rich geological heritage of Nova Scotia. It should also be useful to tourists who want to see some geology during their visit. And, perhaps best of all, it will be perpetuated on the EarthNet website so that it can be continually updated and refined.

SS-09

Paleoenvironmental change and past lake levels

Changement paléo-environnemental et niveaux lacustres anciens

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SS09-01

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SPECTRAL INFERENCES OF LAKE SEDIMENT CHLOROPHYLL: A POTENTIAL TOOL FOR RECONSTRUCTING PALEOPRODUCTIVITY

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Although recent advances in reflectance spectroscopy have made it possible to rapidly and non destructively assess the chlorophyll content of plants and natural waters, to date this technique has not been applied to lake sediments. Here, we explore the relationship between lake sediment visible to near-infrared (VNIR) spectral properties and sediment pigment concentrations for a suite of lakes that have undergone recent nutrient enrichment. Reflectance spectra of sediments from four alpine lakes in Rocky Mountain National Park (Colorado Front Range, USA) have salient troughs near 675 nm which covary in magnitude with sediment concentrations of chlorophyll *a* and derivative pheopigments. Coeval to changes in reflectance spectra and pigment concentrations are shifts in diatom assemblages, nitrogen stable isotopic ratios, and sediment organic matter provenance, together suggesting that these lakes have become more productive since approximately A.D. 1950 as a results of anthropogenic nitrogen deposition. Several indices based on reflectance spectra were developed for calibration against measured sediment photosynthate concentrations. Among these, the area of the trough in reflectance (600-760 nm) produces the highest correlation with the sum of total sediment chlorophyll a and derivative pheopigments ($r^2 = 0.90$, $n = 23$, $p < 0.01$). These findings suggest that fossil chlorophyll a preserved in lake sediments can be remotely sensed using reflectance spectroscopy, thus providing a novel paleolimnological approach for rapid assessment of historical changes in lake trophic regimes.

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SS09-02 APPLICATIONS OF LESSER-KNOWN FOSSIL PROTISTS TO QUATERNARY PALEOLIMNOLOGY

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Unlike in marine environments, fossil protists- with the exception of diatoms- are seldom studied from lacustrine sediments. The relatively low preservation potential of some freshwater protists, such as freshwater dinoflagellate cysts, is largely responsible for the scarcity of studies. For others that preserve readily under most conditions, however, the lack of interest appears to stem from a lack of appreciation for their potential contribution to paleolimnology. Thecamoebians (testate rhizopods), for instance, are studied by only a handful of researchers in North America, and rarely as a major focus of their research. Examples from eastern North America will illustrate the potential of thecamoebians and freshwater dinocysts for reconstructing late glacial to modern paleolimnological and paleoclimatic conditions in both small and large lakes.

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SS09-03 A SUBMERGED BEACH AND SHORE FACE BELOW EASTERN LAKE ERIE IMPLIES EARLY HOLOCENE CLIMATE-DRIVEN, CLOSED-LAKE CONDITIONS

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A relict shore zone, submerged beneath eastern Lake Erie and comprising beach and shore face morphology, is recognized in seismic and acoustic profiles. The shore face forms an erosion surface cut into glaciolacustrine clay. The clay is represented as a seismic facies of moderately strong, coherent parallel reflections. The erosion surface is buried by up to 2 m of lacustrine mud shown on profiles as a near-transparent acoustic unit. The vertical interval comprising the beach and shoreface is between 21 and 27 m below present mean water level about 17 km NNE of Long Point. The paleo-shore zone rises gently eastward presumably as a result of differential glacial rebound, and has been traced as far as 7 km south of Port Colborne. Preliminary studies of sediment cores using pollen-biostratigraphic and paleomagnetic secular-variation data indicate an hiatus in sediment accumulation on the paleo-shore face between 10 ka and 7 ka approximately. The paleoshore, which lies below possible overflow outlets, is evidence of an early Holocene low-level lake that was hydrologically closed in response to a dry climate.

SS09-04 THE STRATIGRAPHIC RECORD OF LARGE LAKES- FAR FROM LAYER-CAKE!

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Lakes in Canada are generally assumed to be quiescent areas of undisturbed sediment accumulation with a continuous record of deposition since deglaciation. However, some large lake basins like Georgian Bay contain a spatially and temporally discontinuous sediment infill since ice retreat. Shallow seismic and subbottom profile data collected on a regional lake-wide grid together with a sediment chronology (obtained by correlating the lake pollen record with the regional pollen zonation) revealed a discontinuous sedimentation history. Holocene sediment thickness does not always conform to bathymetry with the thickest sequences in the deepest depressions. The relatively shallow Severn Sound at the southeast end of Georgian Bay, for instance, contains thicker sequences of Holocene sediments than the very deep western Georgian Bay Flowerpot basin. Holocene sediment thickness varies from more than 6 m to absent across the basin and deposition was not continuous over time. Little sediment accumulated over the last 4000 years. Glaciolacustrine and postglacial sediments outcrop on the lakebed even in deep water over much of the basin. This discontinuous distribution pattern suggests that sedimentation is controlled by waves and currents and sediment supply linked to major lake level fluctuations before the mid Holocene. Thick sediment sequences are associated with dynamic periods when lake levels were rising. Non-deposition and unconformities are associated with lake level still-stands with less dynamic conditions and sediment-starved environments. This discontinuous record of deposition demonstrates the importance of understanding geologic and taphonomic conditions when interpreting paleoenvironmental proxy records. Such records are not ideal for paleoclimatic reconstruction, however an understanding of basin depositional dynamics coupled with the selective sampling of seismostratigraphic units will allow for the reconstruction of a discontinuous paleoclimatic and paleohydrologic record.

SS09-P01 SEDIMENTOLOGY OF QUATERNARY SEDIMENTS BENEATH LAKE SIMCOE, ONTARIO

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Sediment cores and grabs were collected in Lake Simcoe, south-central Ontario between Lake Ontario and Georgian Bay, with sample locations based on interpreted seismostratigraphy from a previous 4 km by 4 km gridded marine geophysical survey. High-resolution single- and multichannel seismic reflection profiles were used to delineate late- and post-glacial sedimentary strata, structures and lake floor features. The seismic survey and the subsequent coring work are part of a baseline program to better understand the lake bottom and the sub-bottom geology for application to issues such as climate change, seismic hazard and regional geological history.

Lake Simcoe (726 km^2, 219 asl, draining to Georgian Bay) has a smooth lake floor with water depths generally 5-9 m but deepening to 30 m in the west. Two prominent bays lie to the west (Kempenfelt Bay) and south (Cook's Bay). Acoustic basement in Lake Simcoe is Ordovician sedimentary rock. The overlying unconsolidated Quaternary sediments are seismostratigraphically designated, from oldest to youngest, as the Red, Purple, Green and Blue Sequences. The first three sequences are widespread but Blue Sequence sediments are restricted to the deepest, western part of the basin. Interpretation of sequence history is based on stratigraphic position, acoustic character, and on comparison with similar seismostratigraphy mapped in Canadian lakes and with known onshore stratigraphy to the south in the Oak Ridges moraine. Red and Purple Sequence sediments are interpreted as glacial till; Green and Blue Sequence sediments are post-glacial. Samples of Green Sequence sediments have a sticky consistency and are grey-brown muds with lamination character ranging from weak to distinct rhythmites, characteristic of glaciolacustrine deposits. Blue Sequence sediments are massive, soft, grey muds, typical of Holocene large-lake deposition.

Samples were extracted from eight cores and processed for exploratory pollen study. Pollen percentages in the Lake Simcoe samples were compared with a radiocarbon-dated pollen record from a borehole in nearby Cookstown Bog, southwest of Lake Simcoe, and with other dated pollen records in south-central Ontario. This comparison made it feasible to assign inferred ages to the Lake Simcoe stratigraphy. The oldest (lower) Green Sequence sediments have an inferred age of 12 to 12.4 ka, indicating the beginning of glacial Lake Algonquin deposition. The youngest (upper) Green Sequence is estimated at 11.8 ka. In the overlying Holocene muds, a younger inferred age of 3.4 ka is based on the bimodal pollen trends of Tsuga (hemlock).

SS09-P02 EVOLUTION OF LAKE OF THE WOODS OVER THE PAST 11,000 YEARS

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As a result of differential isostatic rebound, many lakes in Canada have continued to change their extent and depth since retreat of the Laurentide Ice Sheet. In general, greater uplift in the northern areas of lake basins has led to the southward transgression of waters over areas not previously covered by the lake, and the age of the base of lacustrine accumulation is younger toward the south. At the same time, waters have shallowed or regressed in the northern part of some basins.

During the early postglacial period in northwestern Ontario, 13-9 ka cal. yrs BP (11-8.1 ka ^{14}C yrs), Lake of the Woods remained part of glacial Lake Agassiz, with waters in that basin generally exceeding the modern depth of 8 m by 10 to >100 m. Lake of the Woods became independent when the level of Lake Agassiz fell below that of Lake of the Woods basin. Using GIS techniques, the changing configuration and bathymetry of Lake of the Woods after 11 ka cal yrs BP was reconstructed for 12 points in time at 500- to 1000-year intervals, and was also projected 500 years into the future. This modeling was done by first compiling modern topographic data from an unpublished Lake of the Woods bathymetric database (digitizing 6500 data points) and from subaerial data from the Shuttle Radar Topography Mission (SRTM). This DEM file was then merged with (1) isobase data derived from Lake Agassiz beaches prior to 8.4 ka cal yrs BP (Teller and Thorleifson, 1983) and (2) modeled isostatic rebound trend analysis after 8.4 ka cal yrs BP (Lewis and Thorleifson, 2003, unpublished). Just after the end of the Lake Agassiz phase of Lake of the Woods, only the northernmost part of the basin contained water. Because the lake outlet is at the northern end of the basin, water depths there have changed little through time. However, the differential rebound from north to south has resulted in increasing water depth to the south. In the first 3000 years of independence from Lake Agassiz, the lake transgressed >50 km to the south, expanded its area from 858 to 2857 km^2, and more than doubled it volume. Continued differential rebound after 6 ka cal yrs BP has further expanded and deepened the lake, but by a relatively small amount; today the lake is deepening by only a few cm per century at the southern end.

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SS09-P03 ARCELLACEAN (THECAMOEBIAN) CHANGES IN FRENCHMAN'S BAY, PICKERING, ONTARIO, AND THE IMPACT OF URBANIZATION ON WATER QUALITY

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Two cores obtained from Frenchman's Bay (Pickering, Southern Ontario) were analyzed for thecamoebian content, and magnetic susceptibility. Core 1 was taken from near the centre of the lagoon, at a water depth of approximately 3.5 meters, while Core 2 was taken from the western shallows, at approximately 1.6 meters water depth.

Each core was sampled at 10 cm resolution, and thecamoebian analysis revealed three biofacies, (Marsh, Deep Water and Eutrophic). Both cores were dominated at the top by the Eutrophic Biofacies (Core 1 – 0 to 90 cm and Core 2- 0 to 50 cm) characterized by high abundances of *Cucurbitella tricuspis* (average 49% over both cores) which was coincident with an abrupt change in the observed magnetic susceptibility. *Cucurbitella tricuspis* is a well-established indicator of eutrophic conditions as it has a parasitic relationship with the algae *Spirogyra* and its abundance in the sediment is a reflection of increased algal blooms. The concomitant change in magnetic susceptibility is likely due to nutrient loading of the wetland with the onset of major urbanization (post 1950) with increased storm sewer discharge and magnetic 'urban" sediments. It does not appear that post-contact forest clearance and agricultural practices in the area had any significant impact on the wetland. Blue and green glass shards were found in the cores at depths 200 cm and 180 cm (deeper than the Eutrophic Biofacies) indicating that the change occurred in the recent past and after European contact in the area. The deterioration of water quality in Frenchman's Bay is a recent phenomena, having occurred post large scale urbanization, and high yield fertilizer use since the end of World War II.

SS-10

RARE ELEMENT GEOCHEMISTRY AND ORE DEPOSITS

GÉOCHIMIE ET GISEMENTS DE MINERAIS D'ÉLÉMENTS RARES

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SS10-01 VERTICAL ZONATION OF ALKALIS IN MINERALIZED GRANITES AND PEGMATITES

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Vertical zonation of Na and K in mineralized granite stocks and pegmatites can be generalized as follows. In Cu-Mo-W porphyries, deeper portions of stocks are "granitic", but K* (= K/[Na+K]) increases upward. In F-rich "apogranites", K* decreases upward. Within individual pegmatites, K* increases upward, but throughout a pegmatite group, K* decreases as pegmatites evolve to the albite-lepidolite subtype. Though whole-rock data to substantiate these generalizations are sparse, the question remains, "what drives alkali zonation within each of these systems?"

In base-metal porphyries, the vertical increase in K* is attributed to a redistribution of alkalis between coexisting feldspars via saline (Cl) aqueous fluid in a thermal gradient that decreases roofward. Exsolution of an aqueous chloride solution also slightly increases K* of a coexisting granitic melt, so vesiculation and vapor loss through apical portions of the magma bodies should promote the same trends seen in K* of the whole rocks.

The upward decrease of K* in "apogranites" is attributed to hydrothermal "albitization", which has been linked qualitatively to the F-rich nature of these granites. Recent experimentation confirms that K* of granitic melt decreases when B, P, and F increase via the crystallization of quartz-feldspar assemblages. Melts become increasingly sodic and alkaline as the crystallizing assemblage becomes more siliceous (quartz-rich), aluminous, and potassic (micas, tourmaline, topaz become abundant); thus, there is marked divergence in the composition of fluxed melt and coexisting crystalline assemblage. Miscibility between fluxed melt and H_2O also increase, so that complete miscibility may exist at pressures relevant to pegmatites and shallow granites. Whether the magmatic-hydrothermal transition is continuous or not, the resultant "aqueous" fluid composition is similar to and inherited from that of the fluxed melt.

For pegmatites, increasing concentrations of B, P, and F also account for the fractionation trend toward late-stage albitic (cleavelandite, and quartz-poor) units within individual bodies, and as separate dikes of the albite-lepidolite subtype. Within individual bodies, the Jahns-Burnham model attributed the vertical increase in K* to exsolution and buoyant ascent of vapor from melt, but experimentation shows just the opposite trend in K*. New experimental work on diffusion in melt and the crystallization sequence with liquidus undercooling provide alternative mechanisms to explain the marked fractionation of Na and K seen within pegmatites.

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SS10-02 MAGMATIC HYDROGELS AND HYDROSOLS IN THE PETROGENESIS OF RARE-ELEMENT PEGMATITES AND OTHER ORE DEPOSITS

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Experimental petrology and materials research suggest that vapor saturation of viscous, hydrous melt may permeate supercritical aqueous fluid throughout melt rather than vesiculate within melt during slow isobaric cooling, isothermal pressure reduction, and crystallization of mostly anhydrous solids. Vapor saturation typically occurs when consolidating plutons are 90-99% crystals and may lead to evolved, interstitial vapor-permeated melts (hydrogels) and colloidal solutions (hydrosols) of aluminosilicic to silicic acid compositions. Moreover, this magmatic-hydrothermal transition may be directly responsible for concentrating rare elements.

Rare-element transport is generally thought to be restricted to highly evolved, vapor-undersaturated melts or hydrothermal-pneumatolytic fluids with solubility aided by anions and anionic complexes of principally F, Cl, P and S, though many deposits show little evidence of their presence. However, network-forming hydrated oxides and hydroxides of Al, Be, Ga, Ge, Fe, Mn and HFSE are commonly coprecipitated with silicic acids at pH ~6-8 in many chemical applications, suggesting they may do so during the magmatic-hydrothermal transition. Rare elements concentrated in sols--relatively low viscosity liquids that are either formed directly or through chemical and/or mechanical dispersion of gels--can be rapidly mobilized down pressure gradients and through density differences during deformation and/or containment rupture of mostly crystallized plutons.

After migration, sols can transition to gels, ideal media for growing in particular large and dense crystals due to their functionally infinite viscosities and diffusive capabilities. Moreover, materials scientists commonly crystallize gels as framework silicates. Natural sol-gel processes may produce rare-element pegmatites, greisens, rare metal-bearing quartz veins, etc. associated with parental plutons derived from fertile sources. Therefore, potentially ore-generating liquids may be composed of colloidal solids of silica and other network formers suspended within hydrothermal-pneumatolytic fluids that undergo gelation after emplacement.

Specifically, rare-element granitic pegmatites are envisioned to begin as one of these self-organizing systems, the products of alkali- and rare element-charged aluminosilicic hydrosol transport and gelation following emplacement. Then sequential crystallization of rock-forming and rare element-bearing minerals occurs from within aging hydrogels that possess evolving internal and exsolved external supercritical aqueous fluids and that fractionate to nearly pure silicic acid compositions. These fractionation and aging (long-range ordering) phenomena can lead to extreme monolithnicity, i.e. trace-element homogeneity throughout large crystals comprising massive quartz segregations (e.g. stockscheider quartz) and giant cores of granitic pegmatites. Similar pathways can be envisioned for alkalic and basic pegmatites.

SS10-03 **BULK COMPOSITION OF THE TANCO RARE-ELEMENT PEGMATITE, SOUTHEASTERN MANITOBA AND ITS PETROLOGICAL SIGNIFICANCE**

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The Tanco pegmatite deposit at Bernic Lake, SE Manitoba is a subhorizontal, bilobate, saddle-shaped body with shallow N dip and a double plunge to E and W. It is ~1990 m long, 1060 m in width, and up to ~100 m thick. The highly fractionated pegmatite of the rare-element class, petalite subtype, LCT-family consists of 9 internal zones. The outer zones are concentric, the layered inner zones are irregular and locally complex in shape. Tanco is an undeformed blind pegmatite, almost unaffected by erosion. A 3D computer representation of the pegmatite assisted in calculation of volumes and compositions of individual zones and of the whole pegmatite, based on 102 km of 1355 drillhole intersections, underground observations, measured and estimated mineral modes of the zones, zone-specific compositions plus densities of minerals, and ore grades. The bulk mode of Tanco is, in vol.%, 32.9 quartz, 29.3 albite, 20.0 K-feldspar, 8.8 petalite (incl. spodumene + quartz pseudomorphs), 2.6 muscovite, 2.4 lithian muscovite, 0.6 pollucite, 0.9 primary spodumene, 0.8 amblygonite, 0.4 beryl, 0.5 tourmaline, 0.2 lepidolite and lesser amounts of accessory minerals of Nb, Ta, Ti, Sn, Zr, Hf, U and P. The bulk composition of the Tanco pegmatite is SiO_2 76.0, Al_2O_3 13.6, TiO_2 0.02, Fe_2O_3 <0.01, FeO 0.1, MnO 0.2, MgO 0.01, CaO 0.15, Li_2O 0.74, Na_2O 3.80, K_2O 2.95, Rb_2O 0.57, Cs_2O 0.28, P_2O_5 0.86, B_2O_3 0.07, BeO 0.05, WO_3 0.00004, Nb_2O_5 ~0.003, Ta_2O_5 ~0.02, SnO_2 ~0.015, ZrO_2 0.004, HfO_2 0.001, UO_2 0.005, Sc_2O_3 0.0002, Ga_2O_3 0.010, Sb_2O_3 0.0002, ZnO 0.001, F_2 0.12, H_2O^+ 0.4, -F=O -0.05, total 99.80 wt.%. The bulk composition corresponds to that of a peraluminous leucogranite strongly enriched in Li, Rb, Cs, P (Be, Ta and Sn), close to experimental thermal trough in the Ab-Qtz-Ecr system at 2 kbar P(H_2O), but shifted to the feldspar apex by elevated B, P and F. The Tanco bulk composition is very close to that of its wall zone, which comprises 31 vol.% of the pegmatite, but the bulk composition is enriched in Li, Rb, Cs, Ta, P and F that are concentrated in the inner zones. The Tanco wall-zone and bulk composition (less the above enrichment) also are very close to those of nearby pegmatitic leucogranites parental to genetically related pegmatite groups. The data support derivation of the Tanco pegmatite and its analogs elsewhere by igneous fractionation from a fertile leucogranitic magma.

SS10-04

CONTRASTING ARCHAEAN RARE METAL PEGMATITES AT WODGINA AND GREENBUSHES, WESTERN AUSTRALIA

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Rare metal (Ta-Nb, Sn, Li) deposits in Archaean granitoid-greenstone terranes in Western Australia include the giant rare element class pegmatite deposits at Wodgina in the north Pilbara Craton and Greenbushes in the southwest Yilgarn Craton. Most pegmatites in the Pilbara, including Wodgina, are clustered along structural corridors and tied to emplacement of post-tectonic granite plutons. Although Greenbushes was also emplaced into a major structural corridor there is no known coeval granite.

The complex spodumene type Greenbushes pegmatite group has been syntectonically emplaced into a major shear zone in which a number of lenticular dykes, 2-50 m thick, merge at depth to form a single intrusive body up to 300 m thick. The pegmatite has distinctive primary assemblages, including: marginal aplitic albite-quartz, albite-quartz ±muscovite-tourmaline, quartz-microcline-perthite ±muscovite, spodumene ±quartz-muscovite-albite-microcline and tourmaline-rich assemblages. Crystallisation commenced at pressures of ~5 kbars and temperatures in excess of 800ºC. Most Ta-Nb-Sn minerals (tantalite-columbite, cassiterite) crystallised by about 650ºC, with some remobilisation during late-stage metasomatism at ~500ºC. These P-T-depth conditions are consistent with the prevailing amphibolite facies metamorphic conditions of the host metabasalt/dolerite.

LCT (Li-Cs-Ta) pegmatites in the Wodgina district are within a keel-shaped tongue of greenschist facies supracrustal rocks and adjacent to a post-tectonic granite. The albite type Wodgina main lode pegmatite dyke has been syn-deformationally emplaced into a komatiitic-basaltic sequence. It varies from a 5-40 m thick dyke to a saddle-like bulbous mass containing an irregular 'core' of quartz. This highly fractionated pegmatite has two main primary assemblages: massive cleavelandite albite with primary manganotantalite; and a central unit of banded aplite-granite textured albite-quartz-muscovite ±megacrystic perthitic microcline. Lepidolite alteration partially overprints the central unit, but the cleavelandite unit contains subordinate fine grained albite ±muscovite. In contrast, the albite spodumene type Mt. Cassiterite pegmatite group, adjacent to the Wodgina group, has been syntectonically emplaced into a thick metasedimentary sequence as a set of shallow dipping, stacked pegmatite sheets (2-100 m thick, mostly 5-12 m) that are interlinked by irregular dykes. Massive to comb-textured pegmatite is dominated by megacrystic spodumene and perthitic microcline with a fine-medium grained quartz-albite-muscovite matrix, and minor aplitic and K-feldspar rich layers. These may be overprinted by albite-muscovite alteration. Primary rare metal mineralisation is dominated by wodginite with subordinate columbite-tantalite and cassiterite.

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SS10-05 THE IMPORTANCE OF MAFIC WALLROCKS TO THE GENERATION OF LARGE PEGMATITE-HOSTED TANTALUM DEPOSITS

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One of the features that the world's largest tantalum deposits share is that the host pegmatites intruded metabasalt or metagabbro lithologies. This relationship is observed at the Wodgina and Greenbushes pegmatites, Western Australia, at Kenticha, Ethiopia and at Tanco, Manitoba. Where pegmatites intrude metasedimentary rocks, e.g., Phuket, Thailand, tantalum mineralization may be present, but the grade and/or tonnage of tantalum is lower. The tantalum pegmatite-mafic host rock association potentially can be explained as a geochemical trap or alternatively, by being structurally controlled. In the geochemical trap hypothesis the solubilities of tantalum minerals (tantalite and wodginite) in the granitic melts from which pegmatites crystallize depend on the concentrations of Fe and Mn in the melt, in addition to Ta and Nb. Thus contributions of Fe and/or Mn from the wallrock could control mineralization. In the structural hypothesis, the mafic rocks may be more brittle thereby providing better pathways along which the granitic melts can intrude. Tantalum pegmatites are also proximal to major faults, further indicating a potential structural control, however, this study focuses on the geochemical hypothesis.

It is well established that the mafic wallrocks around tantalum pegmatites gain highly mobile elements such as Li and Cs. However, it is not known whether the mafic wallrocks also lose Fe and Mn to the granitic melt (either by assimilation or fluid transport). The Tanco pegmatite intruded into metagabbro and, in addition, there are metagabbroic rafts within the pegmatite. At some localities tantalum grades increase toward the rafts, suggesting that the rafts may have influenced mineralization. A whole rock geochemical study of the metagabbro rafts was undertaken to establish the nature of the metasomatism of the rafts. Six diamond drill holes were studied and samples were taken at 0.5 to 5.0 foot intervals. Samples were taken at the shortest intervals at the contacts with pegmatite and the rafts are approximately 50 feet thick.

The whole rock geochemical data indicate gains of Li, Cs, Rb and F by the metagabbro, as expected. The Fe and Mn data are much more ambiguous due to the fact that the gabbro is chemically zoned. The mass balance calculations thus are challenging and different methods are currently being used to determine whether the metagabbroic rafts have gained or lost Fe and Mn.

SS10-06

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EVALUATING THE CHEMICAL ROLE OF METAGABBRO RAFTS ON TANTALUM MINERALISATION IN THE TANCO PEGMATITE, MANITOBA, CANADA

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Tantalum is an important 'high tech' metal, mainly mined from 'rare-element' pegmatites. The Tanco pegmatite, one of the world's major tantalum deposit, has the particularity to enclose xenoliths of the host metagabbro that caved off in the melt during pegmatite intrusion. An important observation is that tantalum concentrations are abnormally high close to these rafts. This leads to the question: are metagabbro rafts favourable or even critical to the development of elevated concentrations of tantalum? This study investigates the chemical role of the metagabbro rafts on colombite-tantalite crystallisation. A hypothesis is that Fe and Mn were transferred from the metagabbro to the pegmatite melt via aqueous or aqueous-carbonic fluids, which exerted a control on mineralization because these elements are major components of tantalum oxide minerals. Colombite-tantalite has been chosen among numerous tantalum oxides because of its large extent in all pegmatite zones and its well-known compositional and structural characteristics (Ercit, 1986). In particular, it has long been recognised that colombite-tantalite $(Fe,Mn)(Nb,Ta)_2O_6$ evolves by fractional crystallisation from ferrocolombite to manganotantalite (Cernì et al., 1986). It can thus be predicted that if the pegmatite crystallised in a closed system, then the Fe/Mn and Nb/Ta ratios in tantalite would both decrease with progressive crystallisation, i.e., with distance away from the rafts. By contrast, if fluids that were derived from, or interacted with the metagabbro were involved, the Fe/Mn trend would have been modified from its normal evolution by fractional crystallisation (indeed, these elements are highly concentrated in the metagabbro and easily mobilised by aqueous fluids). However, the Nb/Ta trend would have remained the same because these elements are nearly immobile (not transported by the fluid). In summary, depending on the shape of the Fe/Mn versus Nb/Ta evolution trend for tantalite, it should be possible to distinguish a closed-system magmatic evolution from a partially open magmatic-metasomatic system.

We sampled several transects of tantalum ore in the pegmatite adjacent to a metagabbro raft located in one of the main tantalum-rich part of the mine. Samples were studied in terms of petrography, mineralogy and chemical composition of tantalum oxides, as a function of distance from the rafts. Compositional diagrams for colombite-tantalite permit to conclude that the chemical role of the raft on colombite-tantalite crystallisation is minor. Other hypothesis about the role of the rafts are currently being investigated.

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SS10-07 THE BRAZIL LAKE PEGMATITE, SOUTHWESTERN NOVA SCOTIA: ROLE OF SODIUM METASOMATISM IN AN LCT-TYPE PEGMATITE OF MAGMATIC PARENTAGE

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The Brazil Lake Pegmatite (BLP) occurs in metasedimentary and metavolcanic rocks of the Silurian White Rock Formation, southwestern Nova Scotia, and crystallized at 378 ± 1 Ma (concordant U/Pb tantalite age). The BLP occurs ca. 10 km west of the termination of the chemically evolved, peraluminous, F- and Li-rich Davis Lake Pluton (DLP), part of the 380 Ma South Mountain Batholith. The pegmatites form a NE-trending, steeply-dipping, en echelon dyke swarm ca. 700 m long with individual pegmatites < 10-20 m width. Detailed mapping of the southern dykes revealed the following assemblages: (1) heterogeneous nucleation of coarse (1-2 m) Kfs and Spd crystals oriented perpendicular to the contact; (2) intergranular Qtz-Kfs-Ab-Ms-Spd between the coarse Kfs and Spd with mineral proportions varying considerably; and (3) a locally developed wall zone of fine-grained pegmatite with quartz enrichment. Secondary mineral growth is recorded by: (1) abundant exomorphic tourmaline in the wallrock quartzite and mafic volcanics, and replacing inclusions of volcanic rock near contacts; (2) silicification of the wall rock; (3) abundant, fine-grained sacchroidal-textured albite and euhedral cleavelandite replacing primary pegmatitic Kfs ($Or_{75}Ab_{25}$; K/Rb=20, K/Cs=450-1000); and (4) abundant muscovite (Rb=<5000 ppm, Li=330-1500 ppm) after Kfs. In addition to the major phases, accessory minerals, many of which are secondary and occur in albite-rich rock, include apatite (Mn- and F-rich types), Mn-rich garnet, triplite, beryl, topaz, Ta-Nb oxides, cassiterite, biotite, titanite, lithiophillite, fillowite, and amblygonite/montebrasite. Whole-rock analyses of pegmatite samples indicate positive correlations for P, Ca, Ta versus Na, which reflects metasomatic mobility of the elements. Our observations indicate that a primary assemblage of Kfs-Qtz-Spd-Ms was modified by interaction with a Na-rich, magmatic fluid that formed albite/cleavelandite - rich zones after primary Kfs with enrichment in Nb-Ta oxides and associated secondary Li-P phases. Liberation of K during Kfs destructive alteration was sequestered in secondary muscovite. Preliminary fluid inclusions measurements (Th=200-300oC, 5-25 wt% eq. NaCl) combined with the absence of petalite in the BLP constrains initial formation conditions to ca.550°C and 3-3.5 Kbars with subsequent PT evolution similar to that at the Tanco pegmatite. Initial del18O isotopic analysis (per mil) indicate: Qtz=8.4-10, Ms=7-7.8, Spd=6.2-7.1, Ab=8.5-8.8, Tur=6.8-8.0, Grt=9-11.1. These data indicate an initial magmatic system was contaminated by the country rock via fluid interaction as the system cooled. The BLP melt is considered to represent an evolved fractionate of the DLP found at depth or laterally from this site.

SS10-08 RUTILE COMPOSITIONS IN THE SOUTH MOUNTAIN BATHOLITH, NOVA SCOTIA

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The late Devonian South Mountain Batholith is a highly differentiated peraluminous granite complex ranging in composition from early-stage biotite granodiorite to late-stage topaz leucogranite. Oxide minerals are rare, with ilmenite more abundant than rutile in the primitive rocks and rutile more abundant that ilmenite in the evolved rocks. Rutile is invariably fine grained (generally less than 0.1 mm), and it may occur in several texturally distinct types, including: 1. discrete euhedral-subhedral primary magmatic grains; 2. possible anhedral xenocrysts or restites; 3. possible exsolution needles from titaniferous biotite; 4. anhedral secondary grains after chloritization of biotite; and 5. secondary grains after hydrothermal alteration of ilmenite. Rutiles that appear to be texturally primary magmatic (subhedral to euhedral, blocky to prismatic, inclusions in biotite and feldspar) occur predominantly in the most highly fractionated rocks and have the following compositional ranges (wt%): Fe (0.1-2.7), Nb (0.1-2.2), Ta (0-1.1), Sn (0-0.3), W (0-0.9), and Th (0-0.08). Concentrations of these elements also appear to increase with magmatic evolution. With differentiation in the batholith, the whole-rock Nb/Ta ratio decreases from ~15 to 3, whereas the rutile Nb/Ta ratio increases from ~5 to ~20. Rutile with the highest concentrations of W (3-6%) occurs in a highly enigmatic (diatexitic? cumulitic? hydrothermally altered?) rock that is spatially related to quartz veins containing wolframite-scheelite mineralization. Magmatic rutile acts as a sink for Nb-Ta-Sn-W-Th throughout the evolution of the batholith, and its composition may serve as gauge of magmatic evolution and perhaps even proximity to mineral deposits.

SS10-09 THE LITTLE NAHANNI PEGMATITE GROUP - DECIPHERING THE EVIDENCE

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This study focuses on the Cretaceous Little Nahanni Pegmatite Group (LNPG), a rare element, lithium-caesium-tantalum (LCT)-type pegmatitic dike swarm emplaced into sub-greenschist facies Precambrian to Middle Devonian sedimentary strata of the Selwyn Basin, in the Northwest Territories (62-63° N, 128-130° W, NTS 105I). The dikes are spatially associated with several small (~5 km diameter) mid-Cretaceous S-type granitic intrusions showing W-Sn-Mo-Cu-Au mineralization. The commonly steeply-dipping, high-aspect ratio dikes with up to 500 m of vertical exposure, transect a ridge above tree level, thus providing exceptional access to the system which covers an area of ~55 km^2.

The pegmatitic dikes consist of K-feldspar, plagioclase, quartz, mica (muscovite to lepidolite), columbite-group minerals, cassiterite, tourmaline, beryl, lithiophilite and garnet. The dikes show textural discontinuity, commonly restricted to the decimetre to metre-scale, of classic pegmatitic style (line-rock, comb layering, etc), suggesting a dynamic environment, possibly reflecting pressure variations during initial dike formation.

Tantalum and Sn concentrations are on average higher in mineralogically simple dikes (predominantly quartz and mica; 234 g/t Ta_2O_5 and 0.63 wt% SnO_2), however spodumene-quartz-feldspar-lepidolite and quartz-feldspar-lepidolite dikes can also contain high concentrations of tantalum. The central area of the dike swarm is lithium-rich, and this system-scale zonation of the mineralisation has drawn comparisons with the Greenbushes Pegmatite Group in Australia.

Other primary mineralogical and textural zonations have been observed, which are also believed to be representative of the system. At low elevations one dike contains spodumene, lepidolite, muscovite, potassium feldspar, quartz, albite, garnet, tourmaline, Nb-Ta oxides, fluorite and phosphate minerals, while at 300 m higher elevation the dike shows a decreased mineralogical diversity, with only rare garnet, fluorite and phosphate minerals, and a greater abundance of quartz.

Miarolitic cavities are rare, but cavities resulting from brecciation occur at higher elevations, and commonly display bladed calcite. Preliminary work indicates this is associated with a proximal system of quartz veins and country rock brecciation.

This exceptional exposure of the dikes and the geochemical and textural variations occurring throughout, places constraints on the evolution of the system. This model displays some features common to all pegmatites, but also has some distinct characteristics unique to LNPG.

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SS10-10

GEOLOGY, MINERALOGY, AND STRUCTURAL SETTING OF THE REGAL RIDGE EMERALD PROPERTY, FINLAYSON LAKE DISTRICT, SOUTHEASTERN YUKON

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Emerald at the Regal Ridge property in the Finlayson Lake district of southeastern Yukon is hosted within quartz veins intruding mid-Paleozoic mafic metavolcanic and metaplutonic rocks. The main host rocks for the mineralization are a foliated green-grey chlorite-plagioclase schist, and a biotite-actinolite-plagioclase amphibolite, or leuco-gabbro. Both host rock types plot as high-Ca boninites, and contain anomalously high chromium values (approximately 800 ppm Cr). These rocks overly the shallowly dipping western edge of a 112 Ma quartz monzonite body. At least two of the numerous aplite dikes associated with the quartz monzonite contain beryl (+/- emerald) within quartz-rich segregations. Beryl-bearing aplites chemically differ from non-mineralized intrusions by having lower K and F and higher Be contents. Beryl mineralization occurs in the area of intersection between quartz veins, on the edges of quartz veins within highly-altered schist, and within the quartz veins themselves. Several generations of syn- to late tectonic quartz veins are present at Regal Ridge, and emerald appears to be mainly associated with the latest vein set. All of the quartz veining is thought to be related to progressive Cretaceous deformation and the relatively late emplacement of the quartz monzonite intrusions. Beryl/emerald and tourmaline compositions are being used to study the chemistry of the mineralizing fluids and elemental controls on Be and Cr transport and deposition. Oxygen and hydrogen isotopes will be used to assess the extent of interaction between the mineralizing fluids and the host rocks.

SS10-11 GEOLOGY AND MINERALOGY OF THE TRUE BLUE GEM BERYL PROPERTY, SOUTHERN YUKON

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The True Blue property is located in the Ketza-Seagull District of the southern Yukon Territory, within the Cassiar Platform and southwest of the Tintina Fault. Beryl was discovered on the property in 1976, and gem beryl in 2003. The crystals occurs in a swarm of closely spaced quartz ± siderite ± fluorite ± tourmaline veins that fill tension gashes in a Mississippian-age (~360 My) syenite stock. The veins range in thickness from 0.5 to 20 cm, and locally comprise up to 30% of the rock. The vein zone measures 700 × 200 m in outcrop at the surface, and is exposed over an elevation range of 100 m. Within this area, more than 100 individual occurrences have been discovered. The vein zone is developed near the upper contact of the syenite intrusive body with Lower Paleozoic pelitic and carbonate country rocks. The syenite is sodic in composition (~8 wt% Na2O) and contains moderately high concentrations of Be (to ~10 ppm), F (to ~4000 ppm), and rare-earth elements.

The beryl crystals range in size from a few mm to 5 × 2.5 cm, and in colour from pale to medium green and from pale to dark blue. Some of the crystals, especially those occurring with tourmaline, show a blue core and green rim. The dark blue material is noteworthy for the hue (which is maintained at very small sizes for aquamarine) and for the exceptionally strong dichroism. Electron microprobe analyses show high concentrations of Fe (to 5.81 wt% FeO), Mg (to 3.27 wt% MgO), and Na (to 2.51 wt% Na_2O). Preliminary crystal-structure analysis suggests that all of the Fe is at the octahedral site, and also shows Be substitution at the Si site (to 0.33 Be apfu). Iron is most likely the chromophore responsible for the dark blue colour.

Previous discoveries of gem beryl in northwestern Canada include the Lened (western Northwest Territories) and Regal Ridge (southern Yukon) emerald properties. This most recent discovery confirms that the region is (locally) rich in Be and suggests that the potential exists for more gem beryl mineralization.

SS10-12

Characteristics and geomorphogeny of the columbite-tantalite placer deposits: a case study in the Issia Nb-Ta District, central western Ivory Coast

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The Etienne-Meguhe and Bemadi mines are two of the columbite-tantalite placer deposits, located in the Issia district, Central Western Ivory Coast. They are different in geomorphology, style of mineralization and geological evolution.

The Etienne-Meguhe mine occurs in a large interfluve. The paleotopography of this deposit doesn't reveal any mark of old water channel. The upper part of the soil shows an extreme oxidation characterized by residual lateritic soils of ferralitic type. The mineralized gravel contains almost all the pegmatite minerals, and it's marked by a pronounced lateral discontinuity, an angular shape of the rock debris and a coarse texture. It's also characterized by a great proportion of Nb-Ta minerals having their initial crystalline shapes preserved (about 36 %) or having irregular or fairly irregular contours (about 61 %) with relatively coarse grain.

The Bemadi mine covers a group of three valleys with old rivers flow channels. In this deposit, the paleotopography shows the existence of old drainage channels dug in the micaschists on both sides of pegmatites. These channels have been displaced during the geomorphic processes. In this case, the soil is much leached. The mineralized gravel is marked by a great lateral continuity, the roundness of the rock debris, which contain hardly any minerals of weak resistance to meteoric weathering (feldspars, micas). The proportion of Nb-Ta minerals with rounded contours is very important (34 to 63 %). The Nb-Ta grain size is generally very reduced (comparing to what is observed in the Etienne-Meguhe mine) and decrease from upstream to down stream of the rivers.

The chemical composition of the Nb-Ta minerals from the Etienne-Meguhe mine as well as that from the Bémadi mine hasn't change compared to those from the fresh pegmatites.

It emerges from our studies that the Etienne-Meguhe mine results in the in situ re-concentration of the Nb-Ta minerals. This in situ re-concentration has been favoured by a volume reduction on the spot, due to the kaolinization of large feldspar and muscovite minerals from pegmatites. On the other hand, the Bemadi mine results from a transport followed by a re-concentration of the metal-bearing minerals. In this case, the Nb-Ta mineral's re-concentration was caused by an important aggradation phase which stored the fragmented and rounded metal along natural traps.

Even if the chemical quality of the metal is preserved, the physical quality is, on the other hand degraded gradually from the eluvial zones to the alluvial zones.

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SS10-13

GEOCHEMISTRY AND ECONOMIC POTENTIAL OF COLUMBITE-GROUP MINERALS FROM GRANITIC PEGMATITES OF THE PAMPEAN RANGES, ARGENTINA

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Columbite-group minerals (CGM) were studied from 30 rare-element granitic pegmatites representative of 7 (out of a total of 8) LCT-family pegmatite fields that comprise the Pampean pegmatite province of Argentina. The province extends ~900 km in the N-S direction, and is located in upper-greenschist- to lower-amphibolite-facies rocks of an Abukuma-type metamorphic belt, dominantly composed of metagreywackes and metapelites. The pegmatites belong to the beryl (beryl-columbite, beryl-columbite-phosphate), complex (spodumene, rarely petalite or lepidolite) and albite types. They are are related mainly to late-orogenic, Cambrian to Silurian, calc-akaline, S-(+I)-type granites, and in part to post-orogenic, Devonian to Upper Carboniferous, high-K, calc-alkaline monzogranites. Over 400 EMP analyses of the CGMs were performed. The most primitive ferrocolumbite characterizes the beryl-type pegmatites, particularly the post-orogenic sequence; in the late-orogenic suite, they show incipient enrichment in both Mn and Ta. In contrast, manganocolumbite to manganotantalite are typical of the petalite- and lepidolite-subtype pegmatites. CGMs from spodumene-subtype pegmatites are highly variable across the province, generally with extensive ranges of Ta/(Ta+Nb) and locally with near-extreme enrichment in Mn; however, in some cases the CGM compositions are virtually restricted to ferrocolumbite on one hand, or to manganotantalite on the other. Pegmatites of the albite type cluster at intermediate values of both Mn/(Mn+Fe) and Ta/(Ta+Nb). With very few exceptions, individual and collective concentrations of Mg, Ca, Zn, Bi, Sb, As, Y, U, Sn, Zr, Ti and W are below 10% (at.); in individual pegmatite categories, these trace elements show variations restricted to +10x up to -10x their average contents in CGMs from beryl-columbite pegmatites. Eighty sets of unit-cell parameters on natural and heated CGMs were refined. They cluster at moderately disordered and moderately ordered values, with some intermediate data and none that would correspond to extreme order or disorder. Disorder is positively correlated with trace-element content; however, all heat-treated samples developed a well-ordered structure. Geochemical indicators suggest that the petalite-, lepidolite-, and some of the spodumene-subtype pegmatites are most promising sources of Ta > Nb mineral concentrates; however, none of these pegmatites are sufficiently rich in the CGMs. Thus it is possible that some pegmatites of the spodumene and other categories may be more enriched in Ta because of a higher content of Ta-poorer CGMs. This can be, however, established only by quantitative exploration of individual localities.

SS10-14 CHEMICAL EVOLUTION OF NB-TA OXIDES AND ZIRCON FROM THE KOKTOKAY NO. 3 GRANITIC PEGMATITE DYKE, ALTAI, NORTHWESTERN CHINA

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WITHDRAWN

SS10-15 THE HYDROTHERMAL GEOCHEMISTRY OF THE RARE EARTH ELEMENTS

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The hydrothermal geochemistry of the rare earth elements (REE) is relevant to the formation of economic REE deposits, radioactive waste disposal, and the use of REE as petrogenetic tracers. The REE occur primarily as trivalent ions, and are hard in the Pearson sense, meaning that they preferentially form complexes with hard ligands such as hydroxide, fluoride and carbonate. However, relatively little is known about the behavior of REE complexes or the solubility of REE minerals at elevated temperatures and pressures. Recent experimental studies on this subject will be reviewed in this paper. The stability constants of Nd complexes with chloride, hydroxide and acetate, and the solubility of monazite (Nd phosphate) have recently been measured experimentally up to 250-300°C. Although chloride complexes of Nd are weak at low temperatures, they become increasingly stronger as temperature increases and may play a significant role in REE transport at temperatures above 200°C. Hydroxide complexes also become stronger with increasing temperature but the database for these species is still incomplete. The experimental studies show that recent theoretical estimates of stability constants are too low for chloride and acetate complexes and too high for hydroxide complexes, thus emphasizing the need for continued experiments. Recent studies of REE phosphates (monazite, xenotime) show that, in the absence of strong complexing agents, the solubilities of these phases are very low except at very low pH (< 2). The solubilities of these phases are also retrograde (i.e., decrease with increasing temperature) to at least 300°C. These data are consistent with the generally very low REE contents measured in modern geothermal systems, except in acid-sulfate systems where the pH is low. Most modern geothermal systems lack sufficiently high concentrations of strong ligands such as fluoride to support high REE concentrations. Thus, it can be concluded that hydrothermal concentrations of REE minerals, such as observed at Olympic Dam, Australia; Gallinas Mountains, New Mexico; Pea Ridge, Missouri; Lemhi Pass, Idaho/Montana, etc., must have been formed from solutions with very low pH, very high concentrations of strong ligands such as fluoride or carbonate, much higher temperatures than have been determined experimentally, or some combination of these factors.

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ND ISOTOPIC STUDY OF REE SOURCES IN ECONOMIC VS SUBECONOMIC MINERALISATION IN THE OLYMPIC CU-AU PROVINCE, SOUTH AUSTRALIA

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Mesoproterozoic and Paleoproterozoic basement of the Olympic Cu-Au province on the eastern margin of the Gawler Craton, South Australia, is host to the giant Olympic Dam iron-oxide-Cu-Au-Ag-REE deposit and numerous Cu-Au+U prospects. Although the Olympic Dam deposit contains about 10 Mt of REEs (mainly La and Ce), they are currently uneconomic to recover. Three major regions of hydrothermal Fe-oxide rich alteration and mineralisation are identified from north to south: Mount Woods Inlier, Stuart Shelf basement (including the Olympic Dam deposit), and Moonta-Wallaroo region. Each of these regions contains high-, moderate- and low-temperature Fe-oxide rich alteration, Cu-Au±U mineralisation, and felsic to mafic ca 1580 Ma intrusions of the Hiltaba Suite with or without coeval Gawler Range Volcanics.

Most current models of the Olympic Dam deposit suggest two fluid sources, an early higher temperature fluid and a later lower temperature near surface fluid to explain deposit formation, but the source(s) of ore fluids and metals throughout the Olympic Cu-Au province remains contentious. Existing S and Nd isotopic data from Olympic Dam ore minerals suggests a mantle-derived magmatic fluid source association for that deposit. We have compared the S and Nd isotopic compositions of several prospects from the Olympic C-Au province with regional rock types and with published data from the Olympic Dam deposit. If an external mantle input as indicated by S and Nd isotope data is crucial to Olympic Dam Cu-rich ore, then covariation in Nd and S isotope signature in other Cu-Au regimes may serve to discriminate between weakly vs highly mineralised zones.

Existing $\delta^{34}S$ studies from Olympic Dam yield chalcopyrite values around –7 ‰, and $\varepsilon_{Nd(1580\ Ma)}$ pyrite-chalcopyrite ores values around –2.5. Our isotope data from prospects in the Mt Woods Inlier and Stuart Shelf basement region suggest either largely crustal sources for both S and REE (Emmie Bluff), or mantle source of S and crustal source of REE (sub-economic mineralisation zones at other prospects). This is in contrast to the dominant mantle-derived source of REE components at Olympic Dam.

Recognition of large structures associated with igneous emplacement and Fe-rich alteration are important targets in exploration for Fe-oxide Cu-Au deposits on the Gawler Craton. When a prospect is identified, the S and Nd isotope geochemistry may assist in differentiating economic vs subeconomic mineralisation.

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FLUID INCLUSION CHARACTERISTICS AND GENESIS OF THE REE (PARISITE) MINERALIZATION IN THE SNOWBIRD DEPOSIT, MONTANA

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The Snowbird fluorite-rare earth element (REE) deposit is unusual in that it is characterized by very coarse-grained hydrothermal quartz, calcite and fluorite. Also, the rare mineral parisite-(Ce) {$Ca(Ce,La,Nd,Pr,Y)_2(CO_3)_3F_2$}, which is typically associated with ankerite in the deposit, occurs as exceptionally large (up to 24 cm in length) and abundant crystals. Snowbird is one of a number of ankerite-bearing deposits hosted by the Belt Supergroup metasedimentary rocks that have been linked to mineralization in the Coeur d'Alene district. Fluid inclusions in quartz, fluorite, ankerite, and parisite from the Snowbird deposit were investigated using petrography, microthermometry, bulk leachate and gas chromatographic analyses. Ankerite and parisite are cogenetic and were deposited throughout the paragenesis of the Snowbird deposit. The fluid inclusions most closely associated with parisite and ankerite contain aqueous liquid, one or two carbonic phases, and a halite crystal at room temperature. The fluid from which parisite was deposited had a relatively high-salinity (33-50 eq. wt% NaCl) and was dominated by Na and Ca with Ca/(Na + Ca) = 0.1-0.2. The carbonic component was dominated by CO_2, with minor CH_4 and N_2, and the bulk XCO_2 was less than or equal to 0.11. The minimum temperature and pressure of parisite deposition is estimated to be 400-500°C and 200-300 MPa, respectively. Later fluorite was precipitated from similar fluids, but with more variable CO_2 contents and lower salinities (down to ~ 29 equiv. wt% NaCl). Fluorite deposition was followed by the infiltration of lower-salinity aqueous fluids.

Our paragenetic and fluid inclusion observations combined with previously published radiometric age dates, Sr isotopic data, and mineral chemistry suggest that the entire Snowbird deposit was formed in the Cretaceous from fluids derived from the Idaho batholith and that at least partially equilibrated with the Belt Supergroup metasedimentary rocks. Furthermore, we conclude that Snowbird is unrelated genetically to the base metal and silver mineralization of the Coeur d'Alene district, which generally have been interpreted to have formed from dominantly metamorphic fluids. The fluids from which parisite was deposited at Snowbird are strikingly similar to those responsible for emerald and parisite at Muzo, Columbia, apparently the only other locality with a similar occurrence of coarse-grained parisite.

SS10-18 **HYDROTHERMAL NB—APATITE- (SULPHIDE) MINERALISATION IN CARBONATITES: PETROGRAPHIC, GEOCHEMICAL AND FLUID INCLUSION EVIDENCE FROM THE SOKLI CARBONATITE, FINLAND**

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Most of the world's niobium and a significant proportion of its phosphate reserves are associated with carbonatites either as orthomagmatic/hydrothermal deposits or as secondary enrichments in residual soils. Our understanding of the evolution of orthomagmatic, hydrothermal (carbothermal) fluids and their role in the mineralisation and alteration (fenitisation) processes in carbonatite complexes has improved significantly in recent years. However, the characterisation of these fluids related to specific apatite-pyrochlore-mineralised carbonatites, based on integrated fluid inclusion and paragenetic studies, is somewhat limited. In this paper we report on previously unpublished data for the 363-368 Ma Sokli carbonatite of Northeast Finland, which is one of the world's largest carbonatite complexes with proven reserves of 100,000t Nb and significant P in regolithic soils overlying carbonatites and phoscorites. Apatite and pyrochlore from unweathered rocks display variable and complex textures reflecting extensive metasomatic and hydrothermal processes within these rocks. However, there is a broad association between pyrochore-apatite-(Fe-Cu)sulphides (PAS), tetra-ferri-phlogopite and magnetite in much of the complex; this is less apparent in earlier calcite carbonatites where isolated apatites may also occur. Drill-core assay and whole rock geochemical data for Nb, P, S and Cu support this view. Fluid inclusions in apatites from the PAS assemblage are predominantly primary, aqueous L+V+/-S types. Rarer monophase aqueous and gaseous inclusions probably result from necking-down. L+V+/-S inclusions may contain small amounts of pure CO_2, and the predominant daughter minerals are nahcolite, amphibole and small, unidentified, opaque phases. Halite and sylvite are less common but occur in residues from opened inclusions under the SEM. The K: Na wt. ratios of these fluids from crush-leach analyses range from 0.76 to 0.25. Salinities are mostly in the range 5 to 20 equiv. wt% NaCl and homogenisation temperatures from 70 to 200^{o}C. Isochoric projections to an assumed crystallisation temperature of 400 - 500^{o}C suggest trapping pressures of about 4 Kbar. In other samples, where apatite shows little relationship to the PAS assemblage, a population of inclusions with homogenisation temperatures from 300 to 370^{o}C is also observed. These probably represent early orthomagmatic fluids derived in situ from the cooling carbonatite magma at pressures between 6 and 8 Kbar and temperatures above 600^{o}C. Portions of carbonatite melt are represented by rare multisolid inclusions, which fail to homogenise and often leaked on heating to 600^{o}C. The fluids responsible for PAS mineralisation are interpreted as orthomagmatic, carbonatite-derived fluids, which interacted with the host carbonatites after emplacement and cooling.

SS10-19 METALLOGENY OF THE S-60 ZONE OF THE OKA CARBONATITE, QUÉBEC

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The Oka carbonatite contains several zones of Nb ore. Niocan's S-60 zone is hosted by discontinuous bands of forsterite-magnetite-apatite, diopside-magnetite-apatite, and forsterite carbonatite carrying up to 5% pyrochlore. It forms a circular, sub-vertical, chimney about 125 m in diameter that contains a reserve of 14.37 Mt at 0.66% Nb_2O_5. The HWM-2 is hosted by bands of richterite, magnetite, and phlogopite carbonatite that contain niocalite, latrappite and pyrochlore in a zone parallel to the margin of the complex. The HWM-2 contains 5.95 Mt at 0.56% Nb_2O_5 and it bears similarities to the St. Lawrence Columbium ore zones.

Niobium is partitioned in four types of pyrochlore. Early Type 1 forms idiomorphic inclusions in calcite and apatite. Type 2 is idiomorphic, interstitial to calcite and apatite, whereas Type 3 forms hypidiomorphic inclusions in diopside. Later Type 4 forms hypidiomorphic that are commonly poecilitic and replace calcite and apatite. The chemical composition of pyrochlore covaries with that of its hostrock, without relation to the texture or paragenetic stage. Calcite carbonatite contains pyrochlore depleted in Ta, U and Th, whereas phlogopite carbonatite is depleted in Zr and Th. Pyrochlore hosted in magnetite and diopside carbonatite is enriched in Ta and U and depleted in Th. Pyrochlore in forsterite, forsterite-magnetite-apatite and diopside-magnetite-apatite carbonatite is enriched in Th and depleted in U. Major element geochemistry indicates that fractional crystallization of calcite carbonatite enriched the magma in Fe, Mn and F and led to formation of ferrocarbonatite in the S-60 zone under low oxygen fugacity. A decrease of $FeO/(FeO+Fe_2O_3)$ from a range of 0.38 to 0.44 in calciocarbonatites to a range of 0.31 to 0.35 in ferrocarbonatites suggests increasing oxygen fugacity during the later stages of fractional crystallization. Enrichment of incompatible F in ferrocarbonatite is accompanied by increased Nb grade. Crystallization of apatite, containing up to 4% F, in ferrocarbonatite depress fluorine fugacity causing Nb to be trapped in Type 4 pyrochlore. The distinctive magnetite and apatite rich carbonatites of the S-60 zone therefore are interpreted to be a product of a higher degree of fractional crystallization of the carbonatite magma.

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SS10-20 SCANDIUM AND ZIRCONIUM MINERALIZATION OF THE WESTERN SUBCOMPLEX OF THE DEADHORSE CREEK 'DIATREME'

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The Deadhorse Creek 'diatreme' is an igneous breccia located 25 km northwest of the town of Marathon, Ontario. Following development of the breccia, three events were involved in the formation of this occurrence: intrusion by granitic fluids; alkaline metasomatism; and thermal metamorphism. Following these events, the occurrence experienced weathering. The main mineralized zone is enriched in: first and second period transition metals; REE; Be; and the actinides Th and U. The mineralization is represented by the presence of: thortveitite, aegirine-jervisite, aegirine-natalyite, ilmenorutile, rutile, V-crichtonite, Ba-Mn-hollandite, zircon, monazite-(Ce), xenotime-(Y), uraninite, thorite, thorogummite, barite, barylite, phenakite, pyrite, hematite, magnetite and a few unnamed mineral species. This presentation concentrates on: thortveitite, the Sc- and V-clinopyroxenes and zircon-coffinite-thorite solid solutions.

Scandium mineralization is present in the form of thortveitite (primary) and Sc- and V-clinopyroxenes (secondary). Thortveitite occurs in association with a granitic mineral assemblage of: albite, potassium feldspar and quartz. Associated phases include: calcite, fluorite, apatite and an unnamed Ti-Cr-V-oxide. Because of the small size of the grains, quantitative analysis was not possible. However, X-ray spectroscopic data indicate relatively pure $Sc_2Si_2O_7$, with minor contents of Y_2O_3, MnO, CaO and FeO. Associated minerals do no contain any detectable Sc_2O_3 contents.

Aegirine-jervisite and aegirine-natalyite solid solutions are present in the main mineralized zone in trace amounts. These have the highest reported concentrations of Sc_2O_3 and V_2O_3 in aegirine (15.5 and 16.5 wt%, respectively). In addition, minor amounts of TiO_2 and Cr_2O_3 are present (< 4.0 wt%). The clinopyroxenes are believed to have formed during the waning stages of alkaline metasomatism that affected the main mineralized zone.

Zircon and hydrated metamict zircon are ubiquitous throughout the main mineralized zone. Although a few samples contain euhedral grains, the majority of zircon is present in an anhedral metamict state. This is to be expected, given the abundance of actinides within the complex and the alkaline metasomatic event. ThO_2 and UO_2 are incorporated at the expense of ZrO_2, and CaO contents increase with the degree of metamictization. While ThO_2 contents of the metamict zircon reach a maximum of 22 wt%, UO_2 contents essentially grade into coffinite (81 wt% UO_2). CaO contents of the metamict zircon reach a maximum of 6.5 wt% and are greater in the actinide-enriched grains. Taking into consideration the few experimental solubility studies, these extreme compositions are probably not thermodynamically stable and may represent metastable phases produced by the decomposition of zircon, thorite and coffinite during alkaline metasomatism.

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SS10-21 LANTHANIDE AND ACTINIDE REMOBILIZATION BY ALTERATION OF THE METAMICT ZIRCON IN THE GEORGEVILLE ALKALI FELDSPAR GRANITE, NOVA SCOTIA

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The Georgeville alkali feldspar granite is a small (1.5 km diameter) epizonal stock composed predominantly of quartz, microcline and albite (An_0) with subordinate amounts of biotite near the contacts with the host metaturbidites. Accessory minerals in the granite and associated pegmatites include zircon (cyrtolite) and pyrite, with rare polycrase, fergusonite, cassiterite, ferrocolumbite, beryl and topaz. The granite is characterized by high SiO_2 (75-80 wt%), Th, Nb, Y and Zr, low CaO, TiO_2, MgO, FeO, extreme depletion of LREEs and anomalous epsilon Nd values (-1.0 to -7.25) relative to other crustally-derived felsic rocks in the region. X-ray and electron microprobe analyses and high resolution TEM examination of the metamict zircon reveal extensive remobilization of REEs, Y, Th, and U by aqueous fluids after amorphization. The presence of secondary phases such as REE carbonates in open fissures and Th-rich silicates within and surrounding zircon provides additional proof of rare element mobility in the granite. The patterns of alteration in individual zircon grains correspond closely to radiation-induced domains of high permeability. We suggest that the initial whole rock REE and isotopic signatures were modified by the preferential leaching and redeposition of lanthanides and actinides from the metamict zircons by late hydrothermal fluids.

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SS10-22 THE PROTEROZOIC MANGABEIRA SN-IN MINERALIZATION, CENTRAL BRAZIL: GEOLOGICAL AND GEOCHEMICAL CHARACTERIZATION

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In central Brazil, granite-related tin deposits have been exploited as small mines since 1960, producing around 15,000 t of tin concentrates. The most important deposits are associated with Paleo to Mesoproterozoic (1.78 - 1.50 Ga) within-plate granites, which are rich in F, Sn, Rb, Y, Th, Nb, Ga and REE and have high F/Li ratios and Nb/Ta > 1. The Mangabeira deposit, the only one that is indium-rich, is hosted in the Mangabeira granitic massif (~2 Km^2), which comprises evolved Li-siderophyllite granite, topaz-albite granite, Sn-mineralized Li-muscovite and zinnwaldite greisens and In-rich quartz-topaz rock. The In-rich quartz-topaz rock occurs as an elongated body within the topaz-albite granite and resembles topazites, described as magmatic rocks in the literature. The rock is white, massif, composed of quartz, topaz, zinnwaldite, arsenopyrite and In-bearing cassiterite (0.2-0.4 wt% In), with minor sphalerite, wolframite, löllingite, chalcopyrite, bismuthinite, galena, stannite, tennantite, indium minerals (yanomamite, $InAsO_4.2H_2O$, roquesite, $CuInS_2$, and dzhalindite, $In(OH)_3$) and secondary hydrated arsenates of Sn, U, Ba, K, Pb and Bi. The area was weakly affected by the Panafrican/Brasiliano event (~0.6 Ga).

Primary H_2O-NaCl two-phase and saturated fluid inclusions are preserved in quartz from the topaz-albite granite and in quartz and topaz from the quartz-topaz rock. The granite fluid inclusions are more saline (47-51 wt% NaCl equiv. for three-phase and 18-20 wt% NaCl equiv. for two-phase inclusions) and homogenize at higher temperatures (T_H = 400-450°C) than those from the quartz-topaz rock (42-47 wt% NaCl equiv. for three-phase and 11-13 wt% NaCl equiv. for two-phase inclusions; T_H = 300-400°C). Coeval low saline (0-4 wt% NaCl equiv.) H_2O-CO_2-(NaCl) fluids are preserved (T_H = 250-400°C) in both rocks. The estimated temperature of the greisen formation based on $\delta^{18}O$ obtained on cassiterite-Li-muscovite pairs is around 350°C, which is in agreement with fluid inclusion data. The $\delta^{18}O$ values for Li-muscovite, zinnwaldite and cassiterite from mineralized greisens indicate $\delta^{18}O_{fluid}$ of 3.5-5.0, which denote mixing between magmatic and minor meteoric fluids. Sulphur isotope data on arsenopyrite from the quartz-topaz rock vary from -1.74 to -0.74 ‰, consistent with magmatic origin.

The obtained fluid inclusion and isotopic data are coherent with a similar hydrothermal genesis for the quartz-topaz rock and greisens, as well as for the related Mangabeira Sn-In mineralization, which involved exsolution of Sn-In-bearing volatile-rich saline H_2O-NaCl-CO_2 fluids from the topaz-albite granite during its cooling history and late mixing with meteoric water.

SS10-23 GALLIUM IN K-FELDSPAR: A POSSIBLE DISCRIMINANT FOR LCT AND NYF PEGMATITES?

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Gallium is present as a common trace constituent at widely variable levels in K-feldspar of granitic pegmatites. K-feldspar from several worldwide pegmatite localities was analyzed to evaluate whether the concentration of Ga may be used as an effective means for discriminating granitic pegmatites of LCT and NYF affinity. The LCT pegmatites examined range from simple to highly evolved members of the rare-element and miarolitic classes and include beryl-columbite (± phosphate), spodumene, petalite and lepidolite sub-types. Miarolitic pegmatites hosted by A-type granitoids and pegmatites containing amazonite or substantial REE mineralization were selected as representatives of the NYF geochemical family.

The concentration of Ga in K-feldspars from granitic pegmatites is typically in the range of 10 to 100 ppm, but reasonably good discrimination can be obtained between LCT and NYF affiliated pegmatites based on their relative Ga contents. Gallium contents in K-feldspars from NYF pegmatites commonly fall between 20 and 100 ppm. K-feldspars from LCT pegmatites, by comparison, typically contain Ga contents between 10 and 40 ppm with only the most evolved pegmatites (e.g., Tanco) having as much as 100 ppm or more. A plot of K/Rb versus Ga has proven to be useful in distinguishing K-feldspar between LCT and NYF pegmatites despite showing considerable scatter in the data.

It is proposed that there is a significant difference in the Ga contents of K-feldspar from LCT and NYF pegmatites which can be correlated to their parental sources, i.e., LCT pegmatites generated from S-type granitic magmas and NYF pegmatites derived largely from A-type granitic melts.

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EXTREME FRACTIONATION OF A PERALKALINE PEGMATITE-APLITE DYKE SYSTEM, MCKEEL LAKE, WELSFORD INTRUSION, NEW BRUNSWICK: MINERAL-CHEMICAL TO PETROGENETIC ANALYSIS

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The Ta-Nb-REE-Zr-rich McKeel Lake peralkaline granitic pegmatite-aplite dyke system is hosted within the Late Silurian mantle A-type, multiphase peralkaline Welsford alkali-feldspar granite (422 ± 1 Ma) in southwestern New Brunswick; both share similar major minerals and textures. The pegmatite-aplite dykes (419 ± 20 Ma) are up to 40 cm wide, closely spaced (10-20 cm), with sharp contacts (170°/90°) within the host granite. Fine-grained saccharoidal quartz, perthitic K-feldspar, and albite with zircon and other numerous rare minerals form a rhythmic layering with long riebeckitic amphiboles (up to 3 cm) in the aplite extending towards the core of the dykes. Micrographic to granophyric texture is also common. These textures are consistent with a predominantly magmatic growth history probably related to pressure quenching (depressurization) of the melts, with a volatile phase involved. These mineralized pegmatite-aplite dykes represent a late magmatic, extremely fractionated part of the Welsford alkali granite intrusion, with Ta (74 to 220 ppm), Nb (750 to 3040 ppm), Zr (1450 to 36000 ppm), Y (540 to 3070 ppm), Th (170 to 870 ppm), U (60 to 250 ppm), Ce (430 to 1950 ppm), Yb (110 to 290 ppm), and Be (20 to 103 ppm). Zoned zircon crystals are characterized by enrichment in Hf, Th, and U, corresponding to peralkaline melt evolution. In addition, Ta-Nb-oxide, euxenite, fergusonite, aeschynite, (Y)-aeschynite, REE-fluorcarbonate, and fluorite mainly occur in the aplitic parts of the dykes, although they also are sparsely distributed in the pegmatitic sections.

Bulk distribution coefficients (D) of these elements, assuming Ta as the most incompatible element and using the Rayleigh fractionation equation, were calculated for the extreme fractionation of these peralkaline granitic melts (Welsford alkali granite to McKeel Lake dykes), using the Allégre et al. (1977) method: Sr and Rb (0.96), TiO_2 (0.895), La (0.69), Be (0.54), W (0.53), Pb (0.35), Y (0.26), Yb (0.25), Th (0.17), Zr (0.129), Nb (0.111), U (0.092), and Hf (0.069). The covariation of the observed trends between the two populations reaffirms the genetic parental relationship of the host Welsford intrusion to these pegmatite-aplite dykes. The coherent behaviour of these high-field-strength elements (HFSE) implies a common enrichment process. This suggests that these elements remained as very incompatible until the injection of the dyke swarm, with negligible ferromagnesian or HFSE mineral fractionation consistent with their peralkaline composition, i.e. no volatiles or magmatic-hydrothermal partitioning is required to produce this extreme Ta-Nb-Zr-REE-Y-Th-U enrichment.

SS10-P01 INCORPORATION OF SILVER IN TOURMALINE

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In natural tourmaline, $XY_3Z_6(BO_3)_3T_6O_{18}V_3W$, , and Na predominates in the common solid solutions of□X = Na, Ca, or schorl-dravite-olenite-foitite. In schorl-dravite, $^{IX}Na^+$ (ionic radius ≈1.40 Å) occupies the X-site, which has a polyhedral volume of 32-33 Å^3. Though schorl-dravite commonly crystallizes with K-feldspar, K is highly incompatible in tourmaline, presumably because $^{IX}K^+$ (ionic radius ≈1.63 Å) is too large for the X site. We have synthesized "dravite" containing up to 7.65 wt% Ag_2O in the X site, which corresponds to 66% site occupancy. The ionic radius of $^{VIII}Ag+$ (≈ 1.38 Å, no known data for $^{IX}Ag^+$ or XAg+) is 10% larger than $^{VIII}Na+$(≈ 1.24 Å) but 15% smaller than $^{VIII}K+$ (≈ 1.63 Å). Substitution of $^{VIII}Ag+$ for $^{IX}Na^+$ would produce little volumetric change in the X site; however, the coordination number of Ag^+ in "dravite" is presently unknown.

Ag^-"dravite" was synthesized at 500°-750°C, 200 MPa H_2O, starting with an oxide mix of the composition of dravite to which various reagents, including AgF and AgCl, were added as part of a broader study of tourmaline stability. The fO_2 during experiments was ≈ log(NNO)-0.5. Tourmaline with high Ag content coexisted with Ag oxides, Mg fluorides and cryolite. Provisionally, compatibility of Ag in the X-site correlates best with Al in the Y site, and with the activity of F in the system: tourmaline synthesized with AgCl contained only 0.14 wt% Ag_2O, with a 3σ-detection level of 0.08 wt% Ag_2O by EMPA.

The positive association of Ag with excess Al and with F suggests that tourmaline might be useful for precious metals exploration in Cornwall-type polymetallic ore deposits associated with F-rich peraluminous granites, or other Ag- and F-enriched deposits such as Broken Hill, NSW. An EMPA survey of tourmaline from various Cornish granites and wallrock-hosted tourmaline-cassiterite lodes (none with Ag mineralization) failed to detect Ag above background. Similarly, Ag was below detection in one sample from Broken Hill (provided by John Slack, USGS). At Broken Hill, a high abundance of sulfide would reduce the activity of Ag_2O needed as a component of tourmaline. Patterns of Ag distributions within tourmaline may become evident with more sensitive analytical methods.

Very fine-grained (~3x10 µm) Ag-"dravite" appears colorless to light pink. Fully substituted Ag-"dravite" will have a density of ≈ 3.25 g/cm^3, as compared to ≈ 3.00 g/cm^3 for dravite. The resultant increase in refractive indices might make this a candidate for brilliant synthetic tourmaline gemstones.

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SS10-P02 HIGHLY FRACTIONATED DEVONIAN GRANITOIDS OF THE SIERRA DE LUIS, ARGENTINA: SOURCES FOR QZ-W VEINS

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Late stage highly evolved red leucogranites intruded the voluminous zonal elliptical Devonian batholiths of the Sierra de San Luis. They make up circular or elongated stocks and dykes emplaced in a N to NNE fracture and are spatially associated with W rich quartz veins (WQV)

The red granites are mainly leuco syeno±monzogranites and alkali-feldspar granites characterised by sub- and hyper-solvus textures, late magmatic interstitial biotite and interstitial or vein-fluorite. They are geochemically evolved (SiO_2 = 74–78%), metaluminous to mildly peraluminous, poor in Ca, Fe, Mg, Sr, Ba, Zr, Sc, V and Pb, and strongly enriched in incompatible elements such as Li, Rb, Cs, Sn, Nb and Y. Rocks are rich in fluorine and phosphorus; (0·6–1·8 wt% F and 0·4–0·8 wt% P_2O_5). Contents of Sn and W are relatively high (10–50 ppm Sn, 20–80 ppm W). The REE contents are generally very low. The chondrite-normalized patterns are relatively flat (La/Yb_{CN} 4-8) having prominent negative Eu anomalies.

High degree of magmatic fractionation is demonstrated by low K/Rb and Zr/Hf ratios (90-120, 11–18, respectively), high U/Th ratio (4–6) and the higher concentrations of rare metals. Nb and Ta (50–70 ppm Nb and 30–50 ppm Ta) compared with the host monzogranites (25–50 and 10–25 ppm, respectively).
WQV occupy both a N-NNE fracture system inside the red granites and circular fractures in the host. Breccia textures, miarolitic cavities and hydrothermal alteration of the host granites are recognized. The veins consist mainly of quartz, muscovite, tourmaline, fluorite, apatite, epidote and beryl, with accessory scheelite, wolframite, titanite, pyrite, chalcopyrite, sphalerite, magnetite, hematite, rutile and ilmenite. Tourmaline-beryl Devonian undeformed pegmatoids are locally enriched in wolframite.

Concentrations of F, Nb, Y and Rb in the least differentiated red granites similar to those in the surrounding high K calc-alkaline monzogranites suggests that higher concentrations in the red granite are mostly related to special fractionation processes. A F- rich fluid phase was evolved probably by second boiling and is evidenced by primary fluorite in the granites. The HFSE may preferentially partitioned into this phase. Fluorine also facilitated the strong enrichment of W, Sn, Th, U in the residual melt, by protracting the crystal fractionation due to lowered solidus temperature and melt viscosity.

Contemporaneous ages and emplacement style of the granites, undeformed pegmatoids and Qz veins suggest a genetic connection with the highly evolved red granites as the source for the mineralized Qz veins.

SS10-P03 **MAGMATIC-HYDROTHERMAL EVOLUTION OF POLLUCITE FROM NO.3 RARE METAL PEGMATITE DYKE, KOKTOKAY**

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The Koktokay No.3 rare mental pegmatite dyke is located in the Altai, Xinjiang Autonomous Region, China. It is characterized by a well-developed internal zonal structure and divided into 9 mineralogical-textural zones from border to inward [1]. In the present study two cesium-bearing minerals have been discovered in the No.3 pegmatite: pollucite and “Cs-enriched lepidolite”.

The Fifth zone (Cleavelandite-Spodumene zone) The primary homogeneous pollucite first occurred in the early stage of this zone. It is typically associated with elbaite and “Cs-enriched lepidolite”. Chemical analysis gives Si/Al ratio from 2.26 to 2.43 and CRK = 100 × (K + Rb + Cs) / Scation) between 70.6 and 78.5. During the late stage, the primary pollucite has locally evolved into two phases: Na-enriched domains (73.4 < CRK < 74.8, 2.20 < Si/Al < 2.38) and Cs-enriched vein-lets (81.5 < CRK < 85.8, 2.13 < Si/Al < 2.32).

The Sixth zone (Quartz-Spodumene zone) The pollucite is associated with quartz, spodumene, elbaite, lepidolite and “Cs-enriched lepidolite”. The primary pollucite has a CRK of 79.2-86.5 and Si/Al of 2.19-2.39. The Na-enriched pollucites with CRK of 76.6-83.1 and Si/Al of 2.27-2.49 are found as inclusions in the primary pollucite. But it is very interesting that the primary pollucite is always surrounded with the “Cs-enriched lepidolite” rim. The “Cs-enriched lepidolite” rim has a 100-200μm wide and WCs up to 27.68%, close to the ideal Cs end-member composition of lepidolite ($Cs(Li,Al)_3[(Al,Si)_4O_{10}](F,OH)_2$).

The Seventh zone (Thin slice albite-Muscovite zone) The end-member pollucite bands are up to 30 μm wide and always occur at the boundary between the primary pollucite and albite. The end-member pollucite has an average CRK of 93.4 and Si/Al ratio of 2.05. The occurrence indicates that it is formed as a replacement product of the primary pollucite.

Conclusion Primary pollucite from No.3 pegmatite has a CRK of 71.1-86.5 and closely correspond to those of other primary pollucites. In comparison to six stages for the evolution of pollucites from worldwide [2,3,4], the No. 3 pegmatite has several distinct anomalous features. The alteration degree of pollucite are weaken and some stages, such as fracture-filling Cs-enriched veinlets and analcimisation are scarcity in the examined specimens. In addition, it is unique to this locality that the pollucite is closely associated with the “Cs-enriched lepidolite”.

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SS10-P04 STRUCTURAL ENVIRONMENT OF NB IN DRY AND FLUID-RICH SILICATE GLASSES: A COMBINED XANES AND EXAFS STUDY, INCLUDING A NOVEL APPROACH TO ICP-AES ANALYSIS OF MICRO-MATERIALS

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The speciation and structural environment of Nb in silicate glasses, along with a selection of model Nb-oxides and silicate minerals, was investigated by XAFS at the Nb K-edge (19 keV) at the Stanford Synchrotron Radiation Laboratory (Stanford, USA). The Nb glasses (1000 ppm Nb to 5 wt. % Nb_2O_5) were quenched from melts at 850°C and 2 kbar. Two haplogranitic compositions were investigated: (1) peralkaline (ASI 0.6) and (2) peraluminous (ASI 1.2). Nb-bearing glasses were either dry, wet (water-saturated, ~ 5 wt% H_2O) or contained 4 wt% F. Anhydrous Na-Si glasses (NS_2 and NS_3) were synthesized at ENS (Lyon, France) at 1200°C and 1 bar containing 1000 ppm Nb to 3 wt% Nb_2O_5. Characterization of micro-scale quantities (2 mg) of the glasses followed a unique lithium metaborate ($LiBO_2$) fusion procedure combined with direct solution aspiration into an inductively coupled plasma atomic emission spectrometry (ICP-AES) system. Accuracies for certified reference materials (CRMs) along with sample reproducibility (% RSD) varied 1 to 5% for Nb, Si, Al, K and Na.

In natural Nb-bearing minerals (oxides and silicates), Nb^{5+} is always found in octahedral-coordination. Distances to nearest-neighbour ligands span a range from 1.76 to 2.26 Å. The local coordination geometry of Nb in the silicate glasses is similar to that of $[6]Nb^{5+}$ in the model compound vuonnemite, a Na-Nb-Ti silicophosphate. The dominant contribution in the EXAFS spectra is due to Nb-O bonds, with a smaller Nb-(Si,Na) contribution. Development of a stronger pre-edge feature is observed in ASI 0.6 and 1.2 glasses with > 1 wt% Nb_2O_5, related to saturation of the melt in Nb_2O_5. Changes in the XANES spectra of the Nb-bearing glasses can be correlated to changes in Nb content and alkalinity: a shift in the main edge crest to higher energies and an increase in the intensity of the low-energy peak shoulder is observed with decreasing alkalinity and increasing Nb content, a result of decreasing radial distortion around Nb in more peraluminous glasses. The presence or absence of H_2O does not an affect on the speciation of Nb in the glass compositions studied. However, the addition of F to the melt results in an increased intensity and definition of the pre-edge structure in the spectra. Preliminary FEFF calculations including Nb-F-bearing compounds indicates this pre-edge to be related to a decrease in Nb-coordination from [6] to either [5] or [4] and not due to Nb-F complexation.

SS10-P05 **ABYSSAL PEGMATITE WITH OLENITE AND DUMORTIERITE FROM KUTNÁ HORA, CZECH REPUBLIC: AN EXAMPLE OF FRACTIONATION IN THE LI-POOR, AL,B-RICH GRANITIC SYSTEM**

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Fractionation in granitic rocks commonly tends to high concentrations of lithophile elements. Abyssal pegmatite from the Kuklík locality near Kutná Hora, Czech Republic, represents a less evolved granitic system characterized by high amounts of Al and B, but low concentration of Li and relatively high Ca/Na ratio documented by oligoclase $Ab_{83}An_{16}Kfs_1$. Coarse-grained pegmatite vein, about 0.3 m thick, is enclosed in migmatized MT/MP metapelites. It exhibits simple zoning with the mineral assemblages developed inward: (i) K-feldspar + quartz + oligoclase + muscovite + black Al-rich schorl to schorl-olenite; (ii) quartz + K-feldspar + black to dark green schorl-olenite (subhedral crystals up to 2 cm long) with blue rims of Fe-bearing olenite ± dumortierite I (complicated intergrowths, up to 3 mm in size); (iii) quartz + K-feldspar + dumortierite II (pale green lathes, up to 2 cm in size) + dumortierite III (fibrous aggregates) and rare chryzoberyl. Schorl-olenite exhibits the composition $(Na0_{0.5}Ca0_{0.1}[]_{0.4})$ $(Al_{1.7}Fe_{1.2}Mn_{0.1})$ $(Al_{5.9}Mg_{0.1})(Si_{5.8}Al_{0.2})$ $B_3O_{27}[(OH)_{2.9}O_{1.1}]$, rims of blue Fe-bearing olenite $(Na_{0.5}Ca_{0.1}[]_{0.4})$ $(Al_{2.1}Fe_{0.8}Mn_{0.1})$ $(Al_{5.9}Mg_{0.1})$ $(Si_{5.5}Al_{0.5})B_3O_{27}[(OH)_{2.8}O_{1.2}]$. Three morphological types of dumortierite, $Al_7(BO_3)(SiO_4)_3O_3$, have trace contents of Fe and Ti and exhibit substantial Si-Al substitution.

The paragenetic sequence of Al,B silicates at Kuklík (Al-rich schorl ? schorlolenite ± dumortierite I ? Fe-bearing olenite ± dumortierite I ? dumortierite II ? dumortierite III) is distinct from the evolution of tourmaline (±dumortierite) in LCT granitic pegmatites. They show the simplified sequences: (dumortierite) ? Mg-schorl ? Al-rich schorl in Li-poor pegmatites; (dumortierite) ? Mg-schorl ? Al-rich schorl ? Fe-rich elbaite ? elbaite (rossmanite, liddicoatite) in complex (Li) pegmatites. The paragenetic sequence from the pegmatite at Stoffhütte, Styria, Austria (Mg-schorl ? Al-rich schorl ? lithian olenite with tetrahedral B) solely exhibits similar evolution trend. Abundance of dumortierite II and III as the latest primary Al,B-rich phases at Kuklík documents stability of dumortierite instead olenite in such Al,B-rich but Fe,Li-poor system. It is not clear, whether absence of Fe and/or Li or inadequate PT-conditions, or both explain presence of dumortierite instead olenite in final stages of fractionation of the Kuklík pegmatite.

SS10-P06 CONTROLS ON PGE MINERALIZATION IN THE SEAGULL INTRUSION, NORTHWESTERN ONTARIO

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The Seagull Intrusion is one of a number of exploration targets for orthomagmatic PGE's, nickel and copper in the Thunder Bay-Lake Nipigon region. Extensive diamond drilling has delineated the body of the intrusion and revealed zones of PGE, nickel and copper mineralization, with the most significant zones to date occurring near the base of the intrusion.

The intrusion is a Mesoproterozoic ultramafic intrusion related to Midcontinental rifting occurring at ~ 1100 Ma. With a maximum thickness of 730 m (DDH WM01-08) the Seagull Intrusion is lithologically dominated by cumulate dunites, lherzolites, and olivine websterite, with minor olivine- hornblende pyroxenite. Whole rock analyses indicate that the intrusion is relatively homogenous in composition. Analyses of olivine, pyroxene, and oxide minerals throughout the intrusion by SEM-ED show only minor variations in compositions (olivine Fo80-Fo89, 737 analyses) with the most substantial changes associated with zones of mineralization.

REE and high field strength elements (HFSE) generally exhibit patterns characteristic of Ocean Island Basalts (OIB) on primitive mantle normalised diagrams [(La/Sm)n 0.9-3.0, (Gd/Yb)n 2.7-4.2)]. Samples exhibit a decrease in absolute REE and HFSE abundance with an increasingly negative Eu anomaly towards the top of the intrusion. Three preliminary units are recognized in the Seagull Intrusion on the basis of trace elements. The basal unit found in contact with basement shows light REE enrichment and heavy REE depletion with (La/Sm)n ratios 1.4-3.0 and (Gd/Yb)n ratios of 3.1-4.0. The main unit is characterized by a (La/Sm)n ratio of 0.9-1.9, a negative Eu anomaly and increasing fractionation between Lu and V. The sub-main unit is characterised by REE values plotting between the basal and main units and fractionated HFSE. Mineralized zones are present in all three units, but the most significant mineralization is restricted to the basal and sub-main units.

Mineralization of nickel occurs as disseminated sulfides (bravolite) found interstially to olivine crystals. Copper mineralization is present as sulfides (chalcopyrite) with nickel, but is more often seen as veinlets of copper cross cutting existing sulfides. Platinum group minerals are found on the periphery of NiFe sulfides and are dominated by sperrylite, keithconnite, stiopalladinite, and a copper palladium alloy. Mineralization occurs in two broad forms. The first is present near the basal contact and is thought to be caused by initial sulfide saturation of the magma during initial emplacement. The second appears to be a stratigraphic horizon with major mineralization occurring when both whole rock geochemistry and mineralogy become more primitive, possibly reflecting a new influx of less evolved magma.

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SS10-P07 MINERALIZATION AND REGIONAL GEOCHEMISTRY OF THE NORTON LAKE CU-NI-PGE DEPOSIT, UCHI SUBPROVINCE, ONTARIO

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The Norton Lake Cu-Ni-PGE deposit (delineated in 1981 as 944,000 tonnes at 0.72% Ni and 0.56% Cu) is located approximately 50 km northeast of Fort Hope, within the Miminiska-Fort Hope Greenstone belt of the Uchi Subprovince, northwest Ontario. The deposit is hosted within a sheared amphibolite unit located between an upper basalt and a lower sedimentary unit. A study of the mineralogy of the deposit by reflected light microscopy, scanning electron microscope and electron microprobe have led to the identification of several platinum group minerals (michenerite, testibiopalladite, kotulskite, merenskvite, vysotskite, sperrylite and hessite) that occur as enclosed grains within sulphides and oxides (pyrrhotite, pentlandite, pyrite, chalcopyrite, galena, skutterudite, manganoan illmenite, and magnetite) and along grain boundaries of the sulphide and gangue minerals. A ratio change in Pt:Pd occurs along a narrow linear trend within the deposit. The result is a change from ~1:4 for the majority of the deposit to ~3:1. Preliminary results indicate that this change is associated with an increase in the abundance of Pt bearing minerals.

The deposit is located within the northern most unnamed assemblage of the Miminiska-Fort Hope Greenstone Belt. Limited geological investigations have been undertaken within the belt, due to both its remote location and sparse outcrop. As a result the belt has been subdivided based on available regional stratigraphic and structural interpretations. A 30 km east-west by 15 km north-south block surrounding the Norton Lake Deposit has been mapped and sampled to allow characterization of the volcanic assemblages. Previous work by the Ontario Geological Survey has tentatively correlated the unnamed assemblage with the McGruer assemblage of the North Caribou, located to the west, based on a similarity of rock types and a pervasive aeromagnetic anomaly that xtends between the two. Three suites can be recognised within the assemblage; Suite I basalts are characterized by weakly depleted to enriched LREE [$(La/Sm)_n$=0.9-1.2] and weakly fractionated HREE in conjunction with flat to positive Nb anomalies. Suite II is characterized by LREE depleted basalts [$(La/Sm)_n$=0.4-0.7] and unfractionated HREE, while Suite III consists of basalts to dacites that are LREE enriched with weakly fractionated HREE [$(La/Sm)_n$=2.6-4.7, $(Gd/Yb)_n$=0.8-2.4] and pronounced negative Nb anomalies. Preliminary interpretations suggest these basalts are comparable to the Northern Pickle Assemblage of the Pickle Crow belt rather than the McGruer assemblage.

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COMPATIBLE BEHAVIOUR OF BERYLLIUM IN FRACTIONATING GRANITIC MAGMAS, SELWYN MAGMATIC PROVINCE, YUKON

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Recent emerald discoveries in Yukon have catalysed the need for increased knowledge of Be behaviour in magmatic and hydrothermal systems. Of the 20 or so beryl occurrences in the northern Canadian Cordillera, most are associated with peraluminous granitoids, but about 40% are associated with metaluminous plutons, most having alkalic tendencies. Of the peraluminous occurrences, including the Regal Ridge emerald deposit, most are associated with the Selwyn Magmatic Province which consists of several hundred mid-Cretaceous (112-90 Ma) plutons and batholiths that intrude the ancient North American continental margin in central and eastern Yukon. Lithological, geochemical, isotopic and geochronological characteristics among these intrusive bodies allows distinction into eight slightly peraluminous (ASI = 0.9-1.3) plutonic suites.

A large geochemical dataset (n = 3000) from more than 100 Selwyn granitoids and dykes (Garrett 1992, GSC Open File 2479) includes Be determinations and represents one of the largest regionally coverages available. Analyses range from 0.1 to 20 ppm Be with most plutonic suites ranging from 2 to 10 ppm Be. Mean values are 6.8 ppm Be at ASI = 1 and 5.6 ppm Be at ASI = 1.3. Alkalic plutons (6.8 ppm Be) are slightly more enriched than peraluminous ones (6.1 ppm Be).

Beryllium is generally considered incompatible in fractionating granitic systems such that increases with crystallization are expected. However, geochemical data from Selwyn granitoids are counter to this trend. Most plutonic suites display well-developed linear trends of decreasing Be with decreasing, iron, titanium, manganese and vanadium, and fuzzy trends with increasing ASI and silica. Beryllium typically ranges from 15-9 ppm at 55% SiO_2 to 2-3 ppm at 78% SiO_2. Late felsic dykes (n=50) show similar trends, as do tourmaline- (n=18) and muscovite-bearing (n=10) phases which all decrease from 9 to ~3 ppm Be. A deviation in the aforementioned trends occurs in alkalic plutons, whereby Be-enrichments occur in felsic, but silica-undersaturated phonolitic/tinguaite phases.

The consistency in trends across several plutonic suites, and Be depletions early in fractionation indicates that Be is compatible in a mineral that crystallizes early and throughout the crystallization history. Beryllium depletion by minerals with moderate to high mineral/melt partition coefficients such as biotite, amphibole and plagioclase is possible. Selwyn plutons mostly lack evidence of significant plagioclase fractionation such as Ba or Eu depletions, and amphibole is uncommon in many of the suites considered. Strong linear trends and good correlations (r > 0.6) with Fe, Mg and Mn in most suites indicate that Be may be compatible with biotite crystallization. Alternatively, accessory minerals such as allanite may play a role.

SS-11

GEOSCIENCE DATABASES AND GIS - SPATIALLY ENABLING YOUR DATA

LES BASES DE DONNÉES GÉOSCIENTIFIQUES ET LES SIG B POUR VOIR VOS DONNÉES EN 3 D

JEFF HARRIS (GEOLOGICAL SURVEY OF CANADA),

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SS11-01 THE CANADIAN GEOSPATIAL DATA INFRASTRUCTURE – INTEGRATING GEOLOGICAL MAPS

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Data is the basis of science; the building blocks of new theories. The ability to collect it, store it, use it, share it, is key. With the increasing availability of digital data and maps, the ability to establish links to other data and maps is indeed critical. Only by using the same standards will researchers be able to discover, access and integrate data from other researchers. This will result in decreased duplication of research and saving of precious funding dollars by not redoing science that has already been done. This also allows new lines of research as people find interesting data in compatible formats that allows them to work with that data in ways that they never have before.

In Canada, there is a national initiative (government/private) called GeoConnections created for the purpose of making Canada's geospatial data, tools and related services accessible through the Internet. Part of this initiative has involved facilitating the building of the Canadian Geospatial Data Infrastructure (CGDI); an integrated, on-line mechanism for discovery and sharing of geospatial data such as GIS, imagery, and maps.

Web mapping technology, and associated standards, are an integral part of the CGDI in allowing the visualization of maps with attributes and enabling the overlaying of digital maps, via the Internet, to create new maps. The Canadian Geoscience Knowledge Network, a national organization of geological surveys, is a prime user of web mapping and, together with GeoConnections, is putting geological maps on the Internet that are discoverable, accessible and useable by everyone. One of the goals is to build national, scaleable geological maps along with a national, scaleable taxonomy.

GeoConnections is also at the international forefront of supporting the development of standards that support the CGDI and other international spatial data infrastructures. This paper discusses the benefits of integrating maps from numerous sources, the current status of CGDI/CGKN and suggests actions to meet this goal.

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SS11-02 AN ONLINE SEARCHABLE MAP INDEX OF GEOLOGY MAPS PRODUCED BY THE GEOLOGICAL SURVEY OF CANADA

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The Geological Survey of Canada (GSC) has produced over 4500 geology maps since its inception, and more than 2500 since 1945. There are more than 200 maps known to be in preparation. Nevertheless, lack of access to an easily useable map-based index has been a long-standing point of frustration for all users of these GSC map products. Industry clients, sales staff and staff librarians do not know which maps are current for any specific region of the country. Research staff have trouble discovering what has been done (or is being done) by their colleagues and predecessors. Managers are largely dependent on their research staff for identifying thematic and geographic gaps in mapping coverage. To rectify these problems and to allow better public and in-house access to these publications, an online searchable GIS-based map index has been developed for the current, archival and "in prep" bedrock map collection, together with a more detailed assessment of the content of more than 1500 current GSC bedrock maps. Similar work is in progress on the GSC surficial geology map set. These activities are supported by Natural Resources Canada through the Consolidating Canada's Geoscience Knowledge (CCGK) project. Results are to be released online and promoted cooperatively with the provinces and territories through the Canadian Geoscience Knowledge Network (CGKN).

The index allows the user to search for maps using a scaleable GIS-based digital map tool and other user-defined criteria including scale, vintage and map product line (i.e. A-series, Preliminary or Open File). The map indices allow the user to display the national, regional or local coverage of GSC geology maps using any combination of the search criteria superimposed on a base that includes shorelines and major rivers, political boundaries and the labelled 1:50,000 and 1:250,000 scale NTS map grids.

The assessment draws on the components of each map including: (1) the base map; (2) the geology layer; (3) unit description; (4) line work; (5) measured point data; (6) recorded point data; (7) accessory illustrations; and (8) nature of supplemental text and references. Assessment criteria are designed to provide the user with local, regional and national perspectives on the state of geological mapping as performed by the GSC. In order to obtain a truly national understanding of the state of mapping in Canada it will be necessary to access similar indices and assessments for the provincial and territorial map collections.

SS11-03 TOWARDS AN INTEGRATED CANADIAN GEOCHRONOLOGY KNOWLEDGEBASE

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Although superficially a quantitative measure, a geochronological age is, in actuality, an interpretation of measured data. This interpretation usually encompasses qualitative application of collateral information, such as isotope systematics, geological constraints and other constraining age determinations. As such, the date must also capture the derived knowledge within a geochronological data set, if it is to be accurate and truly useful to end-users. To this end, a relational data model has been developed in order to create a widely-accessible national Canadian Geochronology Knowledgebase. The knowledgebase is made up of tables containing sample location and general geological information, full bibliographic reference, age and complete details on the dating method and associated knowledge. Furthermore, this application will connect into developing lithostratigraphic, paleontological and surficial data sets to provide necessary coherency and integration.

To allow free and easy access to the knowledgebase, we have developed an web-accesible ARCIMS application. This GIS representation of the data set allows the user to search the knowledgebase both geographically and using various criteria and represents an example interface to the information. Search results can be viewed or downloaded. In addition, web services allow the user to download the data from the knowledgebase in either XML or ASCII format more optimized to the user's needs.

Currently the Canadian Geochronology Knowledgebase contains a limited number of data from compiled regions. These compilations were done either by our staff or are the result of cooperation with various provincial/territorial partners. This cooperative approach not only helps build the knowledgebase, but is also beneficial to our partners. As an example, the Yukon Geological Survey currently receives the Yukon-specific subset of data to serve through their web-enabled map applications, ensuring that their data is up to date.

This database should serve as a centrally located knowledgebase which can be freely accessed by anyone. Through our partnerships we are aiming to complete the gaps in a Canada wide compilation by April 2005. To sustain the utility of the information, it is proposed that a panel of geochronological editors, each responsible for key geographic or geological locations, oversee submissions to knowledgebase.

SS11-04 **CANGEOLEX: GEOLOGICAL UNIT NAMES FOR CANADA; A NEW WEB SITE AND SERVICE**

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Consistent use of geological names is critical to integrating geoscientific information across distributed databases through XML and web services. At present, reliable and current information about geological map units for Canada is scattered, and for much of the country unavailable in digital format. Through the Canadian Geoscience Knowledge Network (CGKN) and a Natural Resources Canada's program to consolidate Canadian geoscience, a database of this information is being assembled and made accessible through a web site at www.CGKN.net.

Currently, the contents of the four lexicons published on CD-ROM by the Canadian Society of Petroleum Geologists have been loaded into a database designed following the stratigraphy module of Public Petroleum Data Model. In addition summary information has been entered for other geological units from a card file index at the Geological Survey of Canada. In total, the database contains about 12,000 lithostratigraphic and lithodemic names, including formal and informal, current and obsolete or abandoned. A user-interface to the Oracle database has been created to allow the information to be managed and structured. Rules for who can change the various parts of the database are set and implemented by the database administrator. For example, the ages given as a text string in the lexicon entries have been expressed as maximum and minimum ages through links to chronostratigraphic names that are also stored in the database, and calibrated by ages from the Geological Survey of Canada's geological time chart. This enables searches of lithological units by age. The interface is also used to correct minor errors, and to consolidate the references from each source, and link them to the appropriate section in each lexicon entry.

The information is not current; some was published over 20 years ago. Work is underway to up-date the lexicon for the Arctic Archipelago, and similar updates are needed for the others. Work has started on those parts of Canada for which no published lexicon exists (i.e. central Canada, and most of British Columbia). Even then, there will be names missing, but by making the site publicly available as a work in progress we hope to harness the knowledge of Canada's geological community to complete and then maintain the database as the definitive source of geological names. Initially the information is provided as text pages, but it will be made available as a web service so that it can be used in other applications.

SS11-05 LAND INFORMATION ONTARIO: CREATING A SPATIAL DATA INFRASTRUCTURE FOR ONTARIO

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Like many jurisdictions, land information holdings in Ontario are not widely documented, publicized or accessible; compiled in various formats and media; non-standardized; difficult to integrate, share and maintain; and, become quickly obsolete. Land Information Ontario (LIO), in conjunction with the Canadian Geo-Spatial Data Initiative (CGDI) Project, has created an infrastructure that will support the development of partnerships in the collection, management and distribution of Ontario's land information assets. The Ontario Land Information Infrastructure (OLII) has two major thrusts: ensuring the existence of certain important data sets, and ensuring access to, and widespread general use of, geospatial data. Self-sustaining, well managed, good quality, important data sets are created through a wide variety of cross-jurisdictional projects and policy initiatives. Access to geospatial data are encouraged through data catalogues, data sharing organizational structures and data sharing tools. This discussion reviews the objectives, the history and the reality of Land Information Ontario and its role among the users and managers of geospatial data in Ontario. It focuses specifically on how organizations using Ontario geographic information can, and have already participated in LIO's programs and offerings. One of the main goals is to implement a collaborative approach to spatial data in the province through the development of data sharing opportunities that will benefit a wide variety of organizations. The geologic sector plays a large role in environmental, hydrological and resource management across Ontario. Through data sharing, development of data standards and adoption of collaborative approaches to data collection and management significant benefits can be realized amongst both private and public sector organizations. Those who are interested in Ontario geospatial data will have the opportunity to discover how LIO is developing and fostering relationships and how the geologic sector can become involved.

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SS11-06 PETROGIS – A SPATIALLY ENABLED DATABASE FOR SUBSURFACE 3-D MAPPING IN SOUTHERN ONTARIO

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The Petroleum Resources Centre of the Ontario Ministry of Natural Resources collects and manages a large quantity of subsurface resource and geological data at it's Oil, Gas and Salt Resources Library in London. The Library maintains an extensive collection of drill cuttings samples representing 13,000 wells and drill core from over 1,000 wells. Hard-copy reports are available for over 20,000 wells and includes data on well location, well status, operator identification, drilling dates and depths, well construction, geological formation top depths and elevations, oil/gas/water intervals, geophysical well logs, core analyses, analyses of oil, gas and water samples, subsurface pressures and production volumes. The data is principally acquired from the drilling and operation of petroleum wells by industry clients.

Digital data derived from the well records and samples are maintained in an Oracle relational database known as the Ontario Petroleum Data System (OPDS). The Centre has recently developed a GIS application using Arcview 3.2 for viewing and querying of well data from OPDS. The petroleum well theme is generated by a dynamic link to the Oracle data tables in OPDS. Elevation data for the tops of subsurface bedrock formations can be extracted from the Oracle data tables using the "Petroleum GIS" application, gridded and contoured using specialized software and displayed as a new data theme in the GIS. Three-dimensional maps created from the gridded data are particularly useful for visualization and mapping of subsurface structures such as faults, reefs, salt dissolution and collapse features, regional dip, structural closures, bedrock topography and more. Selected examples from southern Ontario are presented.

Basic well data including corrected geographic co-ordinates are available at www.ogsrlibrary.com and clients are able to purchase data on subsurface geological formation top picks, oil, gas and water intervals and enhanced well data. Access to MNR digital base maps is free to corporate members of the Library under the terms of a data sharing agreement with the Ministry of Natural Resources

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From field collection to end user: keeping up with evolving digital data needs and capabilities

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In the late 1980s, government geologists in the Northwest Territories produced bedrock geology maps using AutoCAD and the Geological Survey of Canada's Fieldlog software. The robustness of the digital files associated with these early maps varied; while some maps were suitable for release as digital files for importing into a GIS, others were released as paper maps only. Within a decade, it was recognized that the added functionality of modeling spatial attributes made GIS-compatible files more useful to our clients than CAD maps. In response, the digital geological atlas concept was developed. These atlases consist of an Arcview Project containing the basic bedrock geology information that is standard on geologic maps (e.g. lithology, structural data, mineral occurrences). They also contain datasets that are difficult to capture on traditional maps, such as field photographs, photomicrographs, lithogeochemical data, assays, age data, and georeferenced images.

Although more useful to the end user than a paper map, the development of a digital atlas from CAD files, Fieldlog data and paper notes is time-consuming. To lessen the workload, Compaq's iPAQ Pocket PC (PPC) running ESRI's ArcPAD software was evaluated as a means to collect digital field data. This system was selected based on two criteria: the ability to collect data in an Arcview-compatible format, and its ease of use. The ArcPAD system enables the geologist to enter data into shape files, which can be downloaded from the PPC into an Arcview 3.x project. Multiple data-entry forms were created for each shape file to aid in data entry and utilize the limited screen size of the PPC. The ArcPAD database consists of a number of flat shape files that can easily be modified into a hierarchical relational database in Arcview 3.x.

The PPC's have been successfully used in the field since 2001, and have proven to be useful for efficiently capturing data. The efficiency gained at the front end facilitates digital atlas production, and allows end users to access more comprehensive datasets than traditional CAD maps and accompanying files. In addition to streamlining data entry, the PPC's have proven to be valuable mapping tools. For instance, they can serve as a navigation aid when linked to a GPS, and they allow the geologist to have any number of spatial datasets at their fingertips on the outcrop (e.g. regional magnetic data, satellite images, existing geology maps, and mineral showings).

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SS11-08 COUPLING TREND SURFACE ANALYSIS AND PROBABILISTIC KRIGING IN A GIS TO MODEL GEOCHEMICAL ANOMALIES

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Detecting and mapping geochemical anomalies of elements is one of the fundamental tasks in most exploration and environmental studies. To differentiate anomalous from background values, many different techniques have been introduced and applied. In several of these methods the threshold between anomaly and the upper limit of background is considered to be constant over the study area, whereas the effects on background such as lithology differ with location. In this study we demonstrate a simple approach to remove spatial trends from geochemical survey data, thereby enhancing residual anomalies, using GIS tools.

By fitting an appropriate polynomial trend surface, the generalized effect of different background values of geochemical elements in different geological environments can be removed. Regional effects such as geology, ice transport and scavenging can often be modelled with an appropriate polynomial trend surface. Calculated residuals represent deviations from a variable background caused by local effects such as mineralization or contamination from anthropogenic sources. Residuals may be tested statistically to determine whether they are simply noise, or due to some identifiable source.

Indicator Kriging of residuals provides a method to estimate the probability of samples to be in the anomalous sets. Results of this approach are compared to other methods for anomaly separation such as percentile classifications, probability plots, the Concentration-Area (C-A) method, and the frequency domain (S-A) method. The drawback of trend analysis is that it is a global method, requiring a polynomial to be fitted to the whole study area, and is not so good for modelling a background surface that has scale effects that differ regionally. Nevertheless, in many situations it works well in practice and is a useful addition to the data analysis toolbox for removing variable background.

SS11-P01 **MULTIFRACTAL AND LOCAL SINGULARITY STRENGTH SHARACTERIZATION AND ITS APPLICATION TO MINERAL EXPLORATION**

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The Abitibi greenstone belt accounts for approximately 80% of total production, reserves and number of significant mineral deposits in the Archean Superior Province. The purpose of this study is to investigate modeling techniques for mineral deposit distribution in part of the Abitibi sub-Province inspired from scale-invariant and multifractal methodology. Spatial distribution of mineral deposits in the Abitibi area of Ontario were analyzed by calculating their generalized fractal dimensions and alpha spectra. This study utilizes an advanced Geographic Information System known as GeoDAS (Geo Data Analysis System) for estimating the strength of singularities locally at an arbitrary resolution. By using the scale-invariance and multifractal methodology, a more objective definition of spatial physical distribution of mineral deposits can be produced. Mineral deposits and their corresponding Voronoi area are linked in order to calculate density measures. The degree of irregularity and the extent of space-filling, can also be determined by multifractal methodology. A multifractal approach can be used for describing spatial distribution of mineral deposits on regional scale. The results of such studies can help the development of theories of ore genesis. The multifractality indices for Zn, Cu, Pt, Pd, Cr, Ni, Cr, Co, Pb and As in lake sediment samples in the Shining Tree area in the Abitibi area of Ontario are also determined. The characterization of multifractal distribution patterns is based on the box-counting moment method and involves three functions: a mass exponent function tau(q); Coarse Holder Exponent alpha (q) and fractal dimension spectrum f(alpha(q)). Properties of these functions at different values of q, characterize the spatial distribution of the variable under study. It is shown that the degree of multifractality can be used as a measure of irregularity of geochemical spatial dispersion patterns. The variations of Zn and Cu in the study area are characterized by relatively low degree of multifractality, whereas those for Pt, Pd, Cr, Ni and Co; and particularly for As and Pb are characterized by higher multifractality indice. In the case of Zn and Cu, singularity spectra are close to a mono-fractal compared to the ones for As an Pb. The determination of multifractality indices allows us, in a quantitative way, to study the pattern of metal dispersions and link them to different physical processes.

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SS11-P02

NUMERICAL TRANSFORMATIONS IN GEOCHEMICAL DATA: OBJECTIVES, PHILOSOPLY AND METHODS TO IMPROVE INFORMATION EXTRACTION AND DATA PRESENTATION

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Geochemical surveys are commonly evaluated using numerical techniques that facilitate data interpretation. Transformations are sometimes used to impart new characteristics to the data that facilitate evaluation. Historically, geochemical data have been transformed for three purposes, that cause the transformed result to: (1) exhibit a 'normal/nearly normal' distribution, so statistical techniques requiring normality assumptions can be applied, (2) exhibit a constant measurement error across the data range, so evaluation can be undertaken on a 'level playing field', or (3) exhibit maximum geochemical contrast (variance), so that all information contained therein can be recognized.

Unfortunately, little consideration has historically been given to the reasons for data transformation. Thus, data transformations have sometimes been applied inappropriately, resulting in mis-interpretation. For example, many geochemists believe that use of the logarithmic transformation will 'normalize' trace element geochemical concentration distributions, allowing use of parametric statistical procedures. Unfortunately, most geochemical data distributions are multi-modal, being derived from several lithologic sources. A monotonic transformation cannot convert a multi-modal distribution into a normal one, and transformation for this purpose is misguided.

Geochemical data is subject to measurement errors whose magnitudes change across the data range. Data interpretation can be complicated by the unequal treatment necessary to accommodate this data feature. As a result, data stabilizing transformations that produce new variables whose propagated measurement error is constant afford substantial advantage because the transformed data can then be treated the same. Variance stabilizing transformations for common sampling and analytical error distributions (proportional, binomial, and Poisson errors) are the logarithmic, angular, and square root transforms, respectively.

Superior geochemical data analysis involves extracting all of the embedded information. Improving geochemical contrast is one method for achieving this end, and power transformations will oftentimes suffice; powers > 1 typically increase skewness and variance, whereas powers < 1 behave conversely. Because variance is a measure of geochemical contrast, transforming data using a power function cannot be used to maximize variance, because the variance will always increase if a higher power transform is used. However, if the data have been scaled to a 0 – 1 interval first, a power transform will not change the data range. Thus, an exponent can be identified that will obtain a distribution with maximum variance, and thus provide the most information.

Examples of variance stabilizing and geochemical contrast maximizing transformations applied to regional geochemical datasets reveal the advantages in transforming data for these purposes.

SS11-P03 DEVELOPING A CENTRALIZED DATABASE FOR MAPPING AND MODELLING IN ILLINOIS

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Since the 1980s, the Illinois State Geological Survey (ISGS) has maintained an archival Oracle database that contains tabular records from oil and gas wells, various test and engineering borings, and water wells. These point data may be queried, but write access is extremely restricted. Spatial data sets have been maintained by various desktop methods.

In conjunction with an ISGS mapping program, multi-disciplinary teams of ISGS scientists are producing diverse field data. They include 1) outcrop and exposure descriptions, 2) detailed records from study-specific drilling, 3) natural gamma logs from both new and old boreholes, 4) shallow seismic reflection transects, 5) photographs and other imagery, 6) spreadsheets with itemized description, classification and interpretation of geologic samples, and 7) compilations of field notes from ISGS library. After collection, these data are processed using task-specific software. These data and the results of analyses are most effectively and efficiently shared among the team members in an open, enterprise database.

Because team scientists desire shared access to common data sets and the ability to enter, update, and append project data, a prototype working database (wDB) for tabular data was developed using Oracle software. Tabular field data including site information, observations, interpretations, and classifications are entered directly into Oracle by the scientists using web-enabled forms or indirectly in batch mode using SQL Loader via data entered in spreadsheet format. Archival data are merged with other data in the wDB. These data may be appended and updated by a scientist and shared by other members of the study team. Tabular data are linked to centralized files and ArcGIS data sets to manage location information, spatial distribution, and imagery.

The wDB is currently being used to prepare maps, develop three-dimensional models of surficial materials, and produce posters and progress reports. Project data will be transferred to ArcSDE and the archival database at the end of each study.

SS11-P04 **FRACTAL CLUSTERING DISTRIBUTION OF GOLD DEPOSITS WITH RESPECT TO FAULTS ATTRACTORS IN ABITIBI AREA, CANADA**

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Anisotropic clustering distributions are observed and characterized using fractal model from the gold deposits in the Abitibi Area, Ontario. The zones around mineralization-associated faults were considered as attractors of location of mineral deposits. A density based fractal model was proposed to characterize the clustering properties of the gold deposits with respect to the distance from linear faults in the study area. Along the faults in various orientations singularity of gold deposit distribution was calculated to show the non-linearity or clustering of gold deposits with respect to distance from faults of different orientations. The result shows that the global singularity of gold deposit with respect to faults of three different striking directions (EW-striking, NS-striking, NE-striking) are 0.42 (for E-W), 0.71(for SN), and 0.88 (NE), respectively. It indicates that the degree of clustering of gold deposits around E-W faults are stronger than along faults in other orientations. The results also imply that gold deposits tend to closer to the EW-striking faults than to SN-striking and NE-striking faults. In other word, EW-striking faults affect the distribution of the gold deposit most, while NE striking faults effect least. The paper concludes that modeling the anisotropic clustering of gold deposits with respect to faults as attractors in various orientations in the Abitibi area can provide insight in characterizing the distribution of the mineral deposits and the relationship to the controlling factor such as faults of different types.

SS-13

UNCONVENTIONAL STYLES OF PLATINUM GROUP ELEMENT MINERALIZATION

STYLES INHABITUELS DE MINÉRALISATIONS D'ÉLÉMENTS DU GROUPE DU PLATINE

R.M. EASTON (ONTARIO GEOLOGICAL SURVEY)

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SS13-01 **PLATINUM DEPOSITS IN SEDIMENTARY ROCKS**

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The term “unconventional” covers a vast, genetically diverse spectrum of deposits and we shall focus here on PGE concentrations in the weathering zone (laterites) and in sedimentary rocks, especially carbonaceous sediments. Lateritization was first recognized in the 1990's as an important factor in the destruction of primary, magmatic platinum-group minerals (PGM). This leads first to the formation of PGE oxides and to the replacement of Fe in the crystal structure of Fe-hydroxides by mobilized PGE. The concomitant loss of optical expression of PGM under the microscope creates problems for diagnostic mineralogy in reflected light: high-reflectance PGM are changed into low-reflectance oxides and hydroxides. Lateritized chromitites at Niquelandia, Brazil, are a case in point: they carry goethites with up to 40% Ru.

Economically relevant changes have been effected by lateritization in the Great Dyke, Zimbabwe. The recently opened Mgezi Mine recovers exclusively PGE oxides, requiring a special mineral processing circuit.

Once mobilized, PGE may form nuggets in rivers, or they may be incorporated into, preferentially carbonaceous, sediments. The Kupferschiefer of Southwestern Poland is a case in point: Certain Cu-rich areas carry thin layers with PGE+Au ccontents of up to several hundred g/t. Presently, palladium is recovered as a by-product in some Kupferschiefer mines Copper-rich (bornite-chalcopyrite) zones in Proterozoic black shales of the Kodor-Udokan basin, Siberia, have up to 3,2 g/t Pd. PGE in Ni-Mo-Zn rich sediments have been recorded from the Nuititang Formation of Southern China and from the Nick deposit in Devonian metasediments of the Selwyn basin, Alaska.

The world-class Serra Pelada Au-Pd deposit in the Carajas Mineral Province, Brazil, occurs in carbonaceous and calcareous metasiltstones. Mineralisation is ascribed to low-temperature oxidising solutions channelled through complex fault systems. Trace elements associated with Au-Pd mineralisation include LREE, Co, Cu, Ni, Pb, Zn, As, Bi W and U as well as Se. The possibility of primary metal concentrations in the black shales has, so far, not been considered. This applies also to the Coronation Hill, N.T., Australia, Au-Pt-Pd deposit in Lower Proterozoic carbonaceous shales, breccias and feldspar porphyries with a complex selenide mineralogy. The latter has been linked to 100-200^{o}C meteoric waters penetrating downwards along a complex fault pattern.

Mobilization of selenium from Silurian black shales into ore veins has been convincingly demonstrated at the now defunct Tilkerode mine, Germany. This raises the question of the derivation not only of selenium but also of the precious metals in the above deposits: external sources have to be considered versus primary pre- to syn-diagenetic concentration.

SS13-02 MAGMATIC PROCESSES IN SHEETS AND SLOTS

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Magma is often called upon to perform unnatural acts. This is no wonder, given that the time sequence of formation and solidification of a magmatic body can only be imagined from the rock record. The best that can be hoped for in unraveling intrusion history is to know from the start the processes most likely and least likely to have occurred. This narrows the ground to a point where the final best guess solution scenario is one that has legs, can be tested, and that can be refined again and again into a robust result compatible with theory, experiment, and, above all, the field evidence itself. The first step is to know in detail the positions and chemical and physical nature of the solidification fronts (SFs), including the rate of propagation. Once this is known, the entire magmatic history can be gauged. The first step is to know the shape, size, composition, and initial temperature of the magma. This is often easier said than done, but there is no substitute for inspired field work and knowing or strongly suspecting what is real and what is believed. It is particularly important to characterize the possible sequence of filling and degree of crystallinity of the initial magma. All magma contains crystals, however small, during emplacement; many magmas are laden with great slugs of phenocrysts that form thick cumulate piles upon emplacement. This is a primary means of differentiation of most basic magmas. Cumulate piles should not be read as protracted crystal nucleation, growth and sedimentation from the magma core. New crystallization takes place only in the SFs; the magma core is crystal free until the fronts arrive. Strong changes and reversals in crystal size inward from the margins indicate phenocryst deposition. Smooth, uniform variations most often reflect a single cycle of emplacement and solidification. It is critical to map the crystal size distributions; a basic model of the heat flow and crystallization is necessary to know what CSDs are to be expected. The dynamics of interstitial melt, which is the essential fluid to understand for ore deposition, in the SFs plays strongly different roles in sheets and slots (walls). Upward and downward near-wall flows, crystal avalanches, migration of late stage hydrothermal fluids, and wall rock interactions are special to walls.

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NO GENETIC LINK BETWEEN THE NORIL'SK-TYPE ORE-BEARING INTRUSIONS AND SIBERIAN FLOOD BASALTS

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There is a strong belief among many petrologists that the ore-bearing Noril'sk-type intrusions are comagmatic with overlying flood basalts. It is proposed that the intrusions acted as feeder channels through which several generations of magma have flowed and deposited sulphides to form the overlying flood basalts (Rad'ko, 1991; Naldrett et al., 1995; Arndt et al., 2003). The intrusions are thought to have been produced from magma parental to basalts of the Nadezhdinsky formation (Naldrett et al., 1995) or the Upper Morongovsky and Mokulaevsky formation (Arndt et al., 2003). It should be emphasized that the belief in comagmatic relations between basalts and intrusions is exclusively based on trace element and isotopic studies. Neither major element nor phase equilibria evidence has ever been presented to support this idea.

In attempt to fill this gap, Latypov (2002) discovered a significant difference in the composition of parental magmas of these intrusions and flood basalts. Specifically, it was demonstrated that the parental magma of the intrusions is silica-undersaturated olivine basalt, whereas that of the flood basalts is silica-saturated tholeiite. The plutonic equivalent of the former parental magma is olivine gabbro or melagabbro (opx-free rocks), while the latter is gabbronorite (opx-rich rock). Phase equilibria relations clearly show that these two types of magmas cannot be comagmatic as there is no way to derive one liquid from another by fractional crystallization. Lee et al. (2003) reconfirmed the above conclusion by showing that the average compositions of nearly all lavas are not likely to crystallize olivine under variable pressures ranging from atmospheric to mantle conditions due to their high SiO_2 contents. In an attempt to resolve this problem, Arndt et al. (2003) have suggested that the composition of magma that erupted as flood basalts was more evolved than intrusive rocks because of crystallization and precipitation of olivine within the intrusive bodies prior to final eruption. This explanation does not work, however, since even the most evolved intrusive rocks that presumably deposited all olivine phenocrysts are still olivine gabbro (opx-free rock), not gabbronorite (opx-rich rock) as is the case with all flood basalts.

We argue that the Noril'sk-type intrusions were formed from specific olivine gabbro to melagabbro parental magma that had nothing to do with the overlying Siberian flood basalts. We strongly recommend therefore that further models for the origin of Noril'sk-type intrusions would be based on the notion of non-comagmatic relations between intrusions and basalts.

SS13-04 METAL ZONATION AT THE LAC DES ILES PALLADIUM DEPOSIT

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Economic palladium mineralization at Lac des Iles is contained within two distinct bulk mineable zones: the Roby Zone and the Twilight Zone. The Roby Zone is characterized by a chaotic assemblage of lithologies most of which may be mineralized and altered, whereas mineralization in the Twilight Zone is more lithologically controlled and the host rocks less altered. Metal distribution trends across these two zones provide evidence for multistage and multiprocess development of the deposit. The strong correlation of PGE with base metals (Cu, Ni) in the Twilight Zone reflects the predominance of primary magmatic mineralization, while the poor correlation of metals in the Roby zone is due to extensive overprinting by deuteric fluids.

Detailed geochemical analysis of drill core has revealed strong metal zonations across the subvertical planar Main High Grade Zone of the Roby Zone. A Cu rich (Cu > 0.35%, Ni < 0.1%, Pd < 1 g/t) zone occurs at the eastern boundary. This is followed by a central Pd rich, base metal poor zone (Pd > 15 g/t, Cu < 0.1%, Ni < 0.1%) and by a base metal rich, Pd poor zone (Ni > 0.25%, Cu > 0.25%, Pd < 2 g/t). This metal distribution pattern can be interpreted to represent sequential metal precipitation at the front (or margins of a hydrothermal plume, initially prior to complete crystallization of the magma but also at subsequent cooler temperatures.

This is supported by mineralogical evidence. Primary sulphide textures and secondary sulphide replacement textures are seen throughout the deposit. Zoned platinum group mineral (PGM) grains and intergrowths of PGM species are common, giving an insight into timing relationships involved in formation of the deposit. The distribution of PGM is also important in that the most abundant PGM (kotulskite) is typically associated with secondary silicate alteration minerals, highlighting the significant role of fluids.

SS13-05

PLATINUM-GROUP ELEMENT COMPARISON OF THE ROBY AND TWILIGHT ZONES OF THE LAC DES ILES COMPLEX, NORTHWEST ONTARIO

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The Lac des Iles Complex contains Canada's only primary Platinum-group element ore deposit; this is known as the Roby Zone. The Twilight Zone is a PGE occurrence to the northwest of the Roby Zone. A remarkable feature of the Roby Zone is the high Pd/Pt ratios of the ores - 9. Most mafic magmas have Pd/Pt ratios of 0.5-2 and the partition coefficients between sulfide liquid and silicate liquid are similar, a simple collection of PGE by a sulfide liquid from a mafic magma does not account for the composition of the Roby Zone ores. This, plus the presence of pegmatitic textures and of amphiboles, and the apparent lack of correlation between S and the PGE led a number of authors to propose models invoking introduction or remobilization of PGE into the Roby Zone by late magmatic fluids.

The average concentration of Pd and Pt from our samples of the Twilight Zone is 2 ppm Pd, 0.25 ppm Pt. Thus, the Twilight Zone samples have similar Pd/Pt ratios of the Roby Zone. In order to investigate the effects of sulfides and fluids the correlations between PGE and S, LOI and S were examined. There is no correlation with LOI, but there is one with S. In the Twilight Zone then sulfides control the PGE. The compositions of the sulfides from pegmatitic rocks, fragments, matrix, and altered rocks were compared and were found to be similar. Thus, these sulfides were introduced into the rocks after all textural types had formed. Closer examination of the Roby Zone data shows that there is a correlation between S and PGE for the common ore types (breccia ore), but not for the high-grade ore (a mafic schist). The compositions of the sulfides recalculated to 100% sulfides for the Twilight Zone and the breccia show similar values to each other and are 5 times lower than Naldrett's (1981). This, combined with the higher Pd/Pt ratio of his samples suggests high-grade ore was over represented in his sample set. In the high-grade ore sulfides appear altered and recalculation to 100% sulfides is not justified. Thus, this data should not be used when comparing 100% sulfide data, rather the data from Brügmann and Naldrett (1987) should be used; Os = 53, Ir = 50, Ru = 1814, Rh = 2500, Pt = 26375, Pd = 264997, Au = 26873 ppb, Ni = 8.2%, Cu = 10.9%.

SS13-06 SUDBURY CU-PGE ENVIRONMENTS: DEFINING 'SHARP WALLED' AND 'LOW SULPHIDE' SYSTEMS

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This study represents an attempt to quantify and define the differences between classic 'sharp walled' Cu-PGE vein systems and 'low sulphide' PGE mineralization in the Sudbury Ni-Cu-PGE camp. The analysed dataset consists of 17369 borehole assays (Ni, Cu, Co, S, Pt, Pd and Au) from FNX Mining's four PGE-rich zones: 700 Complex, PM Deposit, Norman North and Norman 2000 zones. 'Sharp walled' vein systems are characterized by chalcopyrite-rich sulphide veins with minor cubanite, pyrrhotite, pentlandite, millerite, bornite and magnetite that are locally up to 7 m wide (INCO McCreedy East 153 Zone). The associated PGE distribution is varied, with Pt+Pd+Au grades rarely > 100 g/t. However, economic grades (> 5 g/t) are typically limited to within or near the margins of chalcopyrite-rich veins. In this study, the McCreedy West Mine 700 Complex is considered to be representative of end-member 'sharp walled' Cu-PGE systems, with little Pt+Pd concentrated outside the sulphide-rich veins. Like other footwall PGE-rich zones, the 'low sulphide' PM Deposit PGE display an affinity to sulphide distribution, especially chalcopyrite ± millerite. However, the overall sulphide content of the PM Deposit is lower, with a higher proportion of stringer, bleb and disseminated sulphide-associated PGE contributing to its economics. Within the PM Deposit dataset of 6213 assays, 46.6% of samples with S contents from 1 to < 2 wt% contain > 5 g/t Pt+Pd. The Norman North and 2000 zones are considered 'hybrid' Cu-PGE systems whereby PGE distribution is associated with both vein and disseminated sulphides. Both zones are hosted largely within inclusion-bearing quartz diorite and metabreccia of the Whistle Offset, but are considered to have formed as a result of similar processes to the footwall Cu-PGE systems. This preliminary attempt to use assay data to test the use of sulphide content as a visual queue to PGE grade estimation and distribution has shown that: (1) a quantitative distinction can be made between end-member 'sharp walled' and 'low sulphide' PGE systems at Sudbury; (2) it is not possible to visually estimate PGE grades by sulphide content in either 'hybrid' or 'low sulphide' PGE environments; (3) Pt and Pd display decoupled behaviour, resulting in wide variation in Pt/Pd ratios within zones; (4) different zones will contain different PGE grades in massive sulphide and must be analysed on an individual basis; and (5) these observations influence issues as diverse as exploration sampling protocols and mining methods.

SS13-07 AS-RICH NI-CU-(PGE) MINERALIZATION IN THE GARSON MINE, SUDBURY, ONTARIO

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The world-class Ni-Cu-(PGE) deposits in the 1.85 Ga Sudbury Igneous Complex (SIC) occur in three locations at or near the base of the SIC, as contact-, footwall-, and offset-type deposits. Some of the deposits, especially those on the South Range, have been structurally modified. The Garson deposit is located in the southeast corner of the Sudbury basin at the base of the SIC and is characterized by strong structural control and locally abundant As-rich mineralization. Establishing the distribution and origin of the As and associated semi-metals is important because of their implications for the paragenesis of the ores and their deleterious effects during processing. The host rocks of the Garson deposit have undergone multiple phases of penetrative deformation, and the ores are concentrated in several east-west trending shear zones. The ore zones are tabular and pinch and swell in an undulating fashion, along and below the contact between the SIC norite to the north and Huronian metasediments and greenstones to the south. The ore zones and shear zones are cross-cut by late olivine diabase dikes. The ores are composed primarily of pyrrhotite, pentlandite, and chalcopyrite and may locally contain minor amounts of gersdorffite (NiAsS) and cobaltite (CoAsS), trace amounts of niccolite (NiAs), and rare sperrylite ($PtAs_2$) and other PGMs (Ni-Pd-Bi-Te minerals). Arsenic-bearing phases occur within or in association with massive ores, and rarely with disseminated ores. The arsenides exhibit an almost complete range in composition in the system CoAsS-NiAsS-FeAsS, varying between $(Co_{0.95}Ni_{0.05})AsS$ and $(Ni_{0.90}Co_{0.10})AsS$. It is not yet clear whether the range in composition represents more than one episode of arsenide crystallization or whether it implies that the system reached temperatures of ~600°C based on experimental studies. The presence of some grains with Co-rich cores and Ni-rich rims and others with Ni-rich cores and Co-rich rims suggests that the arsenides are not the products of the progressive fractionation of a single magmatic-hydrothermal fluid. The metasedimentary footwall rocks have been proposed as the As source, either by the assimilation of the metasediments or scavenging by hydrothermal fluids. If magmatic, the restricted distribution may be attributed to gravitational settling, whereas if hydrothermal, the distribution may be attributed to proximity to the metasediments. Results from an As-analysis of metasedimentary country rocks discovered no detectable As, which might reflect leaching, but which leaves unanswered questions regarding the source of the As and its restricted distribution to the South Range ores.

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GEOLOGY, MINERALOGY, AND GEOCHEMISTRY OF TRANSITIONAL CONTACT/FOOTWALL MINERALIZATION IN THE MCCREEDY EAST NI-CU-PGE DEPOSIT, SUDBURY IGNEOUS COMPLEX

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The Ni-Cu-PGE deposits associated with the 1.8 Ga Sudbury Igneous Complex occur within 3 distinct environments: within quartz diorite offset dykes associated with the SIC, within embayments along footwall contacts of the SIC, and within brecciated and veined footwall rocks. The ores in contact and deposits are commonly fractionated: contact deposits are Fe-(Ni)-rich and footwall deposits are Cu-PGE-(Ni)-rich. Information on the transition between these two types of deposits is limited and in order to aid in understanding the genesis of the ores, we have studied the transition zone at the McCreedy East deposit, which is a contact type deposit in close proximity to a footwall deposit. Detailed mapping and sampling in the lowest cut of the Lower Main ore body indicate that there are several megascopic differences between Contact and Footwall type ores, including variations in the proportions of clasts and matrix material, and in the compositions, angularity, and orientations of the clasts. Three zones can be distinguished based on these characteristics (from footwall toward the SIC): a Levack Gneiss Zone (LGZ), a Megabreccia Zone (MBZ), and a Granite Breccia Zone (GBZ). Changes in lithology and texture from the LGZ into the MBZ are usually gradational and subtle, whereas changes in lithology and texture from the MBZ into the GBZ are more abrupt. Sulfide textures and wallrock contacts change markedly across the zones: from stringer sulfides with sharp wallrock contacts in the LGZ to diffuse disseminations and blebs of sulfide in the GBZ. Thin rinds of Ccp are common on stringer margins in the LGZ, are absent in the MBZ, and are present as thin, discontinuous veinlets in massive sulfides of the GBZ. On a microscopic level, the presence and shapes of Pn flames can be used to define the same zones, which are most common spanning the contact between the GBZ and the MBZ. Based on these characteristics and geochemical data, the Transition Zone appears to represent an advancing zone of fracture propagation, mechanical erosion, and sulfide fractionation in which the contact ores in the GBZ contain accumulated Mss and the footwall ores in the LGZ contain more residual sulfide liquid.

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THE NATURE OF THE MERENSKY REEF IN THE EXTREME SOUTHEAST PART OF THE BUSHVELD COMPLEX, SOUTH AFRICA

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WITHDRAWN

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THE EAST BULL LAKE INTRUSIVE SUITE: REMNANTS OF AN ~2.48 GA IN THE SUDBURY AREA OF THE CANADIAN SHIELD

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Intrusions of the ~2.48 Ga old East Bull Lake intrusive suite (EBL) occur as an ENE-trending belt along the boundary of the Archean Superior and the Proterozoic Southern provinces in Ontario, Canada. The EBL suite is part of a regional Paleoproterozoic, bimodal magmatic event resulting from a mantle-plume driven, intracontinental rifting event that formed a major basin, filled by sedimentary and igneous rocks of the Huronian Supergroup. Intrusions of similar age and composition in Finland and Wyoming were once contiguous with the EBL suite prior to tectonic dispersion during the Proterozoic.

Field and geochemical evidence indicates that the three largest intrusions (East Bull, Agnew, River Valley) crystallized from similar, low-Ti, high-Al, PGE-rich, tholeiitic parent magmas that originated in deeper, more mafic chambers. The primary magmas were likely second-stage melts derived from a sub-lithospheric depleted mantle source modified by Neoarchean subduction and accretion events. Petrologically, the intrusions reflect plagioclase-dominated fractional crystallisation that generated a pronounced Fe-enrichment trend in the residual magmas. Olivine and orthopyroxene only occur as cumulus phases in the interpreted lower parts of the stratigraphy. Rhythmically and irregularly modally-layered leucogabbronorite and gabbronorite make up much of the middle part of the stratigraphy. Ferrogabbro and ferrosyenite only occur in the uppermost Agnew Lake intrusion. A marginal facies, comprising brecciated and, locally, thermally recrystallized and/or partially melted footwall rocks, is common and is testimony to a high-energy flow regime during initial emplacement. This marginal unit typically grades into a heterolithic, inclusion-rich gabbronorite with erratically distributed leuco- to melanocratic autoliths and footwall xenoliths and eventually into a thick interval of undifferentiated, plagioclase-rich cumulates; locally with spectacular glomerocrystic textures.

Disseminated, bleb and interstitial magmatic chalcopyrite-pyrrhotite-pentlandite mineralization (1-5% sulphide, up to 4 g/t Pt+Pd) occurs in autolith-rich gabbronorite breccia within 5 to 50 m of the contact of the intrusions and is commonly spatially associated with pyroxenite cumulates and autoliths that are otherwise poorly represented in the stratigraphy. Vigorous convection and explosive breccia-producing emplacement of sulphide-saturated magma formed PGE-rich zones at the margins (sidewall? floor?). The magmatic sulphide zones are overprinted and enclosed by a broader envelope of metamorphic and/or hydrothermal sulphide of similar mineralogy (+/-pyrite) that extends into adjacent leucogabbronoritic to anorthositic units, and less so into the country rocks. The hydrothermally enriched zones contain 2-10% sulphide with 1 to 10 g/t Pt+Pd, and represent the main exploration target. The high grade zones are enclosed by broader, lower grade mineralization with Pt+Pd levels in the background range of 20-50 ppb.

SS13-11 NIPISSING-AGED NI-CU-PGE MINERALIZATION IN THE SHAKESPEARE INTRUSION

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The 2717 Ma (Sutcliffe et al., 2002: Ontario Prospectors Association Meeting, Toronto) Shakespeare intrusion is part of the extensive 2.2 Ga Nipissing Diabase suite and is hosted within 2.45-2.2 Ga Huronian Supergroup metasediments in the Southern Province of the Canadian shield, close to the border with the Superior Province. The intrusion hosts semi-massive to disseminated sulfides with an indicated resource of 4.9 Mt at 0.43% Ni, 0.43% Cu and 1.2 g/t Pt+Pd+Au. The aim of this study has been to examine the petrogenesis of the intrusion and to determine the origins of the Ni-Cu-PGE mineralization.

The intrusion is a complex differentiated sill approximately 14 km in strike length and approximately ~300-~430 in thickness. It comprises two magmatic packages: 1) a lower package composed of unmineralized pyroxenite and gabbro, and 2) an upper package composed of mineralized melagabbro, quartz gabbro, and biotite quartz gabbro-diorite. The upper package is variably chilled against the lower package that suggests that the first magma series was variably cooled as the second magma pulse entered the magma chamber. Mineralized melagabbro dykes intrude the lower unmineralized gabbro/pyroxenite package, and may represent feeders for the upper package or small apophyses of the upper package cutting downward into the lower package. Heavily disseminated to net-textured (10-15%) sulfides (po+cpy+pn) occur in the upper zone of the melagabbro near and at the contact with the overlying quartz gabbro and in the melagabbro dykes. Blebby-textured po+cpy+pn (< 5%) occur throughout the remainder of the melagabbro and in the lower sections of the overlying quartz gabbro.

The biotite quartz diorite, quartz gabbro, and melagabbro contain abundant blue quartz eyes and angular to subrounded clasts of quartzite and lesser dioritic clasts, ranging in size from mm to metre scale. The clasts appear to be most abundant in the mineralized melagabbro. Some diorite clasts include small sulfide droplets, and sulfide droplets also occupy boundaries between clasts and the host magma, suggesting that the sulfide droplets formed by contamination during interaction of the magma with the clasts. The presence of sulfides in melagabbro dykes suggests that some of the crustal contamination that induced sulfide saturation may have occurred enroute to the magma chamber.

The Ni-Cu-PGE mineralization in the Shakespeare intrusion appears to have formed as sulfide saturation was induced in the second magma pulse via contamination with country rocks and accumulation of sulfides on top of the accumulating crystal pile.

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SS13-12 MCBRATNEY PGE-AU OCCURENCE HOSTED IN A MAFIC-ULTRAMAFIC SEQUENCE OF THE FLIN FLON GREENSTONE BELT, MANITOBA: PETROGENETIC CHARACTERIZATION AND ORE MINERALOGY

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The Flin Flon Greenstone belt comprises 1.92-1.87 Ga juvenile arc and back-arc rocks, minor oceanic plateau, oceanic island-basalt and evolved plutonic arc rocks. The McBratney platinum-group element (PGE) and gold occurrence is hosted by the sequence of juvenile arc rocks of the Bear Lake Block. The McBratney occurrence is locally hosted in highly metamorphosed and hydrothermally altered primitive basaltic to komatiitic rocks intruded by mafic-ultramafic dykes and sills. The mafic-ultramafic pile is more than 60 m thick and contains three distinct sulphide-rich zones. The rocks are strongly foliated, obliterating most of the primary magmatic textures. The hanging-wall host rocks, interpreted as flows, are pyroxenitic komatiite in composition. They are characterized by a HREE-enriched mantle normalized pattern ($REE_{sample}/REE_{mantle}$ ~1, La:Yb=0.45-0.94, slightly positive Eu anomaly), with Zr:Y and Nb:Yb ratios varying between 1.29-1.71 and 0.37-0.83, respectively. The footwall rocks are altered basaltic komatiites with similar REE pattern (La:Yb =0.59-0.97) and higher abundance in REE ($REE_{sample}/REE_{mantle}$= 3 to 7), higher Zr:Y (2.10-2.90) and lower Nb:Yb (0.20-0.42). Mafic-ultramafic intrusions have Zr:Y and Nb:Yb ratios of 0.9-1.83 and 0.48-1.23, respectively, and REE pattern similar to the hanging-wall pyroxenitic komatiite (La:Yb=0.59 to 0.96); they are interpreted as co-genetic to these volcanic rocks.

The mineralized zones range in thickness from 10-70 cm and are separated by mafic-ultramafic host rocks containing disseminated sulphides. The stratigraphically highest and lowest mineralized zones comprise mainly pyrrhotite and violarite, while the central zone contains predominantly chalcopyrite. The earliest preserved phases within the hosts are hornblende and plagioclase, replaced by actinolite, chlorite, calcite, biotite and muscovite. Actinolite and early chlorite phases are replaced by Fe-rich chlorite and calcite. Quartz occurs predominantly at sheared contacts or in veinlets, and is commonly associated with disseminated sulphides. Proximal to mineralization, the host rocks are intensely foliated and locally brecciated, intruded by hydrothermal quartz-carbonate-chlorite veining. PGE grade is higher in the chalcopyrite-rich zone (up to 200 g/t Pd and 30 g/t Pt) than in the pyrrhotite-rich zones (up to 50 g/t Pd and 5 g/t Pt). The platinum-group minerals (PGM) occur included in the various sulphides, and comprise: sudburyite, tellurian sudburyite, merenskyite, borovskite, sperrylite, temagamite, and an unknown Pd-Te-Sb mineral. Minor PGM occur included in carbonate, chlorite and biotite. Au-Ag alloy was found included only in chalcopyrite.

The McBratney occurrence is interpreted as hydrothermal in origin, formed after the metamorphism of the mafic-ultramafic sequence.

SS13-13

THE UNIQUE KONTTIJÄRVI MARGINAL SERIES PGE ORE OF THE PORTIMO LAYERED IGNEOUS COMPLEX, FINLAND

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The ca. 2440 Ma old Portimo Layered Igneous Complex is composed of four igneous units: the Portimo Dykes, the Narkaus Intrusion (NI), the Suhanko Intrusion and Konttijärvi Intrusion the last two forming the South Portimo Group (SPG).

Difference between the layered series of the NI and SPG intrusions is the presence of marked reversals in the NI, as shown by the thick ultramafic olivine-rich cumulate layers, whereas crystallization in the SPG intrusions continued without any notable reversals. The major reversals enable NI layered series to be divided into MCU I-III. Geochemical evidences show that SPG layered series corresponds to MCU III, while the Portimo Dykes are chemically related to MCU I and II.

The Portimo Complex is exceptional in hosting a variety of PGE mineral deposits. The mineralization types include:

- a PGE-bearing sulphide disseminations in the SPG marginal series and Portimo Dykes
- massive pyrrhotite deposits close to the basal contact of the Suhanko Intrusion
- the Siika-Kämä PGE Reef in the Narkaus Layered Series, at the base of MCU III
- the Rytikangas PGE Reef in the layered series of the Suhanko Intrusion
- the offset Cu-PGE mineralization below the Narkaus Intrusion

Disseminated PGE-bearing base metal sulphide concentrations are encountered throughout the marginal series of the SPG intrusions. Mineralization is erratic, and it often extends 30 m into the basement. The PGE content is generally 0.3-2 ppm, but rises to over 10 ppm in the Konttijärvi and Ahmavaara areas. So highly PGE-enriched marginal series are rare in layered intrusions, and the only other well-known occurrence is the Platreef in the Bushveld Complex. The Portimo Dykes are only known below the Konttijärvi and Ahmavaara areas. The Portimo Dykes are also found locally to carry PGE up to several ppm. A coprecipitation of U-minerals with Pd-Se minerals is also found within the Portimo Dykes. High-grade PGE mineralization has thus taken place when MCU I-II type of mafic material is overlain by MCU III type. The structural position of this enrichment, excludes however the possibility that its genesis could be exclusively linked with processes enacted in the present intrusions only, but suggest that the ore-forming processes started in deeper levels in the crust. The multimillion-ounce PGE deposit in a Konttijärvi Intrusion (c. 2 km^2) signifies the economic possibilities of small mafic bodies.

SS13-P01 MARGINAL ORES OF LAYERED CHINEY PLUTON, RUSSIA

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WITHDRAWN

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PLATINUM GROUP ELEMENT MINERALOGY AND PARAGENESIS IN THE MARATHON PD-CU DEPOSIT, ONTARIO

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The Marathon platinum group element (PGE)-Cu deposit is hosted by the 1108 Ma Coldwell intrusive complex. Three styles of mineralization occur in the deposit: (1) massive to net-textured Fe-rich sulphides in a massive, fine-grained gabbro (the Basal Zone); (2) disseminated, Cu-rich sulphides within variably-textured (medium-grained to pegmatitic) gabbroic rocks (the Main Zone); and (3) magnetitite layers in layered olivine gabbro (the Upper Zone). PGE mineralization is Pd-rich and is principally associated with Cu-rich intervals in the Lower Zone, which generally occur several tens of metres stratigraphically above the sulphide-bearing, Basal Zone rocks. The magnetitites of the Upper Zone also host Cu-PGE mineralization.

Previous workers described a wide variety of platinum group minerals (PGM), from the Marathon deposit, including hollingworthite, sperrylite, kotulskite, and atokite-zvyagintsevite, and found that the majority occurred in or associated with Cu sulphides. In addition to the PGM noted previously, using SEM-EDS, we have tentatively identified As-bearing polarite, mertieite and taimyrite. The textural settings of PGM in the Basal Zone are similar to those described in earlier studies, in that the PGM are closely associated with sulphides. In the Lower Zone, however, which contains the bulk of the Cu-Pd mineralization, we found that the PGM occur exclusively in silicates peripheral to sulphide aggregates. Within the silicates, most PGM are located in altered or fractured plagioclase, but can also be associated with fresh plagioclase, particularly at grain boundaries. In the Upper Zone magnetitites, the PGM mostly occur either in association with Cu sulphides or in magnetite. Furthermore, the PGM mineral assemblages in the Basal and Lower Zones are distinctly different from the Upper Zone assemblage, in that arsenides (e.g. kotulskite and majakite) are the most abundant mineral group present in the former and Pb-bearing Pd alloys (e.g. zvyagintsevite) are dominant in the latter. Some PGM in the Lower Zone occur as aggregates or are zoned.

The association of PGM in the main mineralized zone (the Lower Zone) with altered silicates indicates that these minerals were precipitated hydrothermally, which is consistent with previous observations that the Cu-sulphides replaced primary assemblages. The differences in PGM mineralogy in the three zones further indicates that the conditions under which the PGM precipitated or the reasons for precipitation were different. In order to test models in which the PGE were locally, hydrothermally remobilized from primary phases, we are currently determining PGE concentrations in the sulphides, oxides and PGM by LA-ICP-MS.

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SS13-P03 3-D GRAVITY MODELING OF UNEXPOSED FEEDER INTRUSION CONNECTING WESTERN AND EASTERN PART OF THE KOILLISMAA LAYERED IGNEOUS COMPLEX, FINLAND

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The Koillismaa Layered Igneous Complex (KLIC) in Finland belongs to the group of early Proterozoic 2.45 Ga old layered intrusions of the Fennoscandian Shield. The KLIC consists of two separate exposed intrusions, the Eastern and Western Intrusions. The Eastern Intrusion, called also Näränkävaara, represents the exposed part of an extensive Feeder Intrusion while the numerous mafic igneous bodies in the west are thinner blocks, which before tectonic movements were forming one single lopolith-like Western Intrusion. The Western and Eastern intrusions are connected by a 55 km long strong positive gravity anomaly, which is due to the unexposed part of the Feeder Intrusion. This Feeder Intrusion is capped by felsic volcanic rocks, albite quartz rocks (metasomatic in origin) and Archean gneisses, all having low densities. Previous interpretation of the Bouguer gravity anomalies suggested that Näränkävaara Intrusion has the depth extent even to 10 km. Before this study, the unexposed Feeder Intrusion had been interpreted to be 2.5-5 km wide with the depth of the upper surface from 1 to 2 km. The vertical thicknesses of the three major blocks of the Western Intrusion are from 800 to 2,500 meters.

In this study 3D structure of the Feeder Intrusion between Western and Näränkävaara Intrusions has been modeled and depicted by polygons and prisms. The main aim has been to model the depth of the upper surface of the unexposed part of the Feeder Intrusion as well as the dimensions and position of this high-density mass.

The Feeder Intrusion was modeled using polygonal bodies and, for comparison, plunging prisms. The computer processing gave the depth values for the upper surface between 840–1500 m when using prismatic bodies and 500–1350 m when polygonal bodies were used. In the polygonal-body models the anomalous mass is thinner and distributed wider than in the prism model. In addition, as based on the field observations and ground and aeromagnetic surveys, there are also a number of vertical magnetic mafic dykes, which may have originated from the Feeder Intrusion.

Näränkävaara Intrusion was modeled by polygonal bodies using known lithological boundaries and true density values from core loggings. This study revealed the Näränkävaara Intrusion to extend to the depth of only 5 km instead of 10 km of the earlier interpretation.

GEOLOGICAL ASSOCIATION OF CANADA
MINERALOGICAL ASSOCIATION OF CANADA
JOINT ANNUAL MEETING
BROCK UNIVERSITY, MAY 12-14, 2004

Lake to Lake
GAC-MAC AGC-AMC St. Catharines 2004
D'un lac à l'autre

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CONGRÈS ANNUEL CONJOINT
UNIVERSITÉ BROCK, DU 12 AU 14 MAI 2004

SS-14

KIMBERLITES AND DIAMONDS: NEW DISCOVERIES AND NEW DEVELOPMENTS

KIMBERLITES ET DIAMANTS : NOUVELLES DÉCOUVERTES ET MISES EN VALEUR

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SS14-01 REVEALING MANITOBA'S HIDDEN KIMBERLITES

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Although no discoveries of diamondiferous kimberlite have been announced to date in Manitoba, the geological components essential for kimberlite occurrences are present, as are promising results from indicator mineral surveys from several areas. The local presence of a thick and complex till stratigraphy, however, has complicated effective diamond exploration in some of the more promising areas of the province.

To encourage and support new diamond exploration efforts in Manitoba, the Manitoba Geological Survey is undertaking a number of initiatives:

1) Compilation of existing kimberlite indicator mineral data from numerous surveys and agencies into a single comprehensive and searchable database.

2) Analysis and three-dimensional modelling of till stratigraphy in the Hudson Bay Lowland which demonstrates the concentration of indicator minerals within the second of four till units. Ice flow directions, derived from till fabric analysis and indicator distributions, suggest that indicator minerals were dispersed by ice flowing to the southeast in addition to regionally pervasive southwesterly ice flow events. This improved understanding of the till stratigraphy and indicator distributions allows re-evaluation of past exploration results and clearly aids future diamond exploration in this highly prospective area.

3) Compilation of geophysical and structural features that potentially control the occurrence and distribution of kimberlitic rocks. These features are compiled together with 'young' igneous occurrences in predictive GIS map products.

4) Modelling and comparison of circular geophysical and bedrock elevation anomalies with those associated with known kimberlitic bodies.

5) Petrographic and geochronological investigations of known kimberlitic rocks of Manitoba.

6) Examination of the nature, tectonic evolution and assembly of crustal terrains in the north Superior Province and along its complex margin with the Trans-Hudson orogen. First results show this region to host an ancient platformal supracrustal sequence that indicates parts of the NW Superior Province crust had stabilized prior to 3.0 Ga and could have thick lithosphere. This region is intersected by crustal-scale structures and dyke swarms. Furthermore, the proximity to mantle plume hotspot tracks which crossed northeast Manitoba during the Mesozoic and to a north-south trending Cretaceous corridor of kimberlite magmatism which occurs in central North America also predicts that this region could host kimberlites.

A summary of developments and prospects in the Manitoba kimberlite search will be presented.

SS14-02 SGH - A SOIL GAS HYDROCARBON METHOD TO LOCATE KIMBERLITE PIPES - A CASE STUDY

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The Soil Gas Hydrocarbon (SGH) method developed by Activation Laboratoratories has shown dramatic success in the location of kimberlite pipes. The SGH technique involves collection of material in the B-horizon surface fraction. This material is used as a long-term integrator of the soil gas flux in the area.

The samples are sent to the laboratory where the weakly bound heavy hydrocarbon compounds in the C_5-C_{17} carbon series range are desorbed and analyzed using a technology developed by Actlabs over the last seven years. The desorbed hydrocarbons are then introduced into a gas chromatograph-mass spectrometer (GC-MS) where 162 heavy hydrocarbon compounds are measured. The analysis of heavier hydrocarbons results in a resilient method to factors such as sample handling, shipping, preparation procedures, and storage conditions. Further advantages to SGH are the absence of effects shown by instantaneous soil gas measurements, which are affected by changes of barometric pressure, rain and biodegradation, it's resiliency to cultural activity, and its robustness to the variability in soil type. The method also allows for easy sampling of near surface soils and requires only one trip to the field to collect the samples.

The success of SGH is due to the use and specificity of GC-MS, ultra-sensitive detection limits in the very low ppt (pg/g) range, and a method that has been designed to provide the throughput and economics required for large survey exploration.

Using this successful technique, geochemical maps for soil gas hydrocarbon compounds tend to be very clean and easily interpreted indicating primary anomalies directly over kimberlite pipes and immediately peripheral to them.

A detailed case study will be shown that illustrates the ability of the SGH data to provide confident interpretation and the ability to vector towards a buried kimberlite pipe.

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KIMBERLITE INDICATOR MINERAL DISTRIBUTION IN ESKERS, LAKE TIMISKAMING KIMBERLITE FIELD, ONTARIO AND QUEBEC: PRELIMINARY RESULTS

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Glaciofluvial deposits have been sampled for kimberlite indicator minerals over the past 40 years. Whereas there has been extensive research into optimal sampling methods using stream sediment, no similar attention has been given to esker deposits. Significant differences exist between fluvial and glaciofluvial deposits, particularly esker deposits. In an attempt to improve the ability to strategically sample and interpret indicator mineral concentrations in esker and moraine deposits, a preliminary study was initiated in the Lake Timiskaming kimberlite field of northeastern Ontario and western Quebec. Thirty-eight sample sets were collected from glaciofluvial deposits of the Sharp Lake esker in Ontario (n 6), and from the Paulson esker (n 16), and Lac Baby esker/moraine (n 16) in Quebec. Samples were collected from a variety of sand, pebble, cobble and boulder grave facies for grain size analysis, indicator mineral counting and analysis of pebble lithologies. Results indicate significantly different geological controls on the provenance of the deposits within each of the three sample areas. Consequently, only results from the Lac Baby area are discussed in this abstract.

Samples from four sites were collected from a 2 km north to south transect along the Lac Baby landform. A fifth sample site was located ~2 km to the north in the same upland region. Other than the nature of the sediment facies, it was generally difficult to identify more specifically the depositional environment represented by the samples. In two cases, however, gravel deposits of large foresets of either esker bar forms or kame deltas were sampled. Samples are believed to have been collected from glaciofluvial sediment deposited both before and following the regional glaciolacustrine inundation. For each of the five kimberlite indicator minerals counted, Cr-pyrope, E-garnet, Cr-diopside, Mg-ilmenite, chromite and olivine, an order of magnitude variation in values was common between sites. No systematic increase or decrease in mineral concentration along the N-S transect is evident. Furthermore, within site variability of mineral concentration between different sediment facies, and between similar facies from different stratigraphic position in the sections, ranged over an order of magnitude. In some cases the highest abundances are not in gravel facies, but in coarse sand. The degree of matrix sorting does not seem to have a significant correlation with the quantity of indicator minerals present. Variations in results can be attributed, in part, to the stratigraphic horizons sampled, autocyclic mechanisms of the glacial hydraulic system, and sampling methodology.

SS14-04 THE HYDROGEN CONTENT OF OLIVINE – A NEW TOOL FOR DIAMOND EXPLORATION

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Magnesian olivine (Mg# 88-94) is a principle constituent of upper mantle derived rocks and a common diamond indicator mineral in arctic environments. However, despite its abundance in till samples olivine usually draws limited attention during sample evaluation. This is due to the lack of unambiguous chemical or textural criteria to distinguish kimberlitic olivine and those from other mantle derived sources. Here we show that FTIR analysis of the hydroxyl content provides a simple and cost-efficient technique to recognize olivine that crystallized from or equilibrated with kimberlitic magmas.

We have studied olivines from (1) various kimberlites in the Lac de Gras area, NWT, Canada and (2) garnet and spinel peridotite xenoliths collected from the Boshof dumps at Kimberley, South Africa. Analyses were carried out either on rock thick sections (300 micrometers thick) with both surfaces polished or on olivine grains liberated by crushing of the host rock, using an FTIR spectrometer equipped with IR microscope. IR absorption was measured in transmitted mode on unaltered olivine grains visually free of cracks and inclusions.

The majority of kimberlitic olivine macrocrysts are characterized by very strong IR absorption in the wavenumber range between 3650 and 3400 cm^{-1}. A small fraction of olivine phenocrysts shows somewhat weaker OH absorption in the wavenumber range from 3580 to 3480 cm^{-1}. These phenocrysts are interpreted to have crystallized at lower pressures and generally are less magnesian than neighboring macrocrysts. Olivine from mantle peridotites may readily be distinguished from these kimberlitic samples by a shift in OH related IR absorbance towards significantly lower wavenumbers (3280 to 3380 cm^{-1}) combined with a distinct decrease in hydrogen concentration. The only exceptions were observed for isolated olivine grains in clinopyroxene-rich areas of sheared peridotites, which may exhibit IR spectra similar to those of kimberlitic olivines. This observation is probably related to either the likely process of formation of sheared perditotites (infiltration of proto-kimberlite magma) or re-equilibration of olivine in these xenoliths with the host kimberlite magma.

A comparison of our results with previously reported IR spectra confirms that kimberlitic olivines contain the highest hydroxyl concentrations measured on natural olivines. This can be attributed to great depth of olivine crystallization/re-equilibration in hydrogen bearing kimberlite magmas. Using both intensity and frequency (wave number region) of IR absorption allows distinguishing kimberlitic olivine from similarly magnesian olivine derived from other basic/ultrabasic magmatic rocks or from peridotite exposures.

SS14-05 **CR-DIOPSIDE (CLINOPYROXENE) AS A KIMBERLITE INDICATOR MINERAL FOR DIAMOND EXPLORATION IN GLACIATED TERRAINS**

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In diamond exploration, Kimberlite Indicator Minerals (KIMs) are those minerals characteristic of kimberlite, the dominant host for diamonds, that are many times more numerous in the kimberlite host rock than are diamonds. Typical KIMs include garnet, pyroxene, Cr-spinel, Mg-ilmenite, and olivine. Interpretation of the chemistry of KIM grains, such as clinopyroxene, allows evaluation of the kimberlitic affinities of the grains and delineation of possible glacial dispersion trains suggestive of potentially diamondiferous kimberlite sources. Pyroxenes from both peridotitic and eclogitic mantle sources can be KIMs, with clinopyroxene (cpx) being a common groundmass mineral in kimberlite while orthopyroxene is relatively rare.

However, there have been two historical interpretative problems with the use of cpx as a KIM. Firstly, the colour criteria used in picking KIM cpx (eg. Cr-diopside) appear to vary widely between individual microscopists, and secondly, interpretative problems can arise from the presence of non-kimberlitic (alkalic gabbro, basalt, komatiite, syenite, carbonatite, ultrapotassic volcanic) Cr-diopsides in the till sample.

Given the wide range of cpx host environments, determination of suitable cpx compositions for use in KIM evaluation is important. The chemical data should be constrained to compositions similar to those determined for kimberlitic cpx and diamond inclusion (DI) cpx worldwide. Kimberlitic cpx from peridotitic sources are typically diopsidic or, to a lesser extent, calcic/non-ferrous augitic on a Wo-En-Fs diagram. However, so are many cpx grains of crustal origin, most eclogitic (low-Cr) DI cpx, and many eclogitic non-DI cpx. The data are thus screened for peridotitic cpx, permitting evaluation of only those grains having the selected criteria: diopsidic to calcic/non-ferrous augitic compositions ($27.5\% < Wo < 55\%$ and $En/(En+Fs) > 0.5$) and low-Na content ($J < 0.5$).

Several large kimberlite/diamond indicator mineral data sets were examined for pyroxene chemical trends. The entries of Fe, Al, Na, Ca, and Cr into the cpx structure are strongly affected by the P-T-X conditions present during mineral crystallization, so multidimensional diagrams of cpx atomic cation proportions are used to illustrate the chemical variation of mantle-derived kimberlite cpx relative to the more Fe-rich non-kimberlitic (crustal) grains typically present in glacial till. Antipathic Fe-Cr, Fe-Na, Al-Cr, and Al-Na data trends present in 4-dimensional data can be used to discriminate between 'deeper mantle-derived' grains and 'more crustal' grains. These interpretive guides provide useful discriminations between kimberlitic and non-kimberlitic peridotitic cpx in a suite of cpx KIM chemical data from till samples from glaciated terrains.

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THE CHURCHILL KIMBERLITES: A NEWLY-DISCOVERED DIAMONDIFEROUS KIMBERLITE PROVINCE IN NUNAVUT, CANADA

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The Churchill kimberlites represent Canada's newest kimberlite province discovery made by Shear Minerals Ltd. and partners Stornoway Diamond Corp., and BHP Billiton. Eighteen new kimberlite pipes have been drilled at the property, which comprises in excess of 2.0 million acres near the communities of Rankin Inlet and Chesterfield Inlet in the Kivalliq region of Nunavut. Geophysical evidence suggests that a kimberlite cluster of more than 100 pipes is present on the Churchill property. The Churchill property is located in the Churchill Province cratonic rocks and is underlain by the Rankin Inlet Group, comprised of Archean volcanics and sedimentary assemblages. Numerous granitoid bodies intrude the area.

Preliminary petrographic features, matrix mineralogy and whole rock compositions suggest that the Churchill kimberlites are similar to the South African Group I kimberlites. They exhibit large variations in their macroscopic appearance, ranging from fine grained aphanitic calcitic hypabyssal kimberlite facies to ilmenite/garnet/olivine macrocryst-dominated kimberlite breccia. The observed macrocryst assemblage includes: ilmenite, phlogopite, olivine, calcite, and chromite. Within the Churchill kimberlite field, olivine is a dominant macrocryst in many samples, forming euhedral to anhedral grains. Olivine macrocrysts occur as euhedral fresh unaltered grains, to completely serpentinized pseudomorphs. Backscattered images, coupled with microprobe analyses, reveal compositional differences between the core and the rim of select olivine grains, reflecting a change in the fluid composition during the growth of the mineral. For example, there is a significant range in Fe content, ranging from 9.0 to 18.8 wt% FeO. In addition, small inclusions of orthopyroxene occur within some larger grains of olivine. Ilmenite also has a large range of FeO, from 30-40 wt%. Chromite has a large range of Cr_2O_3, from 39-52 wt%. Phlogopite occurs in three populations; macrocrystal, phenocrystal and as a groundmass phase. In addition to phlogopite, the matrix assemblage includes calcite, serpentine, apatite, ilmenite, clinopyroxene, magnetite and galena. Accessory minerals include djerfisherite, perovskite, zircon, REE-rich apatite, strontianite and barite. Djerfisherite, an alkali metal sulfide, occurs as individual subhedral crystals, and as clusters within the groundmass, which would suggest that it is a late primary magmatic phase of the kimberlite.

SS14-07 **ROOTS OF THE SLAVE AND SUPERIOR PROVINCES OBSERVED WITH DEEP-LOOKING MAGNETOTELLURICS**

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Dramatic upper mantle conductors with resistivities as low as 10 Ohm m embedded within the lithosphere of the Slave and western Superior Provinces provide important clues to the origin of cratonic lithosphere. The conductivity of these anomalies is approximately two orders of magnitude higher than laboratory studies and petrophysical modelling predict for an olivine or pyroxene mineralogy dominated upper mantle. Given the depth location, age, and tectonic setting as well as the observed conductivity of these electrical conductors, we conclude that they are likely due to carbon in the form of interconnected graphite. The evidence for deep-seated graphitic conductors spatially related to other deep-seated geophysical and geochemical anomalies may be taken together with recent independent estimates of upper mantle oxygen fugacities that suggest the mantle was at some point within two log units of the iron-wüstite buffer to suggest that partial melting and formation of the cratonic root may be related to redox melting during Meso and Neo Archean times. The geometrical form of these conductors, in addition to other lines of evidence, can be taken as evidence for Archean subduction near the end of the major phase of craton formation.

SS14-08 THE ILMENITE ASSOCIATION OF THE ATTAWAPISKAT KIMBERLITE CLUSTER, ONTARIO, CANADA

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An electron microprobe study of thirty five composite ilmenite-silicate nodules from the core of several kimberlite pipes from the Attawapiskat kimberlite cluster has been undertaken. Ilmenite occurs as intergrowths with various combinations of phlogopite, Cr-diopside and olivine, all apparently part of a single suite. This assemblage is unlike the ilmenite bearing Cr-poor suite of megacrysts that is typically observed in kimberlites. This assemblage (except for olivine), and the Attawapiskat mineral compositions are similar to the Granny Smith suite of megacrysts locally common in the Kimberley area, South Africa. Ilmenites are Mg- and Cr-rich, typically in the range 2 - 6 wt% Cr_2O_3 and 8-13 wt% MgO. Cr-diopsides are calcic (Ca/(Ca+Mg) = 0.44 - 0.49) and Cr-rich (1.2 - 2.5 wt% Cr_2O_3), distinct from Cr-poor megacryst diopsides from Attawapiskat and elsewhere. The nodules are deformed, recrystallized and are considered to be xenoliths unrelated to their host kimberlites. Compositional overlap of ilmenite from these xenoliths with the Attawapiskat monomineralic ilmenite megacrysts and macrocrysts indicates that the xenoliths are the dominant source of ilmenite in these kimberlites. Ilmenite megacrysts and macrocrysts are compositionally zoned, with rims enriched in Mg relative to cores at approximately constant Cr content. This is thought to be the result of ilmenite partially re-equilibrating with the host kimberlite magma. Because these nodules are xenoliths, and the cores did not re-equilibrate with the host magma, the hematite component of the cores does not reflect the redox conditions within the kimberlite, and therefore the extent of diamond resorption within these pipes cannot be predicted from ilmenite composition.

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SS14-09 MEGACRYSTS AND PYROXENITES FROM THE MUSKOX KIMBERLITE, SLAVE CRATON, NUNAVUT

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The mantle xenolith suite from the Muskox kimberlite in the north-central Slave Craton is similar to that of the well-studied Jericho kimberlite located 14 km to the east. Suites from both kimberlites are dominated by peridotites and have significant numbers of eclogites, pyroxenites and various megacrysts. Here we present the preliminary results of an electron microprobe investigation of the pyroxenite and megacryst suites, in which we have concentrated on the clinopyroxenes. The pyroxenite suite is dominated by garnet websterites, with or without olivine, and clinopyroxenes dominate the megacryst population (which also contains orthopyroxene, garnet, olivine, ilmenite and phlogopite). Compositional overlap of the pyroxenite clinopyroxenes (e.g., 0.9 - 2.3 wt% Cr_2O_3) with the majority of megacrysts (0.8 - 1.8 wt% Cr_2O_3) suggests that most clinopyroxene megacrysts represent disaggregated pyroxenite. A second group of low-Cr clinopyroxene megacrysts at Muskox (trace to 0.5 wt% Cr_2O_3) may represent a separate paragenesis, represented at Jericho by a low-Cr pyroxenite suite not recognized at Muskox. The single clinopyroxene geothermobarometer of Nimis and Taylor has been applied to both our data and that published for Jericho. Muskox pyroxenites and megacrysts yield calculated equilibration conditions from approximately 950°C, 50 kbar to 1200°C, 68 kbar, defining a geothermal gradient somewhat cooler than that for Jericho. Muskox samples extend further into the diamond stability field than do Jericho pyroxenites or peridotites, which have maximum values near 1270°C, 56 kbar.

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DIAMONDS FROM THE K252, K11 AND K19 KIMBERLITES, BUFFALO HEAD HILLS, ALBERTA, CANADA

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Fifty-four diamonds from three kimberlites in the Buffalo Head Hills, Alberta, represent an inclusion-bearing subset of over 2,000 diamonds recovered during exploration by the Ashton/Encana/Pure Gold joint venture. The diamonds show a large abundance of secondary forms, the majority having resorbed octahedral (i.e. tetrahexahedroidal) morphology. Sharp-edged octahedra, octahedral aggregates, macles (twins) and fragments are also present. The diamonds are mainly colorless, although yellow and brown stones also occur. Tetrahexahedroidal surfaces show extensive hillock patterns, whereas residual octahedral faces exhibit an abundance of positive and negative trigons (triangular etch pits). Plastic deformation is present but not noticeably abundant. Nitrogen analyses (FTIR) indicate that approximately 30% of the diamonds have nitrogen contents below detection and thus may be classified as Type II. The remainder has nitrogen contents between 15 ppm and 1600 ppm. Nitrogen aggregation is variable and ranges from IaA (> 90% of nitrogen occurs as pairs) to IaB (> 90% of nitrogen occurs in groups of four atoms surrounding a vacancy), with higher aggregation states being more abundant (IaA <IaAB < IaB). The highest nitrogen contents are present in Type IaAB diamonds. Aggregation from the A- to the B-center proceeds slowly during long mantle residence times but may be accelerated by increased temperature and/or significant strain. Observed Type IaB defects, with low nitrogen contents, indicate that those diamonds had long mantle residence times at high temperature, suggesting a deep, possibly sublithospheric origin. Diamonds with Type IaA and IaAB defects may have resided at lower temperature and shallower depths in the mantle and be indicative of a younger diamond forming event.

Carbon isotope analyses show a bimodal $\delta^{13}C$ distribution, with peaks at -5 ‰ and -15 ‰; this distribution is observed for diamonds from all three kimberlite pipes. Over half of the diamonds are isotopically light ($\delta^{13}C$ < -10 ‰), suggesting a predominantly eclogitic paragenesis. This is in accordance with the occurrence of an omphacitic pyroxene and two almandine-rich garnet inclusions in diamonds from the K252 pipe as such compositions are characteristic for the eclogitic suite. A high proportion of the eclogitic paragenesis has also been reported in inclusion-bearing diamonds from a few economically valuable diamond deposits worldwide (e.g. Premier, Jwaneng and Orapa).

SS14-11

MESSENGERS FROM THE SUBLITHOSPHERIC MANTLE: DIAMONDS AND THEIR MINERAL INCLUSIONS FROM THE JAGERSFONTEIN KIMBERLITE (SOUTH AFRICA)

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The composition of 123 diamonds and their mineral inclusions from the Jagersfontein kimberlite (South Africa) has been studied. Around 70 percent of the diamonds belong to the eclogitic suite. Eclogitic garnet inclusions reflect a broad compositional spectrum (3-12 wt% CaO, Mg# 50-80); similar chemical diversity is also seen among eclogitic clinopyroxenes, which range in composition from diopsidic to omphacitic (Na+Al: <0.1-0.8 pfu, Ca/(Ca+Mg+Fe): 0.3-0.5). More than one third of the eclogitic garnets contain a high pressure majorite component, with a silicon content of up to 3.5 Si pfu, indicating a maximum depth of origin of around 500 km. Polyphase inclusions of garnet, cpx and opx may represent retrograde decomposition of primary garnets with even higher majorite components. The trace element composition of the eclogitic garnets is characterized by an increase from subchondritic to chondritic LREE abundances towards HREE of up to 100 times chondritic levels. All garnets with a significant majorite component show pronounced negative Eu anomalies, whereas non-majoritic garnets show either positive or no Eu anomalies. Eclogitic clinopyroxene inclusions have overall flat, slightly superchondritic REE patterns. Clinopyroxene was never observed together with majoritic garnet inclusions.

The peridotitic inclusion suite is characterized by depleted compositions. Peridotitic garnets are harzburgitic (< 4 wt% CaO), magnesium rich (Mg# 85-90) pyropes and have generally moderate chromium contents (< 10 wt% Cr_2O_3), with the exception of one high chromium garnet (18 wt% Cr_2O_3). The depleted character of the peridotitic source is also reflected in the high Mg-numbers of olivine (Mg#: 93-95) and orthopyroxene (Mg#: 95-97) inclusions. The chondrite normalized REE composition of the peridotitic garnets is characterized by sinusoidal patterns, with a steep increase from La towards the heavier LREE, a maximum at Pr-Nd, a steady decrease towards the HREE with a trough at Er and positive slopes within the HREE.

The carbon isotopic composition of the host diamonds indicates a pronounced bimodal distribution. The majority of samples have $\delta^{13}C$ values around -3 to -6, which includes all peridotitic as well as a number of eclogitic diamonds. The second group of diamonds, which comprises all diamonds with majoritic garnet inclusions, shows lower $\delta^{13}C$ values of -14 to -22.

SS14-12 META-STABLE PERIDOTITIC DIAMONDS FROM GUANIAMO, VENEZUELA

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The garnet xenocryst population of the diamond-rich kimberlite sheets from Guaniamo, Venezuela is overwhelmingly peridotitic (98% P-type), with a significant harzburgitic (G10) component (25%). Although such a garnet signature typically suggests a substantial peridotitic diamond content, the Guaniamo diamond population is 90-98% eclogitic. Equilibration temperatures derived from rare P-type diamond inclusion minerals (published and new data are mostly > 1200°C using Ni in garnet and cht-ol Fe-Mg exchange) place the formation of P-suite diamonds within the diamond stability field. In contrast, the low (and restricted) Ni content of G10 garnet xenocrysts (17 - 36 ppm and one with 45 ppm) suggests substantially lower equilibration temperatures (870 - 992°C, with one value at 1038°C using T-Canil or 756 - 930°C, and one at 999°C using T-Ryan). Although previous studies have suggested that this indicates a significantly lower than normal geothermal gradient, pressure-temperature equilibration conditions of Cr-diopside xenocrysts are consistent with a typical sub-cratonic geothermal gradient (40 mW/m^2 heat flow equivalent). As isobaric cooling from high-temperature diamond formation conditions to a lower geothermal gradient would move material further into the diamond stability field, we suggest that tectonic uplift moved the P-diamond dominated sub-cratonic lithospheric package to cooler and shallower (i.e., graphite stability) conditions, resulting in resorption of the P-suite diamonds. G10 major elements would be preserved, while temperature-dependent Ni contents decreased during cooling accompanying uplift. Evidence of a deeper heritage remains only in the mineral inclusions of the rare metastably-surviving peridotitic diamonds. Speculatively, this process is linked to the emplacement of eclogitic diamond-rich meta-basalt beneath the Guyana Craton during Proterozoic subduction and orogeny.

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SURVIVAL OF DIAMONDS DURING MAJOR TECTONOTHERMAL EVENTS - PERIDOTITIC INCLUSIONS IN DIAMONDS FROM ORAPA AND JWANENG

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The Orapa and Jwaneng kimberlites in Botswana are located along the western margin of the Kalahari Craton on the Kaapvaal and Zimbabwe blocks respectively. Diamonds in both mines are mainly derived from eclogitic mantle sources. Shirey et al. (2002, Science 297: 1683-1686) linked this observation to lower P-wave velocities in the deep mantle lithosphere relative to the bulk of the craton and suggested a major diamond formation event during mid-Proterozoic growth and modification of preexisting Archean lithosphere. In the present study we focus on peridotitic diamonds from both mines to evaluate their relationship with this mid-Proterozoic event.

In their major element chemistry the peridotitic inclusions in diamonds from Orapa and Jwaneng compare well with a world-wide data base but show significant differences to data sets for the classical mines in the Kimberley region in the interior of the Kaapvaal block. The most striking difference is the relative paucity of low-Ca (< 2 wt% CaO) harzburgitic garnets and a high ratio of lherzolitic to harzburgitic garnets (1:2). This suggests that lithospheric mantle accreted to the rim of the Zimbabwe and Kaapvaal blocks was overall chemically less depleted. Alternatively, this more fertile signature may be assigned to metasomatic re-enrichment but the trace element signature of garnet inclusions (as determined by SIMS) is not in support of strong enrichment in major elements. The majority of lherzolitic and harzburgitic garnet inclusions are characterized by moderately sinusoidal REEN patterns and low Ti, Zr and Y contents, indicative of a metasomatic agent with very high LREE/HREE and low HFSE. Such a highly fractionated fluid/melt is expected to have only limited impact on the major element chemistry of the affected rocks.

In contrast to the moderate degree of metasomatism reflected by the inclusion chemistry, lithospheric sections for Orapa and Jwaneng based on mantle xenocrysts and xenoliths (Griffin et al. 2003, Lithos 71: 215-241) reveal extensive mantle metasomatism. This indicates that the formation of peridotitic diamonds predates the intensive modification of the subcratonic lithosphere during Proterozoic rifting and compression, implying that diamonds may survive major tectonothermal events.

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GEOCHEMICAL INVESTIGATION OF KIMBERLITE AND LAMPROITE INTRUSIONS IN NORTHEASTERN LABRADOR AND KILLINIQ ISLAND, NUNAVUT

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The past decade has seen a great resurgence in the exploration for diamonds and diamond-bearing rocks in Canada due to discoveries in the Northwest Territories and northeastern Quebec, Canada, and as well, the discovery of microdiamonds in Eastern Greenland. Areas of northeastern Labrador and Killiniq Island, Nunavut have Archean crustal settings similar to the Northwest Territories, northeastern Quebec, and eastern Greenland. Samples of kimberlite and ultramafic lamprophyre intrusions were collected from dykes within the northern Torngat Mountains and on Killiniq Island. Petrographic examination of the dykes from the Torngat region indicates that they have a kimberlitic to ultramafic lamprophyric affiliation, with macrocrysts of olivine, pyroxene, and philogopite in matrix of calcite, phologopite, and spinel with minor perovskite and apatite. Electron-microprobe analysis of macrocrysts reveal olivine with and Fo contents ranging from 80.5 to 94.2, pyroxene with En contents ranging from 41.1 to 48.1 and phologpite with Al_20_3 from 11.1 to 16.2% and $Ti0_2$ from 2.13 to 5.38%. Dykes from Killiniq Island are more varied in compostion from kimberlite and ultramafic lamprophyre to more calc-alkaline compositions. Samples have also been processed for heavy mineral separates, XRF, ICP-MS and LAM-ICP-MS analysis, to assess their diamond potential as well as derive data on the nature of the mantle underlying the enigmatic Archean crust in this region of northeastern Laurentia.

SS14-P02 VOLCANIC-HOSTED DIAMONDS FROM NORTHERN ONTARIO: A NON-KIMBERLITIC ORIGIN

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Non-alluvial diamond deposits are typically found in kimberlite pipes or in lamprophyre dikes of Phanerozoic age located at margins or within Precambrian cratons. Even thought diamonds have also been found in komatiites, eclogites and impactites, these deposits don't have commercial values. Therefore, exploration for diamond deposits has always been concentrated in kimberlites and lamprophyres. The diamonds that we are describing here are found within volcaniclastic breccias in northern Ontario. Their quality and count are promising for the discovery of economically viable deposits. In the study area, the regional-scale diamondiferous horizon is 5 m wide on average, and composed of metamorphosed mafic rock, which contains decimetre-scale, amphibole-rich nodules. It also includes a lenticular horizon of polygenic breccia composed of mafic matrix and centimetre-scale mafic and felsic fragments. Preliminary petrographic and geochemical studies show that the nodules are of magmatic origin. They could be the result of immiscibility phenomena in the flows or sills associated with the bimodal pyroclastic rocks carrying a lamproitic matrix. The rocks are located within the Catfish assemblage of the Michipicoten greenstone belt, between sequences of gabbro and basalt, and an extensive sequence of intermediate tuff. The sequences show a regional-scale interference pattern revealing a probable primary phase of deformation resulting in axial planes of folds shallowly dipping to the east-northeast, overprinted by a later phase with axial planes moderately dipping to the north. The diamonds described here were recovered principally in the polygenic breccia horizon. They are less than one millimetre in size, have irregular shapes, are free of inclusions, and some have a yellow color. They constitute a new type of occurrence, different from Phanerozoic kimberlites, which may imply an origin under oceanic crust or at the margin of a craton under formation, and transportation to the surface by lamproitic diatreme-like intrusion in a bimodal volcanic environment. Consequently, these diamondiferous horizons represent a new target for exploration in volcaniclastic rocks in Archean greenstone belts.

SS-15

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EXHALITE GEOCHEMISTRY AS A VECTOR TOWARD CU-ZN DEPOSITS IN THE KAMISKOTIA VMS DISTRICT, ABITIBI SUBPROVINCE, ONTARIO

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Exhalites are stratiform accumulations of fine-grained tuffaceous material and chemical precipitates that are ubiquitous in greenstone terranes, and particularly near Cu-Zn volcanogenic massive sulphides (VMS) deposits in the Abitibi Subprovince of Ontario and Quebec. In the Kamiskotia VMS district, sampling has included several types of stratabound sulfide accumulations: exhalites, which occur at several horizons in the volcanic stratigraphy; stratabound stringer-style sulfide veinlets in chloritic-altered rocks, which are along strike or slightly down-section from the VMS deposits; and graphitic, sulphide-bearing argillites, which are present up-section or at distance along strike from the deposits. A total of 125 drillcore samples from a 5 km x 15 km area have been analyzed for major, trace and rare earth elements; for S and C; and for base, precious and trace metals. Additionally, 44 samples have been analyzed for their sulfur isotope compositions. The sulphur isotope data form isopleths that are centered on VMS deposits, and range from $\delta^{34}S$ = -0.3 to +2.5 near ore and in the footwall, to $\delta^{34}S$ = +1.8 to +4.3 at distance and up-section. The sulphur isotope data suggest that proximal sulphides were derived principally from underlying volcanic rocks and precipitated from H_2S-bearing hydrothermal fluids at higher temperatures; whereas the distal sulphides may have formed due to reduction of seawater sulphate, with slight modification due to biogenic activity. When coupled with whole rock metal (S, Zn, Cu, Ag, As, Sb) and other elements (Eu* in particular), the exhalites provide clear vectors toward Cu-Zn mineralization in this district on a scale of hundreds of meters to kilometers.

SS15-02 SEEING THROUGH THICK GLACIAL OVERBURDEN WITH GEOCHEMISTRY

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Cross Lake, VMS (Zn-Cu-Pb-Ag) mineralisation of Archean age, continues to be a prominent site for studying partial leach geochemical signatures in near-surface soils and their genesis. Located ca. 50 km southeast of Timmins in the Abitibi Greenstone Belt of Ontario, this deposit is hosted by felsic pyroclastic rocks and is covered by thick glacial sediments (ca 8 Ka) to a depth of 30-50 m. It is currently the focus of an OMET (Ontario Mineral Exploration Technology)-funded project carried out by the Geological Surveys of Canada and Ontario. Two lines, Lines 6 and 40, studied in detail, provide the different surficial terrains typical of the region: clay, sand and peat. On Line 6, gleysolic soils formed on silty-clayey glaciolacustrine sediments, whereas on Line 40, podzolic soils formed on sandy glaciofluvial sediments. A trench, 200-300 m long, was centred over mineralisation on each line and samples taken every 5 m along its length. Samples (O, A_h, A_e, B) were collected with depth at 10-cm intervals, from surface to ca. 70 cm.

The soils have been analysed for 50-60 elements following aqua regia, Enzymeh leach, ammonium acetate (at pH 5 and 7) and weak HCl digestions, and for various other parameters in addition to pH and oxidation-reduction potential (ORP). Principal component analysis helps to group the element patterns according to lithology, nature of terrain (e.g., reduced environments in water-saturated vs highly oxidised in sand), soil-forming processes, atmospheric deposition and the effects of the "reduced chimney" over oxidising mineralisation. Lead isotope analysis of partial extractions carried out on key samples indicates that this element has indeed moved from mineralisation through the glacial sediments to the near-surface. This presentation will focus on differentiating this response, due to element migration from the deposit at depth, from others such as those caused by terrain changes.

SS15-03 SGH - SOIL GAS HYDROCARBON TECHNIQUE FOR MINERAL EXPLORATION UNDER DEEP COVER

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The SGH technique involves collection typically B-horizon soil samples that are used as long-term integrators of the soil gas flux in the area. The samples are sent to the laboratory where the weakly bound heavy hydrocarbon compounds in the C_5-C_{17} carbon series range are desorbed and analyzed using a new technology developed by Actlabs over the last seven years. The desorbed hydrocarbons are then introduced into a gas chromatograph-mass spectrometer (GC-MS) where 162 heavy hydrocarbon compounds are measured. Heavier hydrocarbons are used instead of the C_1-C_4 range of light hydrocarbons as they are much less affected by factors such as sampling, shipping, preparation procedures, and storage conditions. Further advantages to SGH are the absence of effects shown by instantaneous soil gas measurements, which are affected by changes of barometric pressure, rain, biodegradation, it's resiliency to cultural activity, and its robust to the variability in soil type. The method also allows easy sampling of surface soils and requires only one trip to the field to collect the samples.

As part of a CAMIRO (Canadian Mineral Research Organization) project, a consortium of 8 companies funded a test of the technology over 10 blind mineral deposits. The sponsors ultimately chose study sites that had not previously shown a response to conventional geochemical techniques. Samples were analyzed and plotted by Actlabs with no apriori information on the location of the deposit or the geology of the area. After submission of the SGH plots that Actlabs believed were significant, the location and general geology of the deposits were provided for comparison and presentation of the results.

Additional sponsors have been attracted to a second larger CAMIRO project that is in its final stages. This project was designed to attempt to explain and understand the processes involved in SGH anomaly formation.

Geochemical maps for soils gas hydrocarbon compounds tend to be very clean and easily interpreted, showing anomalies over deposits and directly peripheral to them. The success of SGH is due to the use and specificity of GC-MS, ultra-sensitive detection limits in the very low ppt (pg/g) range, and a method that has been designed to provide the throughput and economics required for large survey exploration. Several case studies will be shown from this successful technique.

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OMET PROJECT: IS SCALING IMPORTANT IN ANALYZING GEO-PATTERNS FOR PREDICTION OF MINERAL DEPOSITS

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We update the progress of a research project on the application of GeoData Analysis System (GeoDAS) technology in mineral exploration in Northern Ontario. This project is part of the Ontario Mineral Exploration Technology (OMET) program and is supported by the Ontario Geological Survey and the Geological Survey of Canada. The main focus is on characterizing and mapping relationships between different datasets, and ultimately, extract information to amplify and reveal signals of blind deposits. GeoDAS (GeoData Analysis System) is a specialized Geographic Information System which combines the conventional GIS tools for database management, data visualization, frequency and spatial distribution testing, data interpolation and mapping with advanced functions such as anomaly enhancement, anomaly separation and pattern recognition (using fractal/multifractal models), raster-based principal component and factor analysis, multivariate statistical analysis and integrated spatial and power spectrum analysis. The unique feature of GeoDAS is the all-in-one ± advanced functions it provides which are required for effective information extraction and multi-layer data analysis to be used for GIS-based target selection and mineral potential mapping. Mineral resource potential maps could provide an overview of the mineral favourability of large regions and employ relationships present among diverse data types to discriminate signatures of mineralization.

This presentation will focus on the principles and techniques of anisotropic scaling analysis of geo-patterns created from geological, geochemical and geophysical exploration datasets. It will demonstrate how scaling property characterized using fractal/multifractal-modeling techniques can enhance identification of geo-anomalies to reveal mineralization and to delineate targets for mineral deposit prediction. Two main concepts involved in non-linear theory: generalized self-similarity and singularity, will be discussed and demonstrated using geological patterns created from mineral deposits, geochemical concentration values from lake sediment and water geochemical samples in Abitibi area in Ontario. It will show that how GeoDAS can be used in assisting anomaly enhancement and anomaly identification from non-linear theory point of view.

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SS15-05 DETECTING AND INTERPRETING EMERGENCE SITES OF MINERALIZED GROUNDWATER IN LAKES AND RIVERS OF NORTHERN ONTARIO

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Groundwater is the messenger that picks up the chemical signature of a blind mineral deposit. In glaciated terrains, lakes and rivers serve as sinks, or sumps, for groundwater discharge. A systematic methodology that detects, maps and samples these discharges of groundwater should be a reasonable exploration tool.

Within a lake, our methodology is to tow an array of sensors just above the sediment-water interface. We rely on sensors for dissolved oxygen (DO), redox potential (ORP), and conductivity to indicate upwelling groundwater. Once an upwelling area is indicated, it is mapped and sampled in detail in order to define the geometries of mineralized plumes. We obtain water and sediment samples. At each sediment sampling site we take two core samples - an upper sample adjacent to ther sediment-water interface, and a lower core sample from a depth of 20 to 40 cm below the interface.

Bottom host water in the vicinity of emergent groundwater is generally a combination of anoxic water (DO less than 10% saturated with oxygen), and anaerobic water (ORP less than zero, indicating growth of anaerobic, sulfate-reducing bacteria). Most transition metals are mobile in anoxic water and immobile - because of sulfide precipitation - in anaerobic water. Iron is immobile in oxic water as well. Metal mobility is also reflected in metal concentrations in the upper sediment core samples. Concentrations increase towards zones of anaerobic bottom water.

Comparing concentrations of calcium, magnesium and strontium in the upper and lower core samples from the same site is most helpful in pinpointing groundwater vents. Sharply increasing concentrations of Ca, Mg, and Sr in the lower core sample indicate degassing of carbon dioxide, with attendant rises in pH and precipitation of carbonate minerals. In some instances, the pH rise has been sufficient to precipitate calcium tungstates and molybdates.

Anaerobic bacterial activity in bottom host water results in elevated sulfur concentrations in the upper core sample. Elevated sulfur levels in the lower core sample are more unusual - and informative, for these are the result of vent degassing of hydrogen sulfide. At several such sites along the West Montreal River, concentrations of transition metals (copper, nickel, zinc, lead, etc.) actually decrease as sulfur increases. This is likely due to the conversion of metastable sulfide minerals to pyrite. At these same sites, concentrations of gold and tellurium rise by one to two orders of magnitude.

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VECTORCHROME™ - VISUALIZATION OF TRIAXIAL ORIENTATION DATA AND ITS IMPLICATION IN MAGNETIC FIELD INTERPRETATION

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Recent advancements in the accurate collection of triaxial data, the advanced precision of GPS data and the ability of faster computers to efficiently utilize the application of a large gamut of colours has resulted in a novel process for the display of vector orientation.

VectorChrome™ is a newly developed versatile computer program utilizing a patent pending methodology for viewing and collectively recognizing the common direction of 3D vectors on 2D surfaces such as a map surface or monitor display. This methodology allows for the selection and identification of 3D vectors with common orientation or exhibiting common symmetry elements.

This presentation will illustrate how the VectorChrome™ process works, its limitations, capabilities and potential benefit to explorationists in the interpretation of triaxial data.

VectorChrome™ conversions of actual magnetic triaxial gradient data sets will be presented from various areas to illustrate the novel features of this application. VectorChrome's™ user interactive capabilities for the analysis of triaxial vector fields will also be illustrated. Enhanced capabilities for quality control of triaxial data will be shown with line data as well as enhanced interpretation with gridded data. VectorChrome's™ ability to enhance symmetry and exhibit variation within the orientation of the residual magnetic flux field will be presented. This being of particular benefit for kimberlite exploration and mapping of detailed geologic structures. The potential for determining variations in the remnant magnetism of rocks with high koeningsberger ratios will be discussed.

SS-17

The Earth Sciences and Wine

Les sciences de la Terre et le vin

J.D. Greenough (Okanagan University College)

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SS17-01 TERROIR OF CANOE RIDGE, WASHINGTON STATE, USA - INFLUENCE OF BEDROCK AND SOIL ON GRAPEVINE VIGOR AND WINE CHARACTERISTICS

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Canoe Ridge is a prominent topographic feature reflecting the Canoe Ridge anticline on the north side of the Columbia River in Washington State. The ridge was first named by Lewis and Clark during their historic travels across the Pacific Northwest. Stimson Lane Vineyard and Estates has planted about 500 acres of vinifera wine grapes on the south-facing slope of Canoe Ridge and these are divided into individual blocks ranging in size from 6-40 acres. Blocks span variations in bedrock and soil characteristics that formed the basis for controlled experiments to assess the influence of bedrock and soil on grapevine vigor and wine characteristics in one chardonnay and two different merlot blocks. Block 13 chardonnay is planted in N-S rows on the Quincy soil series consisting of loess over glacial slackwater sediments, that overlie a N20°E ridge of vesicular basalt of the Pomona Flow of the Columbia River Basalt Group. Trenches dug 2m into the rooting zone identified two end member soil profiles, 1) shallow carbonate-cemented basalt within the rooting zone and 2) deep sand in the rooting zone. Pruning weights of 36 samples in 3 replicates of vines on #1 averaged 0.8 kg versus 1.3 kg for #2. Means of wine pH, TA (g/L), and Brix for 3 replicate 0.5 ton batches are slightly different, 3.36, 7.4, 24.6 and 3.40, 7.1, 24.5, respectively, and qualitative sensory analysis by a 9 member panel indicated differences in sensory characteristics such as color, volatile acidity, fruitiness, and finish. The two merlot blocks were also trenched and have similar differences in bedrock/soil characteristics as the previously described chardonnay block. Pruning weights and wine analyses for the two merlot blocks varied less but in the same manner as the chardonnay: Block 9 - #1 0.69 kg, 3.61, 5.3. 23.4, #2 0.73 kg, 3.63, 4.8, 24.4; Block 16 - #1 0.57 kg, 3.50, 4.9, 24.7, #2 0.61 kg, 3.54, 4.7, 24.9. Sensory analysis indicated #1 merlot from both blocks was better balanced and had less vegetative character than #2. Thus, for multiple trials for two different grape varieties there appears to be a relation between bedrock/soil and grapevine/wine characteristics.

SS17-02 TERROIR IS IN THE DETAILS: TALES FROM NAPA AND SONOMA, CALIFORNIA

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Much that's been written about geology and physical terroir focuses on the geologic character of relatively broad regions or districts. This approach is important as it provides a first level description of different wine producing regions and a broad background for investigating the influence of geology on wine. But winegrowing regions also show significant internal variation at a variety of scales. To be useful, relating geology with wine character must deal with variation on the scale of the vineyard block.

In the Napa Valley, the first level of regional differentiation is the American Viticulture Area (AVA). Designed supposedly for consumers, many of the AVAs contain such disparate geologic ground that they have little meaning in terms of terroir. The Rutherford and Oakville AVAs, for examples, cross the Napa Valley and include several sedimentary and volcanic bedrock units, alluvial fans, fluvial deposits, and sun aspect that ranges from due east to due west. In most of Napa, the terroir of an AVA has little relevance.

This same observation, however, can be applied to individual vineyards. This is not surprising for large vineyards such as Benoist Vineyard in Sonoma County, 650 acres underlain by three different geologic formations. Laid out on the basis of soil surveys, some vineyard blocks are complex terroir in themselves. In Napa, Stag's Leap Wine Cellars consists of two vineyards totaling about 140 acres. Topographically Fay and SLV occupy the same small alluvial fan. Fay, however, is made up primarily of debris flow sediments, while sands and silts deposited under more normal flow regimes underlie SLV. Even within these vineyards, significant variation exists; Fay includes the "Hershey Kiss" zone, a sweet spot within a single vineyard block. Rudd Wines' home vineyard is a 58 acre plot half of which is planted on an alluvial fan, the other on thin residual material over bedrock. Perhaps the epitome of local terroir is Diamond Creek Vineyards, which produces three distinct Cabernet Sauvignon wines from three types of volcanic bedrock in three vineyards that are literally within a stones throw of each other.

Unraveling the links between geology, terroir, and wine character thus will require attention to detail as well as tasting a lot of wine.

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REGIONAL CHARACTERIZATION OF CANADIAN WINES USING TRACE ELEMENT CONCENTRATIONS BY ICP-MS

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Subjective evaluations of the taste and aromatic character of wines have long indicated that wine composition is related to the geographic origin of the grapes they are made from. Previous studies of trace element composition suggest that wines can be characterized at the vineyard level through to the regional level. To further test this hypothesis 78 wines from 4 regions (Nova Scotia, Quebec, the Okanagan and Vancouver Island) were analyzed for 20 elements using ICP-MS and the data merged with existing analyses for Okanagan and Niagara wines. Exploratory statistics (multidimensional scaling = MDS) reveals that the large ion lithophile elements (Cs, Rb, Ba, Sr and Li), high field strength elements (La, Ce, Th, U), and chalcophile elements (Cu, Pb, Zn, Cd, Mo, As, Ag and Bi) tend to form groups consistent with the idea that general geochemical principles governing element solubility are the dominant controls on element behavior in wines. Comparing wines (instead of elements) using MDS shows that samples loosely group according to region, vineyard, and color. Higher concentrations of Ba, Rb Sr and Cs in red wines indicate that processing (contact between skins and must during fermentation) extracts these elements from the skins though a role for the addition of metabisulfite cannot be ruled out. Discriminant analysis shows that wines can be regionally categorized with ~80% accuracy using only 11 elements representing all geochemical groupings. Twelve vineyards with four or more wine samples can be distinguished with similar accuracy. This suggests that factors related to terroir (soil composition, climate and geology) help control the trace element composition of wine at both the vineyard and regional levels.

SS17-04 **CREATING A DEFINITION OF NIAGARA TERROIR FROM CHEMICAL AND SENSORY DESCRIPTIVE ANALYSIS OF CHARDONNAY WINES PRODUCED FROM DIFFERENT SOIL TEXTURES AND VINE SIZES**

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To test a soil texture and vine size-based terroir hypothesis, five vineyards throughout the Niagara Peninsula in Ontario were mapped in detail in 1998 using global positioning systems and geographic information systems (GPS/GIS). Spatial variations in soil texture and composition were delineated for each vineyard. “Sentinel vines” from which data were collected (75-200 per vineyard) were geolocated by GPS in 1998. Wines were made in 1999-2001. In 1998-2001, sentinel vines at each site were sorted into two vine size classes (‘large’ and ‘small’) according to weights of cane prunings within each of two soil textures (‘sand’ and ‘clay’). Berries from each sentinel vine were analyzed for pH, titratable acidity (TA), and total soluble solids (Brix), while wines were analyzed for pH, TA, ethanol, and total phenolics. Wines were also analyzed sensorially using quantitative descriptive analysis and the data were analyzed by analysis of variance and principal components analysis. There were few cases whereby either soil texture or vine size impacted sensory or chemical variables; for example, at one Lakeshore site, wines from vines grown on clay portions of the vineyard were characterized by higher melon and floral aromas, and lower vegetal aroma. At another Lakeshore site, wines produced from low-vigor vines had higher floral aromas and less vegetal and earthy aromas. However, no consistent soil texture effects were observed at any site across the three vintages. Discernible vintage and site effects were nonetheless evident. Lakeshore zone sites appeared to be characterized by citrus, apple, and vegetal aromas and flavors, whereas Beamsville Bench sites were characterized by floral and melon aromas and flavors. This suggests strongly that any terroir model for this region should include site and vintage as major components.

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SS17-05 EVALUATION OF SOIL PLACEMENT AND AMMENDMENT STRATEGIES FOR VITICULTURE IN DEPLETED LIMESTONE QUARRIES IN THE NIAGARA PENINSULA

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The University of Guelph in co-operation with Walker Industries has undertaken a series of experimental vinifera plots on lands in the Vineland area, which have been disturbed by Limestone bedrock extraction. Portions of the extracted area at the Vineland Quarry were regraded by placement of locally stripped mineral subsoil. Regrading strategies were employed to maintain or enhance microclimatic conditions on the site through promotion of air drainage off the site. A series of experimental plots were established on the regraded areas and a variety of ammendment prescriptions, including application of paper waste materials werewere ammended The paper provides an overview of the local bedrock and surficial geology in the Vineland area, a review of experimental soil ammendment and replanting strategies for viticulture on material backfilled and regraded to restore quarry faces in depleted quarry areas, and comments and observations for enhanced restoration strategies for viticulture in such disturbed and restored contexts.

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SS17-06 GRAPEVINE DEVELOPMENT AND THE INFLUENCE OF TOPOGRAPHY AND MACROCLIMATIC INDICES WITHIN THE NIAGARA REGION

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Within the Niagara region there are numerous locations growing premium vinifera grapes that were subject to highly variable climatic conditions. For the past several years, data has been collected to record specific vine developmental stages at locations with weather recording instrumentation. Using day degree models and thermal accumulations, cultivar performance has been fairly consistent from year to year to reach specific growth stages (e.g. bloom, veraison, harvest) but using Julian days to measure the length of time between each stage, there is high variability in the number of days to achieve each growth stage depending on location. This paper will provide a brief summary of grapevine development and potential implications for assisting in the establishment of sub appellations within the Niagara region.

SS17-07

GEOSPATIAL ANALYSIS OF DIGITAL ELEVATION MODELS IN THE EVALUATION OF MICROCLIMATE FOR VINIFERA CULTIVATION IN THE NIAGARA PENINSULA

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Staff and students of the Environmental, Horticultural and Agribusiness Division of Niagara College have undertaken a series of geospatial analyses of High resolution digital elevation information for the Niagara Peninsula. These initiatives have been undertaken to evaluate the role of topography and geomorphology on air drainage and microclimate, to better understand land capability for vinifera cultivation in various areas of the peninsula. This paper presents the results of a number of case studies which illustrate the utility of digital information and geostatial analysis in refining the location and areal extent of high capability areas for cultivation. This information has significant value for the wine industry and for local and regional municipal planning authorities.

SS17-08 DETERMINING SUB-APPELLATIONS IN THE NIAGARA WINE REGION

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GEOLOGICAL ASSOCIATION OF CANADA
MINERALOGICAL ASSOCIATION OF CANADA
JOINT ANNUAL MEETING
BROCK UNIVERSITY, MAY 12-14, 2004

Lake to Lake
GAC-MAC
AGC-AMC
St. Catharines
2004
D'un lac à l'autre

ASSOCIATION GÉOLOGIQUE DU CANADA
ASSOCIATION MINÉRALOGIQUE DU CANADA
CONGRÈS ANNUEL CONJOINT
UNIVERSITÉ BROCK, DU 12 AU 14 MAI 2004

SS-18

THE NIAGARA ESCARPMENT SPECIAL SESSION: EARTH SCIENCE AND ENVIRONMENTAL PLANNING

L'ESCARPEMENT DE NIAGARA: LES SCIENCES DE LA TERRE ET L'AMÉNAGEMENT DU TERRITOIRE

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SS18-01 GEOMORPHIC FORM AND PROCESS IN LAND CLASSIFICATION OF THE NIAGARA ESCARPMENT

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A land classification scheme is proposed for the central Niagara Escarpment that is based on the control of ecological systems at the landscape scale by the dynamics of landforms and geomorphic processes. The classification focusses on the relationships between geomorphic form and process, vegetation composition and dynamics, and avian populations. The physical parameters were primarily landform characteristics including slope angle, aspect, and landscape position as well as geomorphic processes, such as creep and debris slides, measured by level of disturbance. Human disturbance was also recorded for comparative purposes. Eleven vegetation structural parameters were measured, such as deciduous/coniferous ratio, stem density, and canopy cover. This data was collected for 29 land units, divided between upland, slope and valley segments, at 11 sites. Sampling for the avian populations took place during the breeding season between 1996-1999. Ecological parameters were classified using cluster analysis and then compared to geomorphic form and process by ordination analysis to create a set of land units. Overall, Escarpment landscape systems are composed of a heterogeneic series of land units, which is evident in the response of forest and avian components to variations in geology and geomorphology. There were strong relationships between vegetation associations and landscape position as well as geomorphic and human disturbance. Avian populations were strongly related to vegetation cover. Natural disturbance created the greatest variation of species on the slopes, while human disturbance was a stronger control on upland sites. Management strategies need to recognize the role of geomorphic and human processes in creating this heterogeneity and to develop policies that maintain the spatio-temporal pattern of the disturbance regimes.

SS18-02 **PLANNING FOR THE GREAT ARC LANDSCAPE CORRIDOR: THE NIAGARA ESCARPMENT IN A REGIONAL CONTEXT**

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The Great Arc is a landscape corridor that extends from central New York through Niagara Falls, southern and central Ontario, the Bruce Peninsula, Manitoulin Island, northern Michigan, eastern Wisconsin, and northwestern Illinois. The core of the Great Arc is a geological surface feature and other associated landforms which are known as the Niagara Escarpment in Ontario and the ridge, ledge or other descriptions in New York and Wisconsin. In geologic terms the Great Arc forms the margins of an extensive ancient Paleozoic bedrock formation known as the Michigan Basin. The feature consists of harder dolomite and limestone bedrock deposits that form a resistant caprock over softer underlying shale and sandstone. Scarps, cliffs, ridges and ledges form along the edge of the harder caprocks, for example at Niagara Falls and the Door Peninsula adjacent to Green Bay, Wisconsin. Plains, valleys, and low-lying areas form on the softer shales adjacent to the cliff face, for example in the Erie Canal area of New York and the Niagara Peninsula in Ontario. Throughout its length the Great Arc has been recognized by local groups, communities, and government agencies as having significant heritage values. A series of meetings and workshops have been held since 1999 to consider binational cooperative efforts among various partners in Ontario, Wisconsin and New York in regards to the Great Arc. Ongoing efforts have examined the potential for various landscape and bioregional planning opportunities along the Great Arc including recreation and tourism, parks and protected areas, trails, earth science conservation, and public awareness.

SS18-03 ERAMOSA KARST AREA OF NATURAL AND SCIENTIFIC INTEREST (ANSI)

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In April 2000, the Ontario Ministry of Natural Resources (OMNR) introduced a new confirmation procedure for Areas of Natural and Scientific Interest (ANSI). ANSIs are defined as "… areas of land and water containing natural landscapes or features that have been identified as having life science or earth sciences values related to protection, scientific study or education." - Provincial Policy Statement 1996. The first and to date only ANSI to be confirmed using this procedure is the Eramosa Karst. The ANSI confirmation procedure ensures a consistent approach when identifying new ANSIs and modifying or deleting existing ANSIs. It contains nine steps. Steps 1 to 5 address scientific evaluation and identification and steps 6 to 9 are the notification and confirmation processes. Landowners and stakeholders are to be consulted throughout the procedure and their comments on the scientific findings must be considered before any decision on an ANSI confirmation can be reached. The Eramosa Karst is within the former City of Stoney Creek in the City of Hamilton immediately south of the Niagara Escarpment. It contains examples of 16 different karst features, seven of which are provincially significant. A karst is a limestone region with underground drainage and many cavities and passages caused by the dissolution of the rock. The Eramosa Karst was confirmed as a provincially significant earth science ANSI on February 13, 2003. For various reasons it took three years to complete the process but the time was well spent in ensuring the involvement of all concerned and testing and refining the ANSI confirmation procedure. While decisions on the appropriate levels of protection and land uses are the responsibility of the local municipality, OMMR provides ongoing support and advice. Key to this is the Eramosa Karst ANSI science report which maps the ANSI's four sub areas and provides stewardship recommendations for each. Efforts are now underway to safeguard the karst features by the City of Hamilton designating them as an Environmentally Significant Area, transferring key provincial lands to the Hamilton Conservation Authority and looking at the eventual development of a natural resource management plan in consultation with landowners and other stakeholders.

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SS18-04

LANDSCAPE CHARACTERIZATION OF THE NIAGARA ESCARPMENT IN SOUTHWESTERN OHIO BY THE USE OF A GIS PROBABILITY OF OCCURRENCE MODEL

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Within southwestern Ohio the Niagara Escarpment has been modified by numerous glaciations resulting in the erosion or deposition of sediments, transforming the escarpment into a discontinuous surface feature. The purpose of this study was to use Geographic Information Science (GIS) technology to determine the location of the Niagara Escarpment Highland and Adams Counties in Ohio using spatial data available for geological and geomorphological features as provided by the Ohio Department of Natural Resources (ODNR). The distribution of defining features for the Escarpment, such as bedrock geology type, surface exposures, karst features, and specific soil characteristics, and slope are inputs for a probability of occurrence model in order to predict the location of the Niagara Escarpment. The model layers and ranks the spatial data in order to predict locations where escarpment features would be present indicating presence of defining characteristics of the Niagara Escarpment. A spatial autocorrelation technique is used to determine the accuracy of the model. The results of the study suggest a potential for the application of this method to determine the probable distribution of the Niagara Escarpment where it is not a dominate land surface feature and may assist with similar landscape characterization in other locations within the Michigan Basin, including northern areas within Wisconsin, Michigan and Ontario.

SS18-05 **THE INTEGRATION OF EARTH SCIENCES IN ENVIRONMENTAL PLANNING THE NIAGARA ESCARPMENT PLAN**

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Rocks of the Niagara Escarpment have their origins deep in the Palaeozoic Era. The Escarpments bedrock was subsequently moulded and mantled by the glaciers of the Pleistocene Ice Age, and is now protected by a modern environmental land-use Plan – The Niagara Escarpment Plan. Established by the Ontario government in 1973, the Niagara Commission was initially responsible for preparing a plan that would maintain the Niagara Escarpment corridor substantially as a continuous natural environment across southern Ontario from Niagara Falls to the tip of the Bruce Peninsula. Earth science data were critical to the preparation of the Plan for defining the physical parameters of the landform, for fostering an appreciation of its unique geological history and played a role in the policies developed for its protection. Following acceptance of the Niagara Escarpment Plan by the Ontario Government in 1985, the Niagara Escarpment Commission has been responsible for the administration and regulation of land-uses in the Plan area. An understanding of the earth science features and resources continues to be an integral part of the information needed to implement the Plan which aims to balance competing land uses with the protection of the natural environment and open landscape features of the Niagara Escarpment. While the Ordovician and Silurian stratigraphic units of the Escarpment face are laterally consistent in thickness and lithology, the mantle of glacial debris is often quite variable in thickness and character. The relationship between the Palaeozoic bedrock and the latter action of glacial and fluvial erosion and deposition and the resultant landforms are important factors in the physical form of the Niagara Escarpment and has spark significant debate in the implementation of the Niagara Escarpment Plan. For this reason the integration of earth science expertise within the environmental planning process of the Plan remains critical. Several examples of the integration of these two disciplines in recent land-use decisions will be highlighted.

SS18-06

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KARST GEOMORPHOLOGY AND IMPLICATIONS FOR ENVIRONMENTAL AND DEVELOPMENT PLANNING ON THE NIAGARA ESCARPMENT

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The Niagara Escarpment is capped by dolostones of the Amabel/Lockport and Guelph formations. These rocks are soluble in water resulting in the formation of sinkholes, caves, springs and other karst landforms. Karst processes are particularly focussed in the vicinity of escarpments due to locally enhanced hydraulic gradients. As a result, the Niagara Escarpment and its adjacent plain are home to the most complete and widest array of karst landforms in Ontario. Although many of these features have been recognized in conservation geology programs over the past 30 years, implications to development have seldom been recognized or considered. Development planning within areas containing karst can be problematical. The Province of Ontario is currently considering new regulations to designate such areas as hazard lands due to potential problems related to flooding and surface collapse. To date, serious problems have not been encountered in large part due to the The Niagara Escarpment Development Act which has limited large-scale developments within the area designated as the “Plan Area”. However, developments are occurring adjacent to this area which have had implications to karst within the Plan Area, including designated protected areas. Additional developments are currently being proposed which will have direct implications within the Plan Area. Although many karst features along the Niagara Escarpment have been captured in Protected Areas Programs, most are not. Recent proposals for development have encountered serious issues relating to: the protection of adjacent designated areas; impacts associated with water withdrawal in karst terrain; impacts of nutrient and other contamination in karst terrains; surface flooding problems; and the potential for surface collapse. The nature of the Niagaran Karst and examples of recent development conflicts will be examined in this paper. In the future, karst features and processes within or adjacent to the Niagara Escarpment must be evaluated with regard to development limitations and design.

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SS18-07 GEOMORPHIC EVIDENCE FOR GRAVITATIONAL CREEP ALONG THE NIAGARA ESCARPMENT

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Cliffed sections of the Niagara Escarpment have often been assumed to be relict features within the research literature. The current morphology being attributed to the periglacial environment that followed the Pleistocene glaciation, unchanged during the Holocene due to the absence of extensive fluvial action along the base of the cliffs. However, there are a number of morphological features, ubiquitous to the cliffed sections of the escarpment between Hamilton and Collingwood, suggestive of an alternate theory for the postglacial development of the cuesta. These include the cambering of the cap rock, evidence of toppling failure, and the presence of deep crevice caves that generally run parallel to the cliff face. Such features indicate that in the absence of exogenetic processes, a slow development due to endogenetic processes has dominated the recent development of the escarpment. Rheological testing of the shale layers that underlie the cap rock has demonstrated that both the Cabot Head Shale and the Queenston Shale possess a compressive stress that is lower than the principal gravitational stresses expected due to overburden. It can therefore be concluded that in the absence of high confining stresses, as would be expected near the cliff face, slow deformation within these formations is occurring. The presentation will review the geomorphic evidence for deformation within the shale layers and (if completed) present the results of a new, high resolution, survey of a section of the escarpment near Milton Ontario utilizing the ILRIS ground based lidar system. This mapping should well illustrate the morphological features described above and provide a base line survey for future comparison. Such technology may be of interest to earth scientists as it offers the potential to accurately plot surfaces at sub-centimetre scales and thereby process rates over manageable time scales through repeat surveys.

SS18-08

Land ownership and landscape-level effects on biodiversity in the Niagara Escarpment Biosphere Reserve

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WITHDRAWN

SS18-09 **ORIGIN OF RESIDUAL STRESS RELATED TO ONGOING GEOMORPHIC DEVELOPMENT OF THE NIAGARA ESCARPMENT**

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The existence of residual stress in sedimentary strata in Southern Ontario was first defined in 1967 as a result of natural streambed outcrop and construction site interpretation, involving deep open cut or tunnel studies. In many such recent or new bedrock exposures, the free surface was found to displace laterally or vertically in an often-explosively rapid initial manner followed by steady creep. Deformations were mostly evidenced on pre-existing or newly induced fractures by tensional or shear failure. However some component of intrinsic elastic behaviour appears to persist, particularly in the slow, long-term creep condition. More recently the phenomenon has been recognized as being the most likely cause of the majority of planar openings and joints, within both such harder strata as the dolostones that routinely form the Niagara Escarpment rim rock and the lower, weaker shales that dominate the L. Silurian and U. Ordovician sequence. Also, the residual stress mechanism is considered by the Author to be the most likely initiator of karst phenomena, by starting and then progressive widening (or shifting) the tensional joints and sheared bedding planes, thereby constantly exposing new rock to dissolution by groundwater. The origin of such residual stress is herein defined as being the result of shortening of strata during basinal depression in which compression is induced by geoid arc reduction. Actual resultant levels of stress that exist in any particular lithological unit or subdivision within the stratigraphical column are thereafter developed as a function of the lateral compressional stress and confinement fields that existed at time of lithification (or matrix recrystallation). Physical release of residual stress as well as its in situ level is determined by the amount of erosion that follows basinal uplift and by the magnitude, pattern and geometry of surface irregularities. Such release may be expressed by planar slippage with (or without) its confined interbedding rubbling (so-called "rubble zones") or by joint creation and their progressive physical widening. Resultant rock expansion should not be confused with chemically induced swelling. Bedding plane slippage and/or accompanying rubbling plus tension joint widening routinely occurs in association with diurnal earth tide crustal motions, involving stick-slip behaviour. In most cases the sharply released interbed slippages that result are marked by the recording of low intensity shallow earthquakes such as are recorded almost daily by the Southern Ontario Seismic Network (SOSN).

SS-19

MOLECULES TO PLANETS: INFRARED SPECTROSCOPY IN GEOCHEMISTRY, EXPLORATION GEOCHEMISTRY AND REMOTE SENSING

DES MOLÉCULES AUX PLANÈTES : LA SPECTROSCOPIE INFRAROUGE EN GÉOCHIMIE, L'EXPLORATION GÉOCHIMIQUE ET LA TÉLÉDÉTECTION

MIKE RAMSEY (UNIVERSITY OF PITTSBURGH),

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SS19-01 PHYSICAL PROPERTIES OF CALCIUM ALUMINATES FROM VIBRATIONAL SPECTROSCOPY

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Heat capacity (C_V) and entropy (S) as a function of temperature were calculated from IR and Raman vibrational spectra for phases in the CaO-Al_2O_3 system using a quasi-harmonic model. The calculated values of CV for the calcium aluminates at 298°K are more accurate that digital scanning calorimetry (±3 percent), and may have uncertainties as small as ±1 percent, based on the comparison of our calculations to published calorimetric data on CaO, Al_2O_3, and $CaAl_2O_4$. For hibonite ($CaAl^{12}O^{19}$), we predict C_P as 519.3 J/mol-K and S as 391.7 J/mol-K, both at 298°K. For grossite ($CaAl_4O_7$), our calculated values of C_P as 195.9 J/mol-K and of S as 172.0 J/mol-K (both at 298°K) are slightly smaller than the available calorimetric data, which is consistent with acquisition of thermodynamic data from samples containing small amounts of hibonite intergrown with grossite. Thermal conductivity at 298°K (k_0) is predicted from peak widths of the vibrational modes using the damped harmonic oscillator model of a phonon gas. Calculations of k_0 for CaO and Al_2O_3 differ from the measurements by 17 percent and 5 percent, respectively. The discrepancy for lime is larger due to uncertainties in its peak widths. This comparison suggests that our results for the calcium aluminates should be as least as accurate as conventional measurements, which provide k0 within ~25 percent.

SS19-02

FTIR ANALYSIS OF WATER AND CARBON DIOXIDE IN BASALTIC GLASS AND RHYOLITIC GLASS INCLUSIONS IN QUARTZ PHENOCRYSTS

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Quenched glassy pillow rims of submarine-erupted lavas and melt (glass) inclusions trapped in crystals in subaerial volcanic rocks are important because they preserve information on pre-eruption volatile contents. Fourier transform infrared (FTIR) spectroscopy can be used to measure the H_2O and CO_2 contents of such glasses. To prepare the samples for transmission IR, fragments of unaltered basaltic glass from pillow margins and quartz crystals containing rhyolitic melt inclusions must be doubly ground and polished into wafers with two parallel sides. In the case of quartz crystals, the melt inclusions to be analyzed must be intersected on both sides of the wafer.

For basaltic glass, dissolved total H_2O and carbonate (CO_3^{2-}) can be calculated using Beer's Law. Total dissolved H_2O is measured using the intensity of the asymmetric band at 3550 cm^{-1}. Dissolved molecular H_2O can be measured using the intensity of the 1630 cm^{-1} absorption band. Because the high temperature speciation in basaltic melt is known (Dixon et al., 1995), the presence of excess molecular H_2O can be used to recognize submarine glasses that have been affected by low temperature hydration. Dissolved carbonate can be measured from the absorbance of the 1515 and 1430 cm^{-1} bands. We measure absorbance intensities of these bands using a peak-fitting program that fits the sample spectrum with a straight line, a spectrum for carbonate-free glass, a pure 1630 cm^{-1} band for molecular H_2O, and a pure carbonate doublet. The molar absorption coefficient for total H_2O (3550 cm^{-1}) is relatively independent of composition for basaltic glasses (Ihinger et al., 1994) but the molecular H_2O (1630 cm^{-1}) and carbonate (1515 and 1430 cm^{-1}) absorption coefficients are compositionally dependent (Dixon et al., 1995; Dixon & Pan, 1995). For rhyolitic melt inclusions, total dissolved H_2O can be measured by using the bands centered at 5200 cm^{-1} (molecular H_2O) and 4500 cm^{-1} (OH^- groups). Dissolved CO_2 can be measured using the intensity of the band at 2350 cm^{-1} (molecular CO_2). Molar absorption coefficients from Zhang et al. (1997) are used for molecular H_2O and OH^- in rhyolitic glasses and from Blank et al. (1989) for molecular CO_2.

The H_2O and CO_2 data can be used to infer submarine eruption depths, pressures at which phenocrysts crystallize, degassing during magmatic processes, and volatile release to the atmosphere during volcanic eruptions.

SS19-03 **APPLICATIONS OF STORAGE RING INFRARED MICROSPECTROSCOPY AND REFLECTION-ABSORPTION SPECTROSCOPY TO GEOCHEMISTRY AND ENVIRONMENTAL SCIENCE**

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Infrared radiation extracted from a storage ring affords new opportunities for scientific exploration in the areas of geochemistry, geomicrobiology and environmental science. An introduction to the source properties of infrared radiation emitted from relativistically accelerated electrons in a storage ring will be presented. The most important of these properties is the brightness of the source. A bright source can deliver a higher density of photons onto a small (1 micron x 1 micron) sample at normal incidence than a lab based globar source, which is necessary to produce diffraction limited spatially resolved infrared images. Alternatively, this source can couple well to grazing incidence geometry for surface science experiments affording the opportunity to examine low frequency adsorbate-substrate vibrational bands.

Infrared (IR) images of single cells of the microalga *Euglena gracilis* have been measured using synchrotron radiation as a bright IR source. The distribution of lipids, proteins, chlorophyll, and carbohydrates with a few mm spatial resolution for individual algal cells have been obtained for the first time. A comparative chemical analysis was conducted on cells subjected to nutrient limitation and on their nutrient sufficient counterparts. Our results demonstrate the feasibility of using FTIR microspectroscopy for physiological studies.

The far- and mid-infrared broadband absorptions and discrete vibrations have been studied for water adsorbed on an epitaxial 2000 Angstrom Fe_3O_4(100) film using infrared synchrotron radiation. Water on Fe_3O_4 represents an ideal example both since Fe_3O_4 is a prominent subsurface mineral (magnetite). The present synchrotron-based infrared studies extend traditional IRAS measurements to below 400 cm^{-1} with noise levels of approximately .01% attainable in 100 seconds measuring time. In addition, these measurements are complemented by temperature programmed desorption measurements. Notably, three distinct cation adsorption sites are available on the reconstructed Fe_3O_4(100) surface: a tetrahedrally bonded Fe^{2+}; a tetrahedrally bonded Fe^{3+}; and an octahedrally bonded Fe^{3+}. Molecularly adsorbed water is shown to sequentially fill these sites. In additon, adsorbed multilayers of water reveal large anti-absorption resonances in the infrared spectra for the molecular vibrations and the substrate phonons.

SS19-04

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The effect of grain size on the thermal infrared reflectance spectra of opal-A from Ohaaki Hot Springs, New Zealand

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The discovery of opal-A on the surface of Mars would be consistent with hydrous activity, and therefore its discovery would have serious implications for those searching for sites hospitable to life. Reflectance values between 0.5-25 ìm were collected from a suite of amorphous silicates (opal-A) from the Ohaaki Hot Springs located in the Taupo Volcanic Zone, New Zealand. Spectra were collected from fifteen hand samples and cores, and from crushed material of three different grain sizes (0-74 ìm, 74-250 ìm, and 250-500 ìm). This research has documented the complete spectral signature of opal-A from 0.5-25 ìm as observed in two different spectral classes identified from the sample suite. The most obvious spectral features in the TIR were two bands observed at 8 and 9 ìm. Two additional bands were detected between 10.05-10.25 ìm and 11.25-11.67 ìm in fine-grained material. Examining the relative magnitude differences between these four bands was the main criterion for spectra classification. The endmember spectrum of each of the two classes of opal-A are presented and changes in physical properties that alter the opal-A spectral signature are discussed. While limited reflectance spectra of opal-A are available in current literature, this research has examined physical forms of opal-A that would be more compatible with the types of materials that are thought to exist on the surface of Mars.

SS19-05

INFRARED SPECTROSCOPIC ANALYSIS OF SYNTHETIC GLASSES: APPLICATION TO BASALTIC LAVA FLOW EMPLACEMENT

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To better assess and mitigate volcanic hazards associated with lava flows using infrared data, an improved understanding of the relationship between laboratory, field, and remote sensing data coupled with improved knowledge of flow field development is needed. Quantifying the physical changes that occur in silicate melts using infrared emission spectroscopy will provide a means to examine the affects of vesicle formation and distribution, surface chill coats, and short-range crystal lattice formation on the emitted infrared spectrum. The linkage between IR spectroscopy and lava cooling will yield important constraints for application to the basaltic lava flow field development. A suite of glasses will be synthesized in the Experimental Analysis Laboratory at the University of Western Ontario to represent a range of compositions and vesicle contents. Spectra of these samples will be collected using the FT-IR spectrometer housed in the University of Pittsburgh's IVIS Laboratory. This will provide a first-order comparison between the spectral morphology and the crystallinity of the samples. The second phase of the study will be to collect spectra of samples cooling from above liquidus temperatures. The spectrometer will be fit with a heating/cooling/photography stage in order to provide a means to melt the synthetic glasses, collect their emitted thermal spectra, and obtain coincident digital images of the samples. Chilled samples will be analyzed using XRD analysis to determine the percentage and compositions of the crystals formed. These results will be compared with thermal emission spectra of basalt samples that represent distinct styles of lava flow emplacement that have been collected at the 1969-1974 Mauna Ulu flow field (Kilauea Volcano, Hawai'i, USA).

Results from these analyses can then be applied to thermal data collected in the field and by satellite for active lava flows. Field investigations of such flows at the active Pu'u 'O'o-Kupaianaha flow field (Kilauea Volcano) have begun and seek to understand the effects of temperature and glassy crusts on retrieved emissivity. The integration of laboratory, field, and spacebourne remote sensing analyses will provide quantitative constraints on the effects of vesiculation and crystallization, crust formation and spallation, and cooling on the emplacement and inflation of basaltic lava flows. For example, understanding the temporal and spatial changes in thermal emission will allow a more accurate estimate of radiative heat flux, which may ultimately be used to calculate the local eruption rate.

SS19-06 **THERMAL EMISSION SPECTRA OF SECONDARY SILICATES FORMED IN ARID-ZONE BASALT WEATHERING**

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Thermal emission remote sensing measurements of natural surfaces reflect a combination of rock minerals, weathering rind minerals, and soils, which may contain both primary and secondary minerals. Secondary minerals can obfuscate quantitative mineralogical analyses of rocks. But secondary minerals, as measured in thermal emission, also can reveal important information about weathering processes and the extent of alteration of natural surfaces.
We are concerned with secondary silicates that develop on mafic rocks under arid conditions. These include clay minerals (smectites and halloysite) and amorphous or poorly crystalline authigenic silicates (opaline silica and allophane). Clay minerals commonly develop from weathering of basaltic rocks and comprise a significant fraction of mafic soils. Clays may also form a fraction of authigenic silicates in weathering rinds. Poorly crystalline silicates are important constituents of basalt weathering rinds and they are known to form high-silica rock coatings in arid regions. Silicate mineraloids form in mafic soils; allophane, in particular, can make up a significant fraction of soil silicate materials.

As a first step in addressing thermal emission measurements of natural basaltic surfaces, we have performed a detailed thermal emission spectroscopic study of secondary silicate minerals, including characterization of spectra in a crystal chemical sense. We have collected spectra of silicate weathering products including varieties of clay minerals, opaline silica, allophanes, and silica-clay physical mixtures. The positions of absorption features in the 900-1300 cm-1 range resulting from Si-O stretching are a function of silicon-oxygen ratios, with high Si:O material absorption minima positioned at higher energy. As such, the absorption minimum for pure SiO2 opal occurs at ~1115 cm^{-1}; the minima for clays (Si:O = 0.3-0.4) occur in a lower wavenumber region, 1030-1075 cm^{-1}. Absorption minima for secondary amorphous silicates with Si:O between 0.4 and 0.5, such as aluminous opal and some allophanes, are positioned between absorption minima of opal and clays. As a happenstance of their amorphous nature and Si:O ratios, these materials are spectrally similar to high-silica glasses, such as obsidian.

This study has import bearing on interpretations of thermal infrared data for natural, weathered basaltic surfaces on Earth and for thermal emission remote sensing of Mars. For the Martian case, a global unit with a strong absorption measured at ~1085 cm^{-1}, previously attributed to obsidian-like glass, may result from weathered basaltic surfaces containing aluminous opal or allophonic material.

SS19-07 Estimating bulk chemistry and modal mineralogy of igneous cores using thermal infrared spectroscopy

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The bulk chemistry (weight percent oxides) and modal mineralogy of igneous cores was predicted using thermal infrared reflectance (TIR) spectra. The research is motivated by the need to automate underground mining operations such as logging of rock type and ore grading in cores. To calibrate our models we examined the relationship between weight percent oxides and TIR spectra for a wide range of rock types including alkaline granite and dunite. The TIR spectra were pre-processed and transformed to a wavelet domain to isolate mineral spectral features and minimize the controls of sample physical properties (e.g. varying grain size) or varying measurement geometry across the sample suite. Results show that SiO_2, Al_2O_3, K_2O+Na_2O, CaO, MgO, FeO+Fe_2O_3 can be estimated with a model error less than 7% absolute weight. The 100*Ca/(Na+Ca) ratio in plagioclase can be modeled with an error of less than 10 (the ratio ranges from 0-100) absolute.

A validation of the model was conducted using seventeen cut samples of felsic and mafic rocks from mines of the Sudbury basin with over thirty TIR readings per sample. The modeled modal mineralogy of each sample was calculated using the CIPW procedure and the modeled weight percent oxides as inputs. These results were compared with modal abundances estimated from thin sections showing that Quartz (< 6% error) and Orthoclase (< 7%) can be well estimated. Plagioclase shows higher errors (< 12%).

SS19-08

INTEGRATING HYPERSPECTRAL IMAGERY AND AEROMAGNETICS TO DEVELOP A 3D GEOLOGIC MODEL OF THE CUPRITE MINING DISTRICT, NEVADA

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The Cuprite Mining District, Nevada is a geologic province consisting of two acid-sulfate hydrothermal alteration centers. Previous studies have attempted to understand the structural and hydrothermal history of the area using remote sensing techniques. Remote sensing techniques however, provide only surface information. Subsurface information is needed to determine the geologic structure. This study focuses on two aspects; using aeromagnetic data to determine whether the structural model is consistent with that determined by previous research, and developing a 3D geologic model by integrating surface information derived from hyperspectral imagery with sub-surface information derived from the aeromagnetic data.

Two aeromagnetic surveys were acquired over Cuprite. A high-resolution draped aeromagnetic survey over the eastern center and a low-resolution barometric survey over both centers. Both data sets were processed and compared with mineralogy maps derived from hyperspectral imagery. The results show that the eastern center is non-magnetic, while the western center is magnetic. These centers are expected to be non-magnetic since magnetite, the primary magnetic mineral in volcanic rocks, is often destroyed during hydrothermal alteration. Examination of the mineral maps derived from the hyperspectral imagery show that the western center contains abundant jarosite while the eastern center contains only minor amounts. Jarosite is formed by the oxidation of pyrite. Since pyrite is commonly associated with magnetite, magnetite may be producing the magnetic anomaly associated with the western center. This observation supports previous research suggesting different levels of alteration for the two centers. The western hydrothermal center was formed from a deep conduit situated directly below and the eastern center was formed from an offshoot of that same conduit.

3D inversion of the magnetic data was used to model the subsurface geology. The inversion, constrained by the cross-sectional history results from previous research, also suggests that a source body is located beneath the western center. Detailed interpretation of the western center is limited by the regional scale aeromagnetic survey. The high-resolution aeromagnetic data help constrain the extent of the alteration zone in the eastern center but do not confirm the degree of alteration. Individual geologic units are not well constrained due to a lack of magnetic susceptibility measurements, however zones of intense alteration are relatively well defined. Overall, the aeromagnetic data show consistencies with the model proposed in literature. A generalized 3D geologic model is possible by integrating hyperspectral and aeromagnetics but additional constraints are needed to improve the accuracy of the model.

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SS19-09 Review of airborne and orbiting remote sensing systems applied to worldwide mineral exploration – Case histories focused on infrared (IR) spectroscopy

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Remote sensing systems have become an operational and vital part in worldwide exploration for ore deposits. Mineral exploration companies are faced with significant economic hurtles, time constraints, and international politics, which together demand quick assessment and field mobilization to all parts of the world. Remote sensing technology offers a range of reliable and timely solutions necessary for regional reconnaissance, district-level analysis, and field logistics. Those satellite and airborne systems offering visible and near infrared (VNIR) and short-wave infrared (SWIR) wavelength bands allow for prediction of surface alteration and mineral identification. Particularly useful in arid, semi-arid, and temperate terrain, airborne and orbiting sensors with SWIR bands detect alteration minerals and mineral mixtures associated with primary syngenetic/epigenetic and secondary, near-surface mineral deposits. Coupled with image georectification to specific map bases, these sensors provide intelligent alteration mineral maps that vastly reduce the cost and time involved in field geologic investigation. Case histories using currently available and fully operational sensors demonstrate the ability of remote sensing systems with SWIR capability to predict and map alteration minerals and mineral mixtures, critical to mineral exploration surveys.

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SS19-10 APPLICATION OF SPECTRAL ANALYSIS BY NON LINEAR QUANTIFICATION ALGORITHM TO THE STUDY OF BIOMASS AND MINERALOGY

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Hyperspectral visible-infrared (VIR) measurements are a powerful technique to identify and to map surface materials despite their sensitivity to many radiometric effects. One of the major difficulty is to retrieve components and proportions inside combination of linear and non-linear mixtures. An improved approach is proposed by the way of a specific algorithm of spectral analysis and non-linear quantification. This algorithm has first been tested on the Bourgneuf bay (western France). It is being used for terrestrial ophiolite area.

DAIS hyperspectral data are used to study the intertidal coastal zone of the Bourgneuf bay to determine the biomass of a micro-algae forming biofilm on a mineral substrate. The first 32 channels between 496 and 1035 nm were selected as they contain most of the spectral information on vegetation. True components have been identified by field acquisitions with a GER 3700 spectrometer and quantified independently. The presence of both linear mixtures due to geometric juxtaposition within a pixel and non-linear mixtures related to biofilm translucidity do not allow a simple resolution of the inverse problem. A method is proposed by a direct spectral distance comparison of imaging spectrometer data with mixtures built numerically from field and laboratory measurements. Nevertheless, systematic differences remain and may be caused by instrument calibrations and conditions of acquisition. They affect mostly the spectral envelope. This global contribution can be extracted through the Modified Gaussian Model (MGM) by Sunshine et al. (1990) which provides a reliable deconvolution by fitting simultaneously all absorption features by gaussian distributions and a continuum by a straight line in wavenumber. Finally, continuum-corrected data from different sources are compared: each pixel is matched by a library mixture spectrum with a known composition. Absolute biomass mapping on the Bourgneuf bay constitutes an improvement with respect to previous studies with multispectral data (Méléder et al., 2003) and are found to be in agreement with field observations (Combe et al., 2004). This method is now applied for mineralogy both on Earth (Oman and Ronda) and Mars (OMEGA/Mars Express).

SS19-11 Spatial and Spectral Integration for Hyperspectral Image End Member Selection

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Producing accurate geological maps using methods such as linear spectral unmixing, require good spectral representations of each surface component. Poor, or incomplete end member sets, produce poor results. As such, numerous semi- and -fully automated spectral based image end member selection methods have been developed. Because these methods are spectrally based, their ability to discriminate between image components is dependent on the degree of spectral contrast between those components. Improving spectral contrast can be accomplished spectrally (e.g. derivative analysis) or spatially by using the premise that image components are not randomly distributed throughout an image. Thus, image components that have low spectral contrast at a global scale, can be more easily observed by focusing on image regions. This concept is demonstrated using a commonly used semi-automated spectral based end member selection method, Pixel Purity Index (PPI), by applying it in a spatial manner using equal-sized image subsets. PPI was run for each image subset, with the output normalized to the value of the "purest" pixel for the given subset. Normalization was used so that the results from multiple subsets could be combined, and compared with the results on the full image without subsetting. This experiment was repeated for subsets of various dimensions to observe how subset size impacts end member selection. This spatial/spectral approach was assessed using synthetic image data derived from mixtures of known end members; and, a Probe hyperspectral image for southern Baffin Island for which ground data are available. Decreasing the dimensions of the subsets for the synthetic data was shown to increase the number of end members found in the top percentiles of the pixel purity index. Applying this approach to the real data has resulted in a more complete representation of lithological units sampled in the field. The results from this work show that the integration of spatial and spectral information can be used to improve end member selection, specifically end members with low spectral contrast, and that the optimum subset size is dependent on the distribution of the image components.

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SS19-12

THE ERUPTIONS OF BEZYMIANNY VOLCANO AS SEEN IN THE INFRARED: THE LINKAGE OF DOME EMPLACEMENT PROCESSES WITH NEAR-REAL TIME ERUPTION MONITORING

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Silicic domes preserve an enormous quantity of information on the pressure, temperature, flow rate, and degassing state of an active volcanic system. Domes can also change dramatically over a short period of time signaling an increased hazard risk due to the potential of collapse and the generation of ash and pyroclastic flows. Remotely acquired thermal infrared data (TIR) of domes and their lavas provide unique insights into these processes, however the quantitative extraction of parameters needed for emplacement models has not been accomplished to a large degree. Numerous techniques for the mapping, monitoring, and modeling of lava domes have been developed, but much of that work focused on older inactive domes. New infrared sensors, with higher spatial and/or temporal resolution have made it possible to collect detailed data of active domes. For example, the ASTER instrument has the first multispectral TIR capability from space, which is critical for monitoring low temperature anomalies as well as mapping both chemical and textural variations on the surface. However, the higher spatial resolution and relatively long repeat time preclude ASTER from being used for near-real time eruption monitoring. For this the Alaska Volcano Observatory relies on the AVHRR sensor, which captures 1 km TIR data in two bands every 1-6 hours at the latitudes north of 50 degrees. A new NASA project is now underway that will link these two sensors in an autonomous way in order to capture all phases of an active eruption.

The foundation for this new program was the analysis of ASTER TIR data for numerous silicic lava domes on the Kamchatkan Peninsula of Russia since early 2000. The focus here is on the vigorously-active andesitic dome at Bezymianny Volcano. ASTER was used in conjunction with the higher temporal resolution data of the AVHRR sensor to detect the eruption onset and then to map the temperature, composition, and surface texture of the volcanic products deposited after each Bezymianny eruption. This information is now being used to better constrain the modeling of the dome in preparation for a field campaign to Kamchatka in the summer of 2004. Field-based temperature and IR spectroscopy will complement the space- and laboratory-based analyses, and allow a more complete understanding of lava dome emplacement processes as seen in the infrared.

SS19-13 CHARACTERIZATION OF DOME PROCESSES AT SOUFRIÈRE HILLS VOLCANO, MONTSERRAT: SYNTHESIS OF INFRARED REMOTE SENSING DATA WITH A MULTI-PARAMETER DATABASE

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Satellite remote sensing has played an integral part in monitoring and characterizing active volcanic processes or in aiding to identify preliminary stages of activity. The Advanced Spaceborne Thermal Emission Reflectance Radiometer (ASTER) is a high resolution multispectral imager ideal for discerning these physical variations on the surface of active lava domes. The five bands of thermal infrared data at 90 meter spatial resolution can be used to retrieve accurate temperature as well as surface emissivity data. These data provide a quantitative means of estimating glass and vesicle distribution on a changing dome, which can then be used to infer internal processes within the magmatic system. Much of the previous work of IR spectroscopy and silicic flows has focused on model validation using airborne data collected over inactive lava domes. For the first time, this study analyzes data from an actively-deforming silicic dome on the island of Montserrat. Six nighttime ASTER scenes of the Soufrière Hills volcanic dome have been chosen for this analysis. These data cover the entire extent of the dome, show the presence of thermal infrared anomalies and pyroclastic flow activity, as well as contain a relative lack of cloud cover. The linear spectral deconvolution technique utilized in this study employs the spectral signatures of two known end-member materials (glass and vesicles), to resolve the unknown spectrum into areal abundances of each end-member. This technique produces surface maps of the distribution of vesiculated rock across the dome, over time.

Montserrat Volcano Observatory (MVO) weekly reports from 1999 to present (available online) were also ingested into a multi-parameter, searchable database. These data detail specific volcanic activity and were compared against the ASTER data. The database fields include sulfur dioxide flux, high temporal resolution weather satellite-derived radiance measurements, description of dome growth and collapse, and intensities of pyroclastic flows, rockfalls, fumarolic activity, and seismic activity. This database provides a unique cross-reference for the interpretation of the spaceborne data, as well as highlighting observable trends in each of the volcanic activity types. Results from this study have provided a better understanding of the capabilities of the ASTER instrument to accurately describe active dome processes and to characterize these processes both quantitatively and statistically. This knowledge can be applied to other volcanoes with active domes in order to study indicators of future dome growth/collapse, the generation of hazardous pyroclastic activity, as well as the transition from effusive to explosive dome growth.

SS19-14 RAPID ASSESSMENT OF AN URBAN HAZARD: SPECTROSCOPY OF THE WORLD TRADE CENTER DUST

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On September 16th, 2001, five days following the collapse of the World Trade Center Towers, hyperspectral data was collected over ground zero with the Airborne Visible/Infrared Imaging Spectrometer (AVIRIS). Our intent was to rapidly assess the asbestos hazards of the dust that blanketed a large portion of lower Manhattan. Within two days of the overflight, a two person team had collected ground samples of the dust and airfall debris from 35 sites within a 1- km radius of the collapse site including samples from two indoor locations unaffected by rainfall and samples of insulation from two steel beams at ground zero. Spectral measurements of dust-free cement pavement on the top level of a parking garage in New Jersey, located 3 km west of ground zero, were used to calibrate the AVIRIS data prior to spectral mapping with the USGS Tetracorder spectral identification algorithm. The dust and beam-insulation samples were analyzed for a variety of mineralogical and chemical parameters using reflectance spectroscopy, scanning electron microscopy, X-ray diffraction analysis (XRD), and chemical leach tests.

AVIRIS mineral maps do not show widespread distribution of chrysotile or amphibole asbestos above the few-percent detection limit of the instrument at the ground surface, but do show a few isolated pixels of potentially asbestiform minerals. AVIRIS images were also used to locate hot spots in the debris pile hidden from view by smoke, thus allowing firefighters to more effectively battle the fires. Delivery of this information to emergency managers within two weeks of the attack demonstrated how rapidly these urban hazards could be assess on a city-wide scale with imaging spectroscopy. Spectral and XRD analysis of the field samples took several weeks longer and revealed that trace levels of chrysotile were present in two thirds of the dust samples but at concentrations lower than 1 wt%, well below the sensitivity level of AVIRIS. From the field data it is apparent that trace levels of chrysotile were distributed with the dust radially in west, north, and easterly directions perhaps to distances greater than 3/4 km from ground zero. The lack of chrysotile at levels above the detection limits of both methods in all but one sample collected south of ground zero may indicate that chrysotile was not distributed uniformly during the collapse.

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Ontario Oil and Gas, the joining of two basins

Le pétrole et le gaz en Ontario à la jonction de deux basins

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EVOLUTION OF EXPLORATION, DRILLING AND COMPLETION CONCEPTS FOR APPALACHIAN BASIN'S TRENTON-BLACK RIVER PLAY

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The hottest play in the Appalachian basin continues to be the deep Trenton-Black River play(Ordovician), a high-tech, high-risk play that began in New York in 1995 with the discovery of the Glodes Corners Road field. High initial potential tests, followed by high, sustained production, attracted national interest, even before the play was extended to West Virginia in 1999.

Early discoveries in New York were based on an exploration model developed by Richard Beardsley, for which he was awarded AAPG's first Outstanding Explorer Award. The first locations were based on seismic where a basement fault was observed beneath a sag on the top of the Trenton, which Beardsley interpreted as being due to a volume reduction as limestone was converted to hydrothermal dolomite (HTD) adjacent to fault zones.

PTTC (Petroleum Technolohy Transfer Council)became involved in the play soon after the discovery of the Cottentree field in West Virginia (1999). The first Trenton-Black River workshop focused on structural and stratigraphic settings and depositional environments, complemented by drilling updates and limited seismic data. Workshop participants gained an appreciation for the high-risk nature of the play, and a realization that basement-deep faults were necessary for the development of HTD reservoirs in both the Trenton Limestone and underlying Black River Formation.

Development continued in New York with additional discoveries and the first horizontal wells being drilled in 2003. Also, some recent exploratory wells have been drilled in Pennsylvania in an attempt to determine if the Trenton-Black River there is more akin to the HTD reservoirs of New York, or to the fractured limestone reservoirs of West Virginia.

As additional discoveries were made, industry requested that PTTC take the lead in technology transfer. Subsequently, four more workshops were held, attracting more than 500 registrants. During these workshops, it became apparent that: the New York play was different than the West Virginia play; the presence of the basal sandstone could be a key component in a hydrothermal dolomite model; an outcrop model in Kentucky was a good model for the reservoir in New York; various seismic models are necessary to explain the different reservoirs; and there was interest among industry for a detailed study of the Trenton-Black River interval.

Subsequently, a Trenton-Black River research consortium was formed to conduct a regional study of this play. The consortium, consisting of the state geological surveys in Kentucky, New York, Pennsylvania, Ohio and West Virginia, along with their company partners, submitted a successful proposal to the U.S. Department of Energy to prepare a play book and create an interactive website and database for consortium members.

SS20-02 A NEW EXPLORATION TARGET ON THE ORDOVICIAN ANTICOSTI PLATFORM IN EASTERN CANADA: HYDROTHERMAL DOLOSTONES IN THE FORELAND BASIN CARBONATES

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Hydrothermal dolomitization played a key role in the development of hydrocarbon reservoirs for Ordovician carbonates along the ancient continental margin of Laurentia. Significant production in these reservoirs is known from the US mid-west to Ontario and upstate New York. The documentation of hydrothermal fluid circulation in the oil-reservoir host Lower Ordovician St. George Group in Newfoundland generated interest for the adjacent and little studied Ordovician succession on Anticosti Island.

The peritidal-dominated facies of the Lower Ordovician Romaine Formation (=Beekmantown interval) recorded multiple events of dolomitization and a late hydrocarbon migration. A late hydrothermal event generated significant porosities imperfectly filled by high temperature saddle dolomite (average Th: 120°C) derived from a highly saline fluid (24 wt% $NaCl_{equi}$). A later hydrocarbon inclusion-rich calcite (average Th: 70°C) filled some of the pore space. The highly porous Romaine Formation is considered to have acted as a regional aquifer for hydrocarbon migration on Anticosti Island.

The open marine facies of the Middle-Upper Ordovician Mingan Formation (=Black River – Trenton interval) have received less attention. Dolomite has only been documented in recent exploration holes in eastern Anticosti. Dolomite occurs as replacement phase and only pore-filling calcites were observed. The latest replacement dolomite is characterized by high temperature (average Th: 105°C) and highly saline (24 wt% $NaCl_{equi}$) fluid inclusions. Recent seismic profiles clearly documented the presence of significant number of platform sags and associated loss of seismic markers in yet to be tested extensional fault-bounded domains.

It has been assumed that the hydrothermal fluids used the Romaine aquifer for circulation and breached into the Mingan at the erosional edge of the Lower Ordovician platform in northern Anticosti. Circulation of these fluids along some major extensional faults altered the Middle-Upper Ordovician Mingan Formation. The fluids generated secondary porosity as suggested by gas shows from the Mingan Formation in number of exploration holes.

SS20-03 FAULT-CONTROLLED HYDROTHERMAL ALTERATION OF CARBONATE RESERVOIRS

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Hydrothermal dolomite reservoirs have received much attention in North America recently with the discovery of Ladyfern (~750 BCF) in Western Canada and continued exploration success in the Trenton Black River Play in the Appalachian Basin. Analysis of the geology of these fields leads to the conclusion that many other carbonate reservoirs may have formed or been significantly modified by hydrothermal processes. Hydrothermally altered reservoirs may represent one of the largest untapped hydrocarbon resources in the world because they commonly occur in subtle diagenetic traps that are easily overlooked.

Hydrothermal alteration of carbonate reservoirs is not restricted to local dolomitization around faults in a few localities, but occurs in a wide variety of structural and stratigraphic settings all over the world. Hydrothermal alteration products may include, but are not restricted to, matrix and fracture-filling dolomite, recrystallized limestone (including development of microporosity), bedded and fracture-filling chert, induced breccias and fractures, pore- and fracture filling anhydrite, calcite, ferroan calcite, ankerite, quartz, fluorite, barite, bitumen, authigenic clay minerals, sulfides and more. Furthermore, leaching of limestone, dolomite, and other minerals is a common occurrence in hydrothermally altered reservoirs and can be a primary control on reservoir quality.

Hydrothermal alteration occurs when high-pressure, high-temperature fluids flow up active faults and into formations that underlie sealing shales or evaporites. Alteration occurs due to the influx of fluid from the fault, the mixing of that fluid with the fluid in the formation and during the subsequent equilibration with the formation conditions. Solubility of carbonate (and other minerals) is directly affected by changes in temperature, pressure, pCO_2, pH, and salinity and all of these are fluctuating on short time scales in hydrothermal systems.

First order-controls on hydrothermal alteration products include: composition, thickness, porosity, and permeability of the host rock, the pressure, temperature and chemistry of the hydrothermal fluid, the effectiveness of the seal, the efficiency of the fluid recharge, distance to the basement and basal sandstone aquifer, and the type and timing of faulting.

Structural settings where hydrothermally altered carbonates are found include around margin-bounding faults, over newly rifted basement and active normal faults, at fault intersections and around wrench faults that are activated during mountain building events. Reefs and mounds commonly form over faults and are then altered by fluids flowing up the same faults. A better understanding of the processes and products of hydrothermal alteration will lead to further exploration and development success.

SS20-04 **PETROLOGY AND PETROLEUM GEOCHEMISTRY OF THE BLACK RIVER AND TRENTON GROUPS, CENTRAL AND WESTERN PENNSYLVANIA**

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Upper Ordovician carbonates and shales of the Black River and Trenton Groups in central and western Pennsylvania comprise at least five third-order depositional sequences within the Turinian and Chatfieldian North American Stages. Black River rocks include skeletal grainstones, packstones, and wackestones, mudstones, and dolostones. They also exhibit some autochthonous, organically bound limestone textures. Black River rocks were deposited in intertidal, lagoonal, and shallow subtidal environments on a gently sloping barrier-bank ramp. Trenton Group rocks include skeletal rudstones, floatstones, grainstones, packstones, and wackestones, laminated and nodular mudstones, and black calcareous shales. These rocks were deposited in relatively deep subtidal environments on a distally steepened ramp. Centimeter-scale cyclic patterns, induced by storms, were superimposed on larger scale, eustatically-controlled successions in both the Black River and Trenton Groups.

Diagenetic features in the Black River and Trenton Groups reflect mostly submarine and burial environments of cementation and alteration. Evidence for marine diagenesis includes micritization, isopachous and sparry calcite cements, and significant hardground development. Unique, subtidal meniscus-type cements are associated with the latter. Compaction features, fractures, silicification fabrics, idiotopic to xenotopic dolomite, and MVT mineral assemblages all denote burial diagenesis.

The Black River Group, Trenton Group, and overlying Antes and Utica Shales are known petroleum source rocks in central and western Pennsylvania. The petroleum potential, based on total organic carbon (TOC) is good to excellent. In northwestern Pennsylvania, these rocks contain as much as 2.95% TOC. They are at peak thermal maturity, and are gas prone. In central Pennsylvania, these rock contain up to 1.72% TOC, but the kerogens are post mature and their generative potential is exhausted. Pyrolysis data from exploratory wells here, however, indicate that these rocks are generating low-molecular weight hydrocarbons at a rate that might yield commercial gas accumulations. These hydrocarbons (nC_{10} to nC_{24} alkanes, and low-molecular weight aromatics with some nC_9 to nC_{16} alkanes) were generated earlier from the now spent kerogens, and are sorbed on the mineral matrix and organic carbon in the limestones and shales. This bitumen is cracking to gas today.

SS20-05

PALEOMAGNETISM OF SUBSURFACE TRENTON GROUP CARBONATES, SOUTHWESTERN ONTARIO: PRELIMINARY RESULTS

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The Ordovician Trenton and Black River Group carbonates are the subject of renewed interest by the oil and gas industry in Canada and the United States, and are an active target of exploration. While regionally a non-porous limestone, isolated areas of dolomitization are known, and are associated with hydrocarbon reservoirs. Detailed paleomagnetic and rock magnetic analysis of unoriented core from in and around the dolomite-rich Hillman Field in southwestern Ontario has been aimed at determining if previously characterized dolomitic phases are magnetically distinguishable, as has been observed in the Western Canada Sedimentary Basin. Over two hundred specimens have been collected from a single well showing an almost complete section through the Sherman Falls Formation. Pilot specimens were measured using a multi-step alternating field or thermal demagnetization sequence. The specimens measured contain at least two magnetization components: a normal polarity low temperature / low coercivity remanent magnetization (<10-20 mT; <200-250Â°C), a reversed polarity characteristic remanent magnetization (ChRM); and a rare high-temperature magnetization. The low temperature / coercivity remanent magnetization seen in both thermal and AF demagnetized specimens is variable in intensity and direction, and may be correlatable with lithological type i.e. argillaceous dolostones typically have a stronger and better defined remanence. It is likely that this is a viscous remanent magnetization. However, a few specimens show little to no evidence of this component. Thermal demagnetization reveals that some, but not all, of the specimens have a clear intensity drop at 300-350 Â°C, suggesting that pyrrhotite is present, whereas the ChRM is carried by magnetite in other specimens. The reversed polarity ChRM is generally shallow and oriented 70-180Â° clockwise of the low temperature magnetization, suggesting that this magnetization is probably the Permian Kiaman overprint that is observed through the Appalachian Basin. The origin of the high temperature magnetization has not been determined.

SS20-06 The Utica Group shales: the next fractured shale play?

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In 1821, a shallow well drilled in the Dunkirk shale ushered in a new era when natural gas was produced, transported and sold to local establishments in the town of Fredonia, New York. In spite of this early success, the shales have not been a major producer in the northern Appalachian Basin. With new technology, however, all shales are getting another look.

In New York, Ontario and Quebec, the Ordovician Utica Group shales were deposited in the foreland basin as the Taconic Orogeny continued to the east. They drape over the shallow platform carbonates of the Trenton formation and reach a thickness of over 1,000 ft. The group goes from outcrop to nearly 10,000 feet at the Pennsylvania border. These black shales have significant fracturing and abundant pyrite. They are sub-bituminous and fresh samples may ignite. If a fresh sample is submerged in water, “an oily sheen rises to the water's surface.” Though data is sparse, TOC’s have been measured at over 3% by weight in eastern New York, Ontario and Quebec. Gas shows have been encountered in wells in eastern and central New York.

Current shale plays such as the Barnett and Antrim show that every shale play is somewhat unique, each with its own characteristics and problems. It is clear that the fractured Utica Group shales offer the potential to be an economic play. More research is needed that addresses the geologic and reservoir properties of the shale.

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SS20-P01 **POROSITY AND PERMEABILITY ATTRIBUTES IN SPECIFIC LITHOFACIES: AN APPROACH IN THE TRENTON GROUP, SOUTH WESTERN ONTARIO, CANADA**

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The Trenton Group, in southwestern Ontario, is a shallow marine carbonate complex that developed in the Appalachian foreland basin during the Middle Ordovician. The Trenton Group is regionally a nonporous limestone with isolated dolomitized regions. These dolomitized zones have been targets for hydrocarbon exploration since the late 1800s. This study focuses on the Hillman pool, located on the southern flank of a northeastern plunging Findlay Arch. The Findlay Arch is part of an arch system that formed a structurally “high” barrier between the Michigan and Appalachian Basins. The predominant theory speculates that structural features (faults and fractures) penetrated upwards from basement into the overlying stratigraphic units and acted as a conduit for fluid flow. Dolomitization is not restricted to any lithostratigraphic facies within the Trenton Group, although there is preferred dolomitization within skeletal zones and restricted dolomitization in argillaceous facies. The degree of dolomitization is an important factor controlling reservoir quality. Production rates of Ordovician pools are characterized by high initial production followed by a rapid fall and then stabilization.

Standard measurements are usually done on core plugs, the result being a lithofacies-averaged value. As an alternative approach to this expensive and time-intensive technique, this study quickly measures microscopic scale porosity and permeability using inexpensive digital image processing and targeting specific lithofacies. This provides more precise facies-related porosity and permeability measurements, resulting in more accurate reservoir models for hydrocarbon prospecting and production. The measurement of porosity in a single leached crystal can also demonstrate how much intracrystalline porosity contributes to the overall porosity value.

While dolomitization has historically been viewed as producing desirable porosity, this study found that the total porosity of these rocks contributed little to useful permeability since the pore interconnectivity has been lost through overgrowths of interlocking dolomite crystals forming a non-planar fabric. In this case, porosity and permeability are related to leaching and vuggy porosity creation. At a meso scale, dolomite dissolution may provide porosity values up to 30% (measured by image analysis at localized areas), however the interconnectivity of these dissolution vugs is poor (low permeability). At a microporosity scale individual leaching of single dolomite crystals provide lower permeability values as well, because the non-planar fabric does not allow for fluid flow. The resulting porosity and permeability pattern is therefore a reflection of dissolution processes rather than a dolomitization process, and produce reservoirs that may show an initial good production rate with a rapid decay curve.

SS20-P02

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THERMAL HISTORY OF PRECAMBRIAN SHIELD IN SOUTHEASTERN ONTARIO: EVIDENCE FROM APATITE FISSION-TRACK THERMOCHRONOLOGY

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The results of a reconnaissance-scale apatite fission-track (AFT) thermochronology study across the Precambrian Shield of northern Ontario are summarised. Results confirm that AFT ages increase to the north and west and that this pattern results from the gradual removal of the predominantly Paleozoic sediments that covered the Shield. The AFT ages vary from about 150 Ma in the extreme southeast of the study area, to 300-400 Ma in the region between Sudbury and Thunder Bay, to over 400 Ma in the region to the west.

Combining all the AFT data and thermal history models from our study, we observe two major Phanerozoic heating-cooling cycles across the investigated area. The oldest apparent AFT ages are preserved in the area north and west of Thunder Bay. Samples there record only an older Paleozoic heating-cooling cycle, and involve only partial resetting of the AFT clocks. East of the area of older ages, the trends seem to be similar, but the record of the Paleozoic event becomes increasingly overprinted by Permian heating. Only in the northeast, where the Late Paleozoic-Early Mesozoic cycle did not significantly disturb the AFT parameters, can the Paleozoic total resetting be defined. The AFT age contours suggest that regions of the shield with abundant basement-scale fractures such as dykes have had a demonstrably more complex and younger Phanerozoic burial history (FTA < 300 Ma) than the less fractured block in the Kenora region (FTA > 400 Ma). These data support earlier tectonic models in the literature, which suggest that basement structure may have controlled subsidence. Three main Paleozoic orogenies: the Taconic, Acadian, and Alleghanian, were centered in the Appalachian orogen adjacent to our study area. Within southern Ontario, they produced major pulses of orogen-derived clastic sediments during the Late Ordovician, Late Devonian and the Pennsylvanian. The older heating-cooling cycle can be correlated with the Taconic Orogeny. The younger, late Palaeozoic-early Mesozoic cycle was responsible for resetting of AFT ages in southeast Ontario and represents burial beneath Alleghanian foreland sediments. This AFT study provides estimates of the amount of heating and cooling related to the depositional and erosional cycles in time and space, and it confirms that large areas of the shield contain a hitherto unknown record of Phanerozoic events related to orogenic activity at the plate margins.

SS-21

EVOLUTION OF MID- TO DEEP-CRUSTAL TERRAINS THROUGH TIME

L'ÉVOLUTION TEMPORELLE DE TERRAINS CRUSTAUX DE PROFONDEUR MOYENNE À GRANDE

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SS21-01 PROBING THE SECULAR EVOLUTION OF THE MID-TO LOWER CONTINENTAL CRUST

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We examine mid- to deep-crustal evolution from the perspective of secular change. The mid- to lower continental crust (MLCC) is broadly defined here as crust that currently or once resided in the lower half of the crust, either now or during orogenesis. Low temperature examples (e.g., blueschists) are not considered. With the possible exception of lowermost crust, crust of 'normal' thickness (35-45 km) is static, having undergone the bulk of its evolution during formation and orogenic activity. Hence geophysical and xenolith data can be used to examine MLCC of variable age. Uplifted crustal sections and impact structures provide similar opportunity.

MLCC of all ages typically contains a range of mafic to felsic rock types. Combinations of tectonic, magmatic, and metamorphic activity can account for this variability. Seismic reflection profiles generally indicate subhorizontal discontinous layering, and seismic velocities suggest an intermediate (mid-crust) to mafic-intermediate (lower crust) bulk composition irrespective of age. No consistent secular variations in Moho character are known. At face value, these similarities are intriguing as the tectonothermal evolution of continents should have varied due to secular change. The most important variable is heat: although debate continues, the Archean crust and mantle were probably hotter than today. Crustal heat production was 2-3 times greater, suggesting that under 'ideal' conditions (i.e. sufficient abundance of heat-producing elements (HPEs)), Archean crust was less viscous and therefore more susceptible to deformation and partial convective overturn. Secular cooling also appears to have modified some aspects of plate tectonics.

The age-independent features of MLCC noted above suggest that secular influences on crustal evolution are partly to completely masked by first-order features. For instance, substantial growth of continental crust in plate margin settings has likely yielded a broad crustal uniformity over time (within observational resolution). Similarly, geochemical and tectonic modification of the MLCC is unlikely to have substantially varied. HPEs are concentrated in upper crust of all ages due in large part to metamorphic and magmatic extraction from the MLCC. This represents an important cratonization process that drives MLCC toward a common endpoint (melt-depleted, anhydrous, high pressure-temperature deformation history). Lateral ductile flow of MLCC is likely under these conditions, contributing to subhorizontal reflectivity. Geodynamic and seismic data indicate that tectonic activity of all ages will only enhance this deep reflection pattern. Orogenic burial of HPE-rich units will result in crustal anatexis and probable return of HPEs to the upper crust, a form of geochemical self-organization.

SS21-02

A TALE OF TWO CRUSTAL LEVELS: PROBING NEOARCHEAN MID- AND LOWER-CRUSTAL OROGENIC DEVELOPMENT UTILIZING MAGMATIC AND INHERITED ZIRCONS FROM THE SNARE RIVER TERRANE, SOUTHWESTERN SLAVE PROVINCE

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The Snare River terrane (SRT), southwestern Slave Province, which records ~ 90 m.y. of Neoarchean crust formation and evolution, is a distinct polydeformed and polymetamorphosed orogen exposed at three crustal levels: (i) upper-crustal, greenschist- to amphibolite-facies supracrustal belts, (ii) a mid-crustal wedge composed of granulite-facies gneisses and granitoid rocks, and (iii) intervening granitoid and metasedimentary rocks. Geochronological studies, utilizing U-Pb zircon crystallization ages and inheritance trends, of representative plutons are used to probe mid- and lower-crustal development of the SRT.

Formation and growth (~2674-2610 Ma) of the mid-crust of the SRT was characterized by episodic additions of metaluminous magmas derived from the lower-crust. The orogenic peak, (~2600 Ma), which marked a significant change in the rate, abundance and type of magmatism, was characterized by emplacement of voluminous, lower- and mid-crustally sourced meta- and peraluminous plutons and was associated with granulite-facies metamorphism, in part driven by magmatic heat advection at mid-crustal emplacement levels. Post-peak (~2600-2580 Ma) evolution of the mid-crust featured tectonic collapse, mid-crustal exhumation, small-volume meta- and peraluminous magmatism and high temperature – low pressure metamorphism. The U-Pb data imply that crustal growth and evolution were not uniform in time or space. In particular, there is a first-order younging of crust with depth, such that magmas formed at the orogenic peak predominate in the mid-crust.

Inherited zircon age data from magmas that intruded the mid-crust during its evolution provide constraints on the nature of age diversity in lower-crustal protoliths. Inheritance trends of peraluminous magmas exhibit similar age trends to detrital zircon populations determined for meta-turbidites from the SRT, supporting a predominantly metasedimentary origin. Inheritance trends of metaluminous magmas illustrate a progressive evolution from an 'isotopically homogeneous' lower crust (i.e., little to no inheritance) at the onset of crust-formation of the SRT to the gradual development of an 'isotopically heterogeneous' lower crust comprising multiple age components ranging in age from ~2770 to 2630 Ma. These trends can be explained by the processes of magmatic addition and tectonic transport of upper crustal metasedimentary material to the lower crust during orogenesis.

In summary, mid-crustal growth and evolution principally involved redistribution of lower-crustal material by metaluminous and peraluminous magmatism, and lower crustal evolution entailed periodic emplacement of mantle-derived melts and tectonic transport of material into the melt region at the orogenic peak. Collectively, the zircon crystallization and inheritance datasets reveal two separate, yet closely interrelated tales of Neoarchean mid- and lower-crustal evolution in the SRT.

SS21-03 UPPER- AND MID-CRUSTAL DECOUPLING IN THE SOUTHEAST SLAVE PROVINCE

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The Walmsley Lake area of the southeastern Slave Province, NWT, reveals a continuous, inclined, crustal transect from greenschist through upper amphibolite facies metamorphic grade. Recent regional geological mapping, and combined geochronologic and thermobarometric studies allow the area to be subdivided into upper and lower crustal domains with distinct tectonometamorphic histories. A narrow transition zone separates the two domains.

Within the upper tectonothermal domain, D_1 deformation reached lower-amphibolite facies prior to 2614 Ma, and associated M_1 metamorphic conditions outlasted D_1. Peak M_2 conditions reached middle-amphibolite facies prior to 2603 Ma, and outlasted D_2 deformation. The style of deformation and sequence of metamorphic events during these two pre-2600 Ma events are consistent with regional crustal shortening and thickening. At mid-crustal levels, the lower domain preserves a distinctly different tectonometamorphic event, D_3-M_3, which reached uppermost amphibolite facies conditions at ca. 2.58 Ga, more than 20 Ma after peak metamorphism in the upper domain. During D_3 pre-existing D_1 and D_2 structures were transposed into shallow orientations; sub-horizontal fabrics and map-scale recumbent folds were developed. A narrow transition zone exhibits characteristics of both domains, or is expressed as a high strain zone separating the two domains. Whilst the transition zone isolates the upper domain from deformation attendant to the lower domain, the thermal effects of the M_3 event are observed in the upper domain. Heat build up in a radiogenically fertile, tectonically thickened crust, possibly augmented by heat from plutonic intrusions, led to widespread anatexis at mid-crustal levels. Mobilized cognate melt formed layering-parallel granitoid sills. Exhumation of these mid-crustal rocks was accomplished by lateral melt extrusion leading to the orogenic collapse of a thermally weakened, crustal welt.

Recent mapping and geochronological studies in the southwestern Slave Province (Bennett and Rivers, this volume) have highlighted similar mid-crustal extensional structures that are of comparable age. Ca. 2.58 Ga mid-crustal anatexis leading to post-compression collapse may be a widespread feature in the Neoarchean mid-crustal evolution of the craton.

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SS21-04 POTENTIAL-FIELD AND SEISMIC CONSTRAINTS ON THE STRUCTURE AND TECTONIC EVOLUTION OF THE ARCHEAN HIGH-GRADE METASEDIMENTARY ENGLISH RIVER BELT, WESTERN SUPERIOR CRATON

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The structure and evolution of the western part of the metasedimentary English River belt were investigated by using techniques of enhancement and automatic interpretation of magnetic data, and integration of magnetic-derived information with seismic and gravity data. The results indicate that a suite of outcropping felsic plutons that were intruded at ca. 2698 Ma underlies most of the metasedimentary rocks, the extent of this suite being significantly larger than that suggested by its current exposure. The thickness of metasediments is less than 1 km in areas where the basement is formed by the members of this intrusive suite, and 3-4 km in areas bounded by clusters of intrusive bodies, where the seismic signature of the basement appears to be similar to that of the felsic gneisses exposed in the adjacent metaplutonic Winnipeg River Subprovince. This latter observation, in conjunction with previous field observations and geochronological constraints suggests that the English River sediments were deposited on continental crustal rocks of the Winnipeg River Subprovince in the interval 2715-2700 Ma, as a result of the deformation, uplift and erosion of the Uchi volcano-plutonic complexes situated to the north. Subsequent low-pressure, high-temperature metamorphism of the English River sediments at ca. 2691 Ma is linked to the continuation of magmatism at depth after the emplacement of the ca. 2698 Ma felsic plutons, being ultimately related to the advection of mantle heat into the crust during an extensional episode of the Western Superior crust. The integration of enhanced magnetic data with gravity data indicates that the large gravity anomaly that parallels the English River belt correlates well spatially and morphologically with the extensive suite of felsic intrusions that underlies the belt, suggesting that the crustal component of the gravity anomaly is related to this suite of intrusions. Density determinations and petrographic observations of samples indicate that the source of the gravity anomaly is a dense phase comprising anhydrous mineral assemblages (e.g., charnockites) that formed within these felsic intrusions in response to the ca. 2691 Ma low-pressure, high-temperature metamorphic episode.

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NEOARCHEAN HIGH-GRADE METAMORPHISM OF THE PIKWITONEI GRANULITE DOMAIN, NW SUPERIOR CRATON

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To advance our understanding of the temporal and spatial relationships of metamorphic mineral growth in mid to lower crustal rocks, U-Pb zircon studies of granulites from the Pikwitonei Granulite Domain (PGD) are presented. Located near the northwest margin of the Superior craton in Manitoba, the PGD forms one of the largest exposed high-grade terrains worldwide. Tracing of the dominantly felsic and mafic granulites into lower grade plutonic and volcanic rocks of the adjacent granite-greenstone terrains suggests that the PGD represents an oblique cross-section of deeper and remobilized Superior-type crust.

Based on field and petrographic observations, at least two major generations of high-grade metamorphism can be recognised in the PGD. Early amphibolite grade metamorphism caused widespread migmatization that is overprinted by granulite grade segregation. Peak P-T estimates (7-9 kb and 800-900ºC) vary for rocks in close proximity suggesting that mineral equilibrium was attained at different times or was locally controlled by the composition and distribution of metamorphic fluids.

Compilation of > 50 precise U-Pb zircon analyses from PGD granulite samples indicates multiple, distinct metamorphic episodes from ~2705 to 2640 Ma rather than continuous zircon growth. The following succession of events is proposed for the PGD: (1) Rare pre-2.8 Ga remnants of felsic intrusives contain mafic and ultramafic xenoliths. This is in agreement with ~3.3-3.5 Ga Nd model ages of felsic granulite suggesting that much of the PGD originally formed from Mesoarchean crust. (2) A period of felsic and possibly mafic magmatism occurred at or before ~2710 Ma. (3) ~2705 to 2690 Ma amphibolite-grade metamorphism is characterised by possibly fluid-driven growth of U-rich, low Th/U zircon. (4) ~2686 to 2657 Ma granulite-grade metamorphism crystallised relatively low-U, high Th/U zircon (including ~2680 Ma metamorphic zircon of sapphirine-bearing rocks at Sipiwesk Lake) and might have been associated with melting at deeper crustal levels. (5) Distinct ~2654-2635 Ma melt events and ~2629-2598 Ma post-granulite pegmatite indicate that metamorphic conditions reached amphibolite grade shortly after granulite facies.

The PGD U-Pb zircon data indicate that the detailed timing of high-grade metamorphism seems to be controlled by local P-T conditions, fluid availability and rock compositions, so that some events are not recorded on every outcrop. Our observations suggest that zircon growth can be more significantly influenced by fluid activity rather than temperature alone and question the applicability of the concept of closure temperature to zircon grown in polyphase high-grade terrains.

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GEODYNAMIC MODELS OF CONTRASTING STRUCTURAL STYLES AND AGES IN UPPER-AND LOWER-CRUST OF COLLISIONAL OROGENS: RESOLUTION OF THE STRUCTURAL VS. SEISMIC PARADOX

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Many seismic sections of Precambrian terrains display moderately dipping mid- to lower-crustal reflectors, although steep structures are observed on the surface. Geodynamic models of large collisional orogens provide an explanation for this paradox.

The 2D numerical models show a 3-phase evolution. Phase 1: During convergence the crust shortens and thickens by vertical pure shear. Phase 2: Radioactive heating and thermal relaxation of thickened crust produce hot, ductile mafic lower crust and highly ductile quarztofeldspathic middle crust, and relatively cool, strong, frictional-plastic upper crust. The weak middle crust may be in a state of incipient channel flow at this stage. Phase 3 is initiated if a relatively strong crustal block ("craton") collides with the orogen. The craton acts as a plunger, forcing weak middle and lower crust to be expelled over the craton, developing large-scale, gently inclined, ductile fold nappes rooted at the Moho and verging towards the incoming craton. Following this collision, the orogen consists of an infrastructure of diachronously overthrust lower crustal nappes decoupled from the superstructure by highly strained ductile mid-crust. The entire assemblage overlies the underthrust, variably reworked craton. Throughout phase 3, structures recording phase 1 shortening of ca. 40-50% may persist in the orogenic superstructure. In contrast, phase 1 structures in the infrastructure are strongly overprinted by phase 3 flow. In 3D, the process will also involve strike-parallel flow of the infrastructure along the leading edge of the craton.

The structural vs. seismic paradox is therefore resolved because the two approaches sample different parts of the orogenic crust - the steep structures of the superstructure dominate the map pattern and the shallow structures of the infrastructure dominate the seismic section. In nature, strain in the superstructure is expressed as folds with steep axial planes that yield old (phase 1) deformation ages. In contrast, the infrastructure is characterised by gently inclined LS gneisses that yield young (phase 3) deformation ages and locally contain augen with older structures.

Two candidates for the superstructure-infrastructure model are the Archean crust exposed in the Kapuskasing uplift (Superior Province), and the Mesoproterozoic Central Gneiss Belt - Central Metasedimentary Belt (Grenville Province). Both display structure and age relations predicted by the model. Whereas the Grenville Province is thought to have formed during a large, Himalayan-Tibetan scale collision, the Archean example is not. Did Archean thermal conditions permit infrastructure flow in smaller orogens?

SS21-07 AN EXHUMED ARCHEAN CRUSTAL SECTION ALONG THE GRENVILLE FRONT IN ONTARIO

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Exhumed crustal sections provide an opportunity to observe the transition between the mid- to lower-crust. A well-documented crustal section is exposed in the Kapuskasing structural zone in Ontario, however, a lesser known southward-deepening Archean crustal section straddles the Grenville Front east of Sudbury. From N to S, it consists of: (1) greenschist to amphibolite facies metasedimentary and felsic plutonic rocks, (2) Grenville Front, (3) metatextites (upper amphibolite facies) derived from the metasedimentary rocks (Pardo & Red Cedar Lake gneiss). To the west, amphibolite-dominated diatextites dominate (Street gneiss), and, (4) migmatitic, tonalite to granodiorite gneiss (Crerar gneiss). Nd-Sm model ages of 2.7 Ga have been reported from the Crerar gneiss association. Units south of the Front are intruded by mafic plutonic rocks of the East Bull Lake intrusive suite (EBL), which was emplaced into mid- and lower-crust levels at ~2.48 Ga.

New U-Pb dates on plutons from the Pardo, Crerar and Street gneiss confirm the Archean age of the section (Easton and Kamo 2003, Geological Society of America, Abstracts, v.35, no.6, p.596.). An alkali feldspar granite that cuts the Pardo gneiss but is cut by an EBL intrusion yielded 3 discordant zircon analyses, reflecting lead loss related to emplacement of the mafic intrusion — ~2660 Ma is the best estimate. Titanite data indicate Grenvillian metamorphism at 966+/-6 Ma. Three zircon and 2 titanite analyses from a late-tectonic, K-feldspar megacrystic granodiorite in the Crerar gneiss yields an upper intercept age of 2663+/-2Ma; concordant titanite dates Grenvillian metamorphism at 974+/-12Ma. The Street gneiss association is cut by C-type plutons of Geon 24 age that are related to the Murray and Creighton granites, and which have Geon 28-29 Nd-Sm model ages, indicating the presence of older Archean crust at depth. Exhumation of the section likely occurred during the Grenville orogeny.

It is probable that the Grenville Front between Sudbury and Temagami may have been localized along a major Archean terrane boundary that separated ~2740-2700 Ma rocks of the Temagami greenstone belt to the north from 2680-2660 Ma metasedimentary and plutonic gneisses to the south. If so, even though the broad architecture of the Front crustal section is similar to the Kapuskasing section, the Front section differs in that it is composed of younger (~2.68 Ga versus > 2.7 Ga) upper- to mid-crustal rocks.

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SS21-08 MID-CRUSTAL RECRYSTALLIZATION OF ZIRCON IN GRENVILLIAN ECLOGITES - EVIDENCE FROM A CL AND SHRIMP STUDY

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Zircons in eclogites from two areas of the Grenvillian High Pressure (HP) belt with different uplift histories were examined with a cathodoluminescence (CL) detector prior to SHRIMP analysis. In the central HP belt, eclogites were rapidly exhumed following burial, whereas in the western part of the belt they underwent a period of mid-crustal, granulite-facies metamorphism prior to exhumation. Most zircons from both areas have rounded terminations and length:width ratios of 2:1 or less, compatible with growth in a metamorphic environment.

CL imaging of the zircons revealed a range of zoning features that were qualitatively classified into primary (i.e., igneous), modified primary, and secondary (i.e., etamorphic) types, with the overwhelming majority of grains from both areas showing evidence for various types of secondary zoning. Some zircons, typically those with low U and Th contents, display diffuse metamorphic growth zoning, especially radial sector and 'fir-tree' types that are generally associated with growth under high temperature metamorphic conditions. Others, which are commonly partially resorbed, display irregular, strongly contrasting CL-dark and -light zoning unrelated to the crystal margins and are inferred to have undergone within-grain recrystallization after growth. SHRIMP analyses of such grains show that U, Th and Pb concentrations vary significantly between adjacent dark and light zones, implying these elements were redistributed during the recrystallization process.

Interpretation of SHRIMP U/Pb results for zircons from the central HP belt, which display metamorphic growth zoning, is relatively straightforward and in accord with previous TIMS analyses that the eclogite-facies metamorphism took place at ca. 1050 Ma. Interpretation of the SHRIMP U/Pb data from the western HP belt is more complicated. Most grains exhibiting metamorphic growth zoning yield ages in the range 1150 to 1050 Ma, with the mode at 1100 Ma, whereas those with evidence of recrystallization commonly yield two ages. CL-dark zones, enriched in U and Th, typically retain memory of the crystallization age (~1500-1400 Ma in different samples), and CL-bright zones, depleted in U and Th, yield ~1100-1060 Ma ages with large errors due to their low U contents. As with previous TIMS results, we tentatively associate the ~1100 Ma age with the eclogite-facies metamorphism and the younger ages with the granulite-facies overprint. These results imply that eclogite-facies metamorphism was diachronous along the HP belt, and that uplift through the mid crust imparted distinctive U-Pb signatures to zircon in eclogite in different parts of the belt.

SS21-09

DOMING BY INTRACRUSTAL THERMALLY-ACTIVATED LOAD SHEDDING; A MECHANISM FOR METAMORPHIC CORE COMPLEXES?

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Thermal reactivation of cool continental crust reduces the elastic thickness of the upper crust, and thus its ability to support topographic or density loads. Intracrustal density loads (such as a mafic pluton or deeply covered volcanic pile) will drive crustal subsidence locally. If the brittle-ductile transition rises to the level of the load, as a result of crustal heating, the load can tear free from the elastic upper crust, and subside into the ductile lower crust. Elastic rebound of the now-unloaded upper crust can drive surface doming. Uplift so generated will be amplified isostatically by erosion, and by the buoyant rebound of lighter upper crustal material initially entrained in the wake of the subsiding load. Using a thermally dependent viscoelastic rheology in a moving-mesh finite-element model, we present movies of numerical modelling of this process, and suggest that it may contribute to crustal doming, in particular the formation of some Basin and Range Cordilleran metamorphic core complexes. Gravity maps indicate the availablity of such intracrustal loads; additionally, the upper crust in the Basin and Range Province is sufficiently thin that load-driven subsidence, followed by shedding of the load, is plausible for geologically reasonable loads.

SS21-10 A SAMPLE OF THE LAURENTIAN DEEP CRUST: THE EAST ATHABASCA AREA, CANADA

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The granulite-facies East Athabasca area is an isobarically cooled terrane that resided in the deep Laurentian crust from ~2.6 Ga to at least 1.9 Ga. The highest pressures (1.0 to >1.5 GPa) are preserved on the easternmost side of the terrane in the East Athabasca mylonite triangle, which is divided into three lithologically and structurally distinct blocks. The northwestern block is dominated by intrusive rocks ranging from gabbro to granite that were emplaced and heterogeneously deformed during 2.6 Ga dextral shearing. The southeastern block is dominated by sheared tonalite that is cut by a swarm of synkinematic, hornblende-bearing, mafic dikes, the Chipman dike swarm. One population of the dikes underwent synkinematic partial melting at 1.9 Ga, yielding garnet and a tonalitic leucosome. The dikes provide a model for heat and mass transfer between mantle and crust, and the production of tonalite by deep-crustal partial melting of amphibolite. The southernmost block is composed of leucocratic gneiss with sheets of mafic granulite. The structurally lower part of the upper deck underwent a very high-P metamorphism (>1.5GPa), overprinted by regional granulite-facies metamorphism. The three blocks were juxtaposed within the lower crust, possibly during several tectonic events, where they remained until at least 1.9 Ga. Regional exhumation occurred between 1.9 and 1.75 Ga, and although most rocks are minimally overprinted during exhumation, localized shear zones within and adjacent to the high-grade triangle record stages in the exhumation history. Rocks of the Rae domain (further west) also preserve evidence of deep crustal residence, and the ultimate size of the regional high-grade terrane is unknown. The eastern margin is separated from mid-crustal amphibolite-facies rocks of the Hearne domain by the 6-8 km-wide Legs Lake shear zone. This shear zone may represent the Kapuskasing-like exhumation structure for a large part of the western Churchill Province. It accommodated early thrusting and later extensional deformation, and may serve as a model for the multi-stage history involved with the exhumation of large deep crustal terranes and the production of tilted crustal sections. The East Athabasca area is interpreted to be a sample of the 2.6-1.9 Ga Laurentian deep crust. The most notable characteristic of this large exposure is its extreme lithologic, structural, and metamorphic heterogeneity, involving localized high-temperature tectonism and a close interaction with a broad spectrum of igneous rocks.

SS21-11

DEFORMATION AND METAMORPHISM IN HIGH STRAIN ZONES IN A DEEP-CRUSTAL EXPOSURE, SNOWBIRD TECTONIC ZONE, NORTHERN SASKATCHEWAN, CANADA

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The exhumation of deep crustal rocks is recorded by isotopic cooling history, exhumation-related deformation, and retrograde metamorphic processes. The latter two are commonly linked in that retrograde assemblages are best developed in zones actively deforming during the exhumation process. Therefore, the heterogeneous nature of deformation and localized high-strain zones provide an opportunity to develop comprehensive P-T-t-D paths to characterize the regional exhumation history of high-grade terranes. An example is the East Lake Athabasca region, a broad exposure of high-pressure (1.0+ GPa) granulite-facies rocks exhumed during 1.9-1.75 Ga. We highlight characteristics of three km-scale, subparallel, high strain zones of different ages. In the oldest zone (SZ_1), mafic granulites preserve an early assemblage of Grt+Cpx (~1.3 GPa, 850 C) in cm-scale low strain lenses. The mylonitic Hbl-bearing matrix assemblage developed as the result of cooling, rehydration, and decompression during deformation and subsequently records a second heating to granulite-facies at ca. 1.0 GPa that likely occurred at 1.9 Ga. In this case, deformation facilitated reactions during the initial retrograde path and provided an appropriate assemblage to record subsequent reheating.

The Legs Lake shear zone (SZ_2), the main exhumation-related structure in the region, consists of amphibolite-facies mylonite that accommodated ~20 km of uplift of ca. 1.0 GPa deep-crustal rocks (including SZ1) via thrusting over mid-crustal rocks (< 0.5 GPa) in the footwall. Pelitic gneiss in the sheared hanging wall contains early garnet replaced by Crd+Bt+Sil (~0.5 GPa) indicating substantial exhumation during deformation. Monazite enriched in Y and HREE's is texturally linked to resorbed garnet and yields electron microprobe dates of 1.85-1.8 Ga, interpreted as the age of the metamorphic reaction.

The Grease River shear zone (SZ_3 – in the hanging wall of SZ_2) is the youngest of the three zones and records strike-slip shearing during and after ca. 1.8 Ga. It preserves amphibolite- to greenschist-facies assemblages and the transition from ductile to brittle deformation. In summary, SZ_1 records an early part of the path, reflecting high-grade polymetamorphism and partial exhumation, whereas SZ_2 and SZ_3 record regional exhumation to, and cooling at, the mid-crustal level. Of critical importance is the need for timing deformation pulses and linking them to metamorphic reactions. Although, the entire region underwent exhumation from the deep crust to the surface during the same regional events, each zone records different segments of the P-T-t-D history as a function of the timing and local character of deformation.

SS21-12 A TONALITE LACCOLITH IN A SILL COMPLEX AT THE FRINGE OF A PLUTONIC ARC: EVIDENCE FOR LARGE LATERAL MAGMA FLOW AT DEPTH

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We interpret field, petrographic and geochemical data from a suite of plutonic rocks in the Canadian Cordillera to suggest rapid lateral (~100km) transport of magma from a Middle Jurassic arc complex. A row of small intrusions forms a distal northeast fringe to the Middle Jurassic plutonic arc of southeastern British Columbia. The Hobson Lake Pluton (52°40'N, 120°05'W) is a sheet-like laccolith in the Cariboo Mountains at the northern limit of the fringing plutons. The Hobson Lake Pluton and closely associated smaller intrusions are collectively referred to as the Hobson Lake Plutonic Complex (HLPC). The bodies include granodiorite, quartz diorite and tonalite sheets and sills, the Tighe Creek laccolith (tonalite) and the Hobson Lake Pluton (granodiorite). The Tighe Creek laccolith is a well-exposed tonalitic feldspar porphyry set in a swarm of 1-10 m thick porphyry sills oriented sub-parallel to the regional foliation. The 400 m of local relief and the regional dip permit excellent three-dimensional exposure and geometric control on the Tighe Creek laccolith. The roof of the laccolith rises to 350 m above the basal feeder sill. Room was created by inflation and by splitting off screens in the roof. The stratigraphy and structure of the north-central Cariboo Mountains suggest a depth of emplacement of 10-15 km. The mineralogy, chemistry and åNd-åSr values for the HPLC bodies fit well on the geochemical trends for the Middle Jurassic plutonic arc complex as to suggest that the HLPC magmas came from the east portion of the arc some 100 km to the southwest. The presence of igneous epidote along with hornblende barometry suggest onset of crystallization at depth of some 25 km followed by rapid ascent and emplacement of the cooling crystal mush at 10-15 km depths. There are no significant contact metamorphic aureoles or chilled margins around the HPLC rocks, which we interpret to support the crystallization of magmas at depth followed by rapid emplacement. The regional foliation appears to have guided the transport path of the magmas from their origin to the southwest. The HLPC magmas flowed some 100km northeastward along southeast-dipping foliation in the 25-30 km depth range where temperatures were high enough to prevent substantial magma cooling yet not so high as to lead to significant crustal melting and contamination of the passing magmas. This kind of lateral flow of Middle Jurassic magma is also documented in the Valhalla Complex of southeastern British Columbia.

SS-23

EARLY EARTH IMPACTS AND PLANETARY SCIENCE

LES IMPACTS MÉTÉORITIQUES AUX PREMIERS TEMPS DE LA TERRE ET LA PLANÉTOLOGIE

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SS23-01 LESSONS FROM VENUS FOR UNDERSTANDING MANTLE PLUMES ON EARTH

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Mantle plumes are important in the magmatic and tectonic history for both Earth and Venus. However, expression of plumes is distinctive on Venus and complementary to that on Earth, and therefore a cross-comparison is useful for better understanding plume magmatism on both planets. In contrast to the Earth, Venus has no observed record of plate tectonics, a low degree of surface erosion, and an apparently short duration for the formation of the present planetary surface. The absence of plate tectonics indicates that all magmatism is 'intraplate' (in a terrestrial context) and is generated beneath a stagnant lithospheric lid. A low degree of surface erosion preserves the surface structures and short-wavelength topography. The short duration of preserved magmatic activity suggests a global resurfacing event.

Magmatic elements include: a) individual volcanoes with diameters ranging up to 1000 km, which represent hotspots, b) annular structures termed coronae with diameters averaging 300 km, but ranging up to 2600 km, and which appear to lack terrestrial (Earth-based) analogues, c) radiating graben-fissure systems extending up to 2000 km in radius, some of which are purely uplift-related while others mark the plumbing system (dyke swarms) of volcanic systems, d) lava flow fields of scale comparable to terrestrial flood basalts (large igneous provinces, LIPs), and e) regions of small shield volcanoes representing shallow-source melting.

There are several hierarchies of magmatic events on Venus, ordered in terms of increasing scale and significance: 1) isolated coronae, volcanoes, flow fields, and radiating graben systems; these range in scale up to >1000 km diameter; 2a) individual and small clusters of volcanoes and coronae associated with topographic swells, geoid highs, and triple junction rifting; these are most clearly indicative of terrestrial-type plumes originating from the deep mantle; 2b) coronae distributed along rifts (chasmata); these are the clearest examples of melt generation associated with rifting; 3) regional concentration of activity in the Beta-Atla-Themis (BAT) region; this is the closest example of a plume cluster event, sometimes termed a 'superplume event'; and 4) global volcanic resurfacing of the volcanic plains; no terrestrial analogue is confirmed, although the global burst of terrestrial plume activity in the Neoarchean is a possible analogue.

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SS23-02 DETERMINATION OF STRUCTURAL ATTITUDES OF LARGE SCALE LAYERING IN VALLES MARINERIS, MARS, USING MARS ORBITER LASER ALTIMETER DATA AND MARS ORBITER CAMERA IMAGERY

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Valles Marineris, located on the flank of the Tharsis Ridge uplift on Mars, exposes strata along its walls. It is interpreted as an extensional feature and studies have compared its geometry to terrestrial grabens and continental rifts. Large-scale layering within the canyon walls, interpreted as mainly volcanic flood lavas, has been revealed in great detail by the Mars Orbiter Camera (MOC). While Valles Marineris has been the site of extensive structural and other studies, no direct measurements of the layer attitudes, representing the most basic structural feature, have been made.

We combined Mars Orbiter Laser Altimeter (MOLA) elevation data with MOC images using our Orion structural analysis software to compute the attitude of the large-scale layering. Features of interest are initially identified in MOC wide-angle images (~250 m/pixel). Following the positive identification of these features as compositional layers within MOC narrow angle images (< 10 m/pixel), the same layer is located within multiple MOC wide-angle images. Each MOC wide-angle image is then individually registered to the MOLA 1/128° x 1/128° topographic grid file (463 m/pixel) and the orientation of the layer is measured using Orion. Samples are manually selected along the exposed layer trace, giving the horizontal and vertical coordinates of points on the layer. Orion then computes the best-fit plane through these points and provides various fitting statistics to allow the quality of fit to be judged. Individual layers can be followed for trace length in excess of 100 km, with multiple measurements possible along the length.

Initial results are very encouraging. The orientation of a layer measured in multiple images is very consistent, indicating that the measurements are not too sensitive to the manual process of aligning the images to the digital elevation grid. In the eastern part of Valles Marineris layers that are part of the canyon wall dip gently (< 10°) into the canyon. The measurement of a feature inferred to be a fault yields a dip of 63° which is consistent with existing models of fault populations for Valles Marineris. While this study is still in the early stages it is clear that it has the potential to provide much needed data on the basic structure of Valles Marineris. This data will enable a better understanding of the development of this large Martian feature and therefore of the evolution of the planet Mars as a whole.

SS23-03 SLOPE MEASUREMENTS IN VALLIS MARINERIS FOR 3D BASIN ANALYSIS OF LAYERING ON MARS

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An interesting problem for planetary scientists interpreting depositional and erosional histories of features evident in many satellite photos of Mars, such as scarps, terraces and layering, is the correlation of linear and planar features between images to construct a regional or basin-wide three-dimensional visual model. As high resolution (~10 m/pixel) topographic information becomes available, the measurement of linear and planar slopes may be accomplished with ordinary GIS software. Structural features may be correlated between images in order to interpret a regional model of past baselevels for successive periods of deposition and erosion. This paper considers several images from the Mars Orbiter Camera with layering evident, and reports results of structural measurements for the construction on a basin model.

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SS23-04 **IMPACT-SEISMIC EXHAUSTS, AND FLOWS: SANDPIPES, SALT DOMES-DIAPIERS, DIATREMES AND PLUGS - A MINERAL DEPOSIT MODEL**

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Sand pipes measuring tens of metres in diameter occur, both in clusters and fields, some of which possess alignment, in Jurassic sandstones on the Colorado Plateau - with no modern analogue. Dewatering, fluidised sedimentary structures have similar characteristics but on a microscale relative to these sand pipes. Similar, mesoscale, sand pipes occur in Potsdam/Napean sandstone and are considered rift-seismic in origin. These larger sand structures are here considered impact in origin and instructive as economic analogues.

The sand pipes are unmineralized and have received attention only recently, as opposed to other pipe structures in the region that carry uranium, fluorite, barite, copper, gold and diamonds; these occur in similar settings and have been explored extensively.

Several analogous, large circular structures, Northumberland Strait, Burntroot Lake, Cape Parry and Wernecke all with economic implications adjacent the circular structure, are reviewed here; these may reflect the Martian study.

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SS23-05 IMPLICATIONS OF STRUCTURAL TRENDS IN CANADIAN IMPACT CRATERS FOR EARLY IMPACTS ON EARTH

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The lunar record indicates that large impacts undoubtedly occurred on earth during the Archean; however, apart from some stratigraphic evidence, identification of early impact sites has had little success. There is reason to believe that the scars of large terrestrial impacts may differ considerably from those of comparable size and age on the Moon, even when the target rocks are similar. The evidence comes from a comparative analysis of impact craters on the Canadian Shield, based on detailed shock metamorphism studies at Brent (3.8 km) and Charlevoix (54 km) craters plus interpolated, less abundant data from other sites. It is apparent that, with increasing crater diameter, there is a progressive decrease in the depth of excavation relative to the imprint of shock metamorphism in the target rocks. The most likely explanation is that, compared with small craters, gravitational collapse of the rim of large craters in similar rocks occurs earlier in the crater-forming process, thereby changing the stress field, terminating fragmentation and halting deep excavation of shocked and brecciated rocks. As a result, the ratio of the transient crater diameter, D_t, to the final crater diameter, D_f, decreases with increasing size. For example, in a terrestrial crater with D_f ~300 km formed in crystalline rocks, only impact melt is excavated from the down axis direction. Moreover, as the depth of the transient crater will be approximately 45 km, a substantial volume of the shock heated (but not shock melted) parautochthone may also to be melted. Typically, this will be due to heat from the normal thermal gradient, along with the effects of sudden pressure release and work during uplift of the centre. On uplift the fluid center will collapse and flow much like a salt dome, covering much of the impact melt sheet remaining within the crater. The signature of such an impact will be a multi-layered igneous body covering uplifted deep crust and mantle in which evidence for shock may largely be removed by thermal annealing. The Sudbury impact may represent a transition to such a structure.

SS23-06 **THE 450-KM-DIAMETER NASTAPOKA ARC: EARTH'S OLDEST AND LARGEST PRESERVED IMPACT SCAR?**

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Looking at Canada, either from space or in continental-scale map projections, one cannot help but wonder about the origin of the nearly perfect, semi-circular feature in the heart of the Canadian Shield, the ca. 450-km-diameter Nastapoka Arc on the eastern shore of Hudson Bay. This feature, preserving > 160 degrees of arc of a nearly perfect small circle, has received attention as a potential impact scar, but searches for direct evidence of impact have been negative.

An alternative explanation is that of an orogenic flexural arc in response to thrust loading (e.g., Hynes, 1991, Tectonics, 10: 722-728). This explanation argues for a point load near the geometrical center of the Arc. However, the fold-thrust belt through the Belcher Islands is i) more linear in shape and not a point load, and ii) traces a convex arc (to the SE) with an apex that is well offset from the center of the circular feature. In the absence of definitive work to rule out an impact origin, we revisit this possibility, particularly because, if of impact origin, the Nastapoka structure would represent by far the largest and oldest terrestrial impact scar.

An impact origin would argue for the following scenario: 1) Archean Superior crust, stabilized since ca. 2600 Ma, was the target. 2) A large multi-ring impact basin involving deeply penetrating ring faults formed prior to ca. 2000 Ma. 3) By ca. 2000 Ma, this structure was deeply eroded, leaving cryptic ring faults in basement. 4) Paleoproterozoic sedimentary and volcanic rocks of the Superior margin (Nastapoka Group and related successions) were deposited unconformably on the deeply eroded impact scar. 5) Southeast-vergent thrusting of the cover and deformation of the Superior margin, offshore under Hudson Bay, have degraded any circular geophysical signature of the structure. 6) Nevertheless, relict crust-penetrating ring faults have since been reactivated and play a critical role in shaping the Nastapoka Arc and the perfectly inward-dipping homocline of the Paleoproterozoic cover rocks.

Cryptic, crust-penetrating ring faults have been documented in smaller multi-ring impact basins such as Chicxulub. We also note that between ca. 2600 and 2000 Ma, stabilized Archean crust had ample time to record large impacts, few of which have been found. After moderately deep erosion of Archean crust (e.g., 10-20 km on average), cryptic ring faults are perhaps the most likely relict structures of large impacts and hence a key to recognition of the missing early impact record.

SS23-07 ENDOGENIC SUDBURY BRECCIAS: THREE EXAMPLES

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The distribution of “Sudbury breccia” associated with the Sudbury Structure, now agreed to have been formed by impact about 1.85 billion years ago, is a main line of evidence bearing on the original size of the structure. Several occurrences of the breccia on the South Range have been convincingly shown to be pseudotachylytes formed by post-impact faulting. However, breccia occurrences north of the SIC are most important for estimating the original size of the structure. Most of these are part of, or directly associated with, mafic dikes of various swarms. This paper presents three examples of dike-associated breccias for which an endogenic origin seems indisputable. The first is on Hwy. 144 along the southern contact of the igneous contact, occurring in a Sudbury Swarm mafic dike (1238 Ma old) that cuts the igneous complex, and which can not possibly be the result of the original impact. A second breccia occurrence, just west of Lively, grades into a northwest-trending mafic dike mapped as part of the Sudbury Swarm, and hence also younger than the igneous complex. Age relationships alone disprove any relation to the impact. A third breccia occurrence, one of many similar ones, about 50 km north of the north contact of the igneous complex, near Halfway Lake, displays granitic breccia in the core of a diabase dike, possibly a member of the Matachewan swarm. Although the age of the breccia is uncertain, it occurs in direct contact with medium-grained metadiabase, and can not be considered impact-formed. Many other breccia occurrences north of the igneous complex resemble those described here. It is concluded that a detailed re-examination and radiometric dating of “Sudbury breccia,” especially that north of the Sudbury Structure, is called for, since many of these appear to be endogenic.

SS23-08 **THE GRENVILLE PROVINCE : FOOTPRINT OF A MULTIPLE IMPACT EVENT RELATED TO THE TRIGGERING OF THE PROTEROZOIC ERA**

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Observations made throughout the Grenville Province (GP) such as the dehydration of granitoïds related to anorthosite suite emplacement, volatile-related phases, mixing of ductile and brittle domains, closely associated greenschist and anatexis facies, relative lack of pseudotachylite within melted material, high energy breccias, weak extension and thickness of metasedimentary facies, and poorly constrained structural patterns, all call for a reappraisal of its evolution. Will be discussed: the Grenvillian parautochtonous south of the Otish Basin; the proterozoic mafic suites including dyke swarms spatially related to diamondiferous kimberlite fields; and correlation with the Huronian Supergroup evolution.

A new model is thus proposed, the GP anorogenic event would be a product of deeper crustal levels exhumation in response to transient excavations and subsequent isostatic rebounds caused by some impact events. Exhumations and post-impact inward faulting are well expressed in the GP by the diapirism of anorthosite and formation of spatially related basins, which coincide with, respectively, central peaks and ring grabens of complex impact structures (or multi-ring) after readjustment of crater-floors. Such deep influence of impact has been documented within the Chicxulub impact structure where the Moho has been uplifted.

The model deals with a multiple impact event and postulates some large extraterrestrial bodies which have a close relationship in time and space. This cluster of asteroids could have been the result of: (1) breaking up of a larger planetesimal (Comet Shoemaker-Levy 9 on Jupiter in 1994); (2) an ancestral belt; or (3) terrestrial material put into orbit after the impact on Earth of a Mars-size body, a catastrophe thought to have been the event that created the Moon. Whatever the clustering mechanism or possible relationship with the Moon genesis, according to commonly accepted paleoproterozoic plates reconstruction, the GP could correspond to a scar related to an incommensurable impact structure roughly centered somewhere in North Africa. Such catastrophe would explain the GP distribution, the coeval iron formations and mafic assemblages induced after proterozoic plate disruption, and the « oxyatmoversion » by captation of oxygen due to Earth's mass growth, thus progressively ending Archean atmospheric reducing conditions. It is proposed that the Sudbury impact structure and the Vredefort structure are intimately related to the postulated bombardment event. So, the timing observed for the Preissac dyke swarm emplacement as well as a volcanic suite in the Labrador Trough, both dated around 2,14 Ga, well support that event.

SS-25

Holocene and Little Ice Age climate change in western Canada

L'Holocène et le changement de climat dans l'Ouest du Canada au Petit âge Glaciaire

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SS25-01

HOW DID CLIMATES VARY DURING THE "LITTLE ICE AGE" IN THE SOUTHERN CANADIAN CORDILLERA?

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Information about climatic variability during the last millennium in the southern Canadian Cordillera has been considerably enhanced by the development of annually resolved proxy records of precipitation and temperatures from tree rings. Separate chronology networks of high elevation temperature-sensitive (mainly Engelmann spruce) and low elevation, moisture-sensitive, sites (Douglas fir and ponderosa pine) have provided local and regional reconstructions of summer temperatures and annual precipitation that commonly reach 250-300 years and are occasionally much longer. Using new ring-width and maximum density data, we have recently extended and revised the record at the Columbia Icefield (Luckman et al., Holocene 1997) and reconstructed May-August maximum temperatures from 869-1994 AD. The main cooler intervals in this new summer temperature reconstruction (ca.1200-1290, 1310-1350, 1640-1720, 1790s-1840s and 1860s-1880) generally show strong coherence with the known regional history of LIA glacier advances except for the period 1450-1600 for which no glacier evidence has been reported. The coldest summers are reconstructed in the 13th, late 15th, late 16th and early 19th centuries. Summer temperatures appear to have approached late 20th century values in the 1000-1050s and in the first half of the 1400s. Precipitation records are shorter and more variable. We have recently reconstructed annual and decadal patterns of precipitation across the Southern Cordillera from 1700-1995 with longer records at a few sites (to 1460 AD at Banff). The early and later years of the 19th century (1800-1830, 1880-1890, 1898-1916) were generally cold and wet whereas the mid-century (ca.1840 –1860) was drier and slightly warmer. Several shorter, severe droughts occurred during the 1700s which was generally drier than the 19th or 20th centuries.

The reconstructions of synchronous, annually-resolved precipitation and temperature records across the region allow the reconstruction of complex environmental variables such as streamflow and glacier mass balance. Reconstructed mass balance variations for Peyto Glacier (1673-1994) verify well against the regional moraine record and suggest that only moderate glacier recession took place between the regional advances ca 1700-25 and in the mid nineteenth century.

These results indicate that glacier fluctuations during the last 500 years are substantially more complex than suggested by the record derived from the available morphological and stratigraphic record. Assuming these levels of climate variability operated throughout the Holocene, similar complex glacier histories should be anticipated for earlier periods and therefore precise dating control will be critical to resolve problems of correlating and dating these events between regions in the cordillera.

SS25-02 PRECIPITATION CLIMATE OF THE WESTERN INTERIOR FOR THE PAST THREE CENTURIES

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The least annual precipitation in the western interior of North America occurs in the northern Great Plains. A subhumid climate extends to high-latitudes in the rainshadow of the western cordillera. We have established a network of 42 moisture-sensitive tree-ring chronologies extending from the plains of Montana, Alberta and Saskatchewan to the boreal shield of the Northwest Territories (NWT). A network of this geographic extent enables the spatial analysis of climatic variability and the timing of departures from normal conditions at different locations. The hydroclimatic signal is relatively coherent along a north-south gradient; paleo drought is evident at relatively high latitudes in the western NWT. There is less consistency from west to east.

Residual tree-ring indices account for 30-60% of the variance in measured annual or seasonal precipitation. Unexplained variance mostly reflects the tendency for tree-ring widths to underestimate unusually wet conditions, because soil properties and tree physiology limit the response of tree growth to precipitation. Our interest, however, is primarily in dry conditions. Tree rings are a particularly good proxy of the timing and duration of drought. The driest three years in the instrumental record, for many stations in Alberta and Saskatchewan, was 2000-2002. Our tree-ring reconstructions indicate that this recent drought is possibly more characteristic of prairie climate than the short EuroCanadian history of the northern plains would suggest.

The precipitation reconstructions at many sites are marked by a mid-19th century shift from the dominance of decadal variance (sustained wet and dry conditions) to more interannual variance that characterized the 20th century and thus the instrumental hydroclimatic record. This change in variance conforms to a similar shift in the Pacific Decadal Oscillation Index as reconstructed from tree-rings. Prolonged droughts occurred in the late 18th century, when Hudson Bay Company records describe the North Saskatchewan River as unable to support a canoe laden with furs, and during the mid 19th century, when John Palliser surveyed the Canadian plains and declared a large area as "forever comparatively useless". Conversely, multi-year drought is lacking during 1890-1915, when crop production became established on the western plains.

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SS25-03

GLACILACUSTRINE SEDIMENTATION PROCESSES AT LLEWELLYN INLET, ATLIN LAKE, BRITISH COLUMBIA: IMPLICATIONS FOR LITTLE ICE AGE CLIMATE CHANGE

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The Llewellyn Glacier (65 km^2) discharges from the Juneau Icefield into the southwest margin of Atlin Lake in northwestern British Columbia. Llewellyn Inlet of Atlin Lake receives glacier meltwater and sediment derived from the northern margin of the Llewellyn Glacier where sub-glacial and pro-glacial sediment are delivered via one major outlet stream. Sedimentation processes and patterns are reconstructed using gravity and percussion cores (0.35 -1.34 m) and CHIRP sub-bottom acoustic records in order to establish a link between Little Ice Age climate change and the style and quantity of sediment delivered to Llewellyn Inlet. There is an abrupt transition from predominately sandy sediments deposited in the inner 2.2 km of the inlet to thick silt and clay (> 100 m) deposits where horizontal and unconformable layering indicate low-velocity turbidity currents have operated nearly continuously throughout the Holocene. The inlet bottom rises sharply to a sill near the outlet where total sediment accumulation thins to less than 20 m and is dominated by laminated silts and clays. Photographs, sediment thin sections and ^{137}Cs dating from cores recovered on the sill demonstrate that the surface sediments are varved and allow for reconstruction of an accumulation record for the last 300 years. Three distinct sedimentation regimes are apparent over the last 300 years. From approximately 1700 to 1850 AD sediments are characterized by finer-grained, relatively thick (5 mm), varves with simple summer/winter laminae suggesting high, but uniform inputs of sediment from suspension settling. From 1850-1920 AD the varves remain thick (4-9 mm) but grain size is much more variable including 1-3 mm thick, normally graded, fine sand layers deposited in the earliest part of the meltwater season. It is likely much more energetic, sediment-rich, bottom currents moved up the sill (from 173 m water depths to 110 m) depositing traction sediments. The third regime begins after 1920 AD and is characterized by thin (2 mm) silt-clay (only) varves. The dramatic reduction in sediment delivery is related to two mechanism: the opening of a shallow pro-glacial lake at the terminus of the glacier and exhaustion of sub- and pro-glacial sediment supply from the rapidly retreating Llewellyn Glacier. The sediment chronology matches Little Ice Age glacier chronologies developed from moraine records elsewhere in western BC but provides a new and much higher resolution record of climate-induced changes to sediment yield from a large outlet glacier in northwestern BC/SE Alaska.

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SS25-04

MAJOR AUTUMN RAINFALL EVENTS IN NORTHWESTERN NORTH AMERICA IN ASSOCIATION WITH LITTLE ICE AGE GLACIAL ACTIVITY

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In the past, annually laminated (varved) sediments from glacially-fed lakes have provided valuable records of Little Ice Age (LIA) glacial activity, particularly advance and retreat phases. At White Pass in the northwestern Coast Mountains along the British Columbia/Alaska border, we constructed varve records from two adjacent glacially-fed lakes to investigate the LIA dynamics in this region. The record from Summit Lake extends to 1299 AD and consists of varves with complex subannual laminae that likely represent hydrologically-induced sedimentary events (e.g. nival-glacial runoff, rainstorm runoff). Under certain conditions, river discharge events produce subannual sedimentary events within a varve. A comparison of modern discharge and precipitation records with detailed varve sedimentology indicates that the late season sedimentary events are likely produced by rainfall induced runoff and sediment transport into Summit Lake. The frequency and thickness of rainfall induced sedimentary events increased substantially and abruptly at ca. 1675 AD. The second lake (Meadow Lake) provides a continuous varved sequence extending to 1677 AD and was discontinuous prior to that time. The onset of continuous varve formation at Meadow Lake is related to increased sedimentation rates that we attribute to increased glacierization of the cirques in this watershed. Increased glacial activity indicated in Meadow Lake, together with the more frequent subseasonal sedimentary events attributed to autumn rainfall in Summit Lake, suggests that early LIA glacier advances in this area were coincident with an increased frequency in autumn rainfall. These results suggest that moisture was an important control over LIA glacial activity in the White Pass region.

SS25-05 LITTLE ICE AGE CONDITIONS IN THE SOUTHERN SELWYN MOUNTAINS AS INDICATED BY VARVE STRUCTURE IN A SUBARCTIC LAKE

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Mirror Lake, Northwest Territories (62°N, 128°W), is an oligotrophic lake situated within the southern Selwyn Mountains. Strongly seasonal inputs of suspended sediment from glacial meltwater result in a consistently laminated sedimentary record. Analyses of laminae structure using thin sections and 137Cs measurements suggest that the record is annually-laminated (i.e., varved). Comparison of the varve chronology (1452 to 1996 AD) with local meteorological records (1967 to 1990 AD) indicates that melt season temperatures (i.e., June, July and August) are dominant influences on varve thickness, due to their influence on glacial melt. Climatic influences on varve formation, however, change over decadal timescales. These changes result in two identifiable hydrological responses in the catchment, each of which affects varve structure differently. In the first case, simple varves (i.e., those with a simple silt-clay couplet) form during years when July temperature is the dominant climatic influence on glacial melt and, thus, varve thickness. This situation was particularly evident during the 1970s, when melt season temperatures and annual snowfall were below average. In the second case, varves with two silt units and one clay cap form during years when a thick spring snowpack offsets or delays summer glacier melt. The recent record indicates that these years are characterized by above-average melt season temperatures and higher annual snowfall. Although varves with two silt units dominate the long sedimentary record, a section from c. 1720 to 1940 AD contains only ten such varves. Varves with one silt unit dominate this period, which coincides with the main period of Little Ice Age (LIA) activity, identified through rock glacier advances and tree ring records within the region. If the 1970s are considered a modern analog for Little Ice Age conditions in the region, this research suggests that the LIA had below-average melt season temperatures and average to below-average annual snowfall.

SS25-06

MIDGE FOSSILS AND QUANTITATIVE RECONSTRUCTIONS OF HOLOCENE CLIMATE IN THE CORDILLERAN REGION

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Over the past decade, a series of midge palaeoecological studies have been conducted in the Cordilleran region. Surface sample surveys of the modern fauna reveal that aquatic midges (principally *Chironomidae*) are potentially sensitive indicators of both lake water salinity and summer temperature. Altitudinal transects indicate that species turnover is especially high near alpine tree-line; thus, alpine and upper subalpine lakes provide potentially sensitive sites for the assessment of Holocene palaeoclimate.

The palaeotemperature reconstructions from alpine/subalpine sites in the southern interior of British Columbia indicate a rapid climatic amelioration ca. 11,500 cal. yr BP, reaching peak Holocene summer temperatures (about 3°C warmer than present) ca. 11,000 to 7000 cal. yr BP, during the Holocene summer solar insolation maximum. Holocene summer temperatures subsequently declined, reaching near modern values ca. 5000 to 3000 cal. yr BP. Similar analyses are currently underway elsewhere in the Cordilleran region.

Low-elevation saline lakes are also regarded as climatically sensitive sites. Palaeosalinity records from three lakes have been completed. Comparisons with diatom records indicate an excellent correspondence between diatom and midge inferred salinities. Regional comparisons of palaeosalinity records, however, reveal a lack of correspondence among sites. The effects of local hydrological changes seem to dominate, preventing good assessments of regional trends in Holocene evaporation/precipitation balance.

SS25-07

THE BRIDGE ADVANCE: A PRE-LITTLE ICE AGE ADVANCE OF ALPINE GLACIERS IN THE COAST MOUNTAINS OF BRITISH COLUMBIA, CANADA

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New and previously published data from four sites in the Coast Mountains of British Columbia provide clear evidence for a previously unrecognized period of glacier advance several hundred years prior to the beginning of the Little Ice Age. We name this event the Bridge Advance. Radiocarbon ages on buried, in situ tree stems indicate that Bridge Glacier in the southern Coast Mountains was advancing 1500 radiocarbon years ago (^{14}C yr BP). A paleosol and buried forest bed exposed in a composite lateral moraine at nearby Lillooet Glacier suggest that soil development and colonization of morainal surfaces following the mid-Neoglacial Tiedemann Advance were interrupted by a glacier advance that began as early as 1700 ^{14}C yr BP and culminated after 1400 ^{14}C yr BP. Farther north, lichen-dated lateral moraines at Tiedemann Glacier stabilized about 1330 cal yr BP. An advance of Frank Mackie Glacier, in the northern Coast Mountains, about 1600 ^{14}C yr BP blocked Bowser River valley and impounded Tide Lake. The Bridge Advance is broadly coincident with a period of increased summer drought inferred from fire frequency. North Pacific ocean-atmosphere circulation patterns control the present mass balance regime of glaciers in the region, and changes in the intensity of these circulation patterns may provide a plausible forcing mechanism for late Holocene glacier advances in the region, particularly during coincident periods of summer drought.

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SS25-08 HOLOCENE GLACIER FLUCTUATIONS IN GARIBALDI PROVINCIAL PARK, SOUTHERN COAST MOUNTAINS, BRITISH COLUMBIA

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We are conducting a multi-faceted study of Holocene glacier fluctuations in Garibaldi Provincial Park, located in the southern Coast Mountains about 70 km north of Vancouver, British Columbia. To date, ten glaciers have been investigated using dendrochronology, lichenometry, radiocarbon dating of in situ and detrital wood, and analysis of rhythmically laminated lacustrine sediments. All known glacier advance phases in the western Canadian Cordillera are represented in our record: the Little Ice Age, which most likely began as early as about AD 1050 and culminated about AD 1700, and was followed by several readvances dating to the mid- and late-nineteenth century; the Tiedemann Advance between 3000 and 3900 years ago; and the Garibaldi Phase between 5800 and 7300 years ago. We also found evidence for glacier activity at the time of the 8200-year cooling event in the North Atlantic region and for an advance around 1500 years ago. The latter advance has recently been documented at several glaciers elsewhere in the Coast Mountains and in the Rocky Mountains. Several glaciers in Garibaldi Park also advanced about 4500 years ago. The record from Garibaldi Park appears to be the most complete to date from the western Cordillera of the Americas. Glacier advances in Garibaldi Park are broadly synchronous with those in the European Alps. The synchronous histories of glacier fluctuations in the two regions point to the same or similar climate forcing mechanisms, most likely centered in ocean-atmosphere interactions, but as yet poorly understood.

SS25-09

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TREE-RING BASED ESTIMATES OF MASS BALANCE AT PEYTO GLACIER OVER THE LAST THREE CENTURIES

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Mass balance records for Canadian glaciers are short. The longest, from Peyto Glacier, begins in 1966. Tree rings are used to reconstruct mass balance for Peyto Glacier in the Canadian Rocky Mountains from 1673-1995. Summer balance was reconstructed from tree-ring estimates of summer temperature and precipitation in the Canadian Rockies. Winter balance was calculated from tree-ring data from sites bordering the Gulf of Alaska and in western British Columbia based on the teleconnection between winter climate in these areas and the Canadian Rockies. The models for winter and summer balance explain over 40% of the variance in each mass balance series and pass conventional verification tests. Over the 1966-1995 period correlation between the reconstructed and measured net balances is 0.71. Strong positive mass balances are reconstructed for 1695-1720 and 1810-1825 when higher winter precipitation coincided with reduced ablation. Major regional terminal moraine building episodes (ca. 1700-1725, 1825-1850) follow these periods of reconstructed positive mass balance. Positive mass balances in the 1845-1880 period also correspond with intervals of glacier readvance. Mass balances were generally negative between 1760 and 1805. From 1673-1883 the mean net balance is +70 mm w.e./yr. but averages -317 mm w.e./yr from 1884-1995. This reconstructed mass balance history provides a continuous record of glacier change that appears regionally representative and consistent with regional moraine and proxy climate

SS25-10

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INVENTORY AND ANALYSIS OF HISTORICAL CHANGES AT 205 GLACIERS IN THE SELKIRK MOUNTAINS, GLACIER NATIONAL PARK, BC

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Aerial photographs, satellite imagery and Geographic Information System software were used to construct a locational and morphometric database and investigate historical changes at 284 glaciers in Glacier National Park, British Columbia. This work examined all glaciers in 13 of the 15 watersheds in the park. Aerial photographs from 1996 (1:15,000) and Indian Remote Sensing satellite imagery from 2000 (5 m resolution) were used as well as data for the years 1850, 1951/52 and 1978 that were compiled in the 1980s by C.S.L. Ommanney. Summary data are reported here for 205 of the glaciers that were common to both studies.

From 1850 to 1950 the surface area of the 205 glaciers shrunk by approx. 92 km^2, mean glacier length shortened by 0.5 km and mean terminus elevation rose by approx. 175 m. Between 1950 and 1978 total surface area grew by about 16 km^2, mean terminus elevation lowered by 47 m and mean glacier length increased slightly. From 1978 to 1996 mean glacier surface area grew by 3.6 km^2 while mean elevation of terminus and glacier length remained unchanged. From 1978 to 2000, changes in mean surface area, terminus elevation and glacier length were so slight as to be within the margin of error.

Elevational and aspect data show that from 1850 to 1950 the greatest ice losses occurred below 2000 m asl,whereas most of the termini are now found at or above the 2300 m contour. While the most recent surface area and terminus elevation data seem to suggest that the glaciers have reached an equilibrium condition, oblique photographs show that most of the ice is restricted to well shaded north-facing cirques and bedrock notches. Slight changes in surface area and minor changes in terminus position for 1978 to 2000 do not well reflect the overall down-wasting of the ice that is seen but not easily measured in oblique images. Consequently, without detailed field surveys the volume of this ice and its rate of thinning will remain unknown. Examination of historical photographs has also found that some of the glaciers in this study advanced slightly in 1906 and again in the late 1970s. The 1906 advance of the Asulkan and Illecillewaet Glaciers is well documented, but the onset and regional extent of the more recent advance is unknown.

SS25-11

GEOARCHAEOLOGICAL INVESTIGATION OF THE ELBOW SAND HILLS: EVIDENCE OF HOLOCENE ENVIRONMENTAL CHANGES IN SOUTH-CENTRAL SASKATCHEWAN

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The Elbow Sand Hills, situated on the eastern shores of Lake Diefenbaker in south-central Saskatchewan, have long been recognized as an archaeologically rich locality where a number of cultural groups resided throughout the post-glacial period. Current geoarchaeological research in the Elbow Sand Hills aims to determine the extent to which Holocene environmental changes influenced occupation patterns of prehistoric peoples on a northern prairie landscape. An examination of the geomorphology, stratigraphy, sedimentology, and chronology of post-glacial sediments was performed in the sand hills and the adjacent terrain within three physiographic elements; aeolian dunes, a glaciofluvial plain, and hummocky moraine. Preliminary interpretations of these data reveal evidence of significant Holocene environmental changes, where cycles of moist and arid climatic episodes are preserved in the lithostratigraphy as palaeosols interbedded with aeolian deposits. A distinct climatic event of severe aridity is marked in the lithostratigraphy by a layer of calcareous sediment in every profile. These Holocene climatic cycles would have greatly affected the distribution and lifestyle of prehistoric humans. Humans occupied the sand hills during moist climatic conditions where vegetation stabilized the sand hills and soil genesis occurred. During arid climatic conditions, humans probably abandoned the sand hills for the resource abundant South Saskatchewan River valley when the sand hills were unstable and mobile. Understanding the nature of Holocene environmental changes and landscape development of the Elbow Sand Hills is essential in identifying how prehistoric societies adapted to these changes and the processes involved in the preservation of archaeological materials.

GS-01

EARTH SCIENCE AWARENESS

SENSIBILISATION AUX SCIENCES DE LA TERRE

GS01-P01

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THE ROLES OF ENDOGENESIS AND METEORITE IMPACT IN THE EVOLUTION OF THE SUDBURY STRUCTURE

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Events which effected the area may be grouped as follows: doming, impact and post-impact. The site now occupied by the Sudbury Igneous Complex (SIC) and Basin underwent late Archean crustal doming, possibly in response to a magmatic event(s). Evidence for doming includes: 1) radiating diabase dikes (2600 to 2452 Ma); 2) SE to NE- dipping arcuate homocline in basal Huronian rocks; 3) absence of Nipissing gabbro in North Range footwall implies thin or non-deposition of Huronian rocks; 4) uplift of the Levack Gneiss Complex from 25 km to 8 km; and 5) mafic and felsic intrusions on the dome. The area underwent folding about EW to NNE-trending axes (Blezardian Orogeny, 2400 to 2200 Ma). The Sudbury meteorite coincidentally struck the dome, already pregnant with metals, and formed the following: Sudbury and Footwall Breccia, shatter cones and planar deformation features in footwall rocks; fallback and hydroclastic breccia (Onaping Fm.); and impact melt or magma (SIC). The impact event was followed by differentiation and emplacement of the units of the SIC (1850 Ma), formation of the Ni-Cu-PGE deposits, deposition of the Vermilion, Onwatin and Chelmsford Formations, hydrothermal alteration and formation of Zn-Pb-Cu deposits inside the basin. NW-directed compression and a weaker SW compression (Penokean Orogeny, 1900 to 1700 Ma) folded the rocks of the basin about NW-trending, doubly plunging fold axes and developed a prominent cleavage in them. Deformation died out to the NW as the North Range SIC has not undergone ductile deformation. In the South Range the Onaping Fm. and SIC are overturned to the NW and displaced by a SE-dipping zone of reverse shear; on the outcrop-scale, the SIC displays anastomosing conjugate shear zones. Based on impact modelling and geochemistry, many investigators interpret the SIC as an impact melt sheet which was later folded to achieve the present basin geometry. Evidence supporting an intrusive origin (lopolith?) for the SIC includes: 1) in the North Range, no fold-induced ductile strain has overprinted a primary fabric in the SIC and the Foy offset dike, in the footwall, is not folded; 2) if the South Range SIC is rotated to the horizontal, footwall rocks become upside down and, locally, even "face" NW. Lack of ductile deformation of the Copper Cliff and Worthington offset dikes suggest they were emplaced after the Penokean Orogeny. Some aspects of the geometry of the Sudbury Structure, based on seismic data and depicted on published cross sections, is open to question. For example, in outcrop the gneissosity in the Levack Gneiss Complex dips steeply and has a variable strike yet the unit has been interpreted as a conformable layer beneath the SIC. The mechanism by which the South Range Onaping Fm. developed such an inordinate thickness has not been explained.

GS-02

ECONOMIC GEOLOGY

GÉOLOGIE ÉCONOMIQUE

ED VAN HEES

KEVIN ANSDELL

ALEX BROWN

SAEED ALIRZAEI

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GS02-01 A CASE FOR SIGNIFICANT IRON TRANSPORT AND ENRICHMENT DURING THE DIAGENETIC FORMATION OF RIFT-FILLING REDBEDS

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The reddening of immature coarse-grained clastic sediments typical of syn-rift fillings of intracontinental rift basins involves a progressive, low-temperature, diagenetic alteration of iron-bearing mineral constituents. Under prevailing oxidizing conditions in the pore fluids, iron is released to the pores where it is redeposited as a limonitic (eventually as a hematitic) pigment and pore filling. The reddening process may span millions of years, as witnessed in the modern-to-Pliocene rift fillings of the Gulf of California (Zielinski et al., 1983; Walker, 1989).

In many cases, the pore fluids are saline, presumably due, largely if not entirely, to the leaching of marine or lacustrine evaporites in the stratigraphic section of the rift fill. In such cases, iron liberated to the pore fluids during reddening is at least temporarily soluble as ferrous iron and may also form soluble iron-chloride complexes, much as other base metals such as copper, lead and zinc. While the latter metal-chloride complexes are stable as dissolved species under oxidizing conditions, iron is commonly considered insoluble under the same conditions because it tends to form hydroxides and oxides in oxidized aqueous fluids. However, the so-called oxidizing conditions deep within rift sediment and far removed from atmospheric oxygen are more probably only mildly oxidizing, as suggested by the very slow diagenetic reddening process. Under such conditions, a significant iron solubility may exist as dissolved ferrous iron as well as iron-chloride complexes, allowing for an important deep basin transport of iron. The broad circulation of pore fluids in rift basins is a common element of many models for sediment-hosted mineralization, as evident in Boyle et al. (1989).

After moderate- to long-range deep-basin transport, continuing as long as conditions remain only mildly oxidizing, the soluble iron should eventually be deposited abruptly where the pore fluid encounters more strongly oxidizing conditions, such as upon mixing with oxidized near-surface waters or upon venting at surface or into oxidized waters. Rapid precipitation would result in a local iron-rich deposit, possible accompanied by elements sharing some of the geochemical behaviour of iron, such as manganese and barium. Iron-manganese bogs could be one result of the occurrence of this dissolution-transport-precipitation process during reddening of the immature coarse clastic fill of intracontinental rifts.

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BASEMENT HIGH-STRAIN ZONES - THE MAIN CONTROL OF MISSISSIPPI VALLEY-TYPE DEPOSITS AND PROSPECTS IN CARBONATE SEQUENCES OF THE WESTERN CANADA SEDIMENTARY BASIN

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INSIGHTS INTO THE URANIUM-ORGANIC ASSOCIATION AND ORE GENESIS IN THE ATHABASCA: THE VIEW FROM THE RUM JUNGLE MINERAL FIELD, AUSTRALIA

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The Rum Jungle Mineral Field in Australia and the Athabasca Basin in Canada are two examples of unconformity-associated uranium districts. A recent multi-disciplinary study of the Rum Jungle Mineral Field suggests that it is, or at least partially, analogous to the Athabasca Basin. Consequently, understanding the processes that have taken place in the Rum Jungle may help to solve some of the genetic ambiguities and problems of the Athabasca. Two such problems are considered here, the source and formation of the carbonaceous matter, and the origin of the uranium.

The Rum Jungle Mineral Field contains a variety of carbonaceous matter in a number of settings, including metamorphosed disordered graphitic material and very poorly ordered unmetamorphosed migrated organic matter, which contains variable amounts of radioelements, either uranium or thorium. These are considered to be directly comparable and analogous to the basement 'graphite' and the uraniferous bitumen/hydrocarbon buttons present in the Athabasca Basin, respectively. In both areas, the radioelement-rich organic matter is considered analogous to Phanerozoic radioelement-rich bitumen nodules. In the Rum Jungle Mineral Field, the migrated carbonaceous matter is interpreted to have formed from the alteration of primary syngenetic organic matter in low-grade black pelites. The alteration, triggered by post-metamorphic fluid-flow, resulted in intense sericitisation and changes in the geochemical fingerprint of the black pelities. Based on similarities, a comparable model is favoured for the origin of the uraniferous organic matter in the Athabasca Basin, i.e., basement 'graphite' underwent alteration and migration to produce the 'hydrocarbon buttons' present in many uranium deposits in the Athabasca Basin.

Migrated organic matter in the Rum Jungle area exhibits a polarization of the dominant radioelement present; granite-hosted bitumen nodules are thorium-dominated and carry hydrated Th-Y-Si-P phases, whereas nodules within the metasediments are uranium-dominated and carry uraninite. The Th-Y-Si-P phases are interpreted to be the result of the alteration of antecedent monazite. During this alteration process, U, LREE and P were fractionated and removed from the system, while Th, Y and Si remained immobile. The uranium was subsequently redistributed into the metasedimentary organic matter and on a larger scale, the uranium deposits present in the Rum Jungle Mineral Field. These results, when compared to observations in the Athabasca Basin, advocate that a similar process accounts for the origin, source and mechanism for uranium genesis in the Athabasca Basin and possibly unconformity-associated uranium deposits on a global scale.

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GS02-04 SEAFLOOR ALTERATION AND MINERALIZATION OF THE NEOPROTEROZOIC SCHAKALSBERG SEAMOUNT, NAMIBIA

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The Schakalsberg Mountains in southern Namibia, part of the Marmora Terrane of the ca. 740-550 Ma Gariep belt, represent a 1.4 km-thick volcanic-dominated succession interpreted as a remnant oceanic seamount. This succession is possibly correlative with the 740 Ma Zn-rich Rosh Pinah deposit. The two principal lithofacies include: a 1 km-thick basal mafic volcanic, and a 400 m-thick summital volcaniclastic lithofacies. The mafic volcanic lithofacies, which is composed of submarine lava flows and mafic intrusive rocks, has been divided into several lithological units based on phenocryst content: (i) aphanitic, (ii) microporphyritic, (iii) feldspar-phyric, and (iv) pyroxene±feldspar-phyric. These mafic volcanic rocks are massive, pillowed and brecciated. The volcaniclastic lithofacies is either autoclastic or pyroclastic in origin and is commonly reworked to variable degrees. It is divided into (i) tuff, (ii) lapilli tuff, and (iii) lapilli tuff breccia facies. The tuff represents dilute turbidity current and suspension deposits, whereas the lapilli tuff facies resulted from either redeposited high-concentration turbidite and mass flows, or represents a primary pyroclastic deposit produced by subaqueous eruption-fed density currents. The lapilli tuff breccia facies is a reworked volcaniclastic deposit transported downslope via debris flow processes. The volcaniclastic deposits are consistent with shoaling of the edifice.

The Schakalsberg seamount displays a pervasive hydrothermal carbonate alteration traceable for > 20 km that consists of calcite ($CaCO_3$), dolomite [$CaMg(CO_3)_2$] and Fe-dolomite [$Ca(Mg,Fe)(CO_3)_2$]. The alteration is characterized by distal (calcite), medial (calcite+dolomite), and proximal (calcite+dolomite+Fe-dolomite) assemblages. The source of CO_2 is considered the marine carbonates found in the vincinity of the seamount, which are probably the lateral equivalents of the deposits comprising the edifice. This alteration is predominent in the volcaniclastic units and in the volcanic units which are within 10 m of the volcaniclastic rocks. These altered rocks host a low-temperature hydrothermal magnetite (Fe_3O_4) deposit. The mineralization is composed of euhedral magnetite which has been subsequently replaced by hematite (Fe_2O_3). The Fe-source is inferred to have been the lava flows of the seamount and the adjacent seafloor, and this mineralization is consistent with modern low-temperature seafloor alteration (< 150°C). An absence of sulphide-bearing phases indicates that magmatic fluids were not prevalent in the deposits of the study area. Both the carbonate alteration and the Fe (magnetite) mineralization indicate oxidizing conditions during the formation of the Schakalsberg seamount.

GS02-05 THE CHARACTERISTICS, DISTRIBUTION AND CONTROLS OF GIANT PORPHYRY COPPER DEPOSITS

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The twenty-five largest known porphyry copper deposits (in terms of contained copper metal) formed during the Paleocene-Eocene, Eocene-Oligocene and Late Miocene-Pliocene. They are clustered within three provinces, Central Chile, Northern Chile and SW Arizona-Northern Mexico. Other giant deposits occur in Montana, Utah, Panama, Peru, Argentina, Irian Jaya and Iran. Compressive tectonic environments, thickened continental crust and active uplift and erosion were associated with the formation of many of these large deposits. Calc-alkalic magmas are most favourable for the formation of giant porphyry copper deposits, although several of the largest twenty-five deposits are associated with high-K calc-alkalic magmas.

The twenty-five largest gold-rich porphyry deposits are concentrated in the SW Pacific and South America, with other occurrences in Eurasia, British Columbia, Alaska and New South Wales. Many of the deposits formed in the last 13 million years. The largest of the deposits are associated with high-K calc-alkalic magmatism, although calc-alkalic magmas have also produced giant gold-rich porphyries.

In the last 15 million years, the formation of giant porphyry Cu-Mo and Cu-Au deposits around the circum-Pacific has been closely associated with regions where oceanic ridges, seamounts and/or oceanic plateaus have interacted with and/or been subducted beneath oceanic island arcs and continental arcs. In several examples, these tectonic perturbances have promoted flat slab subduction, crustal thickening, uplift and erosion and adakitic or adakite-like magmatism coeval with the formation of well-endowed porphyry and/or epithermal mineral provinces. Similar events have been inferred to be associated with the giant porphyry Cu-Mo provinces of Northern Chile (Eocene-Oligocene) and SW USA (Cretaceous-Paleocene). Some provinces have porphyry mineralisation associated with alkalic magmatism on arc-normal fault systems.

Topographic and thermal anomalies on the downgoing slab appear to act as tectonic triggers for porphyry ore formation. While they are not unique to the giant porphyry systems, they do help to generate a favourable environment for giant ore formation. Other factors, such as sutures in the overriding plate, permeability architecture of the upper crust, efficient processes of ore transport and deposition, and in some cases, formation and preservation of supergene enrichment blankets have also been vital for the development of high grade giant ore deposits. Without these district-to deposit-scale factors operating efficiently, the favourable tectonic environment may only produce a giant, low grade geochemical anomaly in the upper crust.

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GS02-06 PARTITIONING OF AU, SE, BI, AS, SB, AND TRANSITION METALS BETWEEN SULFIDE AND SILICATE FRACTIONS IN MAFIC ROCKS FROM BAMBLE SECTOR, SOUTHERN NORWAY

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Partitioning of certain elements between sulfide and silicate fractions are calculated for several gabbro bodies from Bamble Sector, southern Norway. The gabbros occurred as small stocks, lopoliths, dykes and sills during the Sveconorwegian orogeny (1.25-1100 Ma). They are coronitic in the cores and variably amphibolitized in the margins. They are tholeiitic, enriched in Fe (Mg# = 35-70) and bear features characteristic of basalts emplaced at destructive margin settings.

Sulfides occur as fine grains, interstitial to, and in textural equilibrium with, silicates. Pyrrhotite is the main sulfide commonly associated with chalcopyrite and pentlandite. Pyrrhotite is replaced by pyrite and magnetite in the marginal amphibolites. The transformation was simply an in-situ oxidation reaction without addition or removal of sulfur.

The sulfur contents vary from 200-1500 ppm consistent with 8-18% FeO and 12-5% MgO. Isotopic and geochemical data suggest that S is mostly of mantle origin, and that the parent magmas were not appreciably contaminated with crustal materials.

Distribution coefficients (D) for various elements are calculated from analysis of wholerocks and sulfide concentrates using Nernst equation. D values for Se, Au, Cu, and Bi falls in the range 7000-18000, 400-1400, 300-900, and 250-500, respectively. Mean values are 13000, 750, 650, and 350. Minor sulfides account for 45-85% of the total Au in the rocks. Corresponding values for Se, Cu and Bi are 90-98%, 40-80%, and 35-70%. Variations are large among various bodies, but small within individual bodies.

D values for Ni, Co, Mo and Zn are in the range 100-180, 20-60, 10-40 and 2-6, respectively. A negative correlation exists between Ni contents in sulfides and MgO in rocks. Sulfides account for 20-35% of Ni, 5-10% Co, 2-12% Mo, and 0.5-2% Zn in the rocks, respectively. Arsenic and Sb display highly variable D values (20-200 and 5-50).

Selenium is extremely chalcophile during magmatic crystallization. Gold, Cu and Bi display moderate to strong chalcophile affinity. The affinity declines from Ni to Co, Mo, and Zn. The inconsistent behavior of As and Sb might be of primary origin, or due to variable post-solidus mobility of the elements.

D values were controlled by the size of the magma bodies (higher D resulted when sulfides equilibrated with a larger body of magma), the initial abundances of the elements, and of sulfur, in magma, the order of sulfides in the paragenetic sequence that was mainly controlled by fO_2 and fS_2, and the rate of crystal growth and settling.

GS02-07 GEOTHERMOMETRY AND FLUID INCLUSION STUDIES OF THE E-ZONE BIOTITE SKARN, CANTUNG MINE, MACKENZIE MOUNTAINS, NWT

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The E-Zone at North American Tungsten's Cantung Mine in the Mackenzie Mountains, NWT comprises a typical exoskarn profile in the Sekwi and Vampire formations adjacent to an Upper Cretaceous (~91 Ma) two mica pluton. Skarn assemblages range from garnet-diopside at the upper end, through pyroxene-pyrrhotite, amphibole-pyrrhotite, to biotite-pyrrhotite. Scheelite is the dominant tungsten-bearing phase and occurs generally with pyrrhotite and chalcopyrite. The tungsten skarn is hosted within the locally-named Ore Limestone unit and in lime-rich layers of the underlying Swiss Cheese Limestone. The biotite skarn, a biotite-rich phase of the biotite-pyrrhotite skarn, consists primarily of fluorine-bearing biotite, minor quartz veins, sulphides, and lesser amounts of fluorapatite and the rare earth epidote allanite. Petrographic studies are consistent with contemporaneous precipitation of the biotite, pyrrhotite, fluorapatite and sulphides.

Electron microprobe analyses of F and OH compositions of co-existing biotite and fluorapatite are consistent with maximum precipitation temperatures on the order of 600°C. Cathode luminescence and back-scattered imaging via a scanning electron microscope reveals growth zones in the fluorapatite and allanite. Prior fluid inclusion work (Mathieson and Clark, 1984; Zaw and Clark, 1977) demonstrated that fluid inclusions range in composition from liquid-rich brine to CO_2-bearing brine with varying proportions of vapour. Intersection of the fluid inclusions isochores with these pressure-temperature constraints indicates that the brine fluid inclusions were probably trapped in a one-phase field and that the CO_2-bearing brine inclusions are not the product of phase-separation at the pressures and temperatures of skarn formation. The slightly increased pressures for skarn formation are also consistent with the limited meteoric signature in the stable isotope data. The higher pressures suggest that skarn formation may have occurred at depths on the order of 3 to 6 km as does the lack of evidence for boiling in the system.

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QUARTZ DIORITES OF THE WHISTLE OFFSET, SUDBURY: MULTIPLE PHASES OF IMPACT-RELATED MAGMA

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Impact-related fracture structures (offsets/superfaults) and associated igneous and brecciated rocks of the Sudbury Structure form an important architecture with respect to economic Ni-Cu-PGE sulphide deposits. The quartz diorite of the Whistle Offset in the North Range of the Sudbury Igneous Complex (SIC) varies mineralogically and texturally, as well as spatially and morphologically, and has been mapped as three different units: quartz diorite (QD), inclusion quartz diorite (IQD), and leucocratic quartz diorite (LQD). QD and LQD are distinguished by the presence of abundant K-feldspar (not a normal constituent of QD), whereas IQD is inclusion-bearing.

Detailed mapping (1:100 scale) of selected areas of the offset (proximal, intermediate and distal) has revealed that the LQD is commonly coarser grained than the QD, and may be distinguished by its pink hue representative of K-feldspar (</= 30%): they are otherwise mineralogically and texturally similar. Petrographically, the QD and LQD are composed of quartz, variably altered plagioclase and amphibole, little to no biotite, local granophyric intergrowths, and accessory apatite. Thirty-five electron microprobe analyses of amphibole provide no evidence for magmatic fractionation. Average values of amphibole composition are: 0.20 wt.% Cl, 0.26 wt.% F, and Fe# (Fe/(Fe+Mg)) of 0.42 atomic %. The amphibole is typically unzoned but alteration, occurring along cleavage planes and as irregular patches near grain margins, produced assemblages of chlorite and actinolite.

LQD pods typically occur adjacent to the margins of the offset, and are much larger (2 to 4 times larger, at the present erosional surface) than the QD pods. QD pods occur near the margins as well, but may also be centrally located. The spatial association of LQD and QD along the offset margins implies an obvious conduit system for the melts to travel. The percentage of felsic material indicates the amount of contamination due to assimilation of brecciated and unbrecciated country rocks. The impacted rocks in the Whistle Offset area are dominantly intermediate-gneisses and granites accounting for the felsic nature of the contamination.

The QD and LQD were most likely derived from two separate melt bodies, variably contaminated by felsic country rocks. Considering the leucocratic nature of these LQD bodies, which would be less dense than 'normal' QD, they may have the tendency to rise, as illustrated in a stratigraphic reconstruction of the Whistle Offset.

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GS02-09

HEXAGONAL AND MONOCLINIC PYRRHOTITES FROM THE COPPER CLIFF OFFSET AND TOTTEN MINE, WORTHINGTON OFFSET, SUDBURY, ONTARIO: TEXTURAL AND COMPOSISTIONAL VARIATIONS

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Forty-one samples from the Copper Cliff South mine, 47 samples from the Copper Cliff North mine, 5 samples from the Kelly Lake orebody and 42 samples from the Totten mine were examined petrographically using a magnetic colloid, revealing the presence of both monoclinic and hexagonal pyrrhotites. Monoclinic pyrrhotite occurs in hexagonal pyrrhotite as lamellae (up to 40 microns in thickness), composite lamellae at 60 degree angles (composed of both monoclinic and hexagonal pyrrhotites up to 50 microns in thickness) and boxwork (lamellae attached to each other forming boxes). Composite lamellae and boxwork typically occur in the centre of pyrrhotite grains (textural zoning). The proportion of monoclinic pyrrhotite is higher toward the edges of pyrrhotite grains (compositional zoning), except in the Copper Cliff South mine, where locally the edges of pyrrhotite blebs are composed of hexagonal pyrrhotite. There is an enrichment in hexagonal pyrrhotite along the later veins.

Pyrrhotite in veins contains more monoclinic pyrrhotite (up to 70%) than in blebby and massive sulphide (10-60%). The 100 orebody in Copper Cliff North mine contains only minor amounts of monoclinic pyrrhotite at the edges of pyrrhotite grains.

Four samples from Copper Cliff South mine have been analyzed by microprobe. Based on 16 analyses of hexagonal and 15 analyses of monoclinic pyrrhotite, hexagonal pyrrhotite contains more Fe and Ni, and less S than monoclinic pyrrhotite. The average Ni content is 0.61 wt% (0.17 standard deviation) in hexagonal and 0.39 wt% (0.12 st.dev.) in monoclinic pyrrhotite. The average Fe content is 60.1 wt% (0.79 st.dev.) in hexagonal and 59.8 wt% (0.41 st.dev.) in monoclinic pyrrhotite. The average Ni content of pyrrhotite in veins is 0.35 wt% (0.03 st.dev.) in hexagonal and 0.20 wt% (0.02 st.dev.) in monoclinic pyrrhotite : Ni content is lower than in blebby sulphides, where the average is 0.70 wt% (0.07 st.dev.) in hexagonal and 0.46 wt% (0.08 st.dev.) in monoclinic pyrrhotite.

The increase in proportion of monoclinic pyrrhotite toward the edges of pyrrhotite grains and the textural zoning within the grains are typical of exsolution from monosulphide solide solution after crystallization of sulphide magma. Locally, Fe-rich (S-poor) hydrothermal fluids replaced monoclinic pyrrhotite with hexagonal pyrrhotite along the edges of blebs and veins. The alignment of monoclinic pyrrhotite lamellae parallel to foliation suggests annealing under anisotropic stress conditions. Kink banding and twinning of monoclinic pyrrhotite lamellae are the result of late deformation.

GS02-10 GRANULITES, OXIDIZED LOWER CRUST, AND MOBILIZATION OF GOLD?

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Granulites and/or oxidized lower crustal rocks have been invoked as a possible source of gold in mesothermal gold-quartz veins. This model is investigated in the Bamble Sector of southern Norway, where a transition from amphibolite- to granulite-facies occurs across the 25-km width of the Sector. Supracrustal rocks of mid-Proterozoicages were intruded by felsic and mafic magmas and metamorphosed during the Sveconorwegian orogeny (1.25-1100 Ma).

Four suites of rocks (tonalitic-trondhjemitic gneisses, metabasites, gabbros, and pelitic rocks) from the granulite, transition, and amphibolite zones were investigated for variations of S, Au, and the elements commonly enriched in gold-quartz veins (Se, Sb, Bi, As), as well as LILEs and REEs.

Gold in rocks is principally carried by accessory sulfides. Selenium is extremely chalcophile. Bismuth, arsenic and antimony are moderately to strongly chalcophile. Any significant mobilization of the elements requires breakdown of sulfides.

The gneisses, metabasites, and pelitic rocks from granulite zone display more oxidized mineral assemblages relative to their analogues from transition and amphibolite zones. This is evident from occurrence of ilmenite-hematite exsolution textures, and replacement of pyrrhotite by pyrite-magnetite.

Gabbro bodies are coronitic in the cores but variably amphibolitized in the margins. Gabbros crystallized at QFM buffer; the marginal amphibolites equilibrated at 2-3 log units above QFM which led to phase changes in sulfides as in the granulite-facies rocks.

All Bamble rocks are depleted in gold relative to the average crustal values. They are not so depleted in other chalcophile elements. Mean gold values for gabbros, metabasites, gneisses and pelitic rocks are 0.45, 0.30, 0.2, and 0.3 ppb, respectively. For corresponding rocks from different zones, variations are not significant at 95% confidence interval.

For gabbros and metabasites, geochemical modeling shows that low gold contents were inherited from the parent magmas. No post-solidus mobilization of gold occurred. Pyrrhotite-pyrite phase change was simply an in-situ oxidation reaction, without noticeable addition or removal of S and chalcophiles. This is further supported by similar Nernst D values for gold between sulfide and silicate fractions in corresponding oxidized and non-oxidized rocks. Similarly, low gold in other rocks could be of primary pre-metamorphic origin.

Granulite-grade rocks are considerably depleted in LILEs and LREEs relative to their analogues from transition and amphibolite zones. This could be complementary to the common enrichment of the same elements in the gold-quartz vein systems. However, granulite and/or oxidative metamorphism, as in Bamble, did not lead to mobilization and depletion of gold in lower crust.

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PERMEABILITY PENERATION IN ADVANCE OF CARBONATE ALTERATION FRONTS WITHIN SERPENTINITE

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Carbonate altered serpentinite (listwanite) at Atlin, British Columbia is associated with lode-gold mineralization but also represents a natural analog to greenhouse gas sequestration. The alteration is structurally controlled by a regional scale fault-fracture permeability system and extends into intact wallrock. The fault-fracture system allowed ingress of the mineralizing fluid, but distal infiltration and reaction within the wallrock may be important for precious- and base-metal scavenging within the Atlin ophiolite. In a similar process, industrial greenhouse sequestration systems could exploit bedrock fractures for injection of carbon dioxide into the subsurface. This also requires fluid access to intact bedrock to fully utilize the storage capabilities of mafic rock reservoirs. An understanding of how reactive fluid accessed the interior of the Atlin ophiolite is therefore of economic and environmental interest.

Bedrock alteration proceeded via a three-stage process converting serpentine + olivine to serpentine + magnesite, then serpentine to magnesite + talc and finally talc to magnesite + quartz. The mineralogical changes were accomplished with no detectable mobility of major non-volatile chemical species. Serpentine + magnesite alteration extends the farthest from the fracture permeability system, indicating that altering fluid was able to infiltrate large volumes of pristine ultramafic rock. A dense zone of mm-scale extension fractures is developed within wallrock serpentinite roughly orthogonal to talc + magnesite reaction fronts. The volume strain recorded by the veins is 3.6 +/- 1.8 percent. Geochemical analysis of the volume change of the talc + magnesite reaction predicts positive volume strains of 2.6 percent. The veins may therefore record swelling and extension of unaltered rocks that were mechanically coupled to the dilating alteration zone. We interpret the zone of extensional veins to be a permeability wave that traveled in advance of the alteration front and promoted fluid infiltration into unaltered serpentinite. This permeability generation mechanism may have allowed metal scavenging within the ophiolite and could also be used to generate permeability in CO_2 injection systems by controlling the inlet gas composition.

GS02-12 **A PALEOZOIC IRON-OXIDE-COPPER-GOLD (IOCG) DEPOSIT IN THE GASPE PENINSULA: THE MONT-DE-L'AIGLE DEPOSIT**

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The Mont-de-l'Aigle deposit is located in the northern part of the Dome Lemieux, in Gaspé, a circular anticlinal structure of gently dipping Siluro-Devonian carbonate, siltstones and mudstones cut by numerous mafic to felsic sills and dykes. The Dome Lemieux is underlain by granitic intrusions accompanied by copper-bearing skarns. The southern part of the Dome is cut by sericite-adularia epithermal Ag-Pb-Zn-(Au) veins. The northern part of the Dome Lemieux is characterized by veins, stocwerks and breccias cemented by hematite, magnetite, quartz, chalcopyrite, pyrite and dolomite. Breccias are dominated by angular fragments of the local hostrocks. There is a gradual change in mineralization style, up the stratigraphic section, from hematite-chalcopyrite veins and breccias in carbonates of the Forillon Formation to quartz-chalcopyrite-hematite-sphalerite veins, stockwerks and rare breccias in the sandstones of the York River Formation. The change in mineralization style is accompanied by a vertical decrease of copper grades towards higher stratigraphic levels. Mineralization is controlled by steeply to moderately dipping faulted and fractured corridors striking NNE, ENE, SW and NNW. Mineralization also forms stratabound replacements akin to mantos. It is associated with coincident, or adjacent, positive gravimetric and magnetic geophysical anomalies. Copper mineralization formed in several pulses, preceeding and postdating hematite breccias. Hematite breccias are cataclased and cemented by quartz and chalcopyrite. Hydrothermal alteration comprises potassic alteration of sills and dykes, and decameter-wide zones of chloritic alteration and decarbonation around hematite veins, stockwerks and breccias. Hematite cuts mafic and felsic intrusions, the skarn assemblage, and amethyste veins typical of the epithermal veins to the south. The IOCG mineralization is therefore younger than the skarn and epithermal mineralization. The Mont-de-l'Aigle deposits displays characteristics of sediment-hosted IOCG, with a strong affinity to Mesozoic IOCG described in the Coastal Cordillera of northern Chili-southern Peru in the Andes. It is a rare example of Paleozoic IOCG deposit.

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GOLD IN THE MEGUMA TERRANE, SOUTHERN NOVA SCOTIA. IS THERE A CONTINUUM BETWEEN MESOTHERMAL LODE GOLD AND INTRUSION-RELATED GOLD SYSTEMS?

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The Meguma Terrane (MT) of southern Nova Scotia is dominated by two lithotectonic units, the Cambro-Ordovician Meguma Group metasedimentary rocks and 380 Ma peraluminous South Mountain Batholith and related intrusions. The Meguma Group consists of a lower, sandstone-dominated unit and an overlying siltstone dominated unit. These strata were folded (chevron and box fold styles) and metamorphosed (greenschist to amphibolite grade) during the Acadian Orogeny at ca. 410 Ma. Intrusive activity of 380-370 Ma was dominated by crust-derived peraluminous granites, but lesser amounts of spatially- and temporally-related mafic intrusions occur. Gold production from Meguma lode-gold deposits (MLGD) was from both concordant and discordant, quartz-carbonate-sulphide veins that formed relatively late in the folding history of the host rocks - a metamorphic origin is suggested for their origin. However, integration of past and recent observations with changing global concepts on gold metallogeny suggests that a reassessment of these deposits is warranted. In this regard, the following points are highlighted: (1) recent Re/Os dating of arsenopyrite from several MLGD indicates two vein-forming events at 408 and 380 Ma. These ages for vein formation are significant and coincide with regional deformation and plutonism in the MT; (2) widespread occurrence of MLGD throughout the MT irrespective of metamorphic grade, stratigraphic position, and proximity to intrusions; (3) spatial association of some vein mineralogy (e.g., garnet, amphibole, tourmaline, calcic plagioclase) in MLGD proximal to intrusions (e.g., Newhouse, 1936); (4) elemental enrichment of some MLGD veins in a suite typical of intrusion-related gold deposits (i.e., Bi, Te, Mo, Sb), and (5) arsenopyrite-bearing albitites, quartz veins, and quartz-muscovite-tourmaline-sulphide greisen swarms (e.g., 260 m long by 120 m wide) that are hosted by 380 Ma, reduced, peraluminous granites. These systems are variably enriched in Au (to 2 g/t) and have a metal association (i.e., Bi, Co, W, Sb) typical of intrusion-related gold systems. The foregoing observations are interpreted to indicate that those MLGD of ca. 380 Ma may in fact form a continuum with intrusion-related gold mineralization hosted by intrusions of similar age. Thus, within the MT two distinct gold-mineralizing events are suggested, one at 408 Ma related to regional deformation accompanying accretion of the MT to Avalonia and a second at 380 Ma that is related to emplacement of crust-derived granites. The general similarities of all the MLGD indicates the non-uniqueness of the deposits and suggests, instead, that there may be a continuum between intrusion-related and mesothermal type vein mineralization.

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GOLD DEPOSITING MECHANISMS IN HIGH-GRADE VEINS OF THE PORCUPINE CAMP, TIMMINS, ONTARIO, CANADA

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High-grade ore shoots in mesothermal gold deposits of the Pamour Mine occur in two distinct settings: shallow-dipping (< 45°) and steep-dipping (> 45°) veins. High-grade ore shoots in the economically important steep-dipping veins were formed by phase separation as indicated by the range in composition of individual fluid inclusions extracted from gold, by inclusion fluids in both gold and quartz that have CO_2:CH_4 ratios that increase with H_2O contents, and by the concentration of gold on the footwall of individual sheets. The preferential concentration of gold in the thinnest parts of individual sheets (by a factor of 5 to 1,000 compared to wider sections of the same sheet) suggests that fluid turbulence at constrictions in hydrothermal fractures induced phase separation and the deposition of gold. Pressures estimates made using the composition of gold-hosted and quartz-hosted inclusion fluids are 0.4 kbars and ~1/3 that determined for shallow-dipping veins, suggesting that steep-dipping veins formed at pressures close to hydrostatic. Deposition of gold by fluid turbulence is also an attractive scenario because it could explain the great vertical continuity characteristic of most mesothermal gold deposits.

Gold concentrated near crosscutting fractures in the hanging wall and on surfaces of wallrock fragments in massive or brecciated shallow-dipping veins suggest that fluids reacting with the wallrocks formed high-grade ore shoots. This possibility is supported by a decrease in CO_2:CH_4 ratios with increasing H_2O contents of individual gold-hosted fluid inclusions and carbonate alteration of the wallrocks. Pressure estimates of 1.2 kbars, made using the composition of water-rich fluid inclusions, suggest that the gold was deposited when fluid pressures were close to lithostatic. Shallow-dipping stringer veins also appear to have formed by the interaction of hydrothermal fluids with the wallrocks as indicated by a 1‰ decrease in $\delta^{18}O$ quartz values between foot and hanging walls of a quartz stringer, and strong carbonate alteration of breccia fragments and hanging wall rocks.

The complex interplay of two major ore depositing processes, phase separation and wallrock reaction, during the formation of high-grade ore shoots at the Pamour Mine could have more widespread application to the development of mesothermal gold deposits worldwide.

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GS02-15 **METAL MOBILIZATION DURING PROGRADE METAMORPHISM IN THE VALDEZ CREEK GOLD DISTRICT, SOUTH-CENTRAL ALASKA**

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The Valdez Creek gold district in the Clearwater Mountains of south-central Alaska has yielded almost half a million ounces of placer gold mainly in the 1990s. The source for the ores was small, high-grade orogenic gold vein occurrences within the Maclaren Glacier metamorphic belt, an inverted Barrovian sequence developed within a Jurassic-Cretaceous pelitic flysch assemblage that overlaps the Yukon-Tanana and Wrangellia terranes. The ca. 62-57 Ma veins cut both flysch and Cretaceous stocks and dikes that intrude the metasediments. Significantly, as is common with most orogenic gold provinces, the gold-bearing lodes are exclusively spatially restricted to the greenschist facies rocks (in this case, to the biotite zone) of the metamorphic belt.

A number of traverses were carried out across the 12-km-wide belt, with whole rock flysch samples collected from amphibolite down through prehnite-pumpellyite zones. Samples were analyzed by ICP-MS for major, minor, and many ore-related trace elements. Arsenic concentrations systematically decrease from about 4-12 to < 1 ppm, and antimony from 0.2-0.9 ppm to 0.02-0.03 ppm, between lowest and highest grade zones, respectively. Mercury typically ranged from 10-80 ppb in low grade rocks, but decreases to < 5 ppb in the flysch once the biotite zone of greenschist facies is reached. Data for tungsten, boron, and bismuth show similar, but not as well-defined trends; those for gold and tellurium do not show trends, but it is uncertain as to whether this reflects the fact that many concentrations are at or below analytical determination limits.

Our observations are consistent with a process that involves many of the ore-related elements, which are present at anomalous concentrations in the auriferous veins, being mobilized from the flysch itself. Ore pathfinder elements such as mercury, arsenic, and antimony were transported in the vein-forming fluids as sulfide complexes and the sulfur (e.g., vein $\delta^{34}S$ as low as –10 per mil) may have been liberated from syn-sedimentary pyrite during prograde metamorphism. Timing systematics of the hydrothermal activity are problematic, as the Barrovian event was initiated by emplacement of a tonalite sill as much as 10 m.y. prior to lode emplacement. The data, nevertheless, confirm that Barrovian metamorphism characteristically mobilizes many of the elements recognized to be enriched in orogenic gold deposits and resulting metamorphic belts will inherently contain metalliferous veins enriched in an As-B-Bi-Hg-Sb-W (±Au?, Te?) signature.

GS02-16 **STRUCTURAL CONTROLS AND TEXTURES-RELATED TO AURIFEROUS MINERALIZATION, CONSUELO MINE, PATAZ, PERU**

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The Consuelo Vein is located in the northern Peruvian Andes within the Eastern Cordillera. This vein (312 My) is one of a family of large, Qz-sulphide (Py-Ga-Sph-Aspy) auriferous veins in the Poderosa Gold Mine. All the veins are hosted by the Pataz Batholith (329 My), a 200 km^2 lower greenschist facies dioritic to granodioritic intrusion. Deformation within and at the margin of the veins have been interpreted as a result of a fault-filling event but new detailed observations contradict this interpretation.

This study emphasizes the structural and textural analysis of the Consuelo Vein in order to determine the vein formation and to evaluate the structural control. The Consuelo Vein is a 2 to 3 m thick, N-striking planar structure dipping 45°E that can be followed over 1km in length and 600 m in depth. The vein displays a multi-stage paragenesis that includes Zn-Pb-Cu±Ag±As±Sb±(Bi±Te) with quartz, carbonates, electrum and gold.

Several dip-parallel ore shoots are present within the vein. These ore shoots correspond to the intersection of the vein with subvertical, E-trending, conjugate (N- and S-dipping), reverse faults. These faults are interpreted to provide an important structural control on fluid transport and were active pre-, syn- and post-vein development. A preliminary visual analysis of Qz crystals indicates a subvertical opening vector for the vein. Hornblende dikes are also spatially related to the vein and represent a lithologic control on vein emplacement.

A wide variety of textures and structures are present including primary (comb, dendritic, laminated, crustiform, brecciated), developed during the generation of the vein system; and late (gauge, shear bands, duplication), associated with deformation. Vein development resulted from high fluid pressure, as indicated by multiple breccia morphologies. The crack-seal mechanism is invoked as the principal mechanism for the vein formation. The complexity of this vein is interpreted as a result of multiple hydrothermal filling events in an extensional regime while deformation is a later event unrelated to vein formation.

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CONSTRAINTS ON THE AGE OF GOLD MINERALIZATION AT THE KUMTOR GOLD DEPOSIT, KYRGYZSTAN

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The Kumtor deposit, one of the largest gold deposits in the world, is located in the Tien Shan mountains of eastern Kyrgyzstan. This study combines geological and geochronological relationships to provide constraints on the timing of mineralization, and is important as this improves our understanding of the evolution of the Kyzylkum-south Tien Shan gold belt which extends from Muruntau (Uzbekistan) to northern China.

Gold mineralization at Kumtor is hosted by Neoproterozoic carbonaceous phyllites, the maximum age of which is ca. 815 Ma, and is associated with complex vein systems and associated alteration in the hanging wall of the long-lived Kumtor Fault Zone. The fault zone includes exotic blocks of ca. 810 Ma granites and Carboniferous oolitic limestones, and mineralization is offset by faults spatially related to the main fault indicative of its long-lived, complex history. Structural relationships in the region and the ore body indicate that gold mineralization post-dates two regional deformation events, and may be broadly coeval with a third, which is only observed in Carboniferous clastic sedimentary rocks. These deformation events are generally considered to be associated with the Paleozoic development of the Tien Shan orogenic belt. All three deformation events are preserved in the Neoproterozoic host rocks to the deposit, and the orthogonal relationship between structures may have prepared the ground for the mineralizing fluids.

UV Laser Ar-Ar ages obtained from mica-bearing zones defining S_2 in Neoproterozoic rocks away from mineralization yield ages varying from 321 +/- 6 to 305 +/- 2 Ma, whereas three older ages varying from 575 to 705 Ma were obtained from spots that might represent either detrital components or an earlier deformation phase. Ar-Ar ages of 297 +/-3 and 292 +/- 3 Ma were obtained from fine-grained sericites associated with auriferous pyrite-bearing veins that were precipitated at temperatures of about 300°C. Complex spectra obtained from sericites which yield interpreted ages of 271 +/- 4 and 261 +/-5 Ma probably record waning of the hydrothermal system, as does an Ar-Ar age of 229 +/-3 Ma from a K-feldspar from the same vein as the 297 +/-3 Ma sericite. These ages emphasize that the system was dying over a significant time period, possibly represented in terms of structure by post-mineralization graphitic faults. The direct relationship of mineralization with intrusive activity remains unclear as U-Pb ages obtained from undeformed granodiorite intrusions in the Kumtor region yielded ages of 280 +/-9 and 268 +/1 Ma.

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GS02-18 **CARACTÈRES GÉOLOGIQUES ET STRUCTURAUX DE LA MINÉRALISATION AURIFÈRE DU COMTÉ DE JINPING (SE DE LA PROVINCE DU GUIZHOU, R.P. DE CHINE)**

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Le gisement du Comté de Jinping appartient à la classe des « Turbidite-hosted gold deposits », et constitue la première découverte d'un gisement de ce type en Chine. Grâce à la simplicité de son contexte géologique et structural, le site de Jinping permettrait de contribuer aux études en cours pour ce type de gisement dans le monde (e.g., Nouvelle-Ecosse au Canada et « Central Victoria » en Australie) sur la source du fluide minéralisateur (magmatique vs métamorphique ou météorique) et les mécanismes de concentration de l'or. A Jinping, la minéralisation en or se situe dans des BPVs (Bedding-Parallel Veins) associées à des structures majeures, notamment des plis, des failles et des zones de cisaillement. Les relations entre ces BPVs et ces structures restent à établir.

Nos travaux de recherche visent: (1) à mettre en évidence les caractéristiques de la minéralisation en or et celles du fluide minéralisateur, (2) à identifier les structures qui ont contrôlé la mise en place des filons de quartz aurifères et (3) à proposer un modèle génétique pour cette minéralisation.

Sur le terrain, les rapports géométriques entre les veines de quartz aurifères et les structures seront établies. Les échantillons prélevés serviront pour des études pétrographiques, microstructurales et métallographiques au laboratoire. La composition, l'évolution et les conditions de mise en place du fluide minéralisateur seront analysées à partir de l'étude des inclusions fluides des veines de quartz aurifères par microthermométrie et par spectrométrie de Raman. Ces techniques seront complétées par des analyses chimiques et des études isotopiques.

GS02-P01 PETROGRAPHIC AND MINERALOGIC INVESTIGATIONS OF THE DORIS AND MADRID GOLD DEPOSITS, HOPE BAY GREENSTONE BELT, SLAVE STRUCTURAL PROVINCE, NUNAVUT

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The Doris and Madrid deposits,hosted by the volcano-sedimentary sequences of the Hope Bay greenstone belt, nonecontain estimated resources of 4.3 million-oz. The Doris deposit comprises steeply dipping veins within Ti-Mg and Ti-Fe tholeiitic basalts, folded in an antiformal hinge zone. The veins are composed of variable proportions of quartz (12-72%), dolomite (16-41%), muscovite (6-72%), and minor tourmaline, pyrite, chalcopyrite and gold. Gold occurs at the vein margin, mantling, filling fractures, or included in pyrite. The veins comprise slivers of tourmaline-dolomite-pyrite altered wall rock elongated parallel to the vein margin. The Ti-Fe tholeiitic basalts proximal to the Doris Central Vein are intensively altered and contain up to 52% quartz, 20% muscovite, 17% chlorite, 5% dolomite, and 6% rutile, contrasting with the less altered rocks that contain 42% calcite, 36% quartz, 19% chlorite, and 3% albite. The altered Ti-Mg tholeiitic basalts, in the core of the Central Vein antiform, are composed of 44% chlorite, 28% quartz, 22% calcite, 5% albite, and 1% rutile and the less altered rocks consist of 26% epidote, 24% hornblende, 15% chlorite, 14% quartz, 14% actinolite, and 7% albite.

The Madrid deposit includes basalts, komatiite, and argillites. Mineralization occurs in carbonatized, silicified and albitized breccia zones, associated with stockwork veining. The auriferous rocks are cut by various veinlets: dark grey ankerite with very fine quartz, coarse-grained quartz, and albite veinlets. Gold commonly occurs in the carbonate alteration products at the margin of the quartz-bearing veinlets, or mantling and filling the fractures of chromite and pyrite. The mineralogy of the altered ultramafic host rock is highly variable and consists of 11-57% dolomite, 18-79% quartz, and 1-10% pyrite with minor amounts of muscovite, nimite, rutile and albite. The argillite in the mineralized zones is composed of 42% quartz, 16% illite, 16% muscovite, 11% ankerite, 11% pyrite, and 4% albite. The mafic fragmental unit proximal and distal to the mineralized zone comprises, respectively, 33% quartz, 32% ankerite, 18% chlorite, 8% nimite, 6% albite, 3% rutile, and 32% epidote, 26% nimite, 15% magnesiohornblende, 13% quartz, 13% albite, 1% chalcopyrite, and trace amounts of dolomite.

The auriferous hydrothermal fluids, which interact with Doris and Madrid host rocks, were enriched in silica, CO_2, K and H_2S, favouring the transported of gold as Au $(HS)^{2-}$ complexes. Gold precipitation may have occurred in response to the decrease of the H_2S content due to the deposition of pyrite in the host rocks and veins.

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THE DISTRIBUTION OF MONOCLINIC PYRRHOTITE IN THE CANTUNG TUNGSTEN SKARN, MACKENZIE MOUNTAINS, NWT AND ITS SIGNIFICANCE

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The re-opening of the Cantung Mine in the Mackenzie Mountains, NWT, offered a unique opportunity to re-examine one of the foremost tungsten skarn deposits in the world. The Cantung Mine is an unusually large and high-grade deposit (4.6 million tons produced at 1.6% WO_3 and an indicated remaining resource of 7.3 million tons at 0.77% WO_3) that developed in a package of folded and overturned limestones, above and coeval with, a Cretaceous granite intrusion (91 Ma). From 1962 to 1985, Cantung was the western world's largest tungsten producer and for the past two years the operation has been the source of nearly 10% of global tungsten production. Recent economic pressures have forced the mine to cease production once again.

Previous researchers and mill designers noted the abundance of hexagonal pyrrhotite (non-magnetic) as a main ore constituent. However, as mining activities shifted from the "Main" to the "Western Extension" of the E zone, a new metallurgical problem arose due to pyrite contamination. The mill was not designed to eliminate pyrite from the gravity circuit concentrate, resulting in periodic failures to meet purity specifications. Empirical efforts noted the presence of monoclinic pyrrhotite (magnetic), in addition to pyrite, as an indicator of changes in the ore tenor. Research was conducted to determine the distribution of this new ore type and to determine a method to predict its presence.

Utilizing stope face maps, detailed magnetic susceptibility surveys, and representative sample petrography, it has been determined that late crosscutting brittle faults and associated breccia zones have replaced some of the sulphide-rich ore. The resultant pyrite and low temperature monoclinic pyrrhotite mineralization within the breccia zones indicates a sulphidation and thermal event distinct from that which generated the main skarn ore.

With these findings, face mapping of the faults and fault breccia zones will help to identify and predict the abundance of this ore variant, allowing mill personnel the opportunity to modify ore processing methods to ensure optimum recoveries. The recognition of monoclinic pyrrhotite and its associated magnetic character will also aid in the reinterpretation of airborne geophysical surveys completed in the area. This has important implications for regional geophysical surveys conducted in the Mackenzie Mountains.

GS02-P03 A NEW MAP OF LITTLE CORWALLIS ISLAND, CORNWALLIS ZN-PB DISTRICT, NUNAVUT

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In order to elucidate its structural relationship with the Boothia Uplift (to the east) and the Ellesmerian fold/thrust belt (to the west), Little Cornwallis Island was remapped, within the context of defining regional controls on Cornwallis District Zn-Pb±Cu mineralisation. The updated map differs significantly from its predecessor.

The island is on the western flank of the Boothia Uplift (Caledonian Orogeny; late Silurian - early Devonian), with the uplift to its east (Cornwallis Island) and the Ellesmerian (late Devonian - early Carboniferous) Parry Islands Fold Belt to the west (Bathurst Island). It is dominated by poorly exposed lower Paleozoic rocks and spans two north-northwest-trending anticlines and an intervening, broad syncline.

Three hitherto unrecognised east-vergent thrusts on the flank of the eastern anticline(eastern 2/3 of the island) are marked by the juxtaposition of disparate sub-formation-scale stratigraphic units and contrasting bedding dips. Between thrusts are numerous normal faults, generally parallel to the thrusts. The western 1/3 of the island contains flat-lying (eastern part) to steeply east-dipping (westernmost part) Ordovician strata, and a north-trending syncline in Devonian strata. Steep dips at the western limit of the island are interpreted as the expression of a west-vergent thrust just offshore; this is supported by wrench faults extending to the northeast.

Geometric relationships among stratigraphic units and the sub-Devonian unconformity indicate that east- and west-vergent thrusts are of Caledonian age. The northwest-trending, evaporite-based faults and conglomerate-filled mini-basins extended well onto the Boothia Uplift. Lower Devonian dolostone overlies the conglomerate, or near thrusts, overlies the unconformity, which cuts across tilted, thrusted strata. Deposition of Devonian carbonate units gradually erased the Caledonian paleotopography. A Middle Devonian sandstone influx heralded the Ellesmerian Orogeny.

Normal faults are either the product of local trans-tension during the Ellesmerian orogeny, or extension during opening of the Sverdrup basin (early Carboniferous). The cause of the north-trending fold in Devonian strata is uncertain.

The Polaris deposit, on the southwest coast, is near the leading edge of a segmented thrust fault, at the border between the west-trending, complexly folded and faulted, evaporite-based Ellesmerian fold-thrust system to the west, and the north-trending, rigid, Boothia uplift to the east. Subtle remobilisation of segmented, west-verging Boothia structures during Ellesmerian compression appears to have dilated pre-existing structures at high angles to stress, providing permeable zones for the migration of metalliferous fluids during the Ellesmerian Orogeny. Eclipse is at the junction of two normal faults of either Ellesmerian or Sverdrupian age.

GS02-P04 MAPPING SULPHIDE AU-MINERALIZATION AT THE GOLDCORP INC. RED LAKE MINE, BALMERTOWN, ONTARIO, CANADA

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GS02-P05 MARBLE-HOSTED SAPPHIRE FROM BAFFIN ISLAND, NUNAVUT

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In 2002 gem-quality blue sapphire was found southwest of the community of Kimmirut on Baffin Island. The sapphire occurs in calc-silicate lenses within the Lake Harbour Marble (LHM) unit, a member of the Palaeo-Proterozoic metasedimentary Lake Harbour Group. The LHM is made up of coarsely recrystallized calcite, with accessory ubiquitous phlogopite and graphite and significant lenses of calc-silicate material. Gem-quality apatite, clinohumite, diopside, lazurite, oligoclase, pargasite, spinel, titanite, and uvite have also been found in the LHM.

The sapphire is found in association with oligoclase (An_{13}-An_{21}), violet pyroxene, phlogopite, muscovite, calcite, graphite, apatite, and pyrite. Scapolite, titanite (up to 45 μm), and zircon crystals occur as inclusions in the pyroxene. There are close spatial associations between sapphire and oligoclase and pyroxene and phlogopite, and graphic intergrowths are common between oligoclase and phlogopite. The mineralogy and textural relationships are consistent with the assemblage having formed from aluminous melts that were generated by partial melting of pelitic sediments during high-grade (upper amphibolite to granulite) metamorphism.

The sapphire is nearly pure Al_2O_3; EPMA yielded maximum FeO and TiO_2 values of 0.13 and 0.30 wt%, respectively. Chromium and Mg (other known chromophores), and V, Mn, and Ga (used to classify the deposit type) were sought but not detected. Colour zoning was noted in polished section but was not observed as compositional zoning in BSE images. The pyroxene crystals show little chemical variation; the average formula (based on 18 analyses of 5 crystals) is $(Ca_{0.87}Na_{0.12})(Mg_{0.77}Al_{0.17}Fe_{0.05}Ti_{0.04})[Si_{1.86}Al_{0.14}]O_6$. EPMA analyses show that the muscovite is most stoichiometric; the only substitution is minor (0.09-0.14 apfu) Na for K. Phlogopite compositions are more variable, with up to 0.37 wt% Na_2O (0.37 Na apfu), 3.08 wt% FeO (0.18 Fe apfu), 2.85 wt% TiO_2 (0.15 Ti apfu), and 1.52 wt% F (0.34 apfu). One titanite analysis gave the formula $Ca(Ti_{0.92}Al_{0.07})Si(O_{4.95}F_{0.05})$.

Mineralogical similarities indicate that the Baffin sapphire deposit may be analogous to marble-hosted gem-bearing provinces in Central and Southeast Asia. Future work will include dating, stable isotope, and fluid inclusion studies, in order to better constrain the conditions of ormation.

GS02-P06 TIME ASSOCIATED MAGMATISM AND MINERALIZATION AT THE CENTRAL PART OF MEXICO

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The western North American Cordillera hosts a large number of ore deposits of gold-bearing quartz veins, silver-bearing quartz veins and Zn-Cu-Pb skarns systems at the central part of Mexico. These veins and skarns systems are structurally controlled by major fault zones or weakness zones, which are often reactivated terrane-bounding sutures that formed in orogens built during accretion and subduction of terranes along the continental margin of North America. Mineralization ages span mid-Jurassic to early Tertiary and encompass much of the evolution of the Cordilleran orogen.

We present 14 age K-Ar determinations of rocks and ore deposits, and a geological interpretation of Landsat 5-7 images of the central part of Mexico. The goal of this study is to determine the relation of the age of the ore deposits, the weakness structures and to set them in a regional geologic framework of Central part of Mexico.

The oldest rocks of the region are the mid-upper Jurassic volcanic and volcanic-sedimentary formations, over these rocks are layering the early cretaceous limestones and finally upper cretaceous terrigenous age rocks. There are known about 20 small stocks and two big granite bodies. The majority of these are of alaskitic, monzonitic, dioritic and granitic compositions. A lot of dikes of several compositions, the majority are of porphiritic textures and rhyolitic to andesitic composition. It is often to see subvolcanic bodies like dikes or stocks that cut the oldest sequences.

At the region are known ore deposits of skarn silver-polymetalic type, hydrothermal vein Ag-Au, and the biggest fluorite deposits of the world. From the obtained K-Ar ages and geological mapping we could get several interpretations: (1) There is a trend of decresing age from SE to NW, from several granitic stocks to sub-volcanic and volcanic rhyolite rocks. (2) The ages reflect the evolution of the subducted slab or the wandering of the inclined slab from 43 Ma to 29 Ma and back to 15 Ma to the south of the area studied. The 43 Ma is the oldest age of stocks that intruded the cretaceous rocks after the Laramide Orogeny was already finished. (3) The skarn deposits of the SE are older than the Hydrothermal fluorite deposits for more than 13 Ma. (4) All the ore deposits follow a SE-NW trend along the zones of faults or weakness zones that have been working since the opening of the gulf of Mexico, forming several metallogenetic belts.

GS-03

ENVIRONMENTAL GEOSCIENCES

GÉOSCIENCES DE L'ENVIRONNEMENT

JOHN FRASER

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GS03-01 NRTL AS A METHOD OF ANALYSIS OF SAND TRANSPORT ALONG THE COAST OF THE ST. JOSEPH PENINSULA, FLORIDA

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St. Joseph Peninsula, located along the northeast coast of the Gulf of Mexico, was considered the "best beach in the United States" in 2002. Although important for recreational purposes, the beach is ephemeral, and thus its sand transport regime warranted more detailed study. Natural residual thermoluminescence (NRTL) analysis of quartz grains extracted from sands at 8 localities showed a gradual reduction in NRTL intensity with respect to distance north of the southernmost sample, which is also the accepted direction of longshore transport. This trend is similar to that observed along 150 km of the Israel coast. Differences in NRTL reduction were noted between varying grain size fractions, indicating a differential response to light exposure during travel. Laboratory experiments using simulated sunlight exposure in air and seawater were combined with natural exposure experiments, wherein differences in velocity or residence time between grain size fractions were quantified. Based on this study, drift rates/sediment residence times in the littoral zone along the St. Joseph Peninsula, were estimated. The results of this study indicate the significance of NRTL as a novel method of sand transport analysis.

GS03-02 ARMOURSTONE REVETMENTS, WILL STANDARD DESIGN CRITERIA PREVENT FAILURE?

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Bank stabilization structures are used to prevent the loss of valuable land within the urban environment and the decision for the type of structure used depends on the properties of the stream. If the stream experiences high flow velocities, high shear stresses, and space is limited then decisions are restricted to structural engineering solutions. In the urban areas of Southern Ontario there is a preference for the use of armourstone blocks as bank stabilization. This may be due to its natural appearance, availability, and its apparent structural integrity. Revetments have little or no flexibility and prevent the stream from adjusting its boundaries to changes in flow conditions. An armourstone revetment is a free standing stone structure with large blocks layered vertically or offset from one another. Due to the variable shapes and sizes, adjacent stones do not fit tightly and there are always gaps present leaving the revetment vulnerable to scour. Notable problems that occur are the development of depressions at the top of the structure between the bank and the stone which are enlarged during overbank flows and drainage through the blocks. If the revetment is built on an easily eroded foundation then failure may occur due to basal scour. Although no design standards appear to exist for armourstone revetments, some newly installed structures show design adaptations (vegetation, riprap, and grout) to combat common failures.

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ANNUAL AND EVENT-BASED MEASUREMENTS OF EROSION IN CLAY BED CHANNELS IN THE NIAGARA PENINSULA

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Annual and event-based measurements have been made of erosion on the beds of two small clay bed channels in Niagara Peninsula. Erosion was measured from the exposure of 150 mm galvanised iron nails hammered flush with the bed. Average three years rates were 40 mm in one stream (East Sixteen Mile Creek), and 47 mm in the other (Terrace Creek), with individual measurements ranging from 12 to 95 mm. Event based rates were measured after a series of moderate to near-bankfull flows lasting a few hours to a day in both streams in the spring and summer of 2000. Measurements obtained varied from 2.2 mm to 27 mm with averages of 4.7 mm/event at East Sixteen Mile Creek, and 14.7 mm at Terrace Creek. The figures are consistent with laboratory results reported in the literature which produced rates of the order of 0.2 mm to 1 mm / hour.

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INTERACTIONS OF ASBESTIFORM MINERALS IN THE LUNGS: NEW INSIGHTS FROM REACTION PATH MODELING

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Although the effects on health of the various asbestiform minerals are reasonably well established by the medical community, knowledge of how these minerals evolve by reaction with lung fluid remains poorly understood. Of particular concern for their recognized toxicity are the serpentine-group mineral chrysotile, and asbestiform amphibole-group minerals such as crocidolite (riebeckite) and tremolite-actinolite. Case studies show that the ratio of tremolite/chrysotile asbestos in the lungs of miners and millers of asbestos is generally much higher than in the material to which they were exposed. This can be interpreted as: 1) Chrysotile is more effectively cleared from the trachea, bronchial tubes and lungs than tremolite owing to different mineral morphologies, 2) chrysotile has a higher solubility and/or a faster dissolution rate in lung fluids, and/or 3) chrysotile is converted to tremolite in the lungs. In order to evaluate how asbestiform minerals may evolve in the lungs, we have performed reaction-path modeling using the Geochemist Workbench software to simulate the interaction between an inorganic Gamble's solution (which has a composition similar to blood plasma)and tremolite, chrysotile and small proportions of quartz. Closed-system titration simulations at body temperature suggest that tremolite and chrysotile remain undersaturated at low pH (4.5; close to that in macrophages), and can be replaced by Ca and Mg carbonates, hydroxylapatite, quartz and talc under near-neutral pH conditions (6.8; close to that in blood plasma). Taking into account dissolution kinetics for tremolite,chrysotile and quartz, similar results are obtained for a closed system. Open-system simulations where Gamble's solution is replaced periodically, and allowed to react with the solid products from each successive previous step, also suggest that chrysotile and tremolite would dissolve, leaving a quartz (or amorphous silica) residue at low pH, and be replaced by Ca and Mg carbonates, hydroxylapatite, quartz and talc at the higher pH. These results suggest that both tremolite and chrysotile should remain undersaturated in lung fluid and should dissolve, and that conversion of chrysotile to tremolite does not seem to be a viable mechanism of increasing chrysotile to tremolite ratios in lungs. However, possible transformations of tremolite and chrysotile to other minerals need to be addressed.

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A STUDY OF THE ORIGIN AND BEHAVIOUR OF GASES IN SALT DEPOSITS WITH IMPLICATIONS FOR HAZARDOUS WASTE DISPOSAL

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A petrographic, fluid inclusion, geochemical and gas stable isotope study is reported here for a Permian Zechstein Stassfurt salt deposit in an ongoing study to determine the potential of salt deposits as repositories for hazardous waste. This deposit represents an untectonised, geochemically unaltered sequence. Bromine concentrations show a one-step evaporation profile with no large-scale post-depositional alteration in halite chemistry. Primary, bacterial fermentation gases identified, evolve from a N_2-H_2S-dominated composition in the lower-middle halite series to a CH_4-H_2-dominated composition in the upper halite and potash series. Carbon isotope results for CH_4 show a progressive enrichment up-sequence from typical biogenic values of –45 to –50 ‰ to extremely unusual enriched values as high as +21 ‰. δD values for these enriched CH_4 gases range from –240 to –377 ‰. Associated H_2 have δD values between –667 and –719 ‰. A model is proposed for the formation of the CH_4 gases whereby the dominant isotopic fractionation process controlling the system was evaporation of the basinal brines. This generated a progressive ^{13}C enrichment in the dissolved carbon in the residual brines due to preferential loss of ^{12}C to the atmosphere. The resulting CH_4 trapped in the sediments, as evaporation and precipitation advanced, recorded this enrichment in the carbon reservoir. Therefore, the isotopic profile observed in this sequence today represents a primary depositional feature and indicates that little migration of gases have occurred post-depositionally. This may have important implications for ascertaining the suitability of salt deposits as repositories.

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GS03-06 MONTE CARLO SIMULATIONS OF CHROMIUM (III) OXIDATION BY BIRNESSITE

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Chromium is used in numerous industrial processes and may exist in oxidation states ranging from III to VI. Chromate, a negatively charged anion (CrO_4^{2-}), is a mobile carcinogen in sedimentary environments. Oxidation of chromium III to chromate by manganese oxides consequently has important implications for the risk assessment and remediation of sediments contaminated with Cr-rich waste.

The interaction between $Cr(III)_{aq}$ and MnO_2 has been studied by traditional leach rate techniques and by X-ray Photoelectron Spectroscopy (XPS) where surface composition and oxidation states of both Cr and Mn were monitored. These data provide the constraints necessary to develop a kinetic model to describe Cr(III) oxidation by birnessite (δ-MnO_2).

The developed model utilises a Monte Carlo technique to simulate a complex set of reactions and was tested by comparing simulated results with available experimental results.

The kinetic model consists of four parallel oxidation reactions. These provide an acceptable fit to leach rate data within the constraints provided by XPS and leachate observations. The four reactive species proposed to be involved in the reaction are combinations of three Mn centers within the structure of birnessite. These Mn centers may have oxidation states of IV and/or III, and electron transfers from a central Mn atom (on which Cr(III) is initially adsorbed) to adjacent Mn atoms are proposed to occur. In two of the parallel oxidation reactions, Cr(III) is oxidized to Cr(VI) without Cr being detached from the oxide surface. The other two parallel reactions proceed via a two-step pathway involving Cr(IV) and Cr(V) surface adsorbed intermediate species, as observed by XPS. All four hypothesized kinetic pathways involve the formation of Mn(III) intermediate species.

The model closely reproduces the leach rate data. In the simulation, chromate production is initially rapid, but diminishes as the reaction proceeds as highly reactive sites are exhausted. Relative surface proportions of Mn(IV) decrease during reaction concurrently with an increase in Mn(III).

This simple Monte Carlo technique can be successfully utilized to develop and test kinetic pathways for reactions occurring in the sedimentary environment. An improved understanding of the mechanism by which the oxidation of chromium III by manganese oxides occurs indicates Cr(III)aq and birnessite concentrations, in addition to solution pH, influence oxidation rates. This knowledge is applicable in efforts to limit re-oxidation of chromium and has major implications for wastewater treatment and remediation of contaminated sediments.

GS03-P01

SEDIMENT MAGNETIC RECORD OF POST-COLONIAL ENVIRONMENTAL CHANGES IN FRENCHMAN'S BAY, LAKE ONTARIO

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The colonization of western Lake Ontario was associated with widespread deforestation, soil erosion and a rapid decline in water and sediment quality following the onset of industrialization in the late 1800's. The impacts of these changes on nearshore and coastal environments have been significant but remain poorly understood. In order to better resolve the environmental changes associated with colonization, a detailed study was conducted on the recent sediment record of Frenchman's Bay, in Lake Ontario. Frenchman's Bay (5 km^2) is a shallow coastal lagoon lying on eastern limits of the Greater Toronto Area and was first settled by Europeans in the early 1800s. A total of 15 vibracores (2-4.5 m) were retrieved from the lagoon, the lithofacies logged in detail and magnetic property, micropaleontologic and textural analysis performed on the core samples. Magnetic analyses included measurements of volume magnetic susceptibility, frequency dependence of susceptibility and natural remanence on 8 cm^3 sub-samples. In-situ magnetic susceptibility profiles were also acquired at 40 locations in the lagoon using a probe driven into the sediment column.

The stratigraphic succession in the lagoon consists of a thick upper sequence of gytta and peat-rich silty muds overlying Holocene laminated marls. The correlated magnetic susceptibility profiles identify an uppermost high magnetic susceptibility (÷ = ~15x10^{-6} cgs) unit that extends to 1-1.5 m depth. The unit contains coal fragments and glass shards and records a post-industrial phase in the harbour. The underlying unit consists of peaty marls with abundant wood fragments and Ambrosia pollen, indicating the onset of land clearance and deforestation in the watershed. The third, lowermost unit consists of more carbonate-rich laminated marls (magnetic susceptibility ÷ = ~35x10^{-6} cgs) deposited in a low energy oligotrophic lagoon. The magnetic susceptibililty profiles also identify several discrete sand incursion layers with the marl units that likely record periodic storm overwash events. These results demonstrate the utility of magnetic property measurements as a tool in paleoenvironmental reconstruction of lake basins.

GS03-P02 **SIMULATION OF LANDSCAPE SUCCESSION DYNAMICS BASED ON DELINEATION OF INTEGRATED TERRAIN UNITS: OAK RIDGES MORAINE, ONTARIO**

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The application of Ecological Land Classification (ELC) systems has become increasingly valuable for life science inventories, natural resource planning and landscape scale restoration initiatives. Due to the decreasing cost of remote sensed imagery, and the demand for current data for ecological models, the development of efficient and cost-effective image classification techniques has become an important area of study. However, there are a number of challenges in generating remotely-sensed ELC interpretations including, evaluating accuracy across multiple processes to effectively integrate remote sensed image classification with other more finely resolved interpretive information such as air photo interpretation and site based field investigation of landscape components. We report here on a methodology developed for classifying ELC units in southern Ontario using a 'top-down' remote-sensing approach and a 'bottom-up' spatially-nested Ecological Land Classification field sample design. We have adopted knowledge-based, spatial decision-making approaches in creation of an ecological classification level derived from geomorphic terrain pattern analysis applied to digital elevation data. First, an unsupervised classification is performed for ELC units using mid-resolution (5 meter IRS) satellite imagery. These units are further delineated using interpretation techniques including: 1) detailed aerial photograph interpretation 2) delineation of geomorphically defined terrain units based on feature extraction from data including elevation models and hydrological information, and 3) deriving temporal changes from Normalized Difference Vegetation Index (NDVI) values. The automated delineation of terrain units and the accuracy of the classification are evaluated through air photo interpretation and field evaluation which then serves as the basis for further refinement of classification procedures and decision-making algorithms.

GS-04

ISOTOPE GEOLOGY AND GEOCHRONOLOGY

GÉOLOGIE DES ISOTOPES ET GÉOCHRONOLOGIE

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GS04-01 SULPHUR ISOTOPIC MEASUREMENTS FROM CARBONATITES AND ASSOCIATED SILICATE ROCKS FROM THE SUPERIOR PROVINCE, CANADA

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$\delta^{34}S_{CDT}$ isotopic measurements were made on thirty-four samples from carbonatites and related silicate rocks from five Precambrian carbonatite complexes located within the Superior Province of the Canadian Shield. Pyrrhotite, pyrite and chalcopyrite mineral separates were used. The range in S isotopic compositions are: −4.5 - −3.4 ‰ (mean = −3.9 ‰) for Schryburt Lake, −3.6 - −1.6 ‰ (mean = −2.2 ‰) for Big Beaver House, −1.5 - +0.1 ‰ (mean = −0.7‰) for Cargill, −0.1 - +0.1 ‰ (mean = 0.0 ‰) for Spanish River and +1.3 - +3.4‰ (mean = +1.7‰) for Firesand River. First order observations indicate: (1) variation exists in the S isotopic composition within each complex, outside of the limits of analytical uncertainty (±0.2 ‰), (2) that each complex possesses its own, distinct mean isotopic composition, and (3) overlap in $\delta^{34}S_{V\text{-}CDT}$ between silicate rocks and those from spatially associated carbonatites within the same complex. These data are consistent with observations from elsewhere, e.g. Phalaborwa, Maly, Bol'shoy, Sayan, and in particular those from carbonatite complexes in the Devonian Kola Alkaline Province of Russia, e.g. Sokli, Vuorijarvi and Kovdor.

Many samples have $\delta^{34}S_{CDT}$ values that lie close to the mantle mean of ~0‰, suggesting derivation from a relatively undifferentiated mantle source. The range of $\delta^{34}S_{CDT}$ values is somewhat limited and although small variations can be attributed to different processes (e.g. sulphide mineralogy, oxidation state, rock type and modes of emplacement), our preferred explanation at present is that these differences reflect either an isotopically heterogeneous source or different degrees of isotopic fractionation from an isotopically homogenous source. The S isotopic data presented here are the first ever reported for Superior Province carbonatites.

GS04-02 THE PYRENEAN TALC DEPOSITS: WITNESS OF LARGE SCALE FLUID FLOW

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Talc-chlorite ore deposits in the Central-Eastern Pyrenees were formed by hydrothermal alteration of dolomitic or silico-aluminous rocks to, respectively, talc and chlorite. The more abundant dolomite is in the deposit, the more talc-rich the deposit. Among them, the Trimouns deposit (Ariège) is the world's largest talc mine with estimated reserves of 18 Mt of ore. Pressure-temperature conditions of formation of the talc/chlorite ores range from about 2 to 3 kbar and 250 to 350°C. Fluid inclusions indicate an aqueous salt-rich fluids (up to 30 wt% eq. NaCl). Albian ages ranging from 112 to 97 Ma were obtained by U-Pb dating of xenotime and monazite which crystallised in geods in the Trimouns deposit. This indicates a long-lasting hydrothemal process. This period coincides with the Albian sinistral transtension setting in the Pyrenees, which corresponds to the rotation of the Iberic peninsula around Eurasia along the North Pyrenean Fault. At that time, pull-apart marine sedimentary basins were filled by organic matter-rich black flyschs.

Stable isotopes (O, C, H) show that all deposits have similar signatures. A unique event of regional-scale fluid-rock interaction is therefore suggested for the Central-Eastern Pyrenees talc/chlorite ore formation. The C isotope compositions of minerals range from -6 to 1 ‰. In a single deposit, all these minerals do not equilibrate at the same temperature with the fluid given (i) their different grain size and (ii) the different O isotope diffusion coefficients. A model of down-temperature isotopic equilibration allows a more precise estimate of the fluid isotope composition.Using fluid inclusion data for the temperature of formation, talc, chlorite, calcite and quartz allow to estimate the isotope compositions of the fluid at: $\delta^{18}O$ H_2O = 2.5 to 4.5 ‰ and δD= -30 to 0 ‰. Despite some isotope exchange with the continental crust, the data suggest that origin for the fluid was seawater. This is compatible with (i) the regional scale of the mineralization, (ii) the development of marine basins at the surface, (iii) the large size of deposits which requires high time-integrated fluid fluxes, and (iv) the duration of the hydrothermal system (15 Ma), which implies a fluid source with constant composition.

GS04-03 **HYDROTHERMAL ALTERATION PRESERVED IN A HIGH-GRADE METAMORPHIC SUBMARINE VOLCANIC SEQUENCE, BRAVO LAKE FORMATION, BAFFIN ISLAND, NUNAVUT**

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Stretching eastward across central Baffin Island, the ~1.9 Ga Bravo Lake Formation represents an inter-layered sequence of metaigneous and metasedimentary rocks, which is part of the Paleoproterozoic Piling Group at the northern margin of the Trans-Hudson Orogen. Along the western edge of the Bravo Lake Formation, submarine lava flows, intrusives, and sediments are well exposed. While volcanic textures and structures remain remarkably preserved, petrography indicates that these rocks have undergone almost complete mineralogical replacement since their formation. The present mineralogy preserves peak high-grade upper amphibolite facies and later retrograde metamorphic conditions. In order to understand the fluid/rock interaction between Proterozoic seawater and basic rocks within the Bravo Lake Formation, stable isotopes are used to see through the metamorphism.

Stable isotope analysis of metabasites within the submarine volcanics, intrusives, and sediments of the Bravo Lake Formation indicates a complex history of fluid evolution. Metabasites have whole-rock $\delta^{18}O$ values of +3.0 to +9.5. This deviation from unaltered modern OIB values of +5.7 reflects significant alteration during submarine hydrothermal alteration, with minor effects from retrograde metamorphism and weathering. The stable oxygen, hydrogen, and carbon isotopes measured in individual minerals are related to petrography and stratigraphy, and preserve the signature of the last fluid phase to interact with the rock as well as the original hydrothermal alteration. Some of the minerals preserve the original seawater fluid signature as a record of submarine hydrothermal alteration.

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COMBINED U-PB AND HF ISOTOPIC STUDY OF ZIRCON PROVENANCE FROM TILL SAMPLES, NORTHWESTERN SUPERIOR PROVINCE, MANITOBA

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Detrital zircons in till samples from the northwestern Superior Province (NW of Knee Lake) have been analysed for U-Pb and Lu-Hf isotopes to determine provenance and crustal evolutionary history. Two samples sit within the northern Superior superterrane (NSST; at the northern margin of the Superior Province) and three within the Oxford Lake-Stull Lake terrane (OL-SLT) to the south. A total of 235 zircons have been dated by laser ablation ICP-MS, with 224 of these grains analysed for Lu-Hf isotopes by laser ablation multi-collector ICP-MS.

One grain is 475 Ma, and combined with carbonate clasts in the tills confirms some contribution from the Paleozoic cover to the north. A few grains are 1.0-1.4 Ga and 3.1-3.6 Ga, but the majority are 1.6-2.3 Ga (30% of grains) or 2.6-2.9 Ga (57% of grains).

In detail, the largest age population in each sample occurs between 2702 and 2725 Ma reflecting abundant magmatism in the northwestern Superior Province during this interval. These grains have ε_{Hf} = +8 to –6 with a few –10 to –15 values. The southern samples contain more 2.8-2.9 Ga zircons and these are relatively juvenile with ε_{Hf} = +10 to +2. The 3.1-3.6 Ga grains have 0 to –5 ε_{Hf}.

Hf model ages (using Lu/Hf=0.012) for the Neoarchean grains are typically 2.6-3.3 Ga, and rarely 3.6-3.8 Ga. Model ages are 2.8-3.1 Ga for the 2.8-2.9 Ga zircons, and 3.6-3.8 Ga for the 3.1-3.6 Ga zircons. These data suggest reworking of up to 3.8 Ga crust to produce the Neoarchean magmatic rocks that were the precursors to this detritus. This is similar in age to the oldest zircons dated by previous workers in the NSST. The relatively juvenile nature of the 2.8-2.9 Ga zircons is consistent with previous Nd isotopic studies in the OL-SLT demonstrating that 2.8-2.9 Ga magmatism was juvenile, contrasting strongly with adjacent terranes.

The largest Proterozoic peaks occur at 1.82-1.93 Ga. These zircons have ε_{Hf} values of +8 to –19 and 2.0-3.3 Ga Hf model ages. These data suggest that Proterozoic crust was in part juvenile and in part reworked much older Archean crust. A similar pattern is observed in the Superior boundary zone and adjacent Kisseynew domain of the Trans-Hudson orogen.

Combined U-Pb and Hf isotopic data allow a more accurate reconstruction of provenance in detrital samples than U-Pb data alone, and in this case suggest relatively local origin for zircon from till samples in the far northwestern Superior Province.

GS04-P01

U-PB ZIRCON AND MONAZITE GEOCHRONOLOGY OF GRANITIC GNEISS FROM CREE EXTENSION, WOLLASTON-MUDJATIK TRANSITION ZONE, NORTHERN SASKATCHEWAN

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New, high-quality U-Pb results from basement drill core in the Cree Extension area are presented here for regional stratigraphic correlation and thermotectonic interpretation of the eastern sub-Athabasca basement. Sample CX-28 is an Archean granitic gneiss from the Cree Extension area, Wollaston-Mudjatik Transition Zone, Saskatchewan. The granitic gneiss overthrusts Wollaston Group pelitic to psammopelitic gneisses and Archean tonalitic-trondhjemitic gneisses, in the vicinity of basement-hosted unconformity-type U mineralization. The sample yielded both zircon and monazite for U and Pb analyses by IDTIMS methods.

Most zircons are metamorphically rounded, cracked, hazy, colourless prismatic crystals. Some clear, pale brown fragments are also present, giving the least discordant data. Six, single-zircon analyses are variably discordant (0.8% to 2.8% discordant) and show a small amount of scatter, correlating loosely with U concentration. Analysis sk16p74 with 398 ppm U shows slightly earlier Pb loss than the other lower U grains, and 2 of the lowest U grains plot closest to the concordia curve as is normally expected, although sk16p96, which has the lowest U concentration, is one of the most discordant points. A line calculated through all 6 data gives an upper intercept age of 2727+/-36 Ma and a lower intercept age of 1937+/-260 Ma (MSWD=3.2). If only 4 data are used in the regression, the upper intercept age is 2731+/-25 Ma (MSWD=0.043). An absolute minimum age estimate for the granite is given by the least discordant data with a $^{207}Pb/^{206}Pb$ age of 2705.4+/-4.3 Ma.

Monazite occurs as flat, shiny, yellow crystal fragments that contain moderate concentrations of U (200-300 ppm) and high Th/U of 23-29. Three, single monazite analyses gave discordant (1.9% to 6.6%), colinear data that have an upper intercept age of 1791.3+8/-7 Ma (46% probability of fit). A line calculated through the zircon data and anchored at the time of monazite formation gives an upper intercept age of 2704+/-16 Ma, with a poor MSWD of 4.8. The projection of such a line is extensive, hence the near colinearity of the zircon data strongly suggests that the event that formed the monazite also induced Pb loss and morphological rounding in the zircon grains. However, the best estimate for the granite crystallization age is given by the zircon data alone at 2731+/-25 Ma (96% probability of fit). These zircon results are nearly identical to those obtained from some samples of the ca. 2740-2700 Ma TTG suite in the Close Lake, McClean Lake, and Karpinka Lake areas.

GS04-P02 A PB/PB AGE FOR MONAZITE FROM A REE-ENRICHED QUARTZ-APATITE VEIN, ÈUÈMA, SLOVAKIA

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New U-Pb results from a REE-enriched quartz-apatite vein, Cucma, Slovakia are presented here for regional stratigraphic correlation and thermotectonic interpretation of the early Paleozoic Gemeric Superunit, Slovakia. The Early Paleozoic rocks of the Gemericum Unit are represented by rhyolite metatuff, chlorite - sericite phyllite, quartz - sericite phyllite, black phyllite and lydite, intruded by the strongly peraluminous Gemeric granite suite. The granites were emplaced into upper crust at 5 to 8 km depth. Quartz and quartz - apatite veins with uranium mineralization accompanied by rare earth element minerals are often situated in the vicinity of Gemeric granites in the Early Paleozoic rocks. The quartz-apatite vein yielded monazite for U and Pb analyses by IDTIMS methods.

Monazite and xenotime were identified petrographically and by SEM by both Igor Rojkovic and SRC researchers. However, identifying these minerals under binocular microscope proved to be challenging as they are present as colourless, cracked, hazy fragments dissimilar in appearance to the more "typical" yellow, crystalline monazite that is commonly observed in intrusive rocks. Grains that are similar to those that were dated in this study have been identified as a Ce-rich phosphate mineral using the ROM's SEM energy dispersive analyzer. Seven such crystals were individually analyzed for U and Pb. The data are unusual in that they are all reversely discordant to varying degrees, and attributed to U loss from the system. The $^{207}Pb/^{206}Pb$ ages are independent of recent U migration from the system and should give the time of formation of the grains. The weighted mean $^{207}Pb/^{206}Pb$ age for 7 analyses is 201+/-33 Ma (MSWD=1.05). Determination of a precise Pb/Pb age was not possible due to the low radiogenic-to-common Pb ratios, and specifically the low $^{207}Pb/^{204}Pb$ ratios, which resulted in greater uncertainties in the individual $^{207}Pb/^{206}Pb$ ages. If only the 4 data with the highest $^{207}Pb/^{204}Pb$ ratios are included in the weighted mean age, the age is 195+/-37 Ma (MSWD=1.02).

Monazite crystallized as overgrowths on apatite at ca. 200 Ma, or as a REE-rich replacement product along the surfaces of vein apatite during a post-vein emplacement, REE-mineralization event. Recent data on monazite suggests the oldest Pb-Pb data (271 to 268 Ma) corresponding to monazite dating in granite represent the age of their formation. Younger data (down to 140 Ma) reflect the Alpine thermal overprint.

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GS04-P03 PROVENANCE AND BASINAL FLUID IMPLICATIONS OF A MONAZITE STUDY IN THE LOWER BELT-PURCELL SUPERGROUP, NORTHWESTERN MONATANA

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Chemical dating was calculated for 105 analyses on monazite grains from coarse sandstones and siltstones in the siliciclastic Appekunny and Grinnell formations, from the lower Belt-Purcell Supergroup in Glacier National Park, northwestern Montana. The scope of this study is to determine the age and the monazite REE profile of the provenance area for these two facies, and to establish a timeframe for basinal fluid events.

In other studies the duration of sedimentation within the lower-middle Belt-Purcell Supergroup has been calculated to be up to 25 Ma. A maximum age of sedimentation of 1468 ± 2 Ma has been determined dating magmatic zircons extracted from a sill, situated near the base of the Supergroup. A minimum age of 1454 ± 9 Ma was obtained dating zircons extracted from a tuff horizon in the upper part of the middle Belt sequence.

Two main source areas have been suggested from several studies for the Belt-Purcell Supergroup. The Laurentian craton in the East contributed with coarse material and an unknown terrane in the West for the fine-grained sediment.

Chemical ages that were calculated vary from a minimum of 312 Ma to a maximum of 2,523 Ma for siltstones and from 445 to 2,415 Ma for sandstones. When dates are plotted siltstones cluster between 1,801 and 1,968 Ma, as well as between 854 and 912 Ma. Dates obtained from the coarse sandstone facies group between 1,793 and 1,868 Ma, and between 944 and 815 Ma. A wide range of dates plots between the clusters for both facies.

The wide range of ages is interpreted to be the result of a major contribution from a source area ~1.8 to1.9 Ga old, a marginal contribution of a ~2.5 Ga terrane, which explains the oldest grains, and the reset of most of the monazite grains due to basinal brines that mobilized the REE of the original sediment. The source area for the sanstones and siltstones has the same age. The second cluster for sandstones and siltstones is viewed as a major basinal fluid event dated ~0.81 to 0.95 Ga ago.

GS04-P04 IMPLICATIONS OF THE RESEMBLANCE BETWEEN MONAZITE AND WHITE MICA AGES IN THE ORLICA-SNIEZNIK DOME BOHEMIAN MASSIF, CZECH REPUBLIC AND POLAND

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The Orlica-Snieznik Dome is a metamorphic core-complex that constitutes the internal part of the mid-European Variscides of the Bohemian Massif that is situated between the Czech Republic and Poland. The Dome is intruded by syn-tectonic and post-tectonic granitoids. Gieraltów granulite outlines an isolated boudine surrounded by amphibolitic-grade Gieraltów gneisses.

Monazite grains have been dated using CHIME, the chemical dating technique, for two different locations in the Orlica-Snieznik Dome: the Gieraltów granulite and the Litice microgranite. One hundred and seventy two analyses were performed on monazites from Gieraltów, in south-western Poland, as well as 195 analyses on monazites from Postejn', in north-western Czech Republic.

Age patterns for the Gieraltów granulite are consistent with isochron of ca 289 Ma, with a maximum age of 331 Ma. Litice microgranite yield dispersed ages with a main cluster around 315 Ma and remaining ages at ca 250 Ma. The oldest age found is 350 Ma. The youngest ages could be related to analytical uncertainty due to low levels of Pb and with an over-estimate of YLr interference on PbMa. The lack of older ages indicates that monazite grains were crystallized in a short tectono-thermal event during the Variscan orogenesis.

These results show that CHIME ages on monazites are similar to the cooling age of the Orlica-Snieznik dome crystalline rocks established previously by isotope dating such as: Ar/Ar: 337 to 341 Ma for white mica, 334 to 342 Ma for biotite, 283 to 300 Ma for biotite and hornblende; and ca 342 Ma from U/Pb on zircon using the SHRIMP. The narrow range of these data support the crystallization process occurring slightly before the event of exhumation and cooling of the Orlica-Snieznik Dome complex.

The data are interpreted as the result of a rapid exhumation coeval with the uplifting of the Orlica-Snieznik crystalline Dome as one block made of multiple rock composition. Time span between crystallization of monazite and cooling of the massif to 320°C was limited to several million years.

Research supported by the Polish State Committee for Scientific Research, grant No. 3PO4D04724 and The Matsumae International Foundation.

GS-05

MINERALOGY AND CRYSTALLOGRAPHY

MINÉRALOGIE ET CRYTALLOGRAPHIE

GS05-01 THE CRYSTAL CHEMISTRY OF SILICATE MINERALS WITH CHAINS OF (TiO_6) OCTAHEDRAL

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Currently, the crystal structures are known for about 120 Ti-O compounds, half of them Ti silicates, and half of them Ti oxides. Usually, Ti silicates occur as rare accessory minerals (except titanite) and they are less widespread than Ti-oxide minerals. In many Ti-silicate minerals, Ti <-> Nb substitution is common, and when we refer to (TiO_6) octahedra, we include({Ti,Nb}O_6) octahedra. In a crystal structure, linkage of (TiO_6) and (SiO_4) groups involves only common vertices. There is one common feature of (TiO_6) and (SiO_4) polyhedra: they tend to self-polymerize, forming one-, two- and three-dimensional linkages., connected via common vertices or edges. Diversity in Ti-silicates results from two factors: (1) self-polymerization of (TiO_6) and (SiO_4) polyhedra; (2) the dimensional similarity of motifs of polymerized (TiO_6) octahedra and (SiO_4) tetrahedra that allows these motifs to link together easily in a crystal structure. There are two types of self-linkage of (TiO_6) octahedra: (1) through a common vertex, and (2) through a common edge, each type of linkage producing a chain of (TiO_6) octahedra. Chains of (TiO_6) octahedra occur in several crystal structures as fundamental building blocks, confirming the tendency of self-polymerization for (TiO_6) octahedra. There are two topologically distinct types of chains based on linkage of (TiO_6) octahedra, corner-sharing chains and edge-sharing chains. We focus on the diversity of linkages between chains of (TiO_6) octahedra and (SiO_4) tetrahedra.

In Ti-silicate structures based on chains of corner-sharing ($Ti^{4+}\varphi_6$) octahedra, the chains are neither branched nor looped; they are topologically simple [$Ti\varphi_5$] chains. The chemical formulae of such structures may be written in a very general way as Na_2a (TiO_2)a [Si_c $O_{2(a+c)}$] where a and c are integers. This is not an arbitrary formula; the bond topology is such that all anions obey the valence-matching principle. The formulae of batisite, narsarsukite, titanite, the minerals of the labuntsovite group and quartz (Ti-free) are in accord with this general formula. In structures based on chains of edge-sharing (Ti^{4+} φ_6) octahedra, the chains may be simple, branched or looped, and there is usually another complicating factor to the bond topology: additional components [e.g., (PO_4), Cl, $^{[4]}Al$, Cr^{3+}] are common. There are numerous silicate minerals containing chains of (TiO_6) octahedra. In contrast, layers of (TiO_6) octahedra are rare and occur only in four structure types, and frameworks of (TiO_6) octahedra are not known in silicate minerals.

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A POWDER NEUTRON DIFFRACTION STUDY OF THE ATOMIC STRUCTURE AND HYDROGEN BONDING OF GOSLARITE ($ZnSO_4$•$7H_2O$)

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Mine waste created from the oxidation and hydration of sulfide minerals at mine sites leads to very complex geochemical problems as the ore interacts with surface air and water. Detailed mineralogical investigations of the many phases that result are essential for us to understand the processes at work in these environments. The mineral goslarite ($ZnSO_4$•$7H_2O$) has been observed worldwide as a sphalerite (ZnS) oxidation/hydration byproduct and is known to dehydrate to bianchite ($ZnSO_4$•$6H_2O$), boyleite ($ZnSO_4$•$4H_2O$) and gunningite ($ZnSO_4$•H_2O2O). The atomic structure of synthetic, deuterated goslarite ($ZnSO_4$•$7D_2O$), a 11.811(1), b 12.069(1), c 6.8244(7) Å, space group P 21 21 21, Z = 4, has been refined using two powder neutron diffraction histograms to wRp 1.86 % and Rp 1.39 %. The results of this study confirm the H-bonding scheme for goslarite is the same as that of the other epsomite group minerals. Small but significant distortions of the Zn-O bond lengths can be attributed to details of the H-bonds to the O-atoms of the Zn-octahedra. This investigation of the atomic structure and hydrogen bonding of goslarite is part of the ground work for future studies into phase relationships and the mechanisms of hydration and dehydration in the Zn-SO_4-H_2O system. Future work will involve X-ray diffraction studies of these hydrous phases as they dehydrate and re-hydrate under controlled relative-humidity and temperature.

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GS05-03 COMPLEX GENESIS AND EVOLUTION OF CARBONACEOUS MATTER IN THE BASEMENT ROCKS OF THE ATHABASCA BASIN, CANADA: EVIDENCE FROM RAMAN SPECTROSCOPY

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Twenty samples of graphitic carbonaceous matter (GCM) in metamorphic rocks from various localities in the basement of the Athabasca Basin, Canada, were studied using micro-laser Raman spectroscopy to investigate their crystallinity and potential as source for the organic matter present in the world class uranium deposits of the area.

In situ measurements of GCM in thin section were performed using laser Raman using a Dilor LABRAM confocal-Raman spectrometer equipped with a frequency-doubled Nd-YAG laser (100 mW, 532.2 nm). The spectrum for a single point was collected for 20 seconds and 5 spectra were averaged; several points were analysed per slide. Both first (1100-1800 cm^{-1}) and second (2400-3300 cm^{-1}) order spectrums were collected, but here we focus on the 1100-1800 $^{-1}$ area. Peak position (cm^{-1}), peak intensity (arbitrary units, a.u.), peak area as a percentage of total area, peak width (full width at half maximum, FWHM), the D_1/G peak intensity ratio (R_1), and the D_1/(G+D1+D2) peak area ratio (R_2) were determined for each point.

Results of decomposition of Raman spectrum identify the presence of three peaks: D_1 peak that is located at around 1350 cm^{-1}, the G peak at around 1580 cm^{-1}, and D_2 peak at around 1620 cm^{-1}.

Peak D_1 varies in position from 1344 to 1356 cm^{-1}, FWHM from 39 to 63 cm^{-1}, intensity from 62 to 3370 a.u., and area from 23 to 66 %. Peak G varies in position from 1581 to 1589 cm^{-1}, FWHM from 17 to 50 cm^{-1}, intensity from 383 to 2045 a.u., and area from 22 to 67 %. The D_2 peak varies in position from 1607 to 1653 cm^{-1}, FWHM from 9 to 75 cm^{-1}, intensity from 34 to 831 a.u., and area from 1.95 to 18.76 %. R_1 ratios vary from 0.12 to 2.01, and R_2 ratios vary from 0.23 to 0.66.

Metasedimentary rocks generally contain organic matter, and during metamorphic processes this organic matter is progressively transformed into graphite, and the degree of organisation of GCM is a reliable indicator of metamorphic grade. The results from this study indicate that graphite crystallinity does not concur with the peak metamorphic grade of the host rocks. Consequently, the GCM investigated indicates a complex genesis and history of evolution. Such a complex history can readily be explained by multiple phases of carbon precipitation before (?) and after peak thermal metamorphism, and not by downward migration of organic matter from the overlying sedimentary rocks.

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GS05-04 **M-XRD CHARACTERIZATION OF ASR-REACTIVE AGGREGATE: STRUCTURAL OR TEXTURAL TRIGGERS**

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Alkali-silica reaction (ASR) is a chemical reaction that may occur between certain silica-bearing concrete aggregates and the high-alkali solution in the pores of Portland cement concrete (PCC), producing an expansive alkali-silica gel. Deleterious effects such as expansion and cracking may result in greatly reduced life-span of the affected structure or require costly remediation. The extreme expansion documented at the Beauharnois hydro-electric dam (Quebec) is a classic ASR effect. The culprit in that case is the locally-quarried Potsdam Sandstone (Chateauguay, Quebec) a well-sorted, remarkably pure silica sandstone. Despite macroscopic chemical similarity to the Potsdam Sandstone, the relatively pure quartzite from Petit Lac Malbaie (Quebec) is notably non-reactive in PCC. Thus, silica in itself is not necessarily reactive. The culprits responsible for ASR are generally agreed to be rocks containing metastable silica species or microcrystalline silica. Identification of non-reactive aggregate materials is a challenging problem involving petrographic examination followed by laboratory tests such as the year-long concrete prism test or the less reliable 14-day Accelerated Mortar Bar Test.

Rapid characterization of ASR-reactive aggregates and identification of possible triggers to reactivity is desirable. This has inspired a systematic survey of aggregates by micro-X-ray diffraction (u-XRD). A selection of reactive and non-reactive aggregates have been examined by micro-XRD of polished sections, rock slabs and concrete slabs, using a Bruker D8 DISCOVER with $Cu_{K\alpha}$ radiation and two microbeam diameter settings (50-500 um). Because individual phases are X-rayed in situ, orientational relationships are preserved. A two-dimensional GADDS area detector has allowed documentation of crystallinity as well as strain textures. Chalcedony from a known ASR-reactive limestone (Spratt's quarry, Ottawa) and two different potentially reactive cherts (from Englehart River Bridge concrete, built using Adam's Mine development rock, Kirkland Lake) are characterized by homogenous diffraction arcs reminiscent of powder rings, indicative of microcrystallinity. Lattice strain patterns obtained from the reactive Potsdam Sandstone can be differentiated from lattice strain patterns obtained from the non-reactive quartzite based on the degree to which strained zones contain discrete sub-zones. In the reactive rock, strain arcs often take the form of streaks with fine tails while in the non-reactive rock, each strain arc is resolved into discrete sub-zones with no tails. Microcrystallinity and unresolved lattice strain, likely triggers of ASR, are readily identifiable by u-XRD.

GS05-05 VIOLET LASER INDUCED FLUORESCENCE: A NEW TOOL FOR MINERAL IDENTIFICATION

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Classically, mineral fluorescence under ultra violet light has been utilized as a prospecting tool to locate and positively identify specific ore minerals (scheelite, uraninite, willemite, wernerite) as well as identifying collected minerals occuring in unusual rocks and/or locations (i.e. Franklin and Sterling Hills, Mont St-Hilaire, etc.). Their identification can be ambiguous or difficult, if solely based on the fluorescent colours, as the human eye offers very little resolution in the red and blue parts of the visible spectrum. Moreover, visual descriptions of colours often lack consistency from one individual observer to another.

In our experiments, we use two new tools in order to improve the method: 1) A spectrometer replaces the human eye, distinguishing spectral peaks and broad curves which quantitatively record the fluorescence spectrum. 2) A violet laser replaces the excitation source ensuring a monowavelenght energy of excitation. Most UV sources have spurious peaks which produce a noisy spectrum. It appears that each UV peak (254, 313 and 365 nm for Hg lamps) produces its own fluorescent spectrum.

Our experiments have revealed that several minerals have a unique fluorescent spectrum (willemite, kyanite, wernerite, etc.), others have specific peaks which distinguishes them from other minerals (corundum, beryl, apatite, etc.), and others simply produce variable spectrum from one specimen to another, most probably due to major changes in their chemical composition (beryl, calcite, fluorite, etc.).

The technique holds potential not only as a complimentary tool to identify minerals but as a non destructive method to identify gems or delicate specimens. We relabelled one of our museum specimen after discovering it was an apatite crystal mislabelled as corundum. Minerals such as scheelite, known to fluoresce only under short-wave ultra violet (SWUV) light do not fluoresce under violet laser light, however, fluorescence was observed in minerals that were never documented as fluorescent under UV light, for example, emerald (fluorescent deep red) and kyanite (fluorescent bright red and sky blue).

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GS05-06 STATISTICAL CHARACTERISTICS OF OSCILLATORY ZONING IN CALCITE FROM ROSSLAND AREA, BRITISH COLUMBIA, CANADA

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Cathodoluminescence technique has been used qualitatively to detect the trace element (manganese) distributions in a crystal of calcite from Rossland area, British Columbia, Canada. Observed oscillatory zoning was investigated in terms of grey-level data collected along a traverse at right angle to zoning. To order to statistically characterize the zoning pattern, fractal geometry and Fourier analysis were used. The measured Hurst exponents by methods of the width and the power spectrum are in the range of 0.56-0.6 indicating the oscillatory zoning pattern is persistent.

GS05-P01 THE LUMINESCENCE DECAY-TIME OF CALCITE

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Luminescence decay time data are presented for 18 samples of natural and synthetic calcite between room temperature and approximately 15 K.

The luminescence decay spectra for samples having Mn concentration in the range 0.0001 to 0.01 atoms per formula unit (apfu) are consistent with a single exponential decay. It was necessary to use a "stretched" exponential to obtain adequate fits to the spectra of samples having Mn concentrations higher than 0.036 apfu.

The decay time at room temperature ranges from approximately 40 to 57 ms. At low temperature the corresponding range is 51 to 120 ms, indicating that thermal quenching of the decay-time takes place. The decay-time is dependent on the concentration of Mn, reaching a maximum (at both room- and low-temperature) in the range 0.001 to 0.003 apfu. The composition dependence is greater at low temperature.

The results are discussed in terms of the Mott-Seitz and multiphonon mechanisms of thermal quenching.

GS05-P02 QUENCHING OF LUMINESCENCE IN CALCITE BY FE AND MN

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There is a debate about the roles of self-quenching by Mn and quenching by Fe in calcite, particularly in the sedimentological literature, with some authors favouring the idea that it is the Mn/Fe ratio alone that is important and others arguing that the combination of absolute and relative concentrations is important.

The present work reports some theoretical considerations, from a mineralogical perspective, that provide insight into this issue. It is shown that both absolute concentrations and Mn/Fe ratios must be considered if quenching in natural carbonates is to be understood. In addition, it is shown that order-disorder of activator and quencher will exert an influence on the effectiveness of quenching, and therefore, on the brightness of the resultant luminescence.

GS05-P03 CATHODOLUMINESCENCE AND THERMOLUMINESCENCE OF NATURAL ZEOLITES

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Cathodoluminescence (CL) and thermoluminescence (TL) of natural zeolites have hardly been reported up to present. We have confirmed the CL emission from eight zeolite minerals; bikitaite, brewsterite, edingtonite, ferrierite, gobbinsite, gonnardite, harmotome, stilbite and thomsonite, and TL glow peaks at low temperature for X-ray induced samples.

CL spectra and CL images were obtained employing a new system of SEM-CL, which comprises a SEM (Jeol JSM-5400) combined with an integral grating monochromator (Oxford Mono CL2), at 15 kV and 1.0 to 20 nA. The stage can be controlled with liquid nitrogen and embedded heater. TL measurements were carried out with a low-temperature TL system originally arranged for wide temperature range above liquid nitrogen temperature.

Bikitaite shows the characteristic blue CL, of which spectrum has a broad band peak at 460 to 470 nm. By considering the occurrence of bikitaite in pegmatite, the blue CL of bikitaite might be related to structural defects observed in quartz and other silicates, since the radiation from radioactive pegmatite minerals can yield structural defects (e.g. oxygen hole center) in the lattice of bikitaite.

The other zeolites have similar CL spectra with a broad band peak at 510 to 540 nm. Most samples of brewsterite and harmotome exhibit green CL with relatively high intensity, while only a few samples of edingtonite, ferrierite, stilbite and thomsonite give a weak CL emission. Such green CL is supposed to be caused by the impurity of divalent Mn ions as an activator. Mn concentrations, however, even in brewsterite and harmotome are almost lower than detection limits of quantitative EPMA. Furthermore, rare earth elements substituted for Ba and/or Sr in brewsterite and harmotome seem to be CL centers because all samples of phillipsite, of which Ba analogue is harmotome, show no CL emission.

CL spectra of bikitaite, brewsterite and harmotome at room temperature and low temperature indicate the reduction of the CL intensity with a decrease in temperature. In general, however, the CL intensity can be expected to be increased at low temperature due to temperature quenching effect. X-ray induced samples show distinct TL glow peaks at low temperature, whereas there is none of glow peaks for natural TL. This phenomenon unique to zeolite minerals implies that excited electrons induced by electron irradiation may be captured at trapping centers with shallow energy level in low temperature and non-radiative transition might be consumed for energy transfer and /or cross-relaxation.

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GS05-P04 AUTHIGENIC AU RIMS ON PGMS AND CHROMITE FROM THE NOVY LOG PLACER, NIZHNY TAGIL MASSIF: NEW EVIDENCE FOR THE ORIGIN OF AG-POOR RIMS ON PLACER GOLD

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When a placer gold specimen is sectioned and examined, it is typically observed to comprise an Au-Ag core surrounded by a rim of gold that is Ag-poor in composition. These rims are not considered a primary feature; instead, they develop after the grains have been liberated from their source rock. However, no consensus exists regarding their genesis and development: (1) the rims are the result of Ag-removal; and (2) the rims are the result of Au-addition.

The Nizhny Tagil massif, located c. 40 km southwest from the town of Nizhny Tagil in the Middle Urals, Russia, forms part of the 900 km-long platinum belt of the Urals, and represents an undisputable example of a zoned Uralian-type clinopyroxinite-dunite complex. The complex contains variable amounts of platinum group minerals (PGMs) that are locally associated with chromite, forsterite ± serpentine and diopside; Pt-Fe alloys predominate, and generally occur as a core of Pt_2Fe (Pt=PGE; Fe=[Fe+Cu+Ni]) that is rimmed by Pt(Fe,Cu) and/or tulameenite (Pt_2FeCu). Other PGMs, such as laurite, Ir-Os and Os-Ir alloys occur in subordinate amounts.

Investigation of placer samples from the Novy Log placer, located 2.5 km to the east of the Nizhny Tagil massif, indicate a similar PGM assemblage to that observed in the dunite and chromatite bedrock. In addition to PGMs, gold grains are present within the heavy mineral assemblage. Not all of the gold grains are 'typical placer gold grains'; instead, they comprise a PGE/chromite core surrounded by a rim of Au. This core-rim structure is not observed in the host rock, thus is not considered a primary feature; instead, we propose it to have developed after the PGMs and chromites were liberated from their source, the Nizhny Tagil massif.

We contend that the Au rims present on the PGM minerals may be analogous to the Ag-poor rims present on many placer gold grains. However, the development of Au rims on PGMs must be due to the addition and precipitation of Au from an external source. They cannot be due to the removal of Ag from a primary Au-Ag grain, nor can they be due to the addition of new gold from an internal source by a self-electro refining method.

Consequently, this study conclusively indicates that Ag-poor rims on placer gold are the product of Au-addition from an external source, and supports the low temperature aqueous transport of gold in the surficial environment.

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GS05-P05 UNUSUALLY HIGH-GRADE CONTACT METAMORPHIC MARBLE AT WEST CLEARWATER IMPACT CRATER, NORTHERN QUEBEC

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The meteorite impact that originated the 32 km wide, Upper Pennsylvanian (285 ± 23 Ma) West Clearwater structure, situated about 125 km East of the Hudson Bay arc, has formed a sheet of impact melt that is now exposed on a central ring of islands. At least seven marble enclaves have been mapped in the melt sheet; this report is based on observations made on samples from two of these enclaves. These blocks represent recrystallized remnants of a cover of Middle Ordovician limestone, now completely eroded in the area. While the impact melt was still above its solidus, the locally fossiliferous dolomite-bearing limestone recrystallized to polygonal granoblastic calcite + periclase marble. The silica content of the marble, and small amounts of Si possibly added via a fluid phase released from the impact melt, led to the formation of a sanidine-facies assemblage of unusual nesosilicates such as spurrite - $Ca_5(SiO_4)_2(CO_3)$ -, merwinite - $Ca_3Mg(SiO_4)_2$ - and monticellite - $CaMgSiO_4$. Aluminian srebrodolskite - $Ca_2Fe_2^{3+}O_5$ -, the Fe^{3+} analogue of brownmillerite -$Ca_2(Al,Fe^{3+})_2O_5$ - is found in material with a composition similar to “Portland cement clinker”. At the type locality, srebrodolskite is attributed to the calcining of ankeritic carbonate. Phase equilibrium and stratigraphic data constrain peak conditions of metamorphism at T»815° ± 15°, P < 200 bar and XCO_2 < 0,1. Portlandite - $Ca(OH)_2$ – is one of several species formed during late hydration upon cooling.

GS-06

PETROLOGY (IGNEOUS AND METAMORPHIC) AND VOLCANOLOGY

PÉTROLOGIE IGNÉE ET MÉTAMORPHIQUE, ET VOLCANOLOGIE

BRIAN COUSENS

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GS06-01

THE SIGNIFICANCE OF SPINIFEX TEXTURES IN CONSTRAINING THE MODE OF EMPLACEMENT OF PRECAMBRIAN KOMATIITIC AND FERROPICRITIC ROCKS: THE BOSTON CREEK SILL

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The presence or absence of spinifex textures has been used as an indicator of either extrusive or intrusive mode of emplacement by many authors for Precambrian komatiitic and ferropicritic rocks. However, mapping at Dundonald, Munro, and McArthur Townships within the Abitibi subprovince of Ontario indicates that many units containing spinifex-textures are clearly thin komatiitic sills or dikes. Furthermore, experimental studies have shown that spinifex textures may form by crystallization of moderately- to strongly-undercooled, high-Mg, low-Si melts, regardless of their extrusive or intrusive emplacement. We report here new field observations suggesting that the thick, Boston Creek ferropicrite unit in the Abitibi greenstone belt, which contains a pyroxene spinifex-textured zone locally up to 35 m thick and that has previously been interpreted as extrusive, is intrusive. This new interpretation highlights the dangers of using the presence of spinifex texture as the only criterion in distinguishing between extrusive and intrusive komatiitic and ferropicritic rocks. The Boston Creek unit is an ~100 m-thick, semi-conformable, differentiated meta-ferropicrite that extends over ~36 km along the eastern margin of the Round Lake Dome. The “type-section” in Boston Township comprises, from base to top: a 3.5 m thick fine-grained pyroxenitic lower margin, a 30 m thick peridotitic zone, a 10m thick pyroxenitic zone, a 15 m thick gabbroic zone, a 35 m thick spinifex zone containing several vesicle horizons in its the upper part, and a thin upper chilled margin. The underlying rocks are massive and pillowed high-Mg meta-basalts, whereas the overlying rocks are massive, pillowed and amygdaloidal mafic to intermediate meta-volcanic rocks with lesser volcaniclastic rocks. New mapping and manual stripping of the upper part of the Boston Creek unit at four locations indicates that the upper contact is locally characterized by: 1) xenoliths of the overlying volcaniclastic rocks in the upper part of the unit; 2) apophyses of the upper border zone projecting into the overlying intermediate volcanic rocks; 3) irregular and lobate upper contacts; 4) disappearance of the overlying volcaniclastic rocks; and 5) minor peperite. These features suggest that the Boston Creek unit is a high-level sill, and indicate that 1) thick, well-developed spinifex-textured zones may form in intrusions as well as flows, and 2) that spinifex textures must not be used as the primary evidence for an extrusive or intrusive origin for komatiitic or ferropicritic rocks.

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FRACTIONAL CRYSTALLIZATION OF KOMATIITIC MAGMA IN THE PROTEROZOIC FOX RIVER BELT: NORTHERN MANITOBA

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The Fox River Belt is a homoclinal sequence of sediments and mafic/ultramafic magmatic rocks that forms the boundary between the Superior and Churchill Provinces in north-eastern Manitoba. Its magmatic products share a similar tectonic position, stratigraphy and chemistry with other segments of the Circum-Superior Belt; specifically the Thompson Nickel Belt and the Cape Smith Belt. The Lower and Upper Volcanic formations of the Fox River Belt are chemically and volcanologically indistinguishable and could represent a thrust repeated sequence. Each volcanic formation appears to evolve in composition from komatiites (20% MgO, A member) at the base, to tholeiitic basalt (6% MgO, D member) in the upper portions. The compositional evolution of the rocks can be linked to fractional crystallization of three mineral assemblages: stage 1) olivine and chromite, stage 2) clinopyroxene, plagioclase and olivine, and stage 3) plagioclase, orthopyroxene, clinopyroxene, and magnetite.

The chromite-bearing dunites of the Lower Central Layered Zone in the Fox River Sill may be the products of the first stage of fractional crystallization. The evolving magma from this stage of fractional crystallization is responsible for the A, B, and C members of the volcanic stratigraphy. The other two stages of fractional crystallization are more difficult to link to a cumulate rock, due to complex layering within the Upper Central Layered Zone of the Fox River Sill. The residual magma from stages 2 and 3 is significantly underrepresented within the volcanic stratigraphy. The accelerated rate of crystallization within these stages of fractional crystallization as modelled in MELTS and PELE could account for this compositional gap in the volcanic stratigraphy. Pt and Pd depletion has been identified within the uppermost member of both volcanic formations, suggesting that magmatic sulphide was removed from the parent magmas to these flows. The Upper Central Layered Zone of the Fox River Sill hosts zones of PGE mineralization, which may explain the observed PGE depletion in the upper parts of the volcanic formations.

GS06-03 STRONTIUM IN MINERALS OF MESOPROTEROZOIC IGNEOUS ROCKS NEAR BUCKINGHAM, QUEBEC

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Mesoproterozoic, high-Sr igneous rocks (dated at 1060 Ma by U/Pb in zircon and baddeleyite) extend in a narrow belt, 40 km long, south-southwesterly through Buckingham to just east of Ottawa. South of the Ottawa River, they can be traced below Paleozoic cover by a positive magnetic anomaly, but in Quebec the rocks crop out in a series of small volcano-plutonic complexes (up to 3.0 x 1.3 km) with associated dykes between them. The complexes overlie or cut through Grenville metasediments but are, themselves, transected by Neoproterozoic diabase dykes. Rock types include leucorates (pale alkali-feldspar syenite to leucomonzonite) and melanocrates (dark alkali-feldspar trachyte to latite, alkali-feldspar melasyenite to monzodiorite, and lamprophyres). Lamprophyres comprise minette, kersantite and vogesite.

High SrO in sanidine (up to 1.7%) and oligoclase (up to 2.5%) characterizes the groundmass of minette, coring a small stock of alkali-feldspar melasyenite. Microcline in nearby alkali-feldspar melasyenite, monzonite and trachyte is also rich in SrO (up to 0.8%). Associated plagioclase invariably contains more Sr than neighboring K-feldspar, a feature of alkalic rocks elsewhere but, at Buckingham, some plagioclase and K-feldspar may not represent equilibrium pairs. In a nearby pluton, plagioclase in lamprophyre shows positive linear correlation of Ca and Sr (up to 1.0% SrO at An_{37}). Fluorapatite, and certain generations of calcite and dolomite, in some cases make a considerable contribution to whole-rock Sr. Biotite is locally enriched in SrO (up to 0.4%) but is insignificant in the overall Sr budget. Strontium in clinopyroxene phenocrysts of lamprophyre is low and inconsequential; only rims (with 0.10% SrO) were above detection (0.07% SrO). Strontian barite seems to be important in some trachyte and alkali feldspar melasyenite.

The Mesoproterozoic igneous rocks are believed to represent surface equivalents of deeper potassic-syenite-monzonite-pyroxenite plutons previously described from the surrounding area by Corriveau. At Buckingham, the rocks were emplaced as fissure volcanoes and near-surface intrusions, in successive magmatic pulses.

A specimen of red dolomite-apatite rock, characterizing an envelope around trachyte, is believed to represent metasomatized Grenville marble. Strontium, orphaned from trachyte was trapped in the structure of minerals of the metasomatite: viz. in fluorapatite (with consistent 1.3% SrO) and in dolomite (with up to 1.0% SrO).

GS06-04 **VARIABILITY IN MINERAL ASSEMBLAGE, TEMPERATURE, AND OXYGEN FUGACITY IN A SUITE OF STRONGLY PERALKALINE LAVAS AND TUFFS FROM PANTELLERIA, ITALY**

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Eight samples of pantellerite lava and tuff, plus an inclusion of comenditic trachyte in one of the samples, from Pantelleria, Italy, have been thoroughly analyzed by electron microprobe. These samples reveal five different ferromagnesian mineral assemblages: (1) clinopyroxene + fayalite + ilmenite + magnetite; (2) clinopyroxene + fayalite + ilmenite; (3) clinopyroxene + fayalite + ilmenite + aenigmatite; (4) clinopyroxene + ilmenite + aenigmatite +/- kataphorite; and (5) clinopyroxene + aenigmatite. Microphenocrysts of pyrrhotite are also found in the first three assemblages. Clinopyroxene varies in composition from low-Na hedenbergite in the aenigmatite-free assemblages to higher-Na hedenbergite in the fayalite-free assemblages. Sodium and iron concentration in clinopyroxene increases with increasing peralkalinity.

Whole-rock silica and peralkalinity also correlates strongly with the mineral assemblage: assemblage 5 (aenigmatite-bearing, fayalite- and oxide-free) is associated with the highest agpaitic index and high silica concentrations (A.I. = 1.97, SiO_2 = 69.7 wt%); assemblage 4 (coexisting aenigmatite and ilmenite, fayalite-free) is associated with a slightly lower index and high silica concentration (A.I. = 1.61 - 1.75, SiO_2 = 67.6 – 72.0 wt%); assemblage 3 (coexisting aenigmatite, faylite, and ilmenite) is associated with a lower index and silica concentration (A.I. = 1.55 - 1.63, SiO_2 = 66.8 – 67.8 wt%); assemblage 2 (aenigmatite- and magnetite-free) is associated with an even lower index and silica concentration (A.I. = 1.42, SiO_2 = 67.1 wt%); and assemblage 1 (two-oxides) is found in the sample with the lowest agpaitic indices and silica concentrations (A.I. = ~1.17 – 1.31, SiO_2 = ~63.9 – 64.8).

QUILF95 was used to constrain the temperatures and pressures of the first three assemblages at 1000 bars of total pressure: (1) 990°C, log fO_2 -11.8 to 890°C, log fO_2 -13.9; (2) 793°C, log fO_2 -15.2; (3) 764°C, log fO_2 -15.9 to 756°C, log fO_2 -15.8. It is not possible to determine T-fO_2 from assemblages 4 or 5, but this trend suggests that these very strongly peralkalic magmas may have been even cooler (<756°C) and more strongly reduced (< -15.9 log fO_2).

GS06-05 TRACE ELEMENT AND ISOTOPIC CONSTRAINTS ON THE ORIGIN AND AGE OF UPPER MANTLE METASOMATISM IN CENTRAL-SOUTHERN ITALY

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Trace element and radiogenic isotope geochemistry of Plio-Pleistocene to Recent potassic volcanic rocks from central-southern Italy reflect a strongly metasomatized upper mantle source. The origin of the metasomatic fluid/melt, however, remains controversial. Trace element data including depletion of high field strength elements (HFSE) and enrichment of large ion lithophile elements (LILE) suggest a slab-derived metasomatic fluid, while the lack of calc-alkaline volcanics and the possible presence of a FOZO isotopic component indicate a deep mantle (plume?) contribution. New data from the Pleistocene volcanic centres of Roccamonfina and Ernici support the hypothesis that the Italian upper mantle may have been modified by both a slab-derived fluid and a deep-seated asthenospheric melt. Samples of leucitite to tephritic phonolite (highly potassic series) and olivine basalt to latite (potassic series) from both centres show a "typical" subduction signature characterized by strong enrichments in LILE and LREE coupled with depletion of Ti, P, Ta, and Nb. High concentrations of the extremely fluid-mobile element B (up to 76 ppm) suggest that the central Italian upper mantle has been metasomatized by fluids through recent subduction processes. The ranges of new isotopic data for Italy are: Roccamonfina ($^{87}Sr/^{86}Sr$ 0.70689-0.70955; $^{143}Nd/^{144}Nd$ 0.51218-0.51242; $^{206}Pb/^{204}Pb$ 18.80-19.09) and Ernici ($^{87}Sr/^{86}Sr$ 0.70654-0.71123; $^{143}Nd/^{144}Nd$ 0.51214-0.51241; $^{206}Pb/^{204}Pb$ 18.73-18.95). Smooth mixing hyperbolas in multi-component isotopic space are interpreted as binary mixtures between an enriched "crustal" component (present at depth in the mantle source) and a deep-seated FOZO mantle component. Data from volcanic centres in central-southern Italy support a tectonic model in which Tertiary subduction of the Adriatic microplate westward under the European margin imposed a high LILE/HFSE subduction signature on the mantle wedge. Early Quaternary NE-SW rifting subsequently resulted in extensive partial melting of the heterogeneous Italian upper mantle. Tomographic studies indicate that high-velocity material representing the currently stagnant slab may be discontinuous beneath central-southern Italy, possibly allowing an upwelling of deep mantle material.

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CRETACEOUS ALKALIC VOLCANISM IN THE CANADIAN CORDILLERA: AN ISOTOPIC AND GEOCHEMICAL STUDY OF THE CROWSNEST VOLCANICS

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The southern Canadian Cordillera contains rare occurrences of Cretaceous alkalic igneous rocks. Many questions have yet to be answered about the geochemical and isotopic compositions of these magmas as well as the conditions under which they formed. The focus of this study was to investigate the mineralogy, petrology, and geochemistry of the Crowsnest lavas, as well as the nature of these magmas and their possible relationship to other nearby Cretaceous alkalic suites.

The Crowsnest Formation contains a suite of ~96 Ma volcanics that are exposed in thrust sheets of the southern Cordillera in Alberta. Outcrops of the Crowsnest volcanics are dominantly pyroclastic and epiclastic, with rare flows of phonolite and trachyte lavas. The pyroclastic deposits are impressive in scale and texture, and commonly feature blocks or cobbles of effusive material. The major mineral phases observed in the flow deposits include sanidine, clinopyroxene, melanite garnet, and analcime. Backscattered electron images revealed complex patterns of zonation, growth and resorption features in all phenocrysts. The possible magmatic origin of the analcime phenocrysts has been debated extensively, and our recent microtextural and X-ray study provides additional support for this origin.

Samples of effusive material were selected for major and trace element geochemistry as well as radiogenic isotopic analyses. The analysed samples are predominantly metaluminous, and mostly plot in the trachyandesite, phonolite, and trachyte fields of the TAS diagram. Both LIL and HFS trace elements are enriched over primitive mantle; the REE patterns are LREE-enriched (La at 200-300x chondrite) and flatten in the HREE (Dy Lu at ~10x chondrite). Both Rb-Sr and Sm-Nd isotopic ratios were measured. The initial epsilon Nd values range from -7.4 to -11.8, whereas initial $^{87}Sr/^{86}Sr$ isotopic ratios (0.704187 to 0.704646) are near bulk earth. There is considerable scatter between values for different samples, which does not correlate with sample location or major element geochemistry. We interpret these isotopic results to require either heterogeneities in the source region, or differences in contamination during magmatic evolution.

A unique source region in the lower crust is required to explain the mineralogical, geochemical, and isotopic data. The study of these episodes of alkalic magmatism has implications for magma genesis in the Cretaceous, and on the composition of the lower crust of the southern Canadian Cordillera.

GS06-07

COMPONENTS AND SOURCES OF PUERTO RICAN MESOZOIC ISLAND ARC BASALTS: GEOCHEMICAL LINKS BETWEEN PELAGIC SEDIMENTS AND VOLCANISM IN THE NORTHEAST ANTILLES

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The eastern two-thirds of the island of Puerto Rico, located at the eastern end of the Greater Antilles Island Arc, is comprised comprise five volcanic phases (I - V) marked by northward migrating, east-trending island arc volcanic belts dating from Aptian to latest mid-Eocene (approximately 125 to 45 Ma). Chondrite-normalized incompatible element patterns of central Puerto Rican (CPR) basalts have moderate to high light rare earth element (LREE) slopes, deep negative anomalies for high field-strength elements (HFSE; La/Nb = 3 to 10), and low, flat heavy rare earth element (HREE) segments, all typical attributes of island arc basalt suites (IAB). Major features of patterns are reproduced by multiple component fractional melting models in spinel peridotite (f = 0.25) involving mixtures of at least three components: (1) a fertile MORB mantle- (FMM-) type spinel peridotite source modifed by withdrawal of a low-degree (2%), pressure-release melt in the back arc region, accompanied by various proportions of (2) subducted Atlantic Cretaceous pelagic sediment (AKPS), ranging from 0.5 to about 2% in volcanic phase I to > 5% in phase III; and (3) various proportions of a slab-derived low degree, basaltic melt with elevated Zr/Sm, Sm/Yb, and La/Nb, but low La/Sm, resembling low melt fractions produced from eclogized equivalents of subduted accumulitic hornblende gabbro. Geochemical variations are consistent with continuous south-dipping subduction of the North American Plate, and with progressive thickening of sediment cover in the subducted Atlantic Basin. Magnitude of negative normalized Nb anomalies preclude a significant ocean island basalt (OIB) component at any stage.

GS06-09 SOME FEATURES OF ECLOGITES FROM GNEISSES IN OROGENIC BELTS

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Field facts of eclogites found in gneisses of orogenic belts point at: a) specific tectonic regions of eclogites presence; b) specific P-T-conditions of eclogites formation; c) presence of specific rocks and minerals as inclusions in eclogites and eclogite-bearing rocks; d) P-T-conditions of stability for most important indicator minerals of eclogites and mineral inclusions in eclogites and eclogite-bearing rocks.

Among the most important features of eclogites from gneisses of orogenic belts there are: 1) the extremely high P/T ratio for eclogites formation (average 31.4 bar/°C); 2) obvious reworking of ancient granitoids and granitoid gneisses of eclogite-bearing areas; 3) presence of micro-diamonds and coesites in many cases within eclogite-bearing gneisses; 4) high almandine content of eclogites; 5) presence of ferric and ferrous iron in both omphacites and garnets from eclogites; 6) obvious proof that in numerous cases eclogites and enclosing gneisses were metamorphosed simultaneously; 7) co-existence of eclogites with iron-rich granitoids and granitic gneisses; 8) coexistence of eclogites in numerous cases with glaucophane-bearing rocks; 9) obvious presence in eclogite-bearing orogenic belts ophiolites and/or peridotites/serpentinized peridotites; 10) obvious facts of involvement of continental crust sources in eclogites formation.

Presence of both ferric and ferrous iron in the main eclogite-forming minerals shows that for formation of eclogites both P-T-conditions and ferric-ferrous iron transformation conditions are important. Since ferric iron is unstable under both high-temperature and high-pressure conditions, it is possible that in numerous cases eclogites were formed within the continental crust. Presence of iron-rich granitoids is crucial for formation of eclogites in orogenic zones, and in some cases those granitoids could be the source of rocks and minerals for eclogites formation. Breakdown of biotite, which also contains both ferric and ferrous iron, plays important role in formation of eclogites of orogenic belts.

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GS06-P01 "GLASSHOUSE METAMORPHISM": A CASE STUDY OF THE CALEDONIA SPRINGS GLASSWORKS (C. 1844-46), ONTARIO

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Before there was Banff, there was Caledonia Springs, a former resort town in eastern Ontario. The spring water was bottled in black glass containers initially made in the UK, but later, a glassworks was established at Caledonia Springs itself. Its proprietors made black glass, and reputedly experimented with making other types of glass as well. However, no authenticated extant glassware is known from this factory. The only known samples of Caledonia Springs glass consist of black glass rinds on kiln bricks and mudstone blocks found near the factory site. These glass rinds may have formed when fireclay melting pots (large crucibles) ruptured during firing, causing liquid glass to spill on to the floor of the kiln. Some of this material cooled sufficiently slowly so that crystallites of diopside, labradorite and/or wollastonite formed in some samples. Their formation has modified the composition of the surrounding glass, but crystal-free black glass from the site contains about 56% SiO_2, 11% Al_2O_3, 0.4% MnO, 3% FeO, 2% MgO, 20% CaO, 4% Na_2O and 2% K_2O. Glass of this composition can be made by melting a batch containing approximately 78 wt.% clayey sand, 20% dolomitic limestone, and 2% soda ash.

The mudstone is speckled with small (< 1 mm) plagioclase porphyroblasts and contains spheroidal "vesicles" < 1 cm (but typically 1 mm) in diameter. The "vesicles" likely formed by the partial dehydration of the mudstone during kiln firing. Within about 3 cm of the black glass rind the mudstone is bleached, distorted and contains dark, ameboid, glassy patches with shapes that mirror the adjacent, contorted layering. These glassy domains can contain the same crystallites as the black glass, but in this case, labradorite crystals have served as a substrate for fanning diopside crystallites that extend into a lime-poor, aluminous matrix phase enriched in incompatible elements (e.g., 1.5% TiO_2, 4.3% FeO, 5% K_2O). These features suggest that this matrix either represents the remnants of largely crystallized and perhaps older black glass that intruded the mudstone while it was thermally softened during kiln firing, or vestiges of a melt phase formed from the mudstone itself. The development of Ca silicates and possible formation of initially Ca-rich partial melts in the mudstone would have been facilitated by compositional interaction with the black glass. Indeed, textural evidence points to the local mechanical mixing of both components. Kiln firing conditions are modeled using liquidus relationships in the system SiO_2-Al_2O_3-CaO-MgO.

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GS06-P02 COMPILATION OF GEOPHYSICAL, GEOCHEMICAL, AND CHRONOLOGICAL DATA FOR CHARACTERIZATION AND UNDERSTANDING OF A LATE PROTEROZOIC MAFIC SILL AND ITS ENVIRONMENTS – CAPE ST. FRANCIS, NEWFOUNDLAND

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The aim of this study is to characterize a mafic sill and its environs in the vicinity of Cape St. Francis, Newfoundland, to investigate its implications for late Proterozoic bimodal magmatism in the Avalon Zone of the Applachians. Northwesterly dipping arkosic sandstones and a thick overlying sequence of pillow basalts bound the mafic sill and, in the northern section of the study area, cogenetic rhyolite domes punctuate the sandstones. The sill itself is comprised of unusual rhythmic layers of intercalated leucocratic and melanocratic trachyandesites with a unique trondjhemite seam within each leucocratic layer. An examination of the millimeter scaled variations of minor and trace elements within the layers will be completed using the Microprobe and Inductively Coupled plasma-mass spectrometry (ICP-MS). Detailed sampling and field observations of the sill and its surroundings will be used in the characterization and delineation of units. Rock samples were collected for U/Pb geochronology from: the sill itself, a gabbro unit to the north of the study area, a rhyolite dome to the north of the study area, and the detrital material making up the arkosic sandstone host to the sill. A detailed electromagnetic and elevation survey was carried out to build a three dimensional model of the sill morphology and extent below the surface. Regional geophysical surveys including apparent resistivity, vertical magnetic gradient, total magnetic field, and VLF-EM total field will be analysed.

GS06-P03 PSEUDO MIGMATITE FORMÉE DANS UNE INTRUSION FELSIQUE-MAFIQUE SYNTECTONIQUE

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La région de Tadoussac est située à l'est de la province de Grenville entre le Saguenay et le Saint-Laurent, les principaux types de roches sont, 1) Orthogneiss gris granodioritiques, 2) Métasediements incluant des métapelites métamorphisé au faciès amphibolitique supérieur, 3) Gneiss mafiques et des granites alcalins. Les orthogneiss indiquent un âge de 1.53 ± 0.07 Ga (Sm-Nd). L'âge des autres unités sont inconnus, mais les granites alcalins appelés informellement les plutons des petites Bergeronnes, sont les plus jeunes vu qu'ils injectent les autres formations. Le pluton granitique a été injecté dans une faille de décrochement active pendant la mise en place du magma. À l'échelle de l'affleurement, du coté sud-ouest, ce pluton est en contacte intrusif avec les gneiss mafiques à intermédiaires, et recoupent la foliation générale de même pour les dykes de granites et des pegmatites associés. Ces roches mafiques à intermédiaires se trouvent dans la faille en décrochement dextre, ils enregistrent une foliation importante et hébergent des veines de ségrégation du matériel leucocrate parallèle à la foliation ainsi que des structures extensionnelles, qui ressemble amplement a des leucosomes d'une migmatite, en plus, il y a des zones ou les amphiboles sont transformés en biotite évoquant un patron de fractures.

Sur une base pétrographique, on note que les roches mafiques sont très foliées, mais peu de cristaux montrent les évidences de déformation. Les ségrégations présentent des microstructures magmatiques, une telle observation suggère que la ségrégation s'est produite à l'état magmatique. L'absence de paragenèse minéralogique qui peut suggérer des réactions anatectiques favorise l'interprétation selon laquelle, les roches mafiques dérivent du magma mafique injecté et cristallisé dans la faille active.

Les évidences géochimiques montrent que les unités mafiques sont tholéitique et alcaline, ce caractère proviendrait d'une source magmatique enrichie en alcalins. La composition des ségrégations dans les roches mafiques peut être expliqué plutôt par une ségrégation de liquide résiduel que par une fusion partielle faute d'existence de liquide anatectique, comme les ségrégations dans les granites alcalins. Donc, l'interprétation est celle de deux magma alcalins, l'un felsique l'autre mafique qui s'injectent en même temps dans une zone de décrochement, et la ségrégation des magma leucocrate dans les deux est causé par la cristallisation syntectonique et non pas par anatexie.

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GS06-P04 VOLCANOLOGY AND GEOCHEMISTRY OF THE BRAVO LAKE FORMATION, BAFFIN ISLAND, NUNAVUT

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The ~1.9 Ga Bravo Lake Formation is a complex inter-layered package of metamorphosed volcanic and sedimentary rocks at the northern margin of the Trans-Hudson Orogen on central Baffin Island. This formation is a member of the Paleoproterozoic Piling Group, which represents the transition from a clastic- to carbonate-dominated passive margin that subsequently collapsed during the initiation of mafic rift volcanism (Bravo Lake Formation). This shelf collapse formed a rapidly subsiding basin which was filled with a thick turbidite succession. Himalayan-scale mountain building deformed and fragmented much of the Bravo Lake Formation during the Trans-Hudson orogeny. However, this formation is surprisingly undeformed and exceptionally well exposed on several islands off the western coast of Baffin Island. Geological mapping indicates that these islands represent high-level intrusions and lava flows within a submarine volcanic rift setting. Primary volcanic features are relatively undeformed and include amygdaloidal pillow basalts, drainage cavities, radial columnar and tortoise shell jointed pillows, feeder dykes, lobate lava flows, extensional dyke swarms, hydroclastic breccia, layered intrusions, laminated mafic sediments, massive and fragmental lava flows, and megacrystic intrusions. At least five rock units are recognized based on their field classification and their major and trace element geochemistry. Striking chemical and textural variation between individual lava flows and intrusions is present within just ~140 m of vertical section. Chemical variations appear to represent primary igneous values with extreme variations resulting from submarine hydrothermal alteration, as indicated by variable $\delta^{18}O$ values. The best major and trace element measurements indicate that these rocks were alkali basalts.

GS06-P05 PETROLOGY AND TECTONIC SIGNIFICANCE OF K-FELDSPAR AUGEN GRANITOIDS IN THE YUKON-TANANA TERRANE, STEWART RIVER, YUKON TERRITORY

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Augen granitoids are critical rocks for understanding the architecture and evolution of the Yukon-Tanana Terrane (YTT). Devono-Mississippian potassic feldspar augen granitoids mark the onset of magmatism in the Stewart River area, forming a roughly northwest by southeast trending belt from Alaska to southeast Yukon. The Stewart River area hosts a Permian population not recognized elsewhere in the YTT. Field mapping, geochemical and Sm-Nd isotopic studies of both age suites aim to understand the evolution of the YTT in the Stewart River area, with emphasis on characterizing the basement of the YTT throughout the late Paleozoic.

The Devono-Mississippian augen granitoids have been divided into three geographic groups: 1) Fifty Mile Batholith; 2) Mt. Burnham Orthogneiss; and 3) proximal to dated augen granitoids near the Stewart River. The Permian suite is divided into three geographic groups: 1) a linear belt of augen granitoids in the western portion of the Stewart River map sheet; 2) undated samples that are part of the latter belt; and 3) samples in the eastern portion of the Stewart River map sheet that are likely related to the Permian Sulphur Creek Orthogneiss. Relative to primitive mantle, both age suites have very consistent and similar calc-alkaline trends characterized by LREE enrichment (La/Yb_{avg} = 12.4), and negative Nb and Ti anomalies, indicating derivation from upper crust-like sources within a continental arc environment.

Samarium-neodymium isotope data for both suites yield εNd_t (Devonian: -5.4 to -12.6; Permian: -8.8 to 2.3) and TDM ages (Devonian: 1.49 to 2.26 Ga; Permian 1.37 to 2.08 Ga) that suggest influence from ancient continental crustal materials of Proterozoic age. These characteristics are similar to other YTT rocks and the western side of the North American craton. Neodymium crustal index values indicate that Devono-Mississippian augen granitoids have a larger crustal component (65 to 87%) relative to the Permian granitoids (39 to 72%) which are interpreted to have a greater mantle component. Collectively these data suggest that the YYT evolved an episodic Paleozoic magmatic belt, underlain by Proterozoic crust of probable western North America affinity.

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GS06-P06 THE TRACE ELEMENT CHEMISTRY OF MINERALS IN OCEANIC ISLAND BASALTS

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A preliminary study characterizing oceanic islands, based on the trace element chemistry of clinopyroxene (cpx) and plagioclase (plag), finds that patterns evident in the whole rock data are reflected in the minerals. Basalt samples represent the mantle end members: 1) high μ = high $^{238}U/^{204}Pb$ (HIMU); 2) enriched mantle with the low $^{143}Nd/^{144}Nd$ and high $^{87}Sr/^{86}Sr$ ratios (EM_1); 3) enriched mantle with the highest $^{87}Sr/^{86}Sr$ in the ocean basins (EM_2); and 4) MORB.

Mineral analyses (126) for 27 trace elements (Li, V, Cr, Ni, Zn, Rb, Sr, Y, Zr, Nb, Ba, La, Ce, Pr, Nd, Sm, Eu, Gd, Dy, Er, Yb, Lu, Hf, Ta, Pb, Th, U) by LAM-ICP-MS were determined at GLIER, University of Windsor and supplemented with previously published analyses (31). Trends in the cpx and plag data (mantle incompatible element ratios) lead to the same four-fold classification of basalts as derived from isotopic data. The best set of element ratios for classification is La/Ce versus Ti/Y in both plag and cpx. Concentrations of these four elements in cpx are not significantly affected by the early crystallization of plag. However, the partition coefficients between cpx and melt for both Ce and Y (Ce = 0.092, Y = 0.9;) are approximately double those of La and Ti (La = 0.056, Ti = 0.4), resulting in a greater difference in the two ratios than would be seen in the whole rock data. Combinations of other elements are less effective, and those which partition strongly into plagioclase (Sr, Ba, Rb, K, and Eu) are affected by mineral crystallization order and tend to produce scatter on classification plots. The results indicate that mineral trace element data show great promise for classifying basalts according to the end-member mantle components.

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OBSERVATIONS ON THE CHARACTER OF INFILTRATION-DRIVEN PROGRADE REACTIONS FROM THE COMPOSITIONS OF CALCITES IN THE SILICEOUS DOLOMITES OF THE ALTA AUREOLE

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Prograde metamorphism of siliceous dolomites in the hydrothermal aureole of the Alta stock (Utah, USA) produced a series of isograds: talc, tremolite, forsterite, clinohumite, and periclase with increasing grade. This sequence requires infiltration by water-rich fluids with increasing grade. Field observations (e.g., skarns, periclase distribution, isograd spacing), the metamorphic thermal regime, and whole rock $^{18}0$ data indicate that infiltrating fluids entered the marbles from the adjacent stock, requiring fluid flow down the metamorphic thermal gradient.

Calcite-dolomite geothermometry yields temperatures in the range 410 to 575°C for the tremolite through periclase zones. Compositions of individual calcite grains in the geothermometry samples exhibit a range of weight percent $MgCO_3$ content. The observed intergranular compositional variations exhibit generally normal to positively skewed distributions. However, the observed variation in magnesium content of any individual calcite grain (typically < 0.2 wt%) is significantly less than the range of compositions exhibited by all individual grains in any one sample (typically < 2.0 wt%). These characteristics require that chemical equilibrium on scales larger than a single to a few adjacent grains (approximately 2-3 mm) either was not attained or not maintained during the course of the metamorphic event.

Compositional variations such as these have been traditionally interpreted as a result of differential retrograde reequilibration during cooling. However, retrograde reequilibration is likely to be accompanied by equally significant compositional heterogeneities within individual grains. An alternative explanation for these normal and positively skewed distributions is that they are a primary feature of the marbles that records prograde reaction progress.

To test concept, predicted distributions of calcite compositions generated by the prograde reactions were calculated for a range of infiltration rates using an incremental mass balance approach. The infiltration rates (expressed as an infiltration ratio equaling the number of moles of infiltrate per unit quantity of volatiles produced) were constrained on whole-rock fluid flux estimates obtained from previously published studies of fluid flow in hydrothermal system. The predicted distributions for infiltration ratios between 10 to 50 match reasonably those observed in the geothermometry samples. This suggests that the compositional distributions are prograde features and implies that the isograd reactions both maintained equilibrium with water-rich infiltrating fluids and that the isograd reactions occurred over a range of temperature during the prograde heating in spite of down-temperature fluid infiltration and its associated advective heat flux.

GS-07

PRECAMBRIAN GEOLOGY

GÉOLOGIE DU PRÉCAMBRIEN

FRIED SCHWERDTNER

ADRIENNE HANLY

PRECAMBRIAN GEOLOGY
GÉOLOGIE DU PRÉCAMBRIEN

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GS07-01

NEW INSIGHTS INTO THE EXTENT OF THE TALTSON MAGMATIC ZONE AND THE AGE OF THE CLEARWATER GRANITES OF NORTHERN SASKATCHEWAN

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GS07-02 PALEOPROTEROZOIC SEDIMENTARY SUCCESSIONS OF THE SOUTHERN RAE PROVINCE: AGES, ORIGINS, AND CORRELATIONS

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Circa 1.90 Ga upper amphibolite facies metamorphism in the southern Rae Province is attributed to terrane accretion at the western craton margin (i.e. Thelon-Taltson Orogen). The Thluicho Lake Group, a conglomerate-arkose succession subsequently metamorphosed to greenschist facies, was deposited unconformably upon this upper amphibolite facies basement, presumably as molasse. It was, in turn, intruded by a ca. 1.82 Ga diabase dyke swarm that appears correlative with the 1.83 Ga Sparrow dykes to the northwest. Intrusion of the Sparrow diabase into the lithologically similar Nonacho Group supports a previous suggestion that the Thluicho Lake and Nonacho groups are correlative.

The diabase dykes in the Uranium City area appear to feed basalt of the fault-induced Martin Group redbed succession, which unconformably overlies the Thluicho Lake Group. The inferred ca. 1.82 Ga age, together with strong lithological similarities, suggests that the Martin Group was deposited at the same time, and by the same broad process, as the Baker Lake sequence of the Dubawnt Supergroup to the northeast. Extensive ca. 1.84-1.81 Ga lamprophyre dykes that fed minette flows of the Christopher Island Formation (Dubawnt Supergroup), extend southwestward to within ten kilometres of the preserved Martin Group. The Thelon Formation and Athabasca Group are likely correlative and unconformably overlie the lower Dubawnt Supergroup and Martin Group, respectively.

Both the diabase dykes and the lamprophyres were emplaced in pre-existing fractures, the orientations of which can be related to the stress regime affecting the Rae-Hearne Craton at the time of indentation by the Slave Craton. Since the dykes likely record the time at which crustal-scale brittle-ductile faulting tapped the mantle, the Slave indentation probably took place immediately prior to 1.82 Ga, and resulted from a combination of ca. 1.84 Ga accretion of the Fort Simpson-Nahanni Terrane to the west and several accretionary events culminating with terminal collision in the Trans-Hudson Orogen to the east at ca. 1.83 Ga. Trans-tensional faulting related to this vice-like stress configuration was likely responsible for deposition of the lower Dubawnt Supergroup and the Martin Group.

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STRATIGRAPHIC AND STRUCTURAL INVESTIGATIONS OF THE THLUICHO LAKE GROUP, ZEMLAK DOMAIN, RAE PROVINCE, NORTHWESTERN SASKATCHEWAN

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The Thluicho Lake Group is a sequence of Paleoproterozoic siliciclastic rocks overlying a mylonitized, upper amphibolite facies basement complex in the Zemlak Domain north of Lake Athabasca. A preliminary stratigraphic and structural analysis of this group was undertaken this past summer in the Waterloo-Wellington Lake area, ~15 km west of Uranium City, where it is preserved in a km-scale structural basin. Preliminary inspection of the contact between the Thluicho Lake Group and underlying rocks verifies previous observations that, although locally inverted due to deformation, there is significant angular discordance between the basement and the Thluicho Lake Group. Above the basement contact, the map-scale inter-relationship between stratigraphy and structure supports the interpretation of a single (basal) conglomerate unit that has been repeated by folding. The conglomerate is overlain by the following units: pebbly arkose, arkose and graded arkose/argillite indicating an overall fining-upward succession. The generally arkosic nature of the rocks, along with the make-up of the clast population in the basal conglomerate (massive and foliated granite, gneiss, mylonite and minor greenschist-facies, fine-grained sedimentary clasts), is consistent with deposition in an intracontinental setting. Based on lithological and temporal similarities, the group has been tentatively correlated with the Nonacho Group, a succession of continental clastic rocks that lies about 120 km northwest of the study area. Following deposition, the Thluicho Lake Group was affected by three and possibly four phases of deformation and associated greenschist-facies metamorphism. The first set of folds, recognized mainly by repetition of units, trended approximately east-west. These early structures were subsequently deformed by north-east trending F2 folds, producing a regional-scale fold with “Z” asymmetry. A third episode of deformation is inferred from a set of relatively open F3 folds with axes that plunge gently to moderately southward. A set of ca. 1.82 Ga east-trending diabase dykes cuts first- and second-generation folds, but was affected by the third deformational event. No evidence has been found thus far for a previously postulated fourth generation of folding. The youngest structures in the area include a system of brittle to brittle-ductile subvertical faults and related fractures with two predominant orientations: east-northeast and northwest.

GS07-04

NEW GEOCHRONOLOGICAL CONSTRAINTS ON THE PRECAMBRIAN HISTORY OF THE HEARNE PROVINCE, NORTHEAST SASKATCHEWAN

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Integrated geological and geochronological studies along an E-W transect of the Hearne Province in NE Saskatchewan provide new constraints on the Precambrian geological history of this region. The region comprises suspected > 2.8 Ga Archean migmatitic basement to the 2.71-2.68 Ga Ennadai Greenstone Belt (EGB), both of which are intruded by Neoarchean granitic rocks prior to late Archean thermotectonism. Overlying these units are the Paleoproterozoic (2.45-1.91 Ga) Hurwitz Group (HG) supracrustal sequences, which have undergone Trans-Hudson thermotectonism and been intruded by pre- to post-Trans-Hudson granitoids.

The oldest unit dated is a ca 2.82 Ga tonalite migmatite of the suspected basement. This age is supported by zircon xenocryst ages of ca 2.8-3.0 Ga obtained from the Proterozoic Jones Lake granite. Metarhyolite, in a thrust slice of the EGB structurally interleaved with HG rocks, yields a crystallization age of 2681 ± 4 Ma, nearly identical to a previous U-Pb zircon age of 2682 ± 6 Ma obtained from rhyolite within the EGB proper. Titanite and rutile data from the rhyolite provide ages of ca 1.76 and 1.75 Ga respectively, indicating either growth and/or resetting following the Trans-Hudson Orogen or during Nueltin Granite magmatism. Preliminary U-Pb zircon age results indicate the existence of a voluminous Archean granite suite that includes the ~2.72 Ga leucogranites in the Gilchrist Lake and ~2.76 Ga granites in the Archibald Lakes areas. A lower intercept age of ca 1.91 Ga for the Gilchrist Lake granite is similar to metamorphic and diabase ages in the nearby Snowbird Tectonic Zone.

A number of Proterozoic granitoids have been identified. The moderately foliated Jones Lake granite intrudes metamorphosed HG rocks and has yielded an approximate age of crystallization of ca 1.86 Ga, consistent with emplacement of Hudson granites as defined in Nunavut, and also places a minimum age on metamorphism in the surrounding HG rocks. Three monazite fractions from the granite indicate metamorphism at ca 1.82-1.81 Ga, coincident with peak conditions in Trans-Hudson Orogen. A weakly foliated biotite tonalite at Jones Lake, that also intrudes HG, yields a crystallization age of 1814 ± 3 Ma coincident with the monazite data from the Jones Lake granite. Undeformed, porphyritic fluorite-bearing granite at Spratt Lake gives a crystallization age of 1751 ± 2 Ma. The petrology and age of the granite is characteristic of the Nueltin Granite suite documented in the NWT and Nunavut, and extends their distribution southwest into Saskatchewan.

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GS07-05 **ND ISOTOPE GEOCHEMISTRY OF 2750 – 2701 MA KOMATIITIC ROCKS IN THE ABITIBI GREENSTONE BELT, CANADA**

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Komatiitic rocks occur in four of nine lithotectonic assemblages in the 2.7 Ga Abitibi greenstone belt: the 2750-2735 Ma Pacaud assemblage, the 2723-2720 Ma Stoughton-Roquemaure assemblage, the 2319-2711 Ma Kidd-Munro assemblage, and the 2710-2703 Ma Tisdale assemblage. All komatiitic rocks in the Pacaud assemblage are Ti-depleted komatiitic basalts, those in the Stoughton-Roquemaure assemblage are Al-depleted–Ti-enriched komatiites (ADK–TEK) and Al-undepleted komatiites (AUK), and the majority of those in the Kidd-Munro and Tisdale assemblages are AUK with rare ADK–TEK. The aims of this contribution are to explore the variations in Nd isotopic compositions between komatiites of different ages and geochemical types, and to determine whether the crustal contamination processes observed in some komatiites based on trace element signatures are also resolvable using Nd isotopic signatures. Altered samples and komatiites with extremely low Sm and Nd abundances are not included in subsequent interpretations. The Nd isotopic data for Abitibi komatiites vary between ε_{Nd} = +1.2 and +5.2, indicating derivation from a source with a long history of LREE-depletion. T_{DM} ages can range up to 3.4 Ga, but average ~ 2.7-2.8 Ga. There are no systematic variations of ε_{Nd} in komatiites within and between individual assemblages and there is no clear Nd isotopic evidence of crustal contamination or source enrichment, which are typically recognized by $\varepsilon_{Nd} < 0$, in any of the komatiites, even in those komatiites that display trace element evidence of crustal contamination. However, the presence of juvenile crust is supported by young zircon inheritence data and zircon inheritance ages and primitive Nd isotopic signatures of metasediments in the Abitibi belt, which range between -0.71 and +1.83 ε_{Nd} (Feng et al., 1993: Geochimica et Cosmochimica Acta, v. 57, p. 641-658) with Nd model ages close to depositional ages. Using $^{147}Sm/^{144}Nd$ ratios from Abitibi metasediments and the most depleted Abitibi komatiite, the crust would need to be ~250 Ma older than the new magma to develop an isotopic composition resolvable from the primitive magmas, thus crustal contamination may not have been detectable. In contrast, Heather (2001: Unpublished PhD thesis, Keele University) noted minor crustal contamination ($\varepsilon_{Nd} < 0$) in the Swayze belt, the westernmost part of the Abitibi greenstone belt, in intermediate to felsic volcanics and T_{DM} = 3.09 to 2.80 Ga. This suggests a slightly older basement in the western part of the Abitibi, sufficiently old that it can be detected by the relatively insensitive Sm-Nd isotopic system.

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STRATIGRAPHIC, STRUCTURAL AND GEOCHEMICAL EVIDENCE FOR A PARAUTOCHTHONOUS ORIGIN OF THE ARCHEAN MICHIPICOTEN GREENSTONE BELT, CENTRAL ONTARIO

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Greenstone belt development in the Superior Province has been attributed to accretion of exotic terranes and subsequent deformation, i.e. allochthonous. More recently, autochthonous / parautochthonous origins have been suggested based on inter-assemblage unconformities, isotopic inheritance and geochemical evidence for granitoid contamination of mafic/ultramafic volcanic units. The Michipicoten greenstone belt has been selected to test the two hypotheses because of excellent exposure, previous 1:20k mapping, and a regional geochronological framework. Assemblage boundaries in the Michipicoten were mapped in detail to distinguish tectonic boundaries, and submarine or subaqueous unconformities; specifically between the ca 2.89 – 2.75 Ga, ca. 2.75 – 2.70 Ga arc assemblages and the syntectonic ca. 2.70 Ga arc – Doré metasedimentary assemblages. The three assemblages are characterized by bimodal cyclic volcanism, capped by iron formation and related chemical and marine sediments.

The ca 2.89 – 2.75 Ga boundary is an overturned, east-striking, north-dipping thrust contact, with overlying ca. 2.75 Ga mafic pillowed and massive flows in tectonic contact with ca. 2.89 Ga felsic pyroclastics. Iron formation at this boundary is locally confined to a wedge of magnetite-bearing black argillites interbedded with quartz arenites, the latter representing an erosional event in the source area and multi-cyclic or single cycle weathering. Thus, this contact has aspects of both allochthonous and autochthonous origin. The 2.75 - 2.70 Ga boundary shows a shallowing upward depositional environment based upon primary structures, capped by laterally continuous mass flow units in the iron formation, suggestive of a submarine unconformity. This is also based on observing shallow water, stromatolite-bearing sandstones unconformably overlying pyritic, framboidal black argillites succeeded by non-vesicular pillowed basalt. The 2.70 Ga – Doré assemblage boundary is a subaerial erosional contact truncating Catfish Assemblage felsic fragmental units at the base of the overlying Doré sediments. The belt therefore displays intra-Keewatin submarine unconformities, with the Keewatin – Doré contact representing a subaerial unconformity. Therefore a parautochthonous origin can be interpreted for the Michipicoten greenstone belt, suggesting potential for large scale correlation with the Abitibi greenstone belt in the future.

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GS07-07 **U- PB DATING OF DETRITAL ZIRCONS IN A TIMISKAMING-TYPE SEDIMENTARY GROUP BY LA-MC-ICP-MS: IMPLICATIONS FOR BASIN DEVELOPMENT AND TECTONICS IN THE ARCHEAN**

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GS07-08 COULD CRUSTAL THICKENING IN THE ARCHEAN HAVE RESULTED IN VOLUMINOUS TTG MELT PRODUCTION?

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GS07-09 PALEOMAGNETIC, GEOCHEMICAL AND U-PB GEOCHRONOLOGICAL CORRELATION OF PROTEROZOIC DYKES BETWEEN GREENLAND AND CANADA, AND ITS BEARING ON THE NARES STRAIT PROBLEM

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In 1915, Alfred Wegener proposed a major fault along the Nares Strait between Greenland and Ellesmere Island in Canada to permit the separation of Greenland from Labrador, which requires approximately 200 km of left-lateral offset. A long-standing controversy in Plate Tectonics, the “Nares Strait Problem” arises because marine magnetic anomalies in the Labrador Sea indicate the sinistral displacement of about 200 km, but observations of Paleozoic sedimentary rocks across the Nares Strait allow movement of no more than about 70 km. In the Thule area of northwest Greenland is found a major E-W trending, ca. 700 Ma dyke swarm that does not appear to have a westward continuation along strike across the Nares Strait into central Ellesmere Island. There is, however, a possible offset continuation of the swarm in southeast Ellesmere Island and east Devon Island. A positive correlation of these two sets of dykes would provide compelling evidence for the 200 km sinistral offset required by plate tectonic reconstructions. Paleomagnetic, geochemical and U-Pb geochronological analyses are used to test this correlation.

Initial paleomagnetic results from four dykes and two sills in Greenland indicate stable remanences using either AF or thermal demagnetization, and include a reversed polarity dyke. These measurements of a shallow, westerly-directed remanence direction are not significantly different at a 95% confidence level from those from eleven dykes from Devon and Ellesmere Islands, which also include a reverse-polarity dyke. A baked-contact test of an Ellesmere Island dyke is positive, indicating that the magnetization of the dykes is primary. The samples from Greenland and Canada are very similar in terms of both major-element and rare earth element geochemical analyses carried out at the University of Toronto. Petrographic observations of the two dyke swarms are virtually identical, with variations only in the degree of alteration. Preparation of samples for U-Pb geochronology is currently underway.

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GS07-10 **APPLICATION OF ELECTRON MICROPROBE CHEMICAL BADDELEYITE DATING TO RECONNAISSANCE GEOCHRONOLOGICAL INVESTIGATIONS OF MAFIC DYKE SWARMS FROM THE SLAVE PROVINCE, NT**

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It is now well established that reliable first-order chemical age information can be obtained by Electron Microprobe (EM) chemical dating of the mineral baddeleyite (ZrO_2). Crystallization ages of mafic dykes and sills determined by this technique are typically accurate to within ~50-100 Ma, and the analyses can be completed rapidly (a matter of hours per sample), cost effectively, and can be carried out routinely on miniscule crystals (< 10 microns) which are not currently conducive to mineral separation and conventional U-Pb TIMS or SHRIMP dating. This provides for valuable contextural age information that is particularly well suited to reconnaissance geochronological investigations of mafic dyke swarms in newly mapped regions, in localities where mafic dyke swarms appear to have had a more protracted or punctuated emplacement history with dykes of similar orientation spanning several hundred million years (e.g. the Scourie Swarm, Scotland), and on fine-grained dykes which cannot currently be dated by any conventional isotopic U-Pb techniques.

Recent bedrock mapping projects in the Walmsley Lake and Germaine Lake areas of the Slave Province, have identified numerous Precambrian mafic dyke swarms of unknown age that are suitable for reconnaissance geochronology. Here we present EM chemical baddeleyite ages and whole rock geochemistry for a number of mafic dyke samples collected from these regions. In one study, a prominent, 110 m-wide, NE-SW trending gabbro dyke, traceable from aeromagnetic data for ~100 km, was sampled ~50 km SE of Walmsley Lake to test whether it was the same age as similarly oriented dykes of the ca. 2.23 Ga Malley dyke swarm. In-situ baddeleyite from polished thin section yielded a 30-point EM chemical isochron age of 1824 +49/-50 Ma for that dyke, providing compelling evidence that there may in fact be more than one age component to the so-called Malley swarm. Another, 25 m-wide gabbro dyke striking 160 degrees (similar orientation to the giant 1.27 Ga Mackenzie dyke swarm) was collected from the Germaine Lake area, and yielded an EM chemical baddeleyite age of 2069 +111/-116 Ma. These new reconnaissance age data provide further evidence that in some regions of the Slave Province, mafic dykes with similar orientations may have drastically different emplacement ages.

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EMPLACEMENT AND FRACTIONATION MECHANISMS OF LATE-OROGENIC GRANITES RELATED TO SHEARING - EXAMPLES FROM PROTEROZOIC ROCKS IN SOUTHERN FINLAND

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The country rock in southern Finland formed mainly during the Svecofennian orogeny about 1.9 Ga ago. About 1.83 Ga ago, the middle and lower crust was partially melted as a result of crustal thickening and subsequent extension. During this event, S-type migmatites and granites were formed along a 100 x 500 kilometre long zone. This zone is bordered both in the north and the south by earlier metasediments and volcanics and later by rapakivi granite. The late Svecofennian domain in southern Finland is a large crustal segment characterised by roughly E-W trending sub horizontal migmatites and granites. Combined ductile E-W shear movements and NNW-SSE compressional movements defined a transpressional tectonic regime during the emplacement. Partial melts that moved upwards through the crust formed either granitic massifs in the middle and upper crust or froze as migmatites. It is a tectonic and metamorphic zone that crosscuts the earlier Svecofennian granitoids.

In the Nagu synform in SW Finland, tectonically banded and fractionated granites lie structurally under a layer of amphibolite. Ductile shear zones plastically deform all the granite layers. We show evidence that parts of these granites were re-mobilised and expelled during the shearing.

With the help of fieldwork and geochemical data we can show that the chemically variable late-orogenic granites and migmatites in S Finland were transported and emplaced as small batches over an extended time interval, possibly extracted from different protoliths. These melt batches were transported along repeatedly re-activated channels and collected at some horizontal level in the crust. In the Nagu area, the melt batches were trapped under a layer of amphibolite and the whole complex was simultaneously folded into open folds with steep axial planes. The sheets of microcline granite are, in places, strongly sheared with tiling and subsequent deformation of the microcline porphyroblasts indicating syn-tectonic movements of the layers as well as a syn-tectonic origin for the late-magmatic fractionation.

Depending on the degree of crystallisation of the individual batches and the intensity of the shearing, the granites have a slightly differing appearance. Some sheared zones show a cumulate-like trace element geochemistry, indicating that melt fractions were expelled from the system, leaving layers of deformation enhanced fractionated granites and cumulate layers behind.

Our interpretation is that this area shows shear-assisted fractionation mechanisms in granitic melts, and that similar areas are responsible for the fractionation trends seen in the sub horizontal sheeted granites at higher levels in the crust.

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NEW INSIGHTS INTO THE ARCHEAN CRUSTAL EVOLUTION OF THE NORTH AUSTRALIAN CRATON: THE VIEW FROM GRANITES OF THE RUM JUNGLE COMPLEX

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The Rum Jungle Mineral Field, northern Australia, comprises two Archean basement domes, collectively referred to as the Rum Jungle Complex (RJC), which are flanked by the lowermost strata of the Palaeoproterozoic Pine Creek Orogen. The oldest rocks in the RJC, the Stanley Metamorphics, comprise mainly BIFs and para-schists and -gneisses, intruded by younger granites, which constitute the major part of the RJC.

The granites are metaluminous to peraluminous and alkalic to alkali-calcic in composition. The X_{Mg} is generally high, ranging between 0.14-0.42. Most samples plot within the field of post-collisional granites on an Rb vs. (Y+Nb) discrimination diagram. All the samples, except three that underwent major alteration, can be defined as I-type granites (ASI: 0.9-1.1). On major element variation diagrams, the data of the granites form well-defined fractionation trends, involving a negative correlation of Si with Ti, Fe, Mg, Ca and P; whereas K increases in the same direction. Hydrothermal alteration is marked by increases of K and Rb. All samples display similar chondrite normalized trace element (strong negative slope, troughs for Nb, Ta, Sr, P, Ti) and REE plots (enrichment of LREE, 6.56-114.61 La_N/Yb_N, 3.23 to 9.56 La_N/Sm_N; and negative Eu-anomalies, 0.20 to 0.85 Eu/Eu*). These factors suggest that all granites were derived from a single parental magma that underwent variable degrees of fractional crystallization. The granites have anomalously high Th (8.6-123.3 ppm) and U (2.9-39.9 ppm) compared to the average Upper Crust.

The granites suites display the typical magmatic mineral assemblage of K-feldspar (25-40 vol%), quartz (20-30 vol%), plagioclase (10-30 vol%), biotite (5-15 vol%) and magnetite (3-5 vol%), and accessories such as zircon, monazite, titanite, allanite, thoro-silicate, apatite, ilmenite and sulphides. Most of the samples underwent a variably severe subsolidus alteration, e.g., saussuritization and sericitization of feldspar, chloritization of biotite and white mica, martitization of magnetite, replacement of titanite by rutile. Bluish-green tourmaline is localised along micro-shear zones, which apparently provided excellent pathways for younger fluid flow.

SHRIMP dating of zircons from one granodiorite and three granite samples yield crystallization ages of 2520.9 ± 4.4 Ma and of 2525 ± 5.4 Ma, 2535 ± 7.5 Ma, 2534 +5.6/-13 Ma, respectively. One granite sample contains a series of inherited zircons and zircon cores that extend to ages of circa 3535 Ma, and locally exhibit thin high-U rims, indicating a younger phase of zircon growth, which post-dates the granite emplacement.

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NEW METAMORPHIC STUDY IN THE GRENVILLE FRONT: CHARACTERIZATION OF THE ARCHEAN VS GRENVILLIAN METAMORPHIC SIGNATURE IN THE PARAUTOCHTONOUS DOMAIN, QUEBEC, CANADA

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The Grenville Front Project began in 2003 by the MRNQ in the Parautochtonous Domain of the Grenville Province. The project addresses whether the metamorphism affecting the Archean rocks in this foreland thrust belt is Archean or Grenvillian, as well as patterns of hydrothermal alteration at high metamorphic grades. We present results from two NW-SE traverses across the Abitibi Sub-province and the adjoining Parautochtonous Domain of the Grenville Province. Traverse 1 is along highway 167 south of Chibougamau, traverse 2 leads from Lake Buteux to the Gouin reservoir, south of Chapais.

Traverse 1 starts in a Chl+Pl+Qtz assemblage typical of greenschist metamorphism. The northernmost rocks of the traverse 2 usually show an Amp+Pl+Qtz±Grt assemblage indicating lower to middle amphibolite grade. The presence of garnet is restricted to regional Faults, such as the Frank and Fecteau Faults. Archean alteration zones in the Parautochton Zone show Grt+Ath+Ged/Cum/Gru±Spl assemblages.

The garnet isograd in both traverses coincides with major structural lineaments such as the Dufresne Lake Deformation Zone and the Buteux Fault. Garnets from the Dufresne Lake Deformation Zone appear to be Grenvillian as shown by their exclusive association to the host deformation zone and their overprinting of pre-existing metamorphic assemblages and fabrics. Garnets from the Buteux Fault occur in amphibolite enclaves and seem to belong to an older metamorphic event.

Metamorphic grade increases to the S-SE and isograds are usually associated to deformation zones. Along traverse 1, the transition from greenschist to upper amphibolite is abrupt, as witnessed by the appearance of Grt+Amp+Cpx+Pl±Qtz less than 1.5 km from greenschist rocks. The local occurrence of orthopyroxene along both transects shows that granulite grade is reached. The Amiskotci Fault is believed to be a lateral ramp involved in the exhumation of Archean upper amphibolite migmatites from relatively deep crustal levels. The datation of melt from the SE of traverse 2 is expected to clarify the timing of anatexis. Formation of eclogite is noted in metagabbro dykes bearing Grt+Amp+Cpx (Omp).

This talk will discuss P-T paths from microprobe data obtained from these various assemblages with the intent of discriminating Archean and Grenvillian metamorphic signatures. The latter will test a working hypothesis that metamorphic assemblages of the Parautochtonous Domain retain traces of a Grenvillian exhumative regime distinct overprinting an Archean burial-driven regime. Rocks from the Parautochton Zone show evidence of rapid exhumation, as witnessed by the extensive development of simplectites.

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GS07-P01 SIGNS OF ANCIENT DEVELOPMENT AND ULTRAHIGH PRESSURE CONDITIONS IN PASSIVE CONTINENTAL MARGIN REGION (ON EXAMPLE OF ISRAEL)

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Latest discoveries of diamonds (over 400 micro-diamonds and 5 macro-diamonds) and enormous number of indicator minerals (such as Cr-diopside, orange garnet, pyrope, picroilmenite, moissanite, carbonado, corundum, black spinel, olivine, perovskite, aegerine, Ti-augite, etc.) in southern Israel indicate existence of ultrahigh pressure conditions in lithosphere in ancient time and presence in the lithosphere rocks typical for the Archean - Early Proterozoic periods. Integrated analysis and reinterpretation of some geophysical and geological data for Israel and surrounding regions shows that: (1) mean heat flow in the Dead Sea basin and surrounding areas of Israel and Eastern Mediterranean ranges in interval of 35-40 mW/m^2 and its minimal value was registered in southern Israel, (2) in the igneous complexes of southern Israel a huge amount of olivine phenocrysts was found, (3) eclogite-like rocks and garnet granulites were found in the vicinity of Mt. Carmel of northern Israel, and eclogite rocks and diamonds were found in NW Syria, (4) the Archean - Early Proterozoic rocks were described in Saudi Arabia, Egypt and Mendares massif (Turkey), (5) conditions of extensional tectonics exist in Israel since the Late Proterozoic, (6) in this region involvement of both continental and oceanic lithosphere sources is proven, (7) there are strong proofs of existence paleo-oceans of at least the Middle Proterozoic age, (8) some seismic data allow to suppose that peridotite plate(s), which was under-thrust the continental lithosphere, occurs in the upper mantle of southern Israel, (9) a lot of signatures showing evidence of reworking ancient continental crust in Israel and surrounding regions was recognized, (10) a great amount of potassium-rich granitoids and A-type granites in Israel and surrounding regions was identified, (11) Middle Proterozoic and Late Proterozoic metamorphic and magmatic rocks are known in southern Israel, Sinai, Jordan and Syria, (13) Israeli lithosphere is characterized by a cooling regime. All these facts point at significant tectonic activity in the region prior to the Late Proterozoic.

GS07-P02 PRECISE MAPPING OF THE GRENVILLIAN ALLOCHTHON BOUNDARY THRUST USING ND ISOTOPES

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Although the Allochthon Boundary Thrust (ABT) is the most important Grenvillian-age terrane boundary in the Grenville Province, it has proved hard to locate precisely along much of its length. This is partly due to cover by glacial despots, but also due to the deep level of crustal exhumation, which exposes similar mid crustal rocks types (e.g. grey orthogneiss) on either side of the boundary. However, precise location of ABT is important to understand the evolution of deep crustal terranes during the Grenville orogeny.

One technique used successfully to locate the ABT is geochemical mapping of meta-basic rock types (Ketchum and Davidson 2000). The separation of two different suites of meta-basic rocks types by the ABT suggests that significant crustal shortening occurred across the boundary during the Grenville event. A weakness of this approach is the sparse distribution of suitable outcrops of meta-basic rocks, which are separated by distances of more than 50 km in critical areas.

Another approach to mapping the ABT is based on a contrast in Nd model ages across the boundary. The vast majority of orthognessic rocks NW of the ABT have TDM model ages over 1.8 Ga, whereas orthogneisses SE of the boundary have TDM ages below than 1.8 Ga. In areas where meta-basic rocks types have been distinguished by detailed analysis, the model age boundary is consistent with the distribution of meta-basic rocks types (e.g. Dickin and Guo, 2002; Dickin and McNutt, 2003).

The present study presents new data from the Burk's Falls area of Ontario, where detailed Nd isotope mapping shows conclusively that the ABT runs to the south of Burk's Falls. It separates at Hwy 124 from the shear zone marking the eastern limit of the Ahmic terrane. It is exposed as an extensive high-strain zone in a small quarry 2.5 km east of Magnetawan, before trending ESE about 3 km south of Hwy 520. The location where it crosses Hwy 11 is not exposed, but it curves to the NE and finally trends ENE from Widgeon Lake, running through the northern part of Algonquin Park.

This location of the ABT implies that several small terranes to the NW, with signatures similar to the Allochthonous Belt, are klippen that have been isolated by erosion. Some of these are at North Bay and Mattawa in Ontario, and LacGordon, Lac la Perche and Lac Renzy in Quebec. These interesting structures merit detailed study as Grenvillian type-localities.

GS07-P03 **AVALON-MEGUMA TERRANE RELATIONSHIPS IN THE PALEOZOIC: IMPLICATIONS FOR THE ACADIAN OROGENY IN MARITIME CANADA**

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The Paleozoic evolution of the Avalon and Meguma terranes is crucial to the understanding of the Appalachian orogen and the Iapetus and Rheic oceans. In the Avalon terrane of Nova Scotia, Ordovician-Early Devonian rocks consist of bimodal volcanic rocks at the base (Dunn Point Formation) disconformably overlain by ca. 1900 m of fossiliferous siliciclastics (Arisaig Group) which contain Llandoverian to Lochkovian fossils. U-Pb zircon data from a rhyolite yields an age of 460.0 ± 3.4 Ma for the Dunn Point Formation, and together with paleomagnetic data suggest development on a microcontinent at 30°S, outboard from both Laurentia and Gondwana, possibly in a rifted arc setting. Geochemical, Sm-Nd and U-Pb (zircon) isotopic data of Arisaig Group clastic rocks contrast with the underlying Avalonian rocks, indicating that they were not derived from Avalonian basement. All sedimentary rocks are characterized by negative *Nd (from -4.8 to -9.3), TDM > 1.5 Ga, abundant Neoproterozoic-Early Cambrian zircons (ca. 620-520 Ma), with lesser concentrations at about 0.9-1.2 Ga and 1.5 to 2.2 Ga. Archean zircons are very minor. The Arisaig Group is inferred to be primarily derived from Baltica, but with increasing input from Laurentia by the early Devonian.

Detrital zircons from coeval strata of the Meguma terrane contain zircon populations that are similar to Avalonia and strongly suggest contiguous rather than discrete Paleozoic histories for these terranes throughout the Paleozoic. In addition to abundant Cambrian-Late Neoproterozoic and Paleoproterozoic zircons, Late Ordovician-Early Devonian samples have important Mesoproterozoic zircon populations (1.0 to 1.4 Ga), that strongly suggest contiguity with Avalonia by the Late Ordovician-Early Silurian. These coeval clastic rocks are interpreted to have been deposited adjacent to the trailing edge of Avalonia-Meguma during Appalachian accretionary events. As Avalonia had accreted to Laurentia-Baltica by the Late Ordovician, these data suggest that the Meguma terrane also resided along the same (northern) margin of the Rheic ocean at that time. This interpretation is supported by the absence of a Cambro-Ordovician accretionary event, the lack of intervening suture zone ophiolitic units, and the similarity of Avalonian and Meguma basement Nd isotopic signatures in Paleozoic igneous suites. This conclusion implies that the Siluro-Devonian Acadian orogeny was not related to collision of the Meguma terrane with the Laurentian margin. Instead, we suggest that the Acadian orogeny occurred in an Andean-type setting.

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GS07-P04 GEOLOGICAL INVESTIGATION OF THE IVISÂRTOQ GREENSTONE BELT, SOUTHWEST GREENLAND.

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The Ivisârtoq belt is exceptionally well exposed in 3-D and primary features are better preserved here than in any other Archean greenstone belt in Greenland. The Ivisârtoq greenstone belt is situated 40 km south of the Isua greenstone belt, within the Archean gneiss complex of southern West Greenland. The Isua region has been the focus of intense study because it contains some of the oldest known (~3.8-3.7 Ga) rocks on Earth. However, relatively little research has been conducted within the Ivisârtoq belt. This poster focuses on the Ivisârtoq greenstone belt which is fundamental for understanding the Archean geological evolution of the wider Isua-Ivisârtoq region.

The Ivisârtoq greenstone belt forms a southwest-closing, V-shaped synform and was subjected to amphibolite facies metamorphic conditions. New field mapping has concentrated on the 3 km thick southern limb of the synform, where the most complete section of the stratigraphy is preserved, and where pillow structures with unambiguous way-up indicators are observed. The southern limb has been divided into two groups of amphibolites: a lower group and an upper group. The upper amphibolite unit is characterized by heterogeneously deformed pillow structures interlayered with ultramafic amphibole schists, meta-gabbro, and with boudins of olivine-bearing ultrabasic rocks. The lower amphibolite unit is more heterogenous and intensely deformed than the upper unit. Layers of quartzofeldspathic rocks with sulfides are abundant in both the upper and lower unit and are highly sheared. A thick (~500 m) section of quartzo-feldspathic gneisses and schists in the lower unit has been the focus of preliminary geochronological work.

Previously, only one U/Pb zircon age (~2580 Ma from a "paraschist") has been obtained from the Ivisârtoq belt and was reported by Baadsgaard in 1976. Currently, laser ablation microprobe inductively coupled plasma - mass spectrometry (LAM ICP-MS) and isotope dilution thermal ionization mass spectrometry (IDTIMS) are being used to constrain the age of the greenstone belt. Initial results for the quartzo-feldspathic schist in the lower unit have been obtained using LAM ICP-MS. Approximately 100 zircon grains, ranging in shape from euhedral to round with diverse compositional zoning, were separated. A homogenous age population of 3019 ± 9 Ma was obtained and implies that the protolith of the schist may have been a mid-Archean volcanoclastic rock, a tonalite, or a sedimentary rock derived from a single mid-Archean source.

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GS07-P05 SIGNIFICANCE OF LATE ARCHEAN STRATIGRAPHIC MARKERS: UNCONFORMITIES FROM THE SUPERIOR PROVINCE

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Archean late-orogenic sedimentary basins, which represent integral components of greenstone belts, commonly overlie older rock sequences unconformably. Several volcano-sedimentary belts in the Superior Province of Canada can potentially be correlated using these unconformities as time and stratigraphic markers. Some major unconformities have also been inferred as sites of paleoregoliths or ancient weathering profiles. Paleoregoliths are significant features, as they indicate ancient climatic conditions. Gold-bearing quartz-feldspar porphyry stocks are locally preserved along the unconformities, and thus elucidate the relationship between basin evolution, stock emplacement, and gold mineralization in late-orogenic basins.

Conglomerate-dominated successions that formed diachronously between 2.67-2.71 Ga are characterized by fault-bound margins, rapid lateral and vertical facies changes, fining- or coarsening- then fining-upward sequences, and a similar lithofacies association of conglomerate, sandstone and siltstone/mudstone. Early granitoid suites, mafic and felsic volcanic rocks, komatiites, older turbidite sequences, and quartz-feldspar porphyry stocks represent basement to the late-orogenic, tectonically-influenced sedimentary deposits. Unconformities at six localities in northwestern Ontario were selected for sampling, detailed mapping, and geochemical study for potential paleosols. These include, 1) “Timiskaming-type” deposits overlying basalts near Shining Tree, 2) the Timiskaming conglomerate overlying siltstone (greywacke) in Timmins, 3) the Stormy Lake Group overlying an older quartz feldspar porphyry stock near Dryden, 4) the Kirkland sedimentary sequence overlying basalts near Kirkland Lake, 5) late-orogenic deposits of the Crowduck Lake Group overlying a quartz-feldspar porphyry stock near the Ontario/Manitoba border, and 6) carbonate/conglomerate rocks overlying gneiss at the Hogarth pit in Atikokan. Paleosols are possibly preserved at the Crowduck, Stormy Lake and Hogarth pit unconformities.

Major unconformities combined with U-Pb ages help define the stratigraphy, thus enabling paleogeographic reconstruction. Comparisons of unconformities in the Abitibi and Wabigoon subprovinces create space- and time-lines that can be strung across the largest Archean craton in the world. Detailed mapping of specific unconformities indicates highly irregular and erosive contacts that may reflect an ancient topography. Classification of paleosols is facilitated using major and trace element geochemistry. Comparative studies of this nature are relatively rare and can be tested using modern analogues in arc-related settings, such as the molasse basins of the South Island, New Zealand.

GS07-P06 **THE AGE AND FLUID CHARACTERISTICS OF THE SIBLEY BASIN AND ITS RELATIONSHIP TO OTHER PROTEROZOIC BASINS ON THE CANADIAN SHIELD**

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The Proterozoic Sibley Group is composed of sandstones, dolomitic mudstones, and siltstones that fill a continental sedimentary basin. The age of the Sibley Basin and its relationship to other major continental basins on the Canadian Shield are poorly understood. The minimum age of the Sibley Basin has been previously reported as ca. 1534 Ma, based on U/Pb ages from granite that is associated with felsic volcanics containing fragments of Sibley Group rocks. Other age constraints previously reported for the Sibley Group include a whole rock Rb/Sr isochron age of 1339 +/- 33 Ma.

We obtained Pb model ages of 1690 Ma by LA-ICPMS analysis of galena in veins that crosscut the Sibley Group. Illite from Sibley sandstones and mudstones provided Ar/Ar plateau ages of 1698 +/- 12 Ma and 1379 to 1338 Ma. The older Ar/Ar age is the age of crystallization for illite and provides a minimum age for sedimentation in the Sibley Basin. The younger Ar/Ar age is the same as the previously reported Rb/Sr isochron age and represents resetting due to fluid migration, probably in response to 1.3 to 1.4 Ga felsic magmatism in the region.

Diagenetic illite from the Sibley Basin has low crystallinities and formed at temperatures of < 150°C. The $\delta^{18}O$ and δD values of the fluids that formed in equilibrium with illite are +1.0 to +7.3 ‰ and –47 to –71 ‰, respectively and indicate a predominately meteoric source. In comparison, peak diagenetic fluids in the Athabasca, Thelon, and Sioux Basins are higher in temperature (200-250°C) and have higher δD values, suggesting that the fluids in these basins had a greater seawater component than the fluids in the Sibley Basin.

Our new chronological data indicates that the Sibley Basin is older than previously thought and is similar in age to other major continental Paleoproterozoic basins in North America, such as the ca. 1750 Ma Athabasca and Thelon Basins, and ca. 1730 Ma Sioux Basin. These ca. 1.7 Ga basins record widespread continental sedimentation following the formation of major orogenies (e.g. Trans-Hudson and Penokean) from ca. 1.8 to 1.9 Ga as the result of microplate collisions during the assembly of Laurentia. Therefore, the Sibley Basin formed during an important tectonic interval in the evolution of the North American craton.

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PRECAMBRIAN GEOLOGY
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GS07-P07 SEARCHING FOR BASEMENT IN THE SOUTHWESTERN SLAVE PROVINCE, NT: A PRELIMINARY PETROLOGIC AND GEOCHEMICAL STUDY OF THE GRANITES IN THE WECHO RIVER AREA

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The Wecho River area is located in the southwestern Slave Province, 100 kilometres north of Yellowknife, NT. Field mapping has revealed that the area is underlain by at least three Neoarchean I-type plutonic suites. This study will employ major-, trace-element, and isotope geochemistry (Sm/Nd, Pb/Pb, U/Pb) in order to better constrain the age and petrogenesis of the plutonic suites and determine the extent of Mesoarchean basement in the southwestern Slave Province.

The youngest granitic suite, which cross-cuts all Archean rocks in the map area, is a K-feldspar phenocrystic granite, containing rare mafic and granodioritic enclaves. The phenocrysts are up to 4 centimetres in length and with biotite, define a weak foliation. A second suite comprises mixed equigranular granodiorite to granite that is spatially associated with supracrustal remnants. The granodiorite has a weak foliation, defined by biotite, which is equivalent to a foliation defined by biotite-sillimanite in semi-pelitic rocks, indicating this suite intruded prior to, or synchronous with this deformational event. The oldest suite is a medium-grained granite to granodiorite, which is locally magnetic and contains knots of biotite. This suite shows a moderate to strong foliation that is defined by quartz and biotite. Magnetite-bearing amphibolite (locally mafic granulite) enclaves are common and range in size from several centimetres to tens of metres.

A granodiorite gneiss immediately east of the study area was also sampled. This gneiss is likely older than 2.8 Ga as highly deformed mafic dykes transect it, a feature characteristic of Mesoarchean basement throughout the Slave Province. The age and geochemical attributes of this gneiss will be applied to mixing models to define the extent of similar basement in the Wecho River area.

Previous geochemical work in the Slave Province delineates Nd and Pb isotopic boundaries that resolve the extent of Mesoarchean basement in the eastern part of the craton. Currently the western extent of Mesoarchean basement is inferred to underlie the Wecho River area. Characterization of the plutonic suites in this study will aid in understanding mantle and crustal evolution during the Neoarchean, define the lateral extent of Mesoarchean basement in the area and determine the role of this basement during Neoarchean magma petrogenesis. The nature of the late Archean crust and mantle in the Wecho River area may also help reveal the areas potential for hosting diamond-bearing kimberlite.

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THE GRENVILLE FRONT PROJECT: A MULTIDISCIPLINARY STUDY OF THE PARAUTOCHTONOUS DOMAIN, GRENVILLE PROVINCE, QUEBEC, CANADA

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The Parautochtonous Domain of the Grenville Province separates the Superior Province from the Allochtonous Domain of the Grenville Province. The MRNQ began a three year mapping project of this area at a scale of 1:50 000. The main objectives of the project are improving the state of knowledge of the Grenville Front to look into the tectono-metamorphic history of the Archean rocks along this foreland thrust belt and to promote its mineral potential. Phase I covered areas to the south of Chapais (Lagacé Lake) and Chibougamau (Charron Lake).

Archean rocks of the Abitibi Sub-province underlie the WNW portion of the mapped areas. These consist mostly of tonalite, diorite and granodiorite such as the La Dauversière pluton, dated at 2720 Ma and host to the Joe Mann gold mine. These rocks intrude thick sequences of mostly mafic volcanics such as the Obatogamau Formation. Newly discovered ultramafic volcanics of komatiitic affinity are also noted south of Chapais. All of these volcanic units show metamorphic grades ranging from greenschist to lower amphibolite.

Rocks of the Parautochtonous Domain of the Grenville Province underlie the ESE portion of the mapped areas. This transition zone features strongly folded and migmatized rocks of the Abitibi Sub-province overprinted by Grenvillian deformation and metamorphism. Major structural lineaments such as the Buteux Fault and the Lac Dufresne Deformation Zone coincide with the transition from the Superior Province to the Parautochtonous Domain. Recent mapping has subdivided the latter in several regional litho-tectonic blocks consisting mostly of Archean metavolcanic rocks at upper amphibolite to granulite grade. The geochemical signature of these rocks is similar to that of adjoining volcanics of the Abitibi Sub-province. Structural fabrics are mostly Archean, with a considerable degree of re-orientation by Grenvillian deformation, making the distinction between Archean and purely Grenvillian fabrics difficult. The degree of partial melting is variable and locally leads to complete migmatization of these volcanic units. Migmatites containing enclaves of metavolcanic rocks in this setting suggest these rocks were exhumed from deep crustal levels by major crustal structures such as the Amiskotci Fault and the Ile Ronde Deformation Zone.

Metamorphic grade increases from the Superior Province to the Parautochtonous Domain. This increase is locally abrupt, as demonstrated by the transition from greenschist to amphibolite and from amphibolite to granulite, suggesting that an Archean metamorphic signature is dissected by Grenvillian faulting. Amphibolite enclaves in migmatites show evidence for a polyphased tectono-metamorphic history.

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GS08-P01

EVALUATION OF SEDIMENT SPECTRAL GAMMA MEASUREMENTS AS A TOOL FOR REGIONAL STRATIGRAPHIC CORRELATION OF PLEISTOCENE DEPOSITS IN SOUTHERN ONTARIO

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Many aquifers in Southern Ontario are located within complex Pleistocene sediments deposited during multiple ice readvances and retreats. Current knowledge of the regional continuity of Pleistocene strata remains limited due to the difficulty of identifying diagnostic, chemical, physical, or textural attributes that can be used in regional correlation. Previous studies have employed lithologic and downhole geophysical attributes for regional correlation and determination of sediment provenance. This paper presents the results of one of the first studies that has utilized spectral gamma as a regional stratigraphic tool.

All rocks and sediments include the natural radioactive elements uranium (U^{238}), thorium (Th^{234}) and potassium (K^{40}). Each radioactive element emits gamma rays with characteristic energy levels. The amplitude of the signal at the various energy levels allows discrimination of the relative contribution of the three elements. The mobility of, and the minerals associated with, each radioactive element are unique. These differences lead to fractionation that is dependent on primary source rock, depositional environment, transport and sorting mechanisms, sediment reworking and diagenesis. The summation of these processes leads to a radioactive abundance for each sedimentary unit at each location. If all portions of a stratigraphic unit were formed under similar depositional processes then it should be identifiable by a unique spectral gamma signature.

A hand-held Exploranium GR-320 gamma spectrometer was used to obtain more than 350 measurement on outcropping Pleistocene tills and deltaic deposits in the Greater Toronto Area. Crossplots and three-component plots show that the most sedimentary units have a unique spectral gamma signature. Clay-rich glaciolacustrine strata (e.g. Sunnybrook diamict, Thorncliffe and Scarborough clays) are characterized by more abundant Th, K and U when compared to sandy deltaic units and subglacial tills (e.g. Newmarket Till). The element ratios for each unit show a regional consistency, except for the Halton Till, which has a variable spectral signature that reflects the composition of underlying deposits. This association reflects the sub-glacial reworking and incorporation of pre-existing deposits into the till during ice readvance. The results show that many Pleistocene units have unique spectral gamma signatures and that gamma is a useful attribute for regional stratigraphic studies in Southern Ontario.

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GS08-P02 INVESTIGATING THE CHARACTERISTICS AND THREE-DIMENSIONAL DISTRIBUTION OF QUATERNARY SEDIMENTS INFILLING PARTS OF THE DUNDAS VALLEY, HAMILTON, ONTARIO

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Southern Ontario is underlain by an eroded Paleozoic bedrock surface dissected by numerous bedrock valleys. These valleys are infilled with variable thicknesses of Quaternary sediment that record paleoenvironmental change during the Late Quaternary and also host productive aquifers. The Dundas Valley of the Hamilton-Wentworth region forms a prominent west-east re-entrant in the Niagara Escarpment extending from Copetown in the west to Lake Ontario in the east. The modern valley is underlain by a buried bedrock valley estimated to be infilled with up to 180 m of Quaternary sediment including glacial, lacustrine and fluvial deposits. There are few exposures through these valley infill deposits and their subsurface characteristics and distribution are poorly understood.

Compilation of subsurface data from waterwell and borehole records, construction reports and geophysical investigations has allowed the creation of a series of images showing the three-dimensional subsurface stratigraphy of part of the Dundas Valley underlying the McMaster University campus and adjacent areas of the Westdale Terrace. These images indicate that underlying bedrock of the Queenston Shale has an irregular topography and lies between 40 and 50 m below the McMaster campus. Sediments overlying bedrock include clays and silty clays (containing occasional scattered clasts) that record either glaciolacustrine depositional conditions or subglacial reworking of previously deposited lacustrine sediments. These deposits may have formed during the final stages of Late Wisconsin glacial occupation of the Lake Ontario basin or during the early stages of development of postglacial Lake Iroquois approximately 12,000 y.b.p. Fine-grained deposits are overlain by a distinctive horizon of coarse sands and gravels formed under high energy conditions, probably associated with shoreline environments of Lake Iroquois. The uppermost sedimentary units mapped below the McMaster campus consist of silts and silty sands formed in lagoonal environments created at the western end of Lake Iroquois by the growth of shoreline bars.

This investigation, which integrates numerous data sets in order to create three-dimensional images of subsurface sediment characteristics and distributions, is being extended to include additional areas of the Dundas Valley. Better understanding of the sedimentary infill of the valley allows more accurate reconstructions of late Quaternary paleoenvironmental change and the identification and delineation of major aquifers and aquitards.

GS08-P03 QUATERNARY GEOLOGY OF THE FORWELL PIT, BRESLAU, ONTARIO

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The Forwell sand and gravel pit in Breslau, Ontario provides excellent exposures through the complex assemblage of Quaternary deposits that underlie the Waterloo region of southern Ontario. These deposits contain a rich record of paleoenvironmental change during the late Quaternary and may be used to reconstruct spatial changes in the position of the southern margin of the Laurentide Ice Sheet. Quaternary deposits in this region are host to productive aquifers used for municipal drinking water sources. An understanding of the three-dimensional distribution of subsurface sediment units is necessary for the effective protection and development of these aquifers.

Paleozoic bedrock in the Waterloo region is overlain by up to 90 m of Quaternary sediments but there are relatively few exposures through these deposits. The Forwell pit is an active sand and gravel quarry that covers an area of over 1.5 km^2 and exposes a 28 m-thick succession of Quaternary sediments. Coarse-grained, relatively poorly-sorted gravels interbedded with sands and fines are exposed at the base of the pit and are interpreted to record ice-proximal glaciofluvial and glaciolacustrine deposition. These deposits are overlain by three distinct diamicts separated by discontinuous sands or fines; diamicts probably record episodes of glacial advance across the region during the Nissouri and Port Bruce Stadials. The stratigraphic position and lithological characteristics of the lowermost diamict suggest that it may be equivalent to the Catfish Creek Till. This diamict is relatively coarse-grained and may contain reworked glaciofluvial deposits. The second diamict exposed in the succession is relatively fine-grained, appears to consist of reworked glaciolacustrine materials and may be equivalent to Maryhill Till. The uppermost diamict exposed in the pit shows similar characteristics to diamict that veneers the nearby Breslau Moraine and is interpreted as the Port Stanley Till. Interbedded sands, gravels and fines, interpreted previously as glaciofluvial deposits, form the uppermost deposits exposed in the Forwell pit.

The distribution of coarse- and fine-grained Quaternary sediment types in the Forwell pit may be used to create a three-dimensional depositional model that has application for prediction of the subsurface distribution of aquifers and aquitards elsewhere in the Waterloo region.

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GS08-P04 SURFICIAL GEOLOGY OF THE ZAMA LAKE AREA (NTS 84L)

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The Alberta Geological Survey (AGS) and the Geological Survey of Canada (GSC) are conducting surficial mapping and Quaternary stratigraphic studies in Zama Lake area (NTS 84L) as part of a multi-year multidisciplinary collaborative program. This research will provide crucial information on the Quaternary stratigraphy, sediment characteristics, and glacial history that will have direct implications for Quaternary-hosted shallow gas, aggregate and diamond exploration in northwestern Alberta.

The Fort Nelson Lowland that separates the Cameron Hills Uplands to the north and the Clear Hills Uplands to the south dominates the physiography of the region. The characteristic flat topography and expansive peatlands in the lowland reflect the lake bottom of former glacial Lake Hay, which inundated most of the region below 405 m (asl) during deglaciation. Shales of the upper Fort St. John Group (Shaftesbury Formation, Lower to Upper Cretaceous) outcrop east and south of the town of Rainbow Lake. Dunvegan Formation sandstone (Upper Cretaceous) outcrops along meltwater channels and below a thin veneer of glacial till on Basset Hill, uplands south of Hay River, and the Chinchaga Plain to the south, usually above 700 m (asl). Elsewhere, drift thickness is variable, from < 1 m on topographic highs to > 300 m in the Sousa Creek and Chinchaga River lowlands.

Ice flow history was reconstructed exclusively from streamlined landforms, striated boulder pavements and pebble fabrics. These measurements indicate that the surface till in the region was deposited by ice flowing west-southwest. During initial Late Wisconsin glaciation, the Laurentide Ice Sheet advanced (up-drainage) into the region forming large ice-dammed proglacial lakes. Ice overrode these sediments and deposited clast-poor clayey till over the entire region. During early deglaciation, the glacial ice retreated eastward and northward, blocking drainage and ponding the glacial meltwaters at the ice margin forming Glacial Lake Hay. Extensive permafrost conditions are considered to have existed following deglaciation, as evidenced by widespread relict permafrost patterning in fine-grained glaciolacustrine sediments and peatlands. While much of this is considered to be relict features, discontinuous permafrost is present in the region today.

An extensive ice-contact meltwater complex was observed in the southwestern corner of the map-area extending from Rainbow Lake well into British Columbia. Other notable glaciofluvial features include the Chinchaga River meltwater channels, which occur both east and west of the river south of Highway 58. These are excellent sources of sand and gravel in a region that has otherwise limited aggregate potential.

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GS08-P05 QUATERNARY DRIFT STRATIGRAPHY BUFFALO HEAD HILLS, ALBERTA

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Since 1997 thirty-eight kimberlite pipes have been discovered within the Buffalo Head Hills (BHH) area. During 2002, the Alberta Geological Survey (AGS) conducted auger coring to collect data about Quaternary stratigraphy and glacial dispersal from a kimberlite. These provides three-dimensional information to compliment surface mapping and sampling conducted by the AGS and Geological Survey of Canada in support of diamond exploration in this region.

Nine holes were cored near kimberlite pipe K4 to intersect the dispersal train and two holes were drilled in the thicker drift to the west (hole depths 10 to 44 m). Samples are from the till, bedrock and intertill sediment. All 155 samples were analysed for multi-element geochemistry m (< 0.063 mm fraction), matrix texture (< 2 mm), and carbonate content (< 0.063 mm).

Previously the authors tentatively recognized two tills in this region. Subsequent examination of these data has characterized the two tills and developed criteria to distinguish them from other sediment. The till in each hole has been subdivided into an upper till (group 1), a lower till (group 2) and in a few holes a third group which lacks definitive characteristics. Data types most useful in separating the tills are the concentrations of Ti, V, Li, Mg, Ca, P, and Si, the carbonate and dolomite content, and LOI. The matrix texture is similar for all groups. The shallow Quaternary stratigraphy (< 50 m) consists of an upper till (Late Wisconsin) overlying stratified (glaciolacustrine) sediment overlying a lower till (Early Wisconsin?) with a locally preserved weathered surface.

The upper till was remarkably thin in some holes; possibly < 2 m. This observation may be supported by areas in the southern portion of the BHH where an oxidized till is exposed in a number of pits is within 2 or 3 m of the surface. The reasons for the differences in composition between the two tills are uncertain. However the oxidized surface of the lower till indicates deposition occurred during different glacial advances with a significant nonglacial time interval. The upper till may have been formed by ice flowing over a wider subcrop of the Paleozoic carbonates: the result of either a different ice flow provenance or increased exposure of the carbonate subcrop during the later stages of Late Wisconsin glaciation.

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GS08-P06 DEVELOPMENT OF A THREE-DIMENSIONAL NUMERICAL FLOW MODEL FOR THE QUATERNARY SUCCESSION IN THE COLD LAKE-BEAVER RIVER BASIN, EAST-CENTRAL ALBERTA, CANADA

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Groundwater from the Quaternary succession is an important source of water for both domestic and industrial use in the Cold Lake – Beaver River drainage basin in east-central Alberta. Growing demands on groundwater by expanding thermal in-situ heavy oil extraction projects in the basin, coupled with an extended period of drought, has increased the need for a regional groundwater numerical model to help assess groundwater flow and manage its use in the basin. Two major steps were necessary to complete the study: a) a detailed hydrogeological characterization of the Quaternary succession, and b) the development of a numerical groundwater flow model. This paper focuses on the hydrostratigraphic representation of the Quaternary aquifer system and subsequent transfer into the numerical flow model.

Channel incisions in the bedrock topography by pre-glacial and glacial river systems have created depositional basins in which up to 250 m of drift have accumulated. The hydrostratigraphy of the Quaternary units in this drift sequence is characterized by a succession of sand and gravel aquifers that are separated by, or embedded within, thick glacial tills representing at least four major glacial events. Confinement of some Quaternary units to bedrock channels, combined with stratigraphic superposition resulting from fluvial down-cutting and successive stacking, have produced a complex hydrostratigraphy with a combination of confined, leaky, and unconfined aquifers.

For the development of a numerical groundwater flow model, the hydrostratigraphy was simplified to a 12-layer, glacial-drift aquifer system. The mapping of the aquifer and aquitard layers was performed using three-dimensional mapping software. The surface-elevation grids of the hydrostratigraphic units were directly mapped to a three-dimensional model grid in the groundwater modeling software using a "true layer" approach. Hydraulic properties were then assigned to each layer. Further, GIS map-objects of lakes and rivers were imported into the modeling package and converted into model specific boundary conditions, i.e., river nodes and constant-heads nodes, respectively.

Preliminary results show that the numerical model is very sensitive to the hydraulic rock properties of the aquitards and that lake- and wetland-groundwater interactions are significant. Therefore, a proper geological characterization of the subsurface, and the adequate representation of fluid sources and sinks are essential for developing a well-calibrated numerical flow model and managing water resources in the Cold Lake – Beaver River drainage basin. A key step forward has been the incorporation of lake-bottom bathymetry into the digital elevation model to map aquifer outcrops on the bottoms of lakes.

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GS08-P07 DIGITAL AND 3D GEOLOGICAL MAPPING REQUIRED FOR LAND AND WATER MANAGEMENTS IN SOUTHERN MANITOBA: A REVIEW OF PROGRESS AND PLANS

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Efforts to protect and wisely use groundwater and industrial mineral resources in southern Manitoba have required the development of a new generation of geological map products. Geological maps are being digitized and reconciled with each other, while legends are being made more accessible to a broad range of users, both as a digital version of the unmodified original text, as well as in a categorized, queryable format. For groundwater protection, digital and queryable surficial geological maps, along with associated soil maps, are critical. In addition, for all applications, regional 3D geological models are increasingly in demand as the required data, technology, and protocols to build them become more and more accessible. A pilot 3D model for the 200 km x 230 km Winnipeg area was built using a detailed digital elevation model, bathymetric charts for large lakes, offshore seismic surveys, surficial geological maps, drillhole and seismic information for the Quaternary, and existing models for the Phanerozoic rock units. For the Quaternary, key inputs to the new 3D model were cored holes logged by geologists and geophysical surveys. These high-quality results were extrapolated laterally using drillhole data from provincial databases that include data over 100,000 sites, about half of which are in the pilot area. For the water well database, much effort was required to parse 75,000 unique lithological descriptions as queryable information. The Quaternary stratigraphy of the pilot area was hand-interpreted on 46 large color charts, each depicting all drillhole data, surficial geology, and surface elevation for a 5-km wide swath. The interpretation was captured at predicted stratigraphy points at 5 km spacing, and gridded as 3D surfaces. The model has been used for regional groundwater modeling, and progress is now underway in extending the method over all of southern Manitoba. A key challenge will be reconciling interpretations with those of neighbouring jurisdictions. Current activity is seen as a broadening of our reliance, not only from paper maps to digital models, but also from plan view maps, to drillhole databases, to 3D models, to dynamic models such as groundwater flow models. It is clear that user requirements demand that geological survey work rapidly advance as far along this progression as can be managed.

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GS08-P08 GLACIAL VALLEY-FILLS AND IMPLICATIONS TO WATER MANAGEMENT AND LAND-USE IN NEW BRUNSWICK: THE FREDERICTON EXAMPLE

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In many communities across New Brunswick, glacial valley-fill sediments provide the best source of potable water; supplies that are often considered to be an unlimited renewable resource. Until recently, few municipalities have been concerned with the potential for saltwater intrusion, aquifer contamination or calculation of sustainable yields. However, some supply-aquifers in coastal areas are now experiencing saltwater intrusion, while in other areas aquifers are threatened by surface-borne contamination, unrestricted extraction, and conflicting land uses. As climate changes, saltwater intrusion will worsen with landward migration of the freshwater/saline interface. In other areas, increased rural and urban demands require accurate delineation of supply aquifers and exploration for new resources.

To ensure that communities will have access to freshwater in the future, QUEST is pursuing a research program including: (1) locating buried valleys, (2) subsurface mapping of valley-fill sediments, and (3) quantification of the sustainability of aquifers. Three-dimensional modeling of the sedimentary architecture of valley-fills is a major component of the program. These models will enable characterization of potential aquifers and aquitards, and delineation of their extent and interrelationship to surrounding beds. Such models can facilitate the identification of potential recharge or contamination pathways into buried aquifers, and calculation of unit volumes for estimates of potential storage capacity.

A preliminary study, at Fredericton, New Brunswick is nearing completion. An ideal test site, the city is situated in an estuarine valley at tide-head, with its aquifer buried directly under the urban centre. Underlying sediments are typical of glacial valley-fills and over 1000 boreholes have been drilled into the subsurface. This data set has been collected and culled to approximately 475 records containing significant data and verified positioning. Work is still ongoing as more drilling data is recovered and the data set and model will provide a useful tool for engineers and land-use planners. Three-dimensional modeling represents the best mechanism to calculate exploitable resources and to address and prepare for adaptation to the potential impacts of climate change. Where borehole records exist, this mapping tool is a cost-effective approach to delineating aquifer architecture without incurring expensive and unnecessary drilling that can compromise containment by drilling through protective aquitards.

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THE ROLE OF GEOLOGICAL MAPPING IN SUPPORTING WATER RESOURCE MANAGEMENT IN MINNESOTA

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Land-use planning in Minnesota is largely directed towards preserving the state's abundant but sensitive water resources. Increased pressures on these resources due to population growth have prompted land-use planners to address three broad and overlapping concerns: water quantity, water quality, and surface water–ground water interaction. The Minnesota Geological Survey (MGS), established as a source of sound geologic information for the state, is active in these concerns. This poster presents three examples of how MGS mapping products have evolved to assist an ever-broadening group of decision makers concerned with the management and protection of water resources. The northwestern Twin Cities metropolitan area is experiencing rapid growth towards the eroded edge of bedrock aquifers. In order to help the local Metropolitan Council determine the quantity of water available, MGS provided information on the extent, thickness, and hydraulic properties of bedrock aquifers in this area. Products included isopachs of aquifer thickness, borehole geophysical data, hydraulic data, and an updated water well database. Southeastern Minnesota consists of karst terrain where changing land-use practices may impact ground-water quality. MGS is participating in an Environmental Protection Agency 319 demonstration project to provide information on areas where bedrock aquifers are most susceptible to rapid recharge. Products include maps of bedrock geology, structure, and depth to bedrock, along with a karst features database. Surface water–ground water interaction is a concern of the Carnelian-Marine Watershed district in northern Washington County. MGS provided the district with a bedrock topography map, a surficial materials map showing areas of preferential recharge, digital elevation models of till layers, a water-table map, and an interpretive report. Decision makers need to have information that is easily available and understandable. Project results are provided digitally as customized ArcView projects. Associated databases are available online, and interpretive reports are typically combined with a users' workshop. Our goal is to broaden the list of people who understand the importance of geology in land-use decisions.

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THE APPLICATION OF THREE-DIMENSIONAL GEOLOGIC MAPPING FOR GROUNDWATER MANAGEMENT IN NORTHEASTERN ILLINOIS

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As a pilot study of the Central Great Lakes Mapping Coalition, we created a 3-D stratigraphic model of the glacial materials above bedrock for the Antioch 7.5' quadrangle in northeastern Illinois. The glacial drift is 200 to 350 feet thick and contains multiple aquifers that are the primary groundwater sources for this rapidly developing area.

The mapping revealed a complex succession of glacial sediments representing three major events of the last (Wisconsin Episode) glaciation. Diamictons of these events are generally lithologically distinct and intertongued with proglacial lacustrine and fluvial facies. The stacking and burial of debris-rich ice along the western flank of the Lake Michigan lobe during each event also produced abundant reworked supraglacial and ice-marginal facies in this area.

Three-dimensional modeling was undertaken to image the subsurface distribution of these glacial deposits. The materials were initially grouped based on their lithology (e.g., diamicton, sand, and silt) and then classified into lithostratigraphic units based on material properties (e.g., diamicton color and particle size) and stratigraphic position.

Data used in the model are of highly variable quality and include water-well drillers' logs (275 selected from several thousand), stratigraphic test borings to bedrock (8), and natural gamma logs (31). We acquired the test borings and natural gamma logs as part of this mapping study to provide key lithologic and stratigraphic control to better interpret the drillers' logs. Additional surface and borehole seismic surveys we acquired provide continuous reflection of subsurface materials between boring sites.

After the model was developed, the entire water-well database was further analyzed to determine the percentage of wells in each square-mile section that were screened in the various units. The 3-D model and data analyses illustrate the complexity of glacial units and variation in their water-bearing characteristics. Geologic mapping in the region provides decision-makers the critical geologic interpretations necessary to protect groundwater resources and to explore for new sources.

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GS08-P11 GPR STRATIGRAPHY OF AN END MORAINE AND OUTWASH COMPLEX: PARIS MORAINE NEAR ARKELL, ONTARIO

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One of the best examples of an Upper Pleistocene end moraine system in southern Ontario is the Paris Moraine formed by the Lake Ontario lobe of the Laurentide Ice Sheet. To investigate the stratigraphy and depositional environments in this system, an extensive program of ground penetrating radar (GPR) profiling has been undertaken over the moraine and adjacent outwash complex at and around the Arkell Research Station of the University of Guelph. All of profile lines were acquired using 50 MHz antennae to maximize the depth of investigation; selected lines were also acquired with 100 and 200 MHz antennae to obtain finer resolution images of stratigraphic structures.

Dip profiles on the frontal slope of the moraine ridge are characterized by relatively continuous, sub-parallel reflections, defining a series of vertically stacked, wedge-shaped packages that pinch out in the downdip direction. The internal configuration of these packages is discontinuous, locally hummocky reflections. Strike lines on the frontal slope show that the lateral continuity of these packages tends to decrease as one proceeds up the moraine toward its crest. These wedge packages are interpreted to be aprons (fans) of debris-flow diamicton and waterlaid sediments; their internal configuration indicate wide cuts-and-fills and/or noses of gravity flow emplaced bodies The GPR reflection pattern of the hill crest and back-slope portions of the moraine are significantly different and suggest the possibility of faulting associated to ice push.

Proximal outwash profiles running parallel to the moraine trend show sequences of strong, undulose, reflectors, discontinuous on the scale of 10-20 m; these reflector patterns suggest multiple, nested channels. At least three vertical phases of channeling can be seen on the profiles. A portion of the proximal outwash sequence is overlain by the moraine frontal wedge units. The lower limit of the outwash deposit on the profiles is commonly a strong, continuous basal reflector. The good depth of signal penetration in both the moraine and outwash deposits indicate that these are composed of sandy diamicton and washed sand and gravel, respectively. The thickness of the outwash deposit generally decrease away from the moraine; however, there is significant local variation partly due to the underlying topography characterized by the local presence of buried to partially buried drumlins.

QUATERNARY GEOLOGY
GÉOLOGIE DU QUATERNAIRE

GS08-P12 GEOARCHAEOLOGY OF A ROMAN NECROPOLIS IN PAREDES, NORTHWESTERN SPAIN: A GEOMORPHOLOGIC AND STRATIGRAPHIC STUDY

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A Roman necropolis associated with a Palaeolithic archaeological site was discovered during the building of a foundation for a shopping centre in Paredes, Asturias, northwestern Spain. The scope of this study was to describe the geological context of the necropolis and to search for a Roman villa as the original source, as well as to display how geoarchaeology can be used to describe the interaction of human behaviour and the dynamics of the geological processes. To accomplish this, the geomorphology and stratigraphy of the area were described.

A geomorphologic map (1:10,000) was made using aerial photographs as well as observations made directly from the site to determine the main Quaternary processes involved in shaping the nine square kilometres area. To complete the geomorphologic observations: a stratigraphic study was carried out to analyze the units where the necropolis is located today and its relationship to the other layers; 125 trenches were excavated in an area of 300,000 m^2; and ^{14}C was applied to date key stratigraphic levels.

Two conclusions were established:

1. The stratigraphy of the necropolis exposes three main units: (a) a layer of quartz pebbles interpreted as the old channel deposit which grades laterally into sand and silt floodplains towards the northwest; (b) a layer of poorly sorted, chaotic quartz pebbles which unconformably overlies the latter level interpreted as alluvial material reworked by gravity processes or anthropogenic activity that grades into; (c) a fine-grained level deposited by creep, sub-superficial runoff and antropic action showing the signature of edaphic processes. The necropolis is associated to the second stratigraphic level that is excavated within a terrace at 170-180 m above sea level.

2. The Roman villa was located southwest outside the perimeter of the shopping centre's foundation. This is based on: (a) the correlation of stratigraphic sequences at different levels of the terraces where no artefacts were found; (b) the geomorphologic and stratigraphic analysis of the alluvial fan in the south-western area, which having drained for the last 8,890 years the sector where the Roman villa was expected to be found, does not contain any artefacts; (c) the archaeological material found in a trench in the south-western sector in a layer 1,670 ± 60 years BP, coherent to the archaeological remnants found in the necropolis; and (d) the lack of any natural sedimentary process involved in the deposition of the artefacts found in the latter trench.

GS-09

REGIONAL GEOLOGY

GÉOLOGIE RÉGIONALE

GS09-P01

PERI-GONDWANAN TERRANES IN NOVA SCOTIA AND SOUTHERN NEW BRUNSWICK: NEW INSIGHTS AND ENIGMAS

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Both Nova Scotia and southern New Brunswick consist of fault-bounded areas of rocks which show both similarities and contrasts in their Late Proterozoic - Early Paleozoic evolution. The number of distinct terranes represented by these rocks, and their relationship to the classical Meguma, Avalon and Gander zones of the northern Appalachian orogen, remain controversial, in spite of a large body of accumulated field, petrochemical, and geochronological data. Abundant Carboniferous strata overlie these terranes and where they are exposed a myriad of Carboniferous and younger faults obscure the original nature of these boundaries, and it is apparent that many components of the terrane collage are missing. Rare remnants of high-pressure metamorphic belts provide evidence for the presence of former terrane boundaries. In southern New Brunswick, the Hammondvale metamorphic suite (peak metamorphic conditions at 9.5-12 kbar and 580-420°C) is interpreted to represent a remnant of an accretionary complex formed in association with ca. 620 Ma subduction in Caledonia terrane, and its presence confirms that the now-adjacent Brookville terrane was not part of the Caledonia (Avalon) terrane at that time. Also in New Brunswick, the Pocologan metamorphic suite, at the boundary between the Brookville and Kingston arc terranes, had peak P-T conditions of 9.5 kbars and 550°C, probably at ca. 430 Ma, but a complex later history of terrane transpression is indicated by argon cooling ages as young as ca. 320 Ma. Work is in progress to investigate the P-T conditions of fault-bounded slivers of possible high-pressure metamorphic rocks along the Cobequid-Chedaducto fault zone between the Meguma and Avalon terranes in Nova Scotia. Magnetic and gravity models, constrained by magnetic susceptibility and density measurements from surface samples, indicate that present faulted boundaries are steep, and dip to the northeast in Cape Breton Island but to the southeast in southern New Brunswick. The models require geophysically distinct bodies at depth (ca. 6 km or more) that are interpreted to correspond to the Meguma, Avalon, Brookville, and Gander basements. Tracing terrane boundaries into eastern New England is complicated by abundant Silurian and Devonian igneous units, and by apparent major offsets in the southwestern part of the Bay of Fundy around Grand Manan Island. Studies are in progress on Grand Manan Island to help resolve correlations with mainland New Brunswick and/or Nova Scotia.

GS09-P02

REGIONAL IMPLICATIONS OF THE PRE-MESOZOIC GEOLOGY OF GRAND MANAN ISLAND, NEW BRUNSWICK

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Grand Manan Island in the Bay of Fundy is an enigmatic component of the northern Appalachian orogen, with uncertain relations to peri-Gondwanan terranes on the mainland. New bedrock mapping and petrological and geochronological studies have led to a better understanding of stratigraphic relationships among the pre-Mesozoic rocks on the island. The oldest rocks are black shale, siltstone, and quartzite of the Thoroughfare Formation, and marble of the Kent Island Formation, the latter represented only by marble blocks in the Three Islands Granite. Rocks of the Thoroughfare Formation are faulted against mafic to felsic flows and tuff, mudstone, and banded iron formation of the Ingalls Head Formation, from which a rhyolitic tuff has yielded a U-Pb age of 618±3 Ma. This age is slightly older than the age of 611±3 Ma from the Three Islands Granite. Intermediate to felsic volcanic rocks, siltstone, arkose, and pebble-cobble conglomerate of the Great Duck Island Formation are interpreted to be younger than the Ingalls Head Formation; a U-Pb age of ca. 547 Ma from a granitic unit in the Great Duck Island Formation provides a minimum age. The Great Duck Formation is in faulted contact with black shale, siltstone, quartzite, and minor conglomerate of the presumably overlying Flagg Cove Formation, which is intruded by the ca. 535 Ma Stanley Brook Granite. The Great Duck Island Formation is in faulted contact with the mainly volcaniclastic Priest Cove Formation, from which a crystal tuff yielded a U-Pb age of 539±5 Ma, contradicting a younger age previously suggested on the basis of a poorly documented fossil occurrence. The Priest Cove Formation is interpreted to be a lateral facies equivalent of volcanic flows and breccias of the Ross Island Formation. Volcaniclastic rocks and wacke in the Red Point area in southern Grand Manan Island and subaerial mafic to felsic volcanic and associated arkosic rocks on offshore islands are considered to be younger than all of the above units because of their less deformed character. The relationship of volcanic flows and breccias that form the northern tip of Grand Manan Island to the other units is not known; a felsic porphyry dike with a previously reported U-Pb age of ca. 396 Ma provides a minimum age for these rocks. Gabbroic bodies of uncertain age occur in association with several units on Grand Manan Island; their petrologic features provide additional constraints on unit correlation.

GS09-P03 EOCENE-OLIGOCENE FOREBULGE MIGRATION IN CENTRAL VENEZUELA

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On the bases of sequence stratigraphic analysis and 2D seismic interpretation, an alternative evolution of the Oligocene-Miocene between Guarico and Maturin sub-basins in the Eastern Venezuelan Basin is herein proposed.

After the Jurassic continental break-up at the north of South America, a north deeping Cretaceous-Eocene passive margin was developed over a Jurassic graben system. The foreland evolution, related to the NE-SW oblique collision of the Caribbean Plate against the South American Plate, is recorded diachronically at central Venezuela. The Oligocene basal sands in the North of Guárico sub-basin represent transgresssive deposits thickening NW. Regressive deposits thinning SE subsequently overlap this system.

At Miocene times the foredeep migrates Eastward developing a similar system in the western part of Maturin sub-basin. Upper Oligocene –Lower Miocene deposits represent transgressive basal sands thickening NW, overlapped subsequently by Lower Miocene regressive deposits thinning SE.

During Upper Miocene times, Guarico sub-basin was inverted leading to the erosion of Lower and Middle Miocene sediments while in the East of Maturin sub-basin these sediments are preserved.

The forebulge in the central Venezuela at Eocene and Oligocene times is recognised based on first, the absence of Eocene sediments observed north of Guarico sub-basin with SW-NE orientation parallel to the absence of Oligocene sediments in the west of the Maturin sub-basin, which coincides with the orientation of the Caribbean deformation front; second, the reciprocal stratigraphic effect:regressive deposits in the foredeep correlate in time with transgressive deposits in the uplifted areas, and vice-versa, and third, the overlapping foredeep geometry of Guarico and Maturin sub-basins to the SE. The location of the forebulge is important, because this paleogeographic feature is associated with hydrocarbon migration. Besides, in a non-marine environment, it is associated with fluvial deposits with good reservoir qualities.

GS-10

STRUCTURAL GEOLOGY AND TECTONICS

GÉOLOGIE STRUCTURALE ET TECTONIQUE

GS10-P01

PRELIMINARY RESULTS ON GEOMETRY, AGE AND SIGNIFICANCE OF NORTH-VERGING STRUCTURES PRESERVED IN THE TETHYAN SEDIMENTARY SEQUENCE, HIDDEN VALLEY, NEPAL, HIMALAYA

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The Tertiary collision of India with Asia resulted in the closure of the Tethyan sea, and formation of a dominantly south-propagating thrust system. Paleotethyan and Tethyan sediments from the north Indian paleocontinental margin deformed upon collision, and are now preserved in the northern Himalaya as the Tethyan sedimentary sequence (TSS). In central Nepal, Paleozoic and Mesozoic TSS sediments are exposed in the hanging wall of the Miocene South Tibetan detachment system (STDS), a top-to-the-north fault zone coeval to the structurally lower Main Central thrust (MCT). The STDS and the MCT define the upper and lower boundaries of the Greater Himalayan sequence (GHS), the metamorphic core of the Himalaya.

The GHS underwent two major Himalayan pulses. The Eohimalayan pulse in late Eocene-Oligocene is defined by Barrovian type kyanite-grade metamorphism, and is linked to early crustal thickening. The Miocene Neohimalayan pulse is associated with sillimanite-grade metamorphism, granite emplacement, and southward extrusion of the GHS. The response of the TSS to these orogenic pulses is poorly understood. In central Nepal, the TSS is characterized by five phases of deformation (D_1-D_5), the second of which (D_2) is defined by prominent north-verging structures. This north-verging deformation is either related to Miocene strain along the STDS, or to an older Oligocene shortening event linked to crustal thickening during the Eohimalayan pulse.

The Hidden Valley is located in central Nepal, west of the Kali Gandaki Valley and the Thakkhola graben. The TSS is well-exposed, and consists of weakly metamorphosed Cambrian to Triassic carbonates, shales, and quartzites. Deformation is dominated by large asymmetric north-verging F_2 folds. These F_2 folds are typically chevron to circular, of class 1_B. F_2 fold hinges plunge slightly to the east. S_2 fabrics are axial planar to F_2, and commonly dip 30° to the SSW. S_2 varies from a weak to well-developed disjunctive cleavage, depending on rock composition and competency. Smaller asymmetric south-verging kink and open folds overprint D_2 and are associated with an overprint crenulation cleavage. A late prominent vertical spaced fracture related to the Thakkhola graben also affects the TSS.

Ongoing research includes $^{40}Ar/^{39}Ar$ thermochronology of muscovites and phengites to determine the age of S_2 cleavage formation. Palinspastic restoration of cross-sections will determine thickening and shortening associated with each recognized deformation phase. This study will ultimately result in an increased understanding of the structural evolution of the TSS, and its relationship to the evolution of the underlying Himalayan metamorphic core.

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GS10-P02 PRELIMINARY INVESTIGATIONS ON THE STRUCTURAL GEOLOGY AT THE SUPERIOR CRATON MARGIN AT GULL RAPIDS, NORTHERN MANITOBA

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Mapping in the Gull Rapids area (NTS 54D/6) revealed an Archean amphibolite facies supracrustal assemblage consisting of amphibolite (metabasalt) and metagreywacke with interlayered banded oxide-, sulphide- and silicate-facies iron formation. The supracrustal assemblage is in structural contact with granodioritic gneisses and augen gneisses of currently unknown origin and age. Extensive leucocratic felsic injections occur in both the supracrustal and granodioritic gneissic rocks, and major east-trending Paleoproterozoic mafic dikes cut all the above lithologies. Structural investigations revealed at least four generations of structures, G_1 to G_4, with associated folds, foliations, and lineations. G_1 is best represented by a strong regional tectonic foliation, S_1. Ductile east-trending dextral and sinistral shear zones affected the supracrustal and granodioritic gneissic rocks by cutting and deforming S1 fabrics. As well, these shear zones do not cut or deform any F_2 folds, suggesting that the shears are late-G_1, pre-G_2. Shear zones are not present in relatively undeformed felsic injection phases, which are interpreted to be syn- to late-G_2, consistent with the interpretation that shear zones developed during late G_1. G_2 structures are best represented by meso- and macro-scale folding of S_1 in the supracrustal rocks. Locally, an F_2 axial-planar foliation, S_2, is developed subparallel to S_1. G_2 Boudinaging occurs frequently, and boudin neck axes are parallel to the regional lineation, L_1. In a few localities, pegmatitic injection fills in along G_2 boudin necks, suggesting the injection is syn-G_2. As well, straight-walled pegmatite dikes and veins cut S_1-S_2, indicating they are post-G_2. Samples of these pegmatites have been taken for U/Pb dating, to constrain the ages of deformation for G_1 and G_2. G_3 is an open-style F_3 folding event that modifies S_1-S_2 strike orientations in the map area. Paleoproterozoic mafic dikes cut G_1, G_2, and G_3 structures. One of these dikes has been dated at 2050 to 2070 Ma, thus providing a minimum age of deformation for G_3. G_4 deformation is expressed by brittle faulting. These faults are generally oriented 110 to 160°, subparallel to the presumed nearby Superior Boundary Zone, and affect all rock types in the map area, including the 2050 to 2070 Ma Proterozoic mafic dikes, suggesting that G_4 is related to Hudsonian faulting along the boundary zone.

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SIGNIFICANCE OF SUSPECTED DEBRIS FLOW DEPOSITS FOR THE STRUCTURAL AND STRATIGRAPHIC INTERPRETATION OF THE SILURIAN SECTION BETWEEN THE NIGADOO RIVER MOUTH AND ARMSTRONG BROOK, NORTHERN NEW BRUNSWICK

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It was traditionally believed that two distinct conglomerates existed in the Silurian section of northern New Brunswick. An older one, basal to the Silurian sequence and overlain by limestone, formerly known as Armstrong Brook Formation, now Weir Formation, and a younger one, underlain by the same limestone. By analogy with studies from the Gaspe Peninsular, a fluvial origin was considered the most likely for the lower conglomerates. In New Brunswick's costal exposures, however, there is abundant evidence that the lower conglomerates are resedimented in a marine environment and most likely represent debris flow deposits. Even if the clasts originated in alluvial fans they are now found interbedded with fine-grained calcareous turbidites, apparently in a relatively deep-water environment away of the high-energy coastal zone. Lithologically red, matrix supported pebble conglomerates and gritstones predominate, however, green grits, sandstones and boulder conglomerates are also encountered. The sediments are compositionally and texturally immature. Bedding is rare. At some localities pebbles appear to be injected into the limy turbidites. Calcareous turbidite beds are interbedded with green conglomerates. All observed contacts of the conglomerates are, sharp lithological transitions interpreted here as walls of erosional channels. The base of the formation displays chaotic folding and contains distorted lenses of mudstone torn from the host turbidites. Lensing and inverse grading are common in the lower and middle part of the formation. Thin beds of marine calcilutite appear in the upper part. Abundant rugose and tabulate corals and stromatoporoids are found between the pebbles. Long-axis-parallel arrangement of pebbles is common. Fluvial structures and textures are missing. If marine deposition from debris flows is accepted for these rocks the structural and stratigraphic interpretation of the sequence has to be changed. Because, the flows have been channel-controlled, different channels or channel fans may have been present rather than a single rock body at a distinct stratigraphic level. The catastrophic deposition from possibly different sources may have persisted for a long time and it rules out use of the formation as a time marker. The re-sidementation of fossils from older sediments distorted the time record. Channel sediments probably cut into the basement so they are not conformal with the under- and overlying strata. Exposures of these rocks cannot be connected by a folded surface so the inferred folds are probably incorrect. Most likely the conglomerates represent isolated bodies, deposited at different stratigraphic levels, over an unspecified and probably very long period of time during the emergence of an adjacent landmass.

GS10-P04 MYFAULT: A NEW WINDOWS APPLICATION FOR ANALYZING FAULT SLIP DATA

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MyFault is an easy-to-use Windows application for analyzing fault and slip geometry and calculating the stresses that lead to the formation of these structures. MyFault processes field fault slickenside measurements, earthquake nodal solutions and P-T axes data and gives you a large variety of formats for entering the values. You can even mix formats and data types in the same data file.

With the program, you can make fully customizable scatter plots, histograms, rose diagrams, Mohr diagrams and stereonets. You choose which features or variables to plot, both measured and computed, including the results of the stress analysis. You can examine the interrelationships between features, their statistical properties and orientation distribution. All the plot characteristics can be saved as templates to standardize your presentations. You can even direct MyFault to create plots automatically when you load a new data file, a good time- and effort-saver.

You can also calculate the stresses that may have produced the faults using one of several published methods of stress inversion. MyFault lets you switch easily between the various methods and compare the results. Each method has its own set of assumptions and procedures which may or may not be valid for your particular field situation. All methods use the same data set, user interface and calculation options, although some methods may have additional options particular to themselves. The methods currently included with the program are Angelier's slip misfit minimizing, Reches' nisfit minimizing with a failure criterion, Michael's shear stress minimizing and a tensor averaging method similar to Spang's and Turner and Weiss' method. The program is open-ended, so additional inversion methods can easily be linked in as the coded modules become available.

GS10-P05 THE LAS PIRQUITAS THRUST, A METAMORPHIC HIGH-STRAIN ZONE OF GENERAL SHEAR

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The Las Pirquitas Thrust of the Sierra Pie de Palo, northwest Argentina is characterized as a top-to-the-west high-strain zone of general shear. The mylonitic to ultramylonitic shear zone experienced a considerable component of pure shear resulting in shortening normal to the zone boundary and extension parallel to the margins of the shear zone in early to middle Paleozoic time.

The Las Pirquitas Thrust places amphibolite facies tonalitic, mafic, and ultramafic rocks of the Pie de Palo basement complex over quartzites, carbonates, and volcaniclastic rocks of the Caucete Group. Both structural units display east-west trending mineral and stretching lineations and a shallowly east-dipping foliation that is broadly folded about a north-south axis. Recumbent isoclinal folds and sheath folds are developed within in both of the units. In outcrop and thin section, the mylonitic to ultramylonitic rocks contain shear sense indicators that give a combined top to the west sense of motion. These include S-C fabrics, oblique grain shape fabrics, asymmetric s- and d-type porphyroclasts, mica fish, and quartz c-axis fabrics. However, seemingly contradictory shear sense indicators are locally developed at all scales and include asymmetric porphyroclasts and mica fish.

Qualitative evidence for deviation from bulk simple shear is suggested by Type I quartz c-axis fabrics, back-rotated s-type porphyroclasts, and conjugate shear bands. The shear bands consist of a synthetic member inclined at a low angle to the foliation and a more steeply inclined antithetic member. The conjugate shear bands effect epidote and amphibolite layers of the hangingwall rocks but are absent or poorly developed in deformed quartz layers of the same sample. Where they occur in more quartz-rich lithologies such as tonalites and rocks of the Caucete Group, low-angle synthetic shear bands are typically present within the matrix, with high-angle antithetic shear bands locally effecting rigid porphyroclasts.

Observations from the Las Pirquitas Thrust are consistent with those reported elsewhere and illustrate that metamorphic high-strain zones are commonly characterized by general shear, with end members simple and pure shear the exceptions. In general strain zones such as these, care should be exercised in shear sense determinations, using a variety of criteria from an area of regional significance. The formation of shear bands may be strongly influenced by composition and other rheological factors such as temperature and the direction of maximum shear strain rate.

GS-11

SEDIMENTOLOGY, STRATIGRAPHY AND PALEONTOLOGY

SÉDIMENTOLOGIE, STRATIGRAPHIE, ET PALÉONTOLOGIE

DAN GEORGESCU

EMMANUELLE AMAUD

GS11-01 EARTH'S EARLIEST EDIACARANS, MISTAKEN POINT, NEWFOUNDLAND

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The Mistaken Point assemblage of eastern Newfoundland (575 – 560 Ma) contains the oldest large and architecturally complex organisms known anywhere on Earth. These Ediacaran fossils are preserved on more than 100 large bedding surfaces spanning nearly 4 km of section, each surface littered with tens to thousands of fossil specimens that died in place when they were smothered beneath beds of volcanic ash. Trace fossils are conspicuously absent from the Mistaken Point biota, which consists entirely of cm- to m-scale, soft-bodied, sessile, benthic organisms/colonies. The deep-water setting rules out any possible affinities with plants or other photoautrophs, and the ecological structure of Mistaken Point communities is most similar to that of Phanerozoic and modern communities of suspension-feeding animals. In contrast with the variety of segmented body plans that characterized younger Ediacaran taxa worldwide, most of the fossils of the Mistaken Point biota exhibit a “rangid” architecture, which consists of highly fractal, quiltlike, triangular elements that were used as the “building blocks” of a wide array of different body plans. It is difficult to relate rangids to any living groups of organisms. A myriad of rangid genera and constructions (including isolated elements, fronds, spindle-shaped recliners, bushes, fans, and palisades) dominate the Mistaken Point biota, but few are known from post-Mistaken Point Ediacaran assemblages worldwide, and none have been reported from any Phanerozoic fossil assemblage. Rangids appear to represent a "lost architecture" that characterized the earliest stages of benthic animal evolution.

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GS11-02 DISTRIBUTION OF SPONGES WITHIN THE MIDDLE CAMBRIAN BURGESS SHALE AND STEPHEN FORMATIONS, BRITISH COLUMBIA

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Over 3000 sponge specimens were collected by Royal Ontario Museum parties from the Burgess Shale and Stephen Formations in 18 field seasons between 1975 and 2000. They were found in localities stretching over a distance of 60 km in Yoho and Kootenay National Parks.

In the Burgess Shale Formation, most of the sponges are distributed in six different communities found in different localities in Yoho National Park, at different stratigraphic levels. The three oldest communities occur on Mount Stephen and the three youngest on the west slope of Fossil Ridge, between Mount Field and Wapta Mountain. Biostratigraphically, the oldest, the Collins Quarry community on Mount Stephen, occurs in the *Glossopleura* Zone, *Polypleuraspis* Subzone. The other five communities are in the overlying *Bathyuriscus-Elrathina* Zone, with the three oldest in the *Pagetia bootes* Subzone, and the two youngest in the *Pagetia walcotti* Subzone. All communities are made up of sponges already known, and a number of new species currently being described.

Sponges also occur in the seventh, and youngest, community in the Stephen Formation outcropping in Kootenay National Park.

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GS11-03 REFINED BIOMETRIC METHOD FOR DISTINCTION OF CLOSELY RELATED CERIOID COLONIAL CORALS

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In colonial corals, corallite size is an important criterion for species distinction and recognition. Various conventions, however, have been used for measurement of this parameter and for selection of corallites to measure, yielding different values. Although diameter has commonly been used to represent size, area is a more constrained and reproducible feature, better reflecting the dimensions of the organism. To adequately represent a cerioid corallum, it has become common to measure any 20 contiguous corallites, regardless of size. Recently, however, it was suggested that 20 mature corallites (having six or more sides) in a contiguous area should be measured. The present study further refines biometric methodologies, using the rugosan Crenulites from the Upper Ordovician Selkirk Member, Red River Formation, at Garson, Manitoba.

Statistical analysis of Crenulites demonstrates that corallite area generally increases with increasing polygonality. Corallite frequency within each polygonality class varies among transverse sections in a corallum; thus, mean corallite size is also variable. Six-sided corallites are in equilibrium and are usually the most frequently represented class. To reduce variability among sections, data collection from this class alone is recommended. Statistical comparison of mean areas of six-sided corallites for all sections within central-axis and peripheral-margin sample blocks of coralla revealed values considered anomalously low or high. In order to confine the data set to sections representing normal growth, we recommend exclusion of anomalous values from further analysis. Also, because anomalous values commonly occur in basal and top portions of coralla, exclusion of these portions expedites data collection. Combining data from remaining non-anomalous sections yields a larger sample and an overall mean value of corallite area that is representative of each block. Comparing these values between blocks for each corallum revealed that, where mean areas differ significantly, the value for the peripheral-margin block was greater. Therefore, we recommend confining analysis to central-axis blocks.

Our refined methodology permits efficient, reproducible and consistent measurement of corallite size, yielding large data sets with minimal variation for comparison of coralla and for species distinction. We distinguished two species of Crenulites within the Selkirk Member; one characterized by large corallite size and low intraspecific variability, the other by smaller corallites and higher variability. Coexistence of these two otherwise similar species suggests partitioning of available resources. Application of our methodology to other genera will permit further exploration of the nature, extent, and significance of niche partitioning in the context of paleoenvironmental and biodiversity changes through time.

GS11-04

BORING AND ENCRUSTING ORGANISMS ON MOLLUSCAN SUBSTRATES FROM THE UPPER ORDOVICIAN OF MANITOULIN ISLAND, ONTARIO

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The fossil record of boring and encrusting habits among invertebrates extends back to the Early Cambrian, these niches being occupied in the earliest metazoan reefs, later expanding among hardground and rockground communities which diversified in the Early Ordovician. Calcareous shells of sessile marine invertebrates became increasingly significant substrates for boring and encrusting activity through the Palaeozoic, the importance of molluscs as substrates expanding substantially in the Mesozoic. Association of boring and encrusting organisms with molluscan substrates has been rarely documented from rocks of Early Palaeozoic age, although brachiopods, corals and bryozoans of similar age commonly show borings.

Conclusive evidence of the existence of this association during the Early Palaeozoic is preserved with a silicified molluscan fauna recovered from lagoonal dolostones of the upper Kagawong Member, Georgian Bay Formation (Upper Ordovician-Richmondian) on Manitoulin Island, Ontario.

Borings occur as multiple, often densely clustered surface perforations (diameter 0.4-0.5 mm) in the silicified shells of large bivalves (*Cyrtodonta* spp.) which lead to a series of silicified casts of solitary or interconnected tubular chambers of relatively uniform diameter (typically 0.5-1.5 mm) within the shell. Some boring casts exhibit a distinctive surface microstructure characterized by numerous hemispherical protuberances and minute hair-like projections closely resembling the tubercles and apophyses commonly preserved in natural casts of the ichnogenus *Entobia*. Based on this similarity, the producers of these ancient traces would seem to be endolithic sponges, however, in many cases microbial organisms and/or polychaete annelids appear to be equally likely agents of bioerosion.

Encrusting forms associated with these bivalves consist of numerous sinistrally coiling tubes similar to those produced by spirorbid polychaetes and larger uncoiled tubes of probable serpulid polychaete origin. As is the case with the openings of the *Entobia*-like borings, these tubes occur on the inner and outer surfaces of disarticulated valves of cyrtodontids as well as other bivalve genera, indicating that colonization of the shells occurred post-mortem.

Tabular trepostome bryozoans are also common encrusters on molluscan substrates within the upper Kagawong fauna, occurring as overgrowths on orthoconic cephalopods and lophospirid gastropods. Evidence for serial encrustation (primary encrustation on cephalopod phragmocones by spirorbids, followed by secondary bryozoan encrustation) as well as extensive development of borings, suggests that the shells were exposed above the sediment-water interface for prolonged periods, pointing to a low background sedimentation rate within the environment and/or repeated burial and exhumation of the molluscan bioclasts.

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MECHANISMS FOR ANOMALOUS CALCIUM CARBONATE PRESERVATION IN THE ABYSSAL WESTERN NORTH PACIFIC

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Calcareous sediments have been recovered from well below the present day CCD (Carbonate Compensation Depth) at several sites in the abyssal western North Pacific (ODP Sites 881, 882, 884 and 1179). $CaCO_3$ concentrations were measured onboard the JOIDES Resolution during ODP Legs 145 and 191, using a 5011 Carbon Dioxide Coulometer equipped with a System 140 carbonate carbon analyzer. Sediment ages were determined using biostratigraphic datums and magnetochrons. Sediment samples from Site 1179 (~5586.5 m water depth, 41°4'N, 159°58'E) contain as much as 17.661 weight percent $CaCO_3$, which is concentrated mainly into 4 carbonate peaks with ages of ~0.8, ~1.6, ~2.5, ~3.3 Ma. Several of these peaks correlate across the sampled cores. Analysis of these cores has revealed the calcite to be comprised mainly of calcite crystals as well as foraminifera, the majority being planktonic. Three species represent most of the tests, dextral *Neogloboquadrina pachyderma*, *Globorotalia inflata*, and *Globigerinoides bulloides*. The excellent preservation of these tests, including the highly soluble tests of *Globigerinoides ruber* indicates little or no dissolution within the sediment.

The assemblage is indicative of increased terrestrial flux, which would supply limiting nutrients to the area potentially causing a bloom in phytoplankton. The increased productivity is thought to saturate the water column with $CaCO_3$, suppressing the CCD to allow the deposition of carbonate sediments on the sea floor. This may play a role in late Cenozoic global cooling by sequestering CO_2 from the atmosphere. The timing of the observed carbonate peaks correlates with an increase in grainsize in Asian loess, also interpreted as recording enhanced aeolian flux.

Peaks in foraminifera numbers also correlate well with the timing of polarity reversals in the Earth's magnetic field. As the Earth's magnetic polarity changes, it also weakens, increasing the bombardment of cosmic rays, heavy charged particles, and solar radiation into the troposphere. A mechanism is proposed that would introduce a bias towards small, rapidly reproducing organisms, such as foraminifera, during such events to enhance the observed CCD suppression. Evidence for this may be available in the form of $\delta^{13}C$ records, which have been shown to document changes in solar activity.

GS11-06 PRINCIPLES OF BIOSTRATIGRAPHY RELATED TO SEQUENCE STRATIGRAPHY

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Biostratigraphy proved an extremely useful tool in investigating more or less time-related stratigraphical successions over the last century. Emergence of the sequence stratigraphy followed chronologically by the Exxon and T-R models induced two apparently insurmountable challenges to the classical biostratigraphy. On one hand the scale of correlation has been substantially reduced, far below the limits of a standard biozone that can be recognized today in the range or 150,000 to 2,500,000 years or even more. On the other hand, aligning the results to the geochronological time scale is no longer enough, but the assemblages should be also positioned within a framework of biofacies, more or less related to the encompassing sediments.

Three concepts that are used with extreme frequency in the common biostratigraphical practice are now critically considered.

The concept of first occurrence of a taxon can be regarded in two senses: (i) as evolutionary occurrence, and (ii) as local occurrence. The former is driven by evolution while the latter by a combination of two processes: invasion of new ecological niches and adaptation to the local condition. In a similar way the last occurrence of a particular taxon can be either evolutionary (extinction) or local (disappearance). Accordingly, the concept of taxon range should be regarded as an interplay between colonization and abandonment rather than an interplay between evolutionary occurrence and extinction.

Recognizing a succession of biofacies is extremely important as it is one of the major components in the sequence stratigraphical framework. A substantial improvement in understanding biofacies migrations related to the sea-level changes onto a shelf is achieved if the total microfaunal abundance curve is considered. The shape of this quantifiable parameter is strongly related to the nature of the systems tracts. Moreover, it shows well defined and quite constant patterns in the proximity of the various kinds of sequence boundaries.

The third questioned concept is represented by the sampling philosophy. Commonly, the sampling philosophy comprises equally distributed samples within a stratigraphical succession. If such sampling pattern is used, most likely that some important features of the microfaunal abundance curve can be lost (e.g., the peaks at the top of the transgressive systems tracts, peaks generated by the minor flooding within highstand systems tracts, peaks generated by the fluctuating pattern of the sea-level within transgressive systems tracts, etc). This is obvious when we consider samples prevailed from sediments accumulated at low sedimentary rates (e.g., transgressive systems tracts). Therefore, a new sampling philosophy is proposed, with the sampling step correlated to the rate of sedimentation.

These three parameters are very important as in a sequence stratigraphy related study biostratigraphical data should be correlated with events rather than time.

GS11-07

HOW RARE IS A RARE EVENT?: THE COMPLEX HISTORY OF SHELLY TEMPESTITES IN THE MIDDLE DEVONIAN ARKONA SHALE, SOUTHWESTERN ONTARIO

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The importance of storms as agents of deposition and erosion is obvious in many ancient offshore marine successions. Indeed, tempestites are among the most prominent small-scale features in otherwise monotonous successions, particularly in successions dominated by mudstones. Tempestites are usually interpreted as products of rare episodes of storm-generated disturbance punctuating long periods (tens, to hundreds, to thousands of years) of quiescence, the most prominent tempestite beds representing storms of greatest severity.

The taphonomic attributes of shelly tempestite beds in the Middle Devonian Arkona Shale (southwestern Ontario) indicate that even "simple" tempestite beds can have complex histories. Shell-rich beds dominated by well-preserved remains of small rugose corals, spiriferid brachiopods, and a variety of crinoids, are commonly associated with pavements of shell debris deposited by precursor storms. Taphonomic dissection of these beds reveals a common theme; initial priming of the seafloor by one or more storms, followed by colonization of the primed substrate by shelly benthic fauna, and final disturbance and burial of the faunal remains by a later storm.

For storms to have produced multiple signatures in single tempestite beds of the Arkona Shale, the frequencies of seafloor disturbance must have been very high, probably on the order of a few years. Such frequencies are much higher than those implied by stratigraphic occurrences of conspicuous shelly tempestites (i.e. without considering internal features of the shell beds). This implies that shelly tempestites do not necessarily represent the most severe storms recorded in mudstone successions but can, in some cases, merely represent the most obvious products of storm disturbance by virtue of their shell content. Regardless of storm severity, the disturbance of a muddy seafloor lacking abundant shell material would produce an indistinct mud-on-mud contact that would be much less likely to be noticed than a shell-rich horizon. By the same token, both small, high-frequency storms, and more severe, low-frequency storms can produce shell beds, provided that sufficient shell material is available for reworking. Interpretations of storm severity from shelly tempestites should therefore be approached with caution and be considered in context of the faunal dynamics and depositional characteristics of a sedimentary succession as a whole.

GS11-08 NEOPROTEROZOIC CAP CARBONATE TEPEE STRUCTURES

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Neoproterozoic glacial diamictites are everywhere overlain by cap carbonates that contain atypical tepee structures. Cap carbonate tepee structures have a similar morphology to modern tepee structures from intertidal environments, but in many other respects are substantially different. In comparison, cap carbonate tepees are commonly 20 times bigger in all dimensions, and up to 100 times bigger in lateral extent. This size means thick packages of strata are deformed, which is accompanied by abundant veining (termed "sheet veins"). Unlike the polygonally-arranged axes of intertidal tepee structures, cap dolomite tepee axes are elongated in shelf-normal directions (for up to several kilometers). Most paradoxically, cap dolomite tepees are found within sediments interpreted to be deep marine, suggesting that evaporation-driven crystallization cannot be the driving cause of tepee formations. Despite these differences, cap carbonate tepees have been interpreted as evidence of massive seafloor cementation due to extreme carbonate supersaturation in post-glacial Neoproterozoic oceans. This interpretation means that cap carbonate dolomite carbon isotopic geochemistry is therefore representative of the coeval seawater column, and global biogeochemistry (i.e., these structures underpin much of the biogeochemical basis for the Snowball Earth and Clathrate hypotheses). At Parachilna Gorge, in the Central Flinders Zone of South Australia, cap carbonate tepee structures occur in axial continuity with overlying small (~60 cm), normal, growth faults. Offset on the growth faults demonstrate that the tepee structure deformation started when they were 3.5 m, and ended when they were 6.1 m below, the sediment-water interface, firmly within the zone of early diagenesis. The sheet veins that are concentrated around cap carbonate tepees form, in mineral geology terminology, a typical crackle breccia, indicating pore fluid pressures sufficient to overcome lithologic tensile strength (the tepee structure is evidence of pore fluid pressure greater than lithostatic weight). A cap carbonate deformation model of formation due to early diagenetic fluid overpressure predicts all the features found in these unusual tepee structures. In fact, cap carbonate tepee structures are similar to dewatering mud volcanoes, albeit ones where early diagenetic cementation was the driving cause of fluid overpressure. That these structures are associated with diagenetic and not seafloor cementation suggests that cap dolomite carbon isotopic geochemistry is not representative of the overlying seawater column, and therefore should not be used for interpreting global biogeochemistry.

GS11-09 **MICROBIAL ORIGIN OF LAMINITES IN THE UPPER SILURIAN CARBONATE-TO-EVAPORITE TRANSITION, MICHIGAN BASIN, SOUTHWESTERN ONTARIO**

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Silurian pinnacle reefs in the subsurface of the southwestern Ontario portion of the Michigan Basin display a variety of laminated carbonates (laminites) within predominantly muddy reef-capping facies in the upper part of the Guelph Formation and the overlying A-1 Carbonate of the Salina Group. Laminites, which are limestone, dolomite or partially dolomitized limestones, have a range of morphologies, from simple planar, to a variety of wavy and serrated forms. Individual laminae are composed mainly of micrite, microspar or replacive dolomite, and vary internally from isopachous and continuous over the diameter of the core to non-isopachous and often discontinuous. Clotted and peloidal micrite, sometimes defining small knobs and chambers, are interpreted as being microbial in origin and occur within all types of laminites. Fibrous cement locally comprises laminite clasts in breccias, or coats clasts in breccias, and also occurs as spherulites in the interparticle spaces in breccias.

Although similar laminites have been described from elsewhere in the Michigan Basin and interpreted as caliche, travertine and abiotic subtidal stromatolites, the laminites in southwestern Ontario are most realistically regarded as microbial. The causes for the variations in morphology and characteristics of the constituent laminae are uncertain, although fluctuations in local microenvironmental conditions would have been important, set against a backdrop of an increasingly restricted overall setting. Caliche or travertine origins for these laminites are unlikely in general, except perhaps locally at the subaerial exposure surface at the tops of pinnacle reefs.

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GS11-10 AGGRADATION RATE AND UNIDIRECTIONAL CURRENT AS CONTROLLING VARIABLES IN THE FORMATION OF HUMMOCKY AND SWALEY CROSS-STRATIFICAITON

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Based on recent experimental work this study investigates potential genetic differences between hummocky cross-stratification and swaley cross-stratification. A hummocky bed was aggraded "synthetically" at various rates in order to investigate the resultant stratification. At the higher aggradation rate investigated (4.2 mm/min), stratification resembled hummocky cross-stratification, whereas at the lower aggradation rate investigated (1 mm/min), the stratification was more akin to swaley cross-stratification. Addition of a weak unidirectional current (~ 5-10 cm/s) to a long-period moderate oscillatory flow (~50-90 cm/s) formed anisotropic hummocky cross-stratification. More elevated unidirectional currents (> 10 cm/s) formed high-angle cross-stratification resembling unidirectional dune cross-stratification. On a cross-shelf depositional profile, the optimal preservation and depositional conditions for hummocky cross-stratification are proposed to form above (but near) storm wave base under oscillatory-dominant combined flows, moderate aggradation rates. Swaley cross-stratification, on the other hand, is postulated to form at shallower depth also under oscillatory-dominant combined flows but under lower deposition/transport ratios resulting in lower aggradation rates. The proposed paleogeographic and stratigraphic relationships between hummocky cross-stratification and swaley cross-stratification are consistent with observations from the shallow marine rock record.

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GIANT DEEP-WATER SEEP MOUNDS ENCLOSED BY ANOXIC BASINAL CARBONATE STRATA: IMPLICATIONS FOR BASE-METAL MINERALISATION

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Large (> 200 m; > 4 km width), hitherto unrecognised dolostone mounds are present in the Milne Inlet Graben (Borden Basin, Nunavut), within basinal carbonate rocks of the Mesoproterozoic Society Cliffs Formation, which also host the Nanisivik Zn/Pb deposit and numerous other base metal showings. The graben is characterised by repeatedly reactivated faults, many of them associated with sulphide mineralisation.

Carbonate mounds form dramatic cliffs in the northwestern part of the graben, and are present in core from Nanisivik. Mound growth initiated during deposition of the deep-water upper Arctic Bay Formation shale, and terminated at some time before development of the upper Society Cliffs carbonate ramp and basinal carbonate. Mounds remained topographically pronounced after growth ceased. Massive white mound-core dolostone is devoid of layering, and commonly lacks internal structure; faintly clotted fabrics are locally present. Mound tops are veneered by intraclastic or oncolitic rudstone, overlain by Victor Bay Formation shale.

The mounds do not resemble any of the bioherms hitherto described from the Borden Basin, and lack the stromatolitic framework that is ubiquitous in Proterozoic photic-zone reefs. Their deep-water location, lack of paleogeographic or substrate controls, concentration in an area of unusually dense synsedimentary faults, lack of stromatolitic framework, and common linear plan shape suggest that mound carbonate precipitated from cold-seep gas/fluids emerging on the sea-floor along synsedimentary faults. The presence of coarse-grained angular terrigenous material near faults elsewhere in the same stratigraphic interval attests to tectonic activity coeval with mound growth.

A tectonically active rift basin with syndepositional fluid systems concentrated at structural weaknesses has important implications for base-metal prospectivity. (1) A syndepositional fluid-circulating system, tectonic activity, and anoxic basin suggest that the entire Arctic Bay to Victor Bay succession could have sedex potential. Although fluid exhaled during early Society Cliffs time yielded mineralisation in the form of carbonate mounds, fluids vented at other times might have had metalliferous compositions. (2) Mounds are concentrated in Nanisivik area, where syndepositional faults are especially numerous and deviate from the regional northwest trend, and where Zn-Pb mineralisation is best developed; mounds might therefore signal areas most susceptible to fluid movement and sulphide mineralisation. (3) The Nanisivik ore body is located on the flank of a subtle dome that may be a compactional feature centred over a mound. Domes, overlain by impermeable shale, might have acted both as hydrocarbon traps and focal points for metalliferous fluids conducted through nearby faults.

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GS11-P01 LOW-DENSITY TURBIDITES IN A FLOODPLAIN ENVIRONMENT IN LA MAGDALENA STEPHANIAN COALFIELD, NORTHWESTERN SPAIN: A STRATIGRAPHIC AND SEDIMENTOLOGIC STUDY

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Although turbidites are characteristic of deep-water marine deposits, they are also present in shallower systems. This study documents the presence of turbidites in a shallow water environment characterized by small lakes and ponds on a flood plain.

We studied an interval belonging to the succession of La Magdalena Coalfield, León, northwestern Spain, which is a basin associated with strike-slip faulting during 290 to 306 Ma ago. The stratigraphy of the basin fill consists of a large-scale fining upward sequence of siliciclastics with abundant coal layers, interpreted as an evolution from an alluvial fan into a river system to a lacustrine-dominated environment at the top of the succession. Three types of deposits can be distinguished in the studied interval:(1) Coarsening upwards sequences composed of rhythmic sandstone/siltstone and mudstone intercalations that ranging from one to twenty centimetres thick. Each sandstone/siltstone and mudstone couple is a graded bed defined by sharp contacts at the base of fine, current-rippled sandstones. Beds are interpreted as Bouma´s Tc-e sequences which result from the deceleration and final deposition of low-energy sediment-laden flows entering static water bodies, and evolving into low-density turbidity currents. A shallow subaqueous depositional setting with high and continuous rate of sedimentation is strongly indicated by the generalized absence of rooting in the type (1) deposits. The whole sequence is interpreted to record the filling of ponds/small lakes in a flood plain environment by the progradation of distal crevasse lobes associated to the main river system; (2) Minor channel-fill sequences. (3) Major channel-fill units.

Overall, the evolution of the environment through time is interpreted as a floodplain associated with a river system, characterized by ponds and small lakes with vegetated areas among them. Periodic avulsions onto the floodplain from overflows of small channels produced lobes filling the ponds and small lakes, represented in type (1) deposits. These channels were later deactivated, filled with sediment and colonized by plants as is recorded in the type (2) deposits. The top of the studied interval, displaying an abrupt occurrence in the type (3) deposits, records the installation of the main river system onto the floodplain, possibly due to a rapid lateral shifting.

The beds that comprise type (1) deposits meet all the criteria for interpretation as turbidites composed of base-missing Bouma sequences, which strongly suggest that overflows from channels flowing into the floodplains' ponds and small lakes can result in turbidity currents building crevasse lobes.

GS11-P02 RESPONSE TO SYMBIONTS IN SOME LATE ORDOVICIAN TABULATE CORALS

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Three types of vertical tubes, representing previously undescribed forms of embedment structures, are recognized in certain colonial corals from the Selkirk Member, Red River Formation of southern Manitoba. They occur in *Saffordophyllum newcombae* and *Trabeculites maculatus* (massive, cerioid coralla), and in *Manipora amicarum* and *Manipora* sp. A (cateniform coralla with some multiple ranks and aggregates of corallites). These tubes were formed by the corals in response to soft-bodied biotic associates.

A tube usually developed during recovery following termination or disruption of one or more corallites, especially in cerioid coralla (*S. newcombae, T. maculatus*) and rarely in *Manipora* sp. Apparently, a foreign organism settled on a localized dead or injured area of the coral surface, or perhaps caused polyp death or injury during settlement on a living site. Ongoing upward growth of the surrounding colony formed a skeletal enclosure around this associate. Less commonly, a tube rose from the bottom of a cerioid corallum (*T. maculatus*) or formed during contraction of a lacuna in a cateniform corallum (*M. amicarum*). In these cases, a foreign organism may have become surrounded as the coral spread over the substrate, or become associated with the margin of an expanding colony.

Tubes are of variable length, extending to the top of the corallum or terminating within it. Gradual expansion of surrounding corallites, resulting in contraction and eventual termination of a tube, was common. Sometimes, abrupt termination occurred when one or more corallites expanded into a tube, or when a corallite moved entirely into a tube. Commonly, a lateral offset from an adjacent corallite entered a tube and expanded rapidly, transforming it into a new corallite.

The biotic associates preferred certain corals, and prompted particular responses from their hosts. Type 1 tubes (diameter typically 1 mm) are predominant in *S. newcombae*; just one has been found in *T. maculatus*. A divergent growth pattern, due to rapid production of new corallites by lateral increase, occurred around this type of tube. The only example of a Type 2 tube (maximum diameter 3.1 mm) is present in *S. newcombae*. There was a convergent growth pattern, with decrease in the number of corallites, around this tube. Type 3 tubes (lenticular cross-section up to 3.5 x 2.4 mm) are predominant in *T. maculatus* but also occur in *M. amicarum* and *Manipora* sp. A. Corallites adjacent to these tubes usually grew upward normally, but with incidents of corallite decrease or increase.

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THE GUTTENBERG CARBON ISOTOPE EXCURSION (GICE) ON MANITOULIN ISLAND, ONTARIO: RELATIONSHIPS WITH CONODONT BIOZONES AND CORRELATION WITH NEW YORK STATE AND THE UPPER MISSISSIPPI VALLEY

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Secular variations in $\delta^{13}C$ of carbonates provide the opportunity to test correlations of strata by other methods. These secular variations, or excursions, provide an independent correlation tool, especially in outcrops lacking good stratigraphic controls such as K-bentonites and diagnostic index fossils. One such $\delta^{13}C$ excursion, the Guttenberg Carbon Isotope Excursion (GICE) is a positive carbon isotope excursion in lower Chatfieldian limestones that is now known from occurrences in the Upper Mississippi Valley, southern and central Appalachians, Sweden, and Estonia. This excursion is useful for the correlation of limestones from the lower Trenton Group.

The Bobcaygeon Formation (middle Simcoe Group), or Cloche Island beds, at Birch Island, Manitoulin Island, Ontario was sampled for $\delta^{13}C$ to detect the GICE. Data from conodont samples taken from the upper part of the section were added to previous biostratigraphic data from the section. Preliminary data shows the GICE occurs in the section several meters above a thin K-bentonite. This suggests that previous identifications of this K-bentonite as the Deicke are correct. The GICE reaches maximum values of 2.41‰, 14 m above the K-bentonite. Above this level, the GICE returns to baseline $\delta^{13}C$ levels and the conodont zone index species *Belodina confluens Sweet* appears at the top of the section. The wackestone-packstone and interbedded shale lithology, conodont distribution and $\delta^{13}C$ values within this section are characteristic of the Midcontinent aquafacies.

The GICE correlates the Bobcaygeon Formation (Cloche Island beds) in the Manitoulin District with the Napanee and Kings Falls Limestone of New York and Guttenberg Member of the Decorah Formation in the Upper Mississippi Valley, the Logana Member of the Lexington Limestone in Kentucky and the Salona-Coburn Formations of Pennsylvania.

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GS11-P04 CRETACEOUS PLANKTONIC FORAMINIFERAL PALEOBATHYMETRY AND THEIR USE IN SEQUENCE STRATIGRAPHY STUDIES

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The role of the planktonic foraminifera in depicting paleobathymetric settings has been neglected for quite a long period of time. The argument brought was that that their tests can be transported by the oceanic water currents both during the development of their life cycles and post-mortem. Moreover, it has been claimed a certain homogeneity of the Cretaceous planktonic foraminiferal assemblages with respect to the paleolatitudes.

This point of view has been drastically changed when it has demonstrated that test architectural features can be correlated with the paleodepth necessary for developing the life cycles. Accordingly, there could be demonstrated that the peripheral structures, umbilical system morphology and test shape in edge view become more complex with increasing depths.

The above mentioned morphological observations could be further combined with the patterns in the paleobathymetrical distribution of the Cretaceous planktonic foraminiferal species and genera. Such a paleobathymetrical framework combines the planktonic foraminiferal distribution related to sea level changes in the shelf environments with that related to sedimentary episodes as recorded in the basin sediments.

A paleobathymetrical framework consisting of approximately seventy Upper Cretaceous (Cenomanian throughout Maastrichtian) planktonic foraminiferal species is now proposed. If quantitatively interpreted, it can be successfully used in sequence stratigraphy related studies.

GS11-P05 GLOBAL COOLING EFFECT OF EOLIAN DUST FROM EAST ASIA TO WESTERN NORTH PACIFIC ODP SITES 1179, 881, 882, AND 884 SINCE THE MID-PLIOCENE

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The Pliocene transition period between the warm Miocene and preceding the Pleistocene cooling is a key period of climatic change. Samples from ODP Site 1179 (~5586 mbsl, 41 4'N, 159 57'E), Site 881 (~5531.1 mbsl, 47 6', 161 29'E), Site 882 (~3255 mbls, 50 22'N, 167 N36'E), and Site 884 (~3824.8 mbsl, 51 27'N, 168 20'E) were studied to determine concentrations of terrestrial flux to the western North Pacific since the mid-Pliocene.

Erosion of material from the sustained uplift of the Tibetan Plateau has formed extensive loess sequences in China, some dating back over 100 Ma. In this region there is a definite fining of grain size to the margins of the Chinese Loess Plateau. Dust-sized particles (including pollen) are re-suspended from the far reaches of the loess plateau into the mid-latitude northwest Pacific Ocean by the westerly flowing winds of the winter Monsoons and Jet Stream traveling over East Asia and Japan. The uplift of the Tibetan Plateau has caused dramatic change in the weather patterns of East Asia intensifying the effects of the winter East Asian Monsoons.

High concentrations of terrigenous sediment in marine cores is a widely used proxy for climatic cooling, continental aridity, and strong winds indicative of glacial environments. Late Pliocene-Pleistocene glacial-interglacial fluctuations are evident in marine cores by peaks of pollen and spores occurring approximately 3.5, 2.5, 2.0, 1.6, 1.45, 1.0, 0.9, and 0.8 Ma (based on magnetostatigraphic and biostratigraphic datums). These peaks in terrestrial flux correlate with increased grain size during in the magnetostatigraphically- dated loess of the Qaidam Basin in the Chinese Loess Plateau. Peak fluxes of dust also coincide with dinocyst and calcium carbonate peaks recording plankton blooms resulting from the increased nutrient flux. An increase of sedimentation rates over the abyssal Pacific Ocean leads to rapid carbon burial and subsequent sequestration of CO_2 contributing to the late Cenezoic global cooling.

GS11-P06 **EPIPHYTES ON *THALASSIA TESTUDINUM* – A MAJOR SOURCE OF CARBONATE SEDIMENT: CASE STUDY FROM GRAND CAYMAN, BRITISH WEST INDIES**

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Sea grasses have significantly influenced sedimentation rates in coastal regions around the globe since their appearance in the late Cretaceous. The plants are integral to shallow water ecosystems and help to stabilize coastlines worldwide. *Thalassia testudinum*, which is the most common sea grass in the Caribbean Sea, contributes to carbonate sedimentation by: (1) causing deposition of suspended sediment through the baffling of currents, (2) stabilizing substrates with its complex root system, and (3) providing substrates suitable for epiphytes that, upon death, become part of the sediment. There is, however, little information on the composition of the epiphytic biota and estimates for the amount of sediment generated by epiphytes ranges from nothing to all of the calcareous mud found in a lagoon. For sea grasses to thrive there needs to be adequate cover of sediment. Since sea grass influences the amount of sediment that accumulates in a lagoon, thus aiding its own expansion possibilities, it is important to fully comprehend the affect epiphytes have on sedimentation.

Extensive *Thalassia* banks are found in the shallower, near shore areas of the lagoons around Grand Cayman. Diverse biotas of epiphytes live on leaves of these *Thalassia*. Red algae, which are the most common epiphytes, colonize *Thalassia* leaves starting at the tip and gradually extend toward the base of the plant. Other epiphytes include various species of foraminifera, gastropods, coccoliths, and scattered bivalves. All of these organisms have calcareous skeletons that become part of the sediment once they have died, either separating from the *Thalassia* leaves upon death, or when the leaves themselves die. Diatoms and sponges, which are commonly not mentioned in literature to date, have siliceous skeletons and upon their death will contribute silica to the system. Preliminary data indicate that the diverse epibiont fauna and flora found on *Thalassia* are major contributors to the sediment budget of the Cayman lagoons.

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ARCHITECTURE OF TWO DEEP-MARINE SUBMARINE CHANNEL COMPLEXES IN THE NEOPROTEROZOIC ISAAC FORMATION, WINDERMERE SUPERGROUP, CARIBOO MOUNTAINS, BRITISH COLUMBIA, CANADA

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Well-exposed channel complexes located in the southwestern Canadian Cordillera comprise continental slope deposits that formed along the ancestral passive margin of western North America following its separation from southeastern Australia. These channels occur in the Isaac Formation, which is part of the Neoproterozoic Windermere Supergroup in the Cariboo Mountains of east-central B.C. Laterally extensive and outstanding periglacial exposures allow detailed mapping of bedding geometry, stacking patterns and facies distribution within two channel complexes, informally termed Channel I and III. Architectural styles of both channel complexes differ, which most probably is the result of differences in basin floor accommodation. The base of both channel complexes is erosional. Channel I is a multistory, vertically-stacked, ~95 m-thick succession of sandstone and conglomerate channels fills that can be traced laterally for several kilometers. In contrast, Channel III is ~90 m thick and consists of multiple channel fills that aggraded and migrated laterally (toward the northwest) forming a lateral offset stacking pattern that onlaps abruptly finer-grained levee and debrites deposits.

Strata of both channel complexes comprise three principal depositional elements: channel-fill, interchannel and abandoned-channel units. Channel fills, in general, range from 7 to 25 m thick, have a general upward-fining trend and are composed of turbidites, concentrated density flow and hyperconcentrated flow deposits. Channel-fill units of Channel I typically exhibit sheet-like geometries and consist mainly of amalgamated, normally graded beds (granule conglomerate to coarse sandstone and very-coarse to medium sandstone), cross-stratified, coarse sandstone and mudstone-clast conglomerate. In contrast, channel-fill units of Channel III display wedge geometries and consist of thick bedded, structureless to graded, pebble conglomerate and sandstone (very-coarse to medium) and mudstone-clast conglomerate. Interchannel units, which separate channel-fill bodies, are up to 30 m thick and consist of interbedded/interlaminated rippled and parallel laminated fine sandstone and silty mudstone. Channel-abandonment units, located primarily at the top of channel complexes, are 20-40 m thick and form distinctive upward-fining and -thinning successions. Strata consist of thin-bedded, cross-laminated fine sandstone and silty mudstone that grade upward up to claystone. Near their base, these fine-grained strata are interstratified with sharply bounded, poorly sorted, ungraded or poorly normally graded coarse sandstone that form tongue-, wedge- or lens-shaped beds.

Channel fills of the Neoproterozoic Isaac Formation are superb ancient examples of passive margin continental slope deposits, and as such form excellent outcrop analogues for understanding and predicting hydrocarbon reservoir architectures and compartmentalization geometries in tectonically-similar deep-marine strata.

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UNCONFORMITIES, THEIR SIGNIFICANCE, AND CHARACTER WITHIN A MIDDLE ORDOVICIAN CARBONATE PLATFORM: LOURDES FORMATION, WESTERN NEWFOUNDLAND

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The nature of an unconformity offers valuable information about the possible roles of tectonics versus eustasy. Investigation of the Long Point Group on the Port au Port Peninsula provides, in the early stages of stratigraphic analysis, evidence that the Lourdes Formation comprises an unconformity-bounded carbonate platform, which is also subdivided by a prominent erosional unconformity. The boundary with the underlying Humber Arm Allochthon, recently interpreted as a thrust fault, represents an erosional unconformity subsequently modified by local displacement due to later (Acadian?) folding. The Lourdes Formation is therefore parautochthanous, and may illustrate regional transgression, possibly associated with an early Caradoc eustatic rise, following tectonic emplacement of the allochthon. Previous authors have not described the top of the Lourdes Formation. It is well exposed at the northern tip of Long Point Peninsula and shows that wackestone to packstone beds of the Lourdes Formation are capped by a likely marine hardground that preserves borings, some of which are rimmed by pyrite. Immediately overlying this surface is a thin bed of floatstone containing angular, bored clasts of the Lourdes Formation in a matrix of skeletal grainstone. This bed appears to represent a lag deposit, and is overlain abruptly by the Winterhouse Formation, which consists of silty shale and variably calcareous, fine grained sandstone. The presence of a hardground and associated lag deposit indicates a depositional hiatus accompanied by submarine erosion. Together with the termination of carbonate production, this points to a major paleoceanographic change which occurred at the end of Lourdes Formation deposition. This change probably reflects the influence of a tectonic event; however the exact linkage remains unclear. A third unconformity divides the Lourdes Formation stratigraphy in two, and truncates coral patch reefs and inter-reef limestone. The unconformity is likely a subaerial exposure surface; it varies laterally from a flat "planed" surface to a pyrite-encrusted, pitted to scalloped karst surface, and, importantly, is locally overlain by quartz arenite and cobble conglomerate of quartz arenite clasts and highly abraded coral heads. This succession illustrates lowering of base level and seaward transport of terrigenous sediment prior to resumption of shelf carbonate deposition. Significant erosion is highlighted by partially truncated inter-reef strata that dip away from reefs; this geometry indicates that compaction had occurred prior to erosion. Still in its preliminary stages, this study begins to place certain lithologic constraints on the interpretation of stratigraphic boundaries, and furthermore, on the regional influence of tectonics and/or eustasy.

GS11-P09 PUZZLING STRUCTURES IN A MESOPROTEROZOIC SHALLOW MARINE PALAEOECOSYSTEM, LOWER BELT SUPERGROUP, NORTHWESTERN MONTANA

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Stromatolites, microbes and protists in shallow water environments and microorganisms on land characterized Mesoproterozoic life. However, molecular phylogenetic analysis of the ribosomal RNA of living multicellular organisms is consistent with the origin of metazoans taking place 1.5 Ga, yet the earliest definite animal fossils, the Ediacaran fauna, are not more than 0.6 Ga old.

Microbial ground textures as "elephant skin" have been identified in the argillaceous facies of the lower Appekunny Formation in the Belt Supergroup in Glacier National Park, northwestern Montana. Associated with the mats other problematic structures have been found in the same facies and stratigraphic levels. In the present study we propose that these structures associated with the microbial mats are the remains of a shallow marine ecosystem where complex biogenic structures were potentially involved.

Six different structures have been described: (1) bedding marks that comprise lenticular beads in a string-like pattern ranging from 1.2 to 5 mm in diameter, rounded and ellipsoidal to trilobite variable in plane view. Distances between beads range between one and nine times the diameter of the beads. The beads are composed of clay, strongly contrasting with the argillaceous silty matrix that surrounds them. Several of the strings of beads were guided by the paleo-relief of ripples; (2) Net-like patterns of beads connected to each other through a lamina of clay where the distance between beads fluctuates between 2 - 5 times the diameter of the beads. These patterns are occasionally associated with tool marks; (3) Solitary semispherical beads up to 0.4 mm diameter; (4) An amoeboid impression 7 cm long by 3 cm wide; (5) Arrow-like positive relief, 3 cm by 1.3 cm; and (6) an amorphous shape 9 cm by 6.6 cm characterized by a granular pattern of evenly distributed rounded beads of one mm.

These patterns occur within plane-laminated argillaceous siltstones. The string beads are found in very fine sandstones and cross-laminated coarse sandstones as well. The association of some of the structures with tool structures, and the lack of deformation in the lamination surrounding the structure, supports the interpretation of the bedding-marks being primary structures and not related to diagenetic processes. The regularity of the strings, net-like patterns, the lateral symmetry of the arrow and amoeboid impressions, as well as the uniform texture of the latter, may suggest a complex biogenic origin.

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DEFORMATION IN THE NEOPROTEROZOIC SMALFJORD FORMATION, VARANGERFJORDEN, NORTHERN NORWAY: AN INDICATOR OF GLACIAL DEPOSITIONAL CONDITIONS?

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Analysis of deformation structures has been shown to provide important information about the depositional origin of various deposits. This may be particularly useful in the interpretation of poorly-sorted sediments that can form under ice-contact, glacially-influenced, or non-glacial depositional conditions. Detailed sedimentological analysis of the Smalfjord Formation was carried out with particular emphasis on identifying the significance of deformation structures found within these coarse-grained sediments. This study is based on outcrops located on the north shore of Varangerfjorden and on the island of Skjaholmen where diamictite, conglomerate and sandstone overlie a regional unconformity and rocks from the underlying Vadso Group.

Sandstone and conglomerate exhibit various degrees of deformation including zones of highly complex deformation exposed over several metres of outcrop. The deformation is predominantly ductile, with centimetre- to metre-scale simple shear structures. Sediments sometime exhibit brittle deformation with centimetre-scale offsets. These deformed sediments are predominantly associated with massive, graded or cross-bedded conglomerate, sandstone, and pebbly sandstone, which exhibit progradational geometry in some places. Diamictite can be found as a small isolated lens on Skjaholmen, and is otherwise noticeably absent at these sites.

The Smalfjord Formation is thought to record glacially-influenced sedimentation in the extensional Gaissa Basin. The coarse-grained deposits documented in this study are thought to have accumulated under deltaic/fluvial conditions. Complex ductile deformation of sandstone and conglomerate results predominantly from shearing and may record glacial advance over proglacial outwash and deltaic sediment. However, the near-absence of diamictite associated with these conglomerates and sandstones is unusual for an ice-marginal setting. Deformation structures may instead record slumping and sediment instability associated with the tectonic development of the basin.

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GS11-P11 INCISED VALLEY LOCATION AND GROWTH FAULT SUBSIDENCE PATTERNS IN A SHELF MARGIN DELTA COMPLEX, LOWER CRETACEOUS MISSISAUGA FORMATION, VENTURE AND WEST VENTURE FIELDS, OFFSHORE NOVA SCOTIA

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Shelf margin deltas commonly have an offset stacking pattern, presumably because lowstand fluvio-deltaic shorelines tend to prograde into topographic lows between older shelf margin sand bodies. Several sand bodies in the Venture and West Venture fields interpreted to be ancient shelf margin delta deposits exhibit the opposite trend in that they are vertically stacked on top of each other. Incised valleys are consistently located where sand bodies are thickest in strike cross-section, suggesting that growth-fault-related subsidence negated depositional topography and created topographic lows that attracted subsequent lowstand fluvio-deltaic systems. Because lowstand deltas commonly host commercial amounts of hydrocarbon and can link downdip to sand bodies on the slope and basin floor, this finding may have implications for sand body (i.e. reservoir) distribution both within and downdip of highly growth-faulted shelf margin deposits in passive margin basins.

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AN ARCHITECTURAL AND SEDIMENTOLOGICAL STUDY OF TWO DEBRIS FLOW DEPOSITS, LOWER ISAAC FORMATION (NEOPROTEROZOIC), CARIBOO MOUNTAINS, BRITISH COLUMBIA

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This study documents the sedimentology of two submarine debris flow deposits in the Neoproterozoic Lower Isaac Formation (Windermere Supergroup). Both debris flow deposits form reliable local stratigraphic markers due to their distinctive stratal characteristics and wide lateral extent. The deposits are separated stratigraphically by about 500 m and are informally referred to as the upper and lower debris flow deposit, LDF and UDF, respectively. Both units were described and mapped in detail. In addition, gamma-ray profiles were constructed for several vertical transects located across each deposit. Field observations are supplemented by petrography.

Although both have erosive bases, a number of important characteristics differentiate LDF and UDF. LDF is interpreted to consist of a single event deposit that ranges from 0 m to a maximum of 9 m thick; thickness varies significantly and rapidly along the outcrop. UDF, on the other hand, ranges from 20-30 m in the study area (increase to 90 m a few hundred metres to the east) and is made up of at least 3 sharply-bounded event deposits. Although clasts are common in both LDF and UDF, some ranging up to boulder size, shallow-water carbonate clasts (oolites and stromatolites) are present only in UDF. Boulder clasts in LDF consist of undeformed to moderately deformed intraclasts of interbedded thin-bedded, fine sandstone turbidites and mudstone. Differences between LDF and UDF are interpreted to be related to differences in sediment provenance, but more importantly, to differences in relative sea level change. LDF is interpreted to be unrelated to changes of relative sea level, but instead to happenstance instability and subsequent movement along the continental slope – sediment supply included sediment in the area of sediment mobilization and any new sediment incorporated into the flow during transport. UDF, however, is believed to be related to a major fall of relative sea level. An important additional sediment source for these flows was from the erosion and export of carbonate sediment from an exposed(?) shallow-water carbonate platform that lay some distance to the east of the study area.

GS11-P13 **CONTROLS ON SEDIMENTATION AND ORE DEVELOPMENT IN THE TERTIARY YANDI CHANNEL IRON DEPOSITS, WESTERN AUSTRALIA**

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The Yandi and Robe River channel iron deposits (CID) of the Pilbara region in Western Australia (WA) together make WA the third largest producer and leading exporter of iron ore in the world. These paleochannel-hosted iron deposits are internally complex although their sedimentary architecture is obscured by post-depositional alteration resulting in a limited understanding of CID deposition. This study of the Yandi channel iron deposit has resulted in a better understanding of the sedimentary architecture and evolution of the Yandi deposits. These data provide a basis for improved orebody models for grade prediction and control during mining.

Palynological data obtained from basal black mudstones support commencement of channel deposition in the Early-Oligocene. This age links formation of the Yandi deposits with disruption of regional and global climates at the Eocene-Oligocene boundary (Terminal Eocene event), and suggests that ore genesis was triggered by the onset of strongly seasonal and erratic rainfall. This hypothesis is supported by the coarse texture of the Marillana Formation, the ~100 m thick succession of cemented goethitic conglomerate that hosts the Yandi CID.

The Yandi deposit consists mainly of planar bedded granule conglomerate with subordinate granule conglomerate-channel fills. These channel fills are 5 to 300 m wide, 2-10 m deep and preserved mainly in paleochannel meander bends. Mid-channel bars and scour-and-fill structures that occur along the same gradient are associated with large zones of poorer quality ore. This alteration may have occurred during emergence when water levels temporarily subsided and water flow in the channel became sluggish.

GS11-P14 DIVERGENT DOLOMITIZATION PATTERNS IN THE UPPER DEVONIAN WABAMUN GROUP, WEST-CENTRAL ALBERTA: AN EXAMPLE FROM THE PINE CREEK AND GOLD CREEK FIELDS

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The Fammenian Wabamun Group, in west-central Alberta, is a carbonate-dominated sequence formed in a ramp setting. This Group consists of the Stettler and the Big Valley formations. The Stettler Formation has four members (in ascending order): the Dixonville, Whitelaw, Normandville, and Cardinal Lake while the Big Valley Formation represents a single stratigraphic unit. The Wabamun Group is equivalent to the Palliser Formation, which occurs as outcrops in the Rocky Mountains. The Wabamun dolomites in the Pine Creek and Gold Creek Fields host a great deal of natural gas reserves (ca. 725 billion cubic feet). These reservoir dolomites exhibit different morphology with divergent depositional and diagenetic controls. Dolomitization of the Wabamun carbonates in the Pine Creek is mostly facies controlled; whereby the porous stromatoporoid reef facies is pervasively dolomitization and the less porous, off-reef facies is partially dolomitized. In contrast, the major controls on dolomitization in the Gold Creek Field are faults and fractures. These faults and fractures acted as conduits for diagenetic fluids, which resulted in pervasive dolomitization of the nearly the entire limestone substrate. Dolomites from both fields also exhibit various types, volume, petrographic and geochemical charaterestics. In the Pine Creek Field, several generations of dolomite are present. These dolomite are mostly represented by interlocking crystals in the matrix (non planar); as planar-e and saddle dolomite cementing vugs and replacing early dolomite generations; lining fractures (cap and saddle dolomite) and showing zebra type fabrics (saddle). Saddle dolomites are controlled by sub-vertical fractures that extend to the younger slightly argillaceous lithofacies of the Cardinal Lake Member. In the base of the Wabamun, the fractures are cemented with calcite and anhydrite almost exclusively and at the top they show a wide variety of sulphide mineral phases, quartz and saddle dolomite. Stable isotopic compositions of these dolomites reflect precipitation/recrystallization in high-temperatures realm. In contrast, dolomitization in the Pine Creek Field is dominated by fabric-destructive, planar and non-planar dolomite replacing both matrix and allochems as well as occurrence in bed-parallel stylolites. These dolomites formed at shallow to intermediate burial and show petrographic and geochemical evidence for recrystallization. Rare saddle dolomite occurs filling vugs, in contrast to the wide occurrence of saddle dolomite occluding fractures in the Gold Creek Field.

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GS11-P15 COMPLEX CEMENTATION HISTORY OF A LATERALLY EXTENSIVE SECTION WITHIN THE CAMBRO-ORDOVICIAN NEPEAN FORMATION, OTTAWA, ONTARIO

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Vertical sections up to 4 m thick along the southern and eastern margins of the Centrum Shopping Centre in west Ottawa display an almost continuous 1.5 km panel within quartz arenite of the Nepean Formation, estimated to be just a few metres below the contact with the overlying March Formation. Created by recent excavation, this extensive outcrop has been divided into five facies on the basis of sedimentary structures. The lowermost is characterized by thin beds containing biofilm structures, heavy mineral streaks and ripple cross-stratified sandstone. The second facies consists mainly of (subaqueous) dune cross-stratified sandstone infilling erosionally-based tidal channels. The third facies is much like the lowermost facies, but ripple cross-stratified sandstone is more abundant, as are coarse single-grain layers suggestive of lag accumulation. A fourth facies characterized by soft-sediment deformation is overlain by a fifth which contains quartz-sand stromatolites.

Frameworks of all facies consist almost entirely of fine- to very coarse-grained quartz; minor components are microcline, chert and extremely well-rounded zircon and tourmaline as well as traces of opaques (iron oxides and possibly pyrobitumen). Biofilms, now degraded, may have played a role in accumulation of these trace components. Interstitial clay minerals occur as discontinuous films around some framework grains in the least-cemented zones. Quartz alone is the cement for well-indurated beds up to 3 cm thick in all facies, and for most crossbedded sandstones in the dune facies; a few beds that stand out as glassy markers are abruptly truncated, suggesting that they were penecontemporaneously cemented and then eroded. Restricted mainly to the dune facies, subspherical clusters of quartz sand show a distinctive blade-like external morphology comparable to modern desert rose structures, suggesting that they are pseudomorphs after evaporite-cemented rosettes which grew interstitially within the quartz sand before cementation by silica.

Different cementation styles in the dune facies compared to the enclosing thin-bedded facies are attributed to contrasts in permeability and the flux of silica-bearing solutions in relation to water-table variations. Rosettes in the dune facies probably grew soon after emergence above sea level of the highly permeable dune facies; subsequent precipitation of quartz cement in pore spaces between framework components of this facies resulted in widespread preservation of original grains within overgrowths. Having escaped this early cementation, the beds above and below were more subject to grain-contact solution during subsequent burial compaction, leading to the development of pervasive mosaic textures and abundant stylolites.

GS11-P16

NUCLEATION, GROWTH AND DEMISE OF SUB-MICRON, DENDRITIC CALCITE CRYSTALS FORMING ORIENTED NUCLEI FOR MICRITE AND CEMENT PRECIPITATES, BIG HILL SPRINGS COLD-WATER EXTANT TUFA, ALBERTA

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Calcite fibres approximately 100 nm in diameter form three-dimensional lattice-like domains (to 13 µm) that emerge from mucus films on the surfaces of calcified bryophytes in splash zones of a cold-water fluvial system downstream of a freshwater spring in Big Hill Springs Provincial Park, AB. In each domain, the fibres' three equal orientations are parallel to the directions of radii from the centre of an ideal calcite unit cell towards the locations where three crystal faces on the scalenohedral calcite unit cell meet (there is no fibre direction parallel to crystallographic c-axis). The ideal shape of the voids between the fibres in any domain is therefore a rhombohedron. Fibre orientation and growth conform to dendrite crystal growth theory; no evidence of nanobacteria is present. Lattices are oriented such that their c-axes are normal to moss-leaf substrates, resulting in plaque-like domains that are triangle-shaped and flat-topped when viewed perpendicular to the substrate. Infilling of lattice interstices accompanies dendrite growth, resulting in porous triangle-shaped subhedra, which then grow according to normal crystallographic constraints to form euhedral cement crystals. No evidence of the former presence of the dendritic crystal nucleus remains.

Fibre-dendrites nucleate in or on mucus films on moss leaves or surrounding cyanobacterial/algal filaments, likely because of electrostatic attraction between negatively charged microbial extracellular polymeric substances and dissolved cations. Given that that microbial EPS, whether spatially associated with microbes or not, is now assumed to be virtually ubiquitous in earth-surface environments, it is proposed that nucleation of carbonate minerals in earth-surface systems may commonly take place by this dendritic-nucleation mechanism. No record of the tiny dendritic nuclei would remain in the rock record, or even in modern environments, because their size is so small, their existence brief, and their features obliterated by infilling and epitaxial, normal crystal growth. The tendency of negatively charged EPS to cause nucleation of calcite crystals with c-axes perpendicular to the substrate may have widespread implications for the genesis of oriented carbonate crystal fabrics in the rock record.

GS-12

REMOTE SENSING AND GEOMATICS

TÉLÉDÉTECTIN ET GÉOMATIQUE

WILLIAM A. MORRIS

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GS12-01

AN PETRI NET BASED SPATIAL INFORMATION SERVICE COLLABORATION MODEL AND ITS APPLICATION IN SERVICES-ORIENTED WEBGIS

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Traditional spatial information techniques can't satisfy the increasing demands of application and are to be faced some problems such as enormous data, complexity of processing, and difficulty in sharing, which are obstacles to realize sharing, integration and collaboration of spatial information. As a novel and general web application technology, Web services will make distributed and heterogeneous spatial information easier to be managed, accessed, analyzed and integrated. An online spatial information service frame (OWS) was proposed by OGC and service-oriented webGIS has become the focus of research and application. Accordingly, some key issues of spatial information services and service-oriented webGIS are illuminated. In most service-oriented applications and works, integration and collaboration of many different services are indispensable. The course of spatial information service collaboration needs to be described, analyzed and evaluated. So, spatial information service collaboration model is introduced to meet the requirements, and Petri net is used as the modeling method. To model dynamic and conditional service collaboration courses, some additional elements, such as time, condition, resource taxonomy, and etc, are introduced to extend basic Petri net. Moreover, some new algorithms based on graph theory are presented as the complement of traditional methods of basic Petri net for model analyzing and evaluating. Then, a new spatial information service collaboration model (Service/Resource Net, SRN) based on Petri net and graph theory is proposed and discussed in detail. SRN is used in our research project to combine spatial information services in a dependent series to achieve larger tasks, and it proved to be an effective and practical model in service-oriented webGIS.

GS12-02

SURFICIAL MATERIAL HYDRAULIC CONDUCTIVITY MAPPING USING MULTI-TEMPORAL RADARSAT IMAGERY

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As a primary data input to both hydrology and hydrogeology modelling, hydraulic conductivity values are commonly extracted from Quaternary geology maps in glaciated environments. This approach however does not always represent the intrinsic variability, such as facies changes, within or across map unit polygons. The objective of this study was to determine if surficial material's hydraulic conductivity could be characterized utilizing multi-temporal RADARSAT imagery.

Radar backscatter can be a function of numerous ground variables, including topographic relief, land cover, groundcover, surface roughness and soil moisture. Just after spring break-up however, in the active agricultural areas of southern Ontario, radar backscatter is known to be dominated by soil moisture conditions. Contrasts in soil moisture, at this time of year, are at near maximum and can be related to the textural properties of the surficial materials. By exploiting this backscatter/soil moisture relationship, there is potential for utilizing active radar imagery for mapping hydraulic conductivity.

The chosen test site, the Ganaraska watershed in southern Ontario, contains a full suite of glacial derived materials, representing 12 orders of magnitude in hydraulic conductivity variability. For this test site, a time series of 4 fine-mode RADARSAT images were acquired during the fall of 2000 (September 28) and spring of 2001 (April 16, 23 and May 2). In sequence with the May 2 spring image, 26 soil samples were collected across the study area in agricultural fields. For a geologically representative sub-area, statistics were gathered and analyzed at the pixel, neighbourhood, and segmented polygon levels in order to train and explore several classifiers. Early results have shown that each date of imagery contains extractable information about the surficial material properties. It was also found that the temporal soil moisture responses could in several areas be quantified and then related to the hydraulic conductivity values of the surficial materials and moisture values obtained from the field observations.

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GS12-03 **TOPOGRAPHIC EVIDENCE FOR BASEMENT REACTIVATION: AN EXAMPLE FROM SOUTHERN ALBERTA, CANADA**

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Radar altimetry data collected simultaneously with aeromagnetic data provides a DTEM image and an aeromagnetic grid of the same area. The Cypress Hills area of southern Alberta, Canada was mapped by two independent aeromagnetic surveys: a 1992 survey was flown on E-W oriented flightlines, and a 1997 survey of the same area flown on N-S oriented flightlines. In this region of southern Alberta the magnetic signal is associated with the Archean basement, which underlies 2500+ metres of overlying sedimentary rocks. Combining and correcting the topographic data from the two aeromagnetic surveys resulted in a regionally extensive high resolution DTEM. Regional – residual subtraction of individual expressions of the topographic surface calculated from fine and coarse grid cell sizes helped isolate linear depressions that are believed to represent fault structures. These topographic lineaments are co-linear with discontinuities between regions in the basement identified on the basis of total magnetic field and texture in the analytical signature. Magnetic models of the basement are used to discriminate between basement uplift and basement lithological contrasts. Basement maps derived from drill hole information confirm the magnetic models. Derivatives of the calculated slope of the topographic surface were used to isolate horizons having varying resistance to erosion. These horizons closely correspond with lithological boundaries previously identified by field mapping. Lithostratigraphic surfaces then computed from the elevation of the individual horizons exhibit displacements between adjacent regions identified on the basis of the topographic and magnetic lineaments. The observed linkage between stratigraphic surface displacement and basement boundaries provides direct evidence for basement reactivation faulting.

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GS12-P01 SPATIAL INFORMATION ELEMENTARY SERVICE MODEL: AN APPROACH TO IMPLEMENT SHARING OF GEOSPATIAL DATA

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Of all the information people may have, geospatial information is of particular importance. With the development of web technologies, Geographical Information System encounters the problem of sharing dynamic, distributed, multi-sources, and heterogenous geospatial data on web. The study on sharing, integration and collaboration of geological information has become an important research field, and its some related novel technologies include OpenGIS, Web services, and etc. Traditional application patterns and technologies can't satisfy spatial application demands on web; sharing and integration of geospatial data are hard to be implemented as well. To meet increasing spatial information application requirements, we need new technologies and methods to share and integrate enormous geospatial data. As a new technology to implement sharing and cooperation of web resources, Web service has become the focus of research and web-based applications. Spatial information services based on Web service provide a new, open and effective framework for sharing distributed and heterogeneous data. By analyzing and abstracting basic functions and modules existed in GIS, a novel concept and architecture, e.g. Spatial information Elementary Service (SES) is presented based on group theory. SES can be classified into data SES and processing SES, and it enables users to access and process heterogenous geospatial data from a variety of sources across a general computing interface. The architecture of SES is built and some key technologies are discussed, such as integration and cooperation of SES, semantic sharing, and etc. Based on SES, a basic framework for sharing geospatial data is formed.

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