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Atlantic Universities Geological Conference 2010

ABSTRACTS

60th Annual Conference, October 28–30, 2010

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Abstracts from the Atlantic Universities Geological (now Geoscience) Conference (AUGC) are published annually in Atlantic Geology. Such publication provides a permanent record of the abstracts, and also focuses attention on the excellent quality of the oral presentations and posters and the interesting and varied geoscience topics that they cover.

THE EDITORS

Constraining the origin of metals and mechanisms of metal precipitation in the Bushveld Complex, South Africa: a fluid and melt inclusion study of pegmatites below the Merensky reef.

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There are two commonly referenced models describing the origin of metals and mechanisms of metal precipitation in magmatic Ni-Cu-PGE (platinum-group element) reef-type deposits: (i) magmatic mixing and sulfide liquid settling, whereby sulphide liquid saturation and PGE enrichment of the sulphide liquid occurs by silicate melt and sulphide liquid mingling, followed by sulphide mineral settling and (ii) volatile fluid percolation, whereby saline fluids or vapour migrate upward through the lower units of the complex, extracting metals and sulphur, and re-precipitating them higher in the sequence. Hydrous silicate minerals, hydrous silicate melt inclusions, and saline aqueous fluids in the Merensky reef pegmatites are spatially associated with PGE-rich base metal sulphide minerals. Characterization of this association is imperative in constraining the mechanism for precious metal transportation and precipitation. The motivation for this study is to constrain (i) the chemical conditions and timing of formation of silicate pegmatite and associated volatiles contained within them as fluid inclusions; and, (ii) the amount of metal transported by fluids at the time of pegmatite formation. A revised model for the formation of the reef horizons and their associated PGE tenor is proposed that integrates the magmatic and hydrothermal models.

Data for the study are being collected via (i) microthermometric study of fluid inclusions in accessory primary (magmatic) and secondary (post-cumulus) quartz in the pegmatite; (ii) argon-argon dating of biotite; (iii) SEM analysis of accessory and precious metal (PGE) phases occurring as inclusions in the base metal sulphide minerals within the pegmatite; (iv) LA-ICPMS data of ore metals within fluid and melt inclusions; (v) Cl and O isotope data for magmatic minerals that grew in the pegmatite.

Petrology and metamorphism of a potential SEDEX-type deposit from the Paleoproterozoic Penrhyn Group, Melville Peninsula, Nunavut

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A suite of highly metamorphosed and hydrothermally altered sedimentary and chemogenic rocks was sampled from an area on the northern flank of Barrow River, Melville Peninsula (N 67°24'08.44", W 82°35'43.23"), Nunavut. The study area resides within the Proterozoic Penryhn Group, which is stratigraphically equivalent to the Piling Group of Baffin Island, Nunavut. The Penryhn Group generally consists of alternating layers of pelitic and psammitic gneisses, amphibolites, marbles and calc-silicate rocks, all intruded by continental arc and syn-collisonal plutons and pegmatites.

Samples were collected from 19 outcrops spanning an area of about 400 by 100 m, in order to identify the protoliths and the nature and extent of superimposed hydrothermal and metamorphic processes. Preliminary petrographic analysis indicates that the samples are highly variable in composition, but typically contain a fine- to coarse-grained matrix dominated by quartz, potassium feldspar, plagioclase, and fine-grained euhedral tourmaline. Fine-grained sulphide and oxide minerals comprise generally greater than 30% of the groundmass as well. The small presence of sillimanite indicates upper amphibolite- to granulite-facies metamorphism.

Mineral exploration has been conducted in the area within the past forty years, notably by BHP Minerals. Aquitane Company blasted trenches in 1972 and found 20.4% Zn, 4800 ppm Pb, 1640 ppm Ni, 980 ppm Cu, and 5000 ppm Mo. BHP conducted an extensive drilling program in 1986, noting the presence of widespread gossans in the area even though no previous economically viable deposits had been found. BHP documented galena, sphalerite, pyrite, pyrrhotite, and minor chalcopyrite hosted by calc-silicate and metasedimentary rocks at low, non-economically viable, concentrations. The objective of this study will be to document the petrogenesis of the various lithologies forming this zone of gossan, determine sulphide mineral paragenesis, and the paleo-environment of deposition.

The origin of Ordovician plutonic rocks in the northern Antigonish Highlands

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The Antigonish Highlands are part of the Avalon terrane (or Avalonia), an exotic peri-Gondwanan terrane which is found along much of the northeastern flank of the Appalachian orogen. In the Neoproterozoic, the Avalon terrane is interpreted to have been a volcanic-arc regime located along the northern margin of Gondwana. It separated from Gondwana by the Early Ordovician and accreted to Laurentia during the Silurian or Devonian. Plutonic and volcanic rocks occur throughout the highlands. Most recent geochronology suggest that the igneous rocks are of two predominant ages: ca. 620–600 Ma arc-related mafic to felsic rocks that occur throughout the highlands and ca. 470–460 Ma mafic, syenitic and felsic rocks with alkalic compositions that have recently been identified in the southern highlands. The geographic extent of the Ordovician

magmatic event is as yet unknown. The plutons examined in this study include bodies of syenite and gabbro that are located in a fault-block in the northern Antigonish Highlands that is bounded by the Hollow Fault to the north and an unnamed fault to the south. These plutons intrude the Cambrian-Ordovician Iron Brook Goup (IBG), which is dominated by platformal strata, and the lateral facies-equivalent McDonald Brook Group (MBG) which is dominated by bimodal volcanic rocks. The syenitic intrusion is exposed along Iron Brook, where it intrudes the MBG, and the larger gabbroic intrusion outcrops along the eastern bank of the MacKinnon Brook, where it intrudes the IBG. The structural setting of the gabbro is complicated by local thrust faulting so that both faulted and intrusive contacts with the IBG are exposed.

The syenite is red to orange and displays porphyritic texture and a primary flow pattern of feldspar that is visible to the naked eye. Petrographic examination shows that the phenocrysts consist of K-feldspar and plagioclase that are intensely saussuritized. The gabbro outcrops are highly weathered, and petrographic analysis reveals a mineral assemblage including olivine, orthopyroxene, clinopyroxene, plagioclase and opaque minerals.

Geochemical analyses indicate that the syenite is characterized by a SiO_2 content of 57–62 wt %, an intermediate Fe_2O_3 content (5.3–7.9 wt%) and low MgO (<1 wt%). The pluton contains alkalies that vary in concentrations, such as a relatively high Na_2O content (5.5–6.3 wt%) and a lower K_2O content of 3.5–4.5 wt%. The concentration of CaO is also low (<1.6 wt%). The range in alkalies is consistent with petrographic evidence for intense alteration of feldspar, indicating these elements were mobile during metasomatism. These observations indicate that determining petrogenesis should rely on relatively immobile high field strength (HFS) and rare earth elements (REE). The syenite has high Nb/Y ratio (4–4.5), indicative of an alkaline melt. A high degree of fractionation is also indicated by the high Zr (up to 880 ppm), Nb (132–175 ppm) and Hf (10–13 ppm). The REE pattern reveals LREE enrichment, with an average La/Sm ratio of 9.02, and a flat HREE profile with a very subtle europium anomaly. The chemistry of this pluton is similar to other Ordovician plutons in the Antigonish Highlands, indicating that magmatism of this age is more extensive than previously realized.

Carbon dioxide in mafic magmatic systems: an experimental study to test the importance of CO_2 in the formation of magmatic sulphide deposits

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Experiments are being undertaken to determine if carbonic fluids (carbon dioxide-rich, water-poor) are capable of dissolving and transporting transition ore metals (Ni, Cu) at low temperature and pressure (200–400°C and 250–400 bar). The experiments involve reacting a fluid phase (water, pure CO_2, water-CO_2 mixtures) with the minerals chalcopyrite and pentlandite, as well as the pure metals nickel (Ni) copper (Cu), in large volume hydrothermal autoclaves with a particular aim of understanding and quantifying how CO_2-rich fluid react with and dissolve each mineral/metal.

Solubility data will be collected via (i) a qualitative study of the extent and style of dissolution features on the surface of each mineral and metal (comparison made before and after the experiments) using scanning electron microscopy and laser confocal scanning microscopy, and (ii) a laser ablation ICP-MS analysis of synthetic fluid inclusions trapped in quartz during the experiments. This data will aid in developing an understanding how such fluids influenced the metal tenor and sulphide textures in mafic-ultramafic magmatic Ni-Cu sulphide deposits where carbonic fluids have been reported as a magmatic volatile phase (e.g., Lac des Iles, Ontario; Bushveld Complex, South Africa; Stillwater Complex, USA; Sudbury, Ontario).

Seafloor records of sediment dispersal patterns in the Nelson River, Hudson Bay

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Patterns of sediment deposition in the Nelson River Estuary, southwestern Hudson Bay, have been examined using radioisotope-geochronological analysis of sediment cores and seabed sonar data, in order to gain a better understanding of sedimentary processes and sediment transport from fluvial to marine systems at high latitudes. This is important because the majority of previous sediment-dispersal studies on estuaries and deltas have focused on low to mid latitudes. The Nelson River was chosen because: it is the largest source of freshwater input to the Hudson Bay, the mouth is a classic example of a macrotidal estuary, and it is ice-bound for much of the year, producing an interesting contrast between the dampening effects of ice, and the dynamic effects of tides.

Two gravity cores were collected from the Nelson River Estuary in 2009, and have been sub-sampled for granulometry and radiochemical analysis during July 2010. Analysis of the particle-bound radioisotopes Pb^{210} (half-life = 22.3y) and Cs^{137} (half-life = 31y), using a low energy gamma spectrometer, are used to determine sediment flux over ~decadal timescales. Previously processed analysis of box-cores from the same area is used to supplement findings. Multibeam bathymetry and sub-bottom seismic profiles are being analyzed to evaluate seafloor morphology and depositional patterns. The physical data, radiochemical data, and structural images are being integrated to elucidate sediment dispersal patterns. The preliminary results show a region of sediment bypass in the inner estuary, with sediment accumulation rates increasing from 0.4

cm/y to >0.9 cm/y in the middle and outer estuary. The results are consistent with high sediment supply from the river and decreasing tidal current energy in a seaward direction. These observations will be compared with ice-coverage and river-flow data, to explore relationships among spatial deposition patterns, ice extent, and river forcing.

Partial digestion geochemistry of pediment over the Toki Cluster porphyry copper deposits, Atacama Desert, Chile

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Copper is an important economic metal with many uses in today's society. It is used as electrical wire, in cooking utensils, and in various alloys such as bronze and brass. Due to its economic importance, the ability to locate sources of mineable copper is of great value. Unfortunately, locating copper deposits is difficult as many of the largest ones (porphyry Cu deposits) are buried under thick exotic gravel sequences. A number of techniques are being developed to more easily locate these buried deposits; one of these techniques involves the use of partial digestion geochemistry of soil samples.

The locations of mineral deposits containing elements that are soluble in groundwater can be identified using two different types of mineral layers that are postulated to form in gravels overtop the deposits. One type of layer is hypothesized to have formed via the evaporation of groundwater, and the subsequent enrichment of the remaining groundwater in elements derived from the underlying mineral deposit. This causes saturation of the groundwater with respect to soluble salts of the elements derived from the mineral deposit at depth, and the subsequent precipitation of salts containing those elements. The second layer is hypothesized to form via ferrolysis, a process where ferrous iron dissolved in groundwater encounters atmospheric oxygen diffusing downward from the surface, and oxidizes to form Fe-oxy-hydroxide minerals. These poorly crystalline precipitates then adsorb soluble metals derived from the mineral deposit at depth. Partial digestion geochemical analysis of the fine-grained portions of gravels above mineral deposits can thus detect the transported ions contained in both of these types of layers, and will produce anomalous concentrations in the gravels above mineral deposits.

Field observations over the Toki Cluster porphyry Cu camp in the Atacama region of northern Chile indicate that mineral layers produced via evaporative saturation do exist (pedogenic calcite and gypsum were observed). As a result, other layers composed of salts derived from transported metals from below may also exist. Although Fe-oxide stains were observed in the soils, this is not evidence that ferrolysis has occurred or that Fe-oxy-hydroxide minerals have adsorbed transported ions. However, future partial digestion geochemistry using a de-ionized water leach, along with inductively coupled plasma mass spectroscopy (ICP–MS) analysis will hopefully chemically confirm the presence of these expected evaporative saturation and ferrolysis layers and their contained metal load.

The role of Anaximander Seamounts in an active transform fault zone in the eastern Mediterranean: processing and interpretation of EMED2010 seismic reflection profiles 6-10

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The region separating the African plate from the Aegean-Anatolian microplate in the eastern Mediterranean contains an active subduction/collisional plate boundary. A transform fault zone divides this active subduction/collisional plate boundary into two sections, the Cyprus and Hellenic arcs. A wide strip of complex structures, which are thought to have originated from episodic strike-slip and thrust faulting, as well as extensional motions, which have been observed, distinguishes the fault zone. The complexities in this area appear in bathymetry as excessive lows (Rhodes, Finike Basins) and highs (Anaximander Seamounts). This thesis is particularly focused on the region linking the Rhodes Basin with the southwestern extension of the Anaximander Seamounts.

The purpose of this thesis is to process and interpret approximately 200 km of marine multichannel seismic reflection data in terms of Miocene (and subsequent) geological history, using the new seismic images created as well as those from previously available seismic lines to map the structures in the area, and develop conclusions as to the Neogene history of the area, with distinct focus on the interrelation between the structural highs (i.e., Anaximander Seamounts) and lows (i.e., Rhodes Basin).

Inversion and interpretation of marine Controlled Source Electromagnetic (CSEM) and Magnetotelluric (MT) data

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The use of the geophysical electromagnetic method in a marine environment has become remarkably attractive, as there have been many advances to applications for hydrocarbon exploration. This project will examine the use of marine Controlled Source Electromagnetics (CSEM) and Magnetotellurics (MT), and will investigate their effectiveness in hydrocarbon exploration. CSEM transmits synthetic electromagnetic signals into the ocean floor and the fixed seafloor receivers then measure the reaction of the earth's magnetic field. CSEM can be applied to hydrocarbon exploration since layers of rock containing high amounts oil and/or gas will have

an electrically resistive signal. Magnetotellurics is an electromagnetic method in which the responses to changes of the earth's natural time-varying magnetic field are measured. MT is less sensitive to layers or structures at shallow depths than CSEM, but can identify conductive units or formations where CSEM would respond to more resistive units.

This project will be concentrated on data sets made available online by the Scripps Institution of Oceanography, located in La Jolla, California, USA. The data sets are from surveys collected over the San Diego Trough, which is located approximately 50 km west of San Diego, and has a water depth of over 1 km. The data sets will be analyzed and conductivity models will be produced by inversion. The inversions will be done using Occam inversion codes. 1-D inversions will be applied to the CSEM data and 2-D inversions to the MT data. Interpretation of the inversions will be done in conjunction with bathymetry and coastal relief models as well as with seismic lines.

Measurement of the effect of uniaxial compression upon remanent magnetization of hematite ore

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The Wabana and Bell Island groups of the Avalon Peninsula of Newfoundland contain oolitic hematite beds of Early Ordovician age, with a dip of ~11° north-northwest. The effect of external stress on magnetization of hematite has rarely been studied, although it has been suggested that internal stress in hematite is an important source of its remanence stability. To study the effect of stress, the hematite ore is cut into cylinders and given a remanence in magnetic fields up to 800 mT in strength parallel or perpendicular to the cylinder axis. The samples are loaded and unloaded stepwise increasing the pressure to a maximum compression of about 17.5×10^6 Pa. The changes in remanence as stress is varied will be measured by looking at the changes in magnetic field due to the sample using a fluxgate probe. Ore sample B6-1 has been collected and is devoid of magnetite and shows that the compression causes both permanent and reversible decreases in the remanence of a magnitude comparable to that of magnetite.

Petrology and tectonic implications of mafic dykes in the Kellys Mountain area, Cape Breton Island, Nova Scotia

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The Kellys Mountain area of Cape Breton Island is located in the central-eastern part of the Bras d'Or terrane. The pre-Carboniferous geology of this area is characterized by four main units: Bras d'Or Gneiss, George River Metamorphic Suite, Late Proterozoic plutonic rocks and Late Cambrian plutonic rocks, all intruded by abundant mafic dykes. Carboniferous sedimentary rocks of the Horton and Windsor groups unconformably overlie all of these units, constraining the age of emplacement of the dykes to between Late Cambrian and Late Devonian. This study focuses on the petrography and geochemistry of the mafic dykes, in order to determine their petrological characteristics and decide whether they represent a single suite or were emplaced in more than one episode. Preliminary petrographic examination indicates that the dykes are of several types: amphibole-bearing dykes, clinopyroxene-bearing dykes, fewer plagioclase-rich dykes and some samples showing more varied mineralogy. The dykes are altered and contain abundant secondary minerals including chlorite, epidote, calcite, quartz, sericite, actinolite, and prehnite, but the extent of alteration is variable. Most of the dykes are fine-grained and some are amygdaloidal, indicative of shallow emplacement. At least two of the dykes are lamprophyric, and contain biotite phenocrysts. More detailed petrographic study is needed to determine if systematic variations exist with geographic location or host unit. Mineralogical compositions will be determined by electron microprobe in the least altered dykes. Whole-rock geochemical data will assist in assessing chemical affinity and tectonic setting during emplacement. The results will be compared to those from other studies of mafic dykes in the Bras d'Or terrane and adjacent Mira terrane to help interpret the tectonic implications of the emplacement of the dykes.

The presence of carbonic-dominant volatiles during the crystallization of sulfide-bearing mafic pegmatites in the North Roby Zone, Lac Des Iles Complex, Ontario

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Mafic pegmatites in the platinum-group element (PGE)-mineralized Roby Zone, Lac Des Iles Complex ("LDIC"), northwestern Ontario, comprise dykes, veins and irregular pods of coarse-grained magnesiohornblende, pyroxene, and labradorite-andesine with minor biotite, apatite, Fe-Ti-oxides and intercumulus quartz that grades into massive quartz or graphic quartz-base metal sulfide-vysotskite [Pd, Ni(S)] intergrowth at their cores. Quartz, apatite and magnesiohornblende host primary and secondary assemblages of one- or two-phase carbonic fluid ($CO_2 \pm$ up to ~10% $CH_4 \pm$ minor H_2O, N_2) inclusions that contain ore metals (Ni, Cu, Pd, Bi, Te, Fe). Rare trails of late stage, high salinity aqueous fluid inclusions are secondary in origin and therefore unrelated to the crystallization of the pegmatites. Assemblages of primary carbonic fluid inclusions show considerable variation in mode and tem-

perature of homogenization, reflecting large fluctuations in confining pressure at the time of quartz crystallization of up to ~ 1 kbar (in single quartz crystals) and ~2.8 kbar (all data). Independent thermobarometric methods constrain conditions for two stages of pegmatite formation (and carbonic fluid entrapment): (i) the crystallization of magnesiohornblende-plagioclase intergrowth at T ~ 650-850°C, and P ~ 1-3 kbar, and (ii) the crystallization of quartz at T ~ 535–650°C, and P ~ 0.4-3.2 kbar, setting the maximum depth of emplacement of the LDIC North Roby Zone magma at 10–12 km. The results indicate that aqueous-dominant volatile phases were absent during the crystallization of pegmatitic gabbroic rocks at LDIC, and that water-poor, carbonic fluid entrapment persisted to well below solidus conditions. A role played by carbonic fluid as a potential transport medium for ligands involved in the precipitation and remobilization of the PGE and base metals is strongly suggested and warrants further investigation.

The petrogenesis of calc-alkaline lamprophyres from Mali, West Africa

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Lamprophyres from west of the Morila Gold Mine, South Mali, and are being evaluated for their gold and REE potential and are being placed in a regional context. The lamprophyres are hosted in the Birimian paleoproterozoic metasedimentary rocks which were deformed and metamorphosed during the regionally extensive Eburnean orogeny (2.13–2.00 Ga). This orogeny caused the accretion of the Birimian volcano-sedimentary and plutonic belts onto the margin of a pre-Rhyacian continental block.

The lamprophyres have been termed calc-alkaline due to their modal mineral content, which is also how the types of lamprophyres were identified. Two variations of lamprophyres occur at the Morila Mine: (1) kersantites (plagioclase > orthoclase) with biotite phenocrysts; (2) minette (orthoclase > plagioclase) with biotite phenocrysts. The lamprophyres are porphyritic with phenocrysts of biotite and amphibole set in a feldspathic groundmass. The distribution of sulphide minerals is preferential to the phenocrysts and they can be used to infer the original sulphur contents of the magma. Several textures were observed petrographically including glomerocrysts of biotite and amphibole as well as poorly developed sagenitic biotite. The sagenitic biotite consists of sub- to euhedral grains of titanite that have aligned to form three-rod asterisks and equilateral triangles. Pilite recording the breakdown of olivine to Mg-silicates is locally observed. Also contained within these lamprophyres are several REE-rich minerals that are scattered throughout the samples. A metamorphic overprint has also been recognized based on the mantle overgrowths on biotite and amphibole, the pilite and sagenitic textures, and zoned titanite. The titanite will be analyzed using the LA-ICP-MS in order to identify the age at which metamorphism occurred.

Mineralogical and chemical analysis of Rumuruti (R) Chondrite: sample NWA 6145

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Meteorite sample NWA 6145 is classified as a Rumuruti (R) chondrite, a group that does not belong to any major class of chondrite such as ordinary, carbonaceous, or enstatite. R chondrites are characterized by having highly oxidized mineralogy, low chondrule/matrix modal abundance ratio, abundant sulphide minerals (mainly pyrrhotite and pentlandite), and very small amounts of metallic Fe-Ni. R chondrites display a metamorphic grade of 3.6 to 3.9 and shock stages S1 to S4. NWA 6145 is a find that was located in the Sahara of Northwest Africa in November of 2009. The sample is a part slice weighing 3.973g and has dimensions of 21 by 19 by 3 mm and is considered to be one of the freshest samples on Earth.

A characterization of the petrography, mineralogy, and mineral chemistry of NWA 6145 will be performed. Differences in composition between matrix, chondrule, and melt veins will be identified using a false color mineral map of the meteorite section using the Scanning Electron Microscope Mineral Liberation Analysis (SEM/MLA) and electron probe microanalyzer (EPMA). This will be used to define the differences in composition between matrix, chondrule, and melt veins as well as metamorphic grade and shock level of the meteorite.

The U-Pb age and Nd isotopic composition of apatite grains within the meteorite will be evaluated using Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS) measurements. The data will be used to determine the cooling history of the R chondrite parent body, by using the U-Pb apatite ages of NWA 6145. No apatite ages have been reported for R chondrites and this should help constrain the cooling rate. The Nd isotopic measurements of NWA 6145 will be used to confirm that it formed from condensate material similar to that of the chondrite groups.

The partial extraction of soil samples across a Pb-Zn deposit via a cation exchange mechanism

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Most mineral deposits that are exposed at the surface have already been found by mining companies over the last 50 years. The ones that have not been discovered are typically buried by some form of surficial materials such as gravels, tills,

or volcanic ash. This material makes mineral deposits difficult to detect and therefore causes difficulties during exploration. However, groundwater can travel through the deposit and transport metal ions from the mineral deposit to the surface where they can absorb onto organic matter and Fe-Mn oxyhydroxides will be present in the soil. Extracting the labile components of the soil could detect these metal ions, and thereby detect mineralization at depth.

Samples were collected along a soil traverse over the Northwest orebody at the Gays River Pb-Zn mine in Shubenacadie, Nova Scotia. The B-horizon of the soils was sampled because of the abundance of possible cation exchange sites at that level. Metals were solubilised from these soil samples using experiments involving weak chloride salt extractions (KCl, NaCl, $MgCl_2$ and $CaCl_2$). The reagent cation and the salt concentration (0.001, 0.01 and 0.1 *M*) differed in each experiment, and so splits of each sample were analyzed 13 times using the ICP-MS, as DI water was employed as a control. This allowed for the concentration of metals present in the soils to be measured.

The cation in the reagent was expected to 'push' the metal ions off of the surface of the soil via a cation exchange process; the strength of this 'push' would depend on its concentration and the size-to-charge ratio of the cation. As a result, $MgCl_2$ at a concentration of 0.1 *M* would be expected to extract the highest concentration of metal ions. Unexpectedly, the $CaCl_2$ extractants solubilized the largest amounts of metal ions. Anomalies were present very close to (but just south of) the location of mineralization, and these occurred in consistent locations for each reagent. These anomalies are thus located immediately downhill and down-ice of the vertical projection of mineralization, suggesting that soil creep and glaciation may have contributed to the minor displacement of the geochemical anomalies away from mineralization.

The origin and composition of polyphase inclusions in tourmaline from the Greenbushes pegmatite, Western Australia

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The (2.5 Ga) Greenbushes rare-element pegmatite in Western Australia is an important source of lithium, tin, and tantalum. The pegmatite, which was emplaced syngenetically into the Donnybrook-Bridgetown shear zone within the Yilgarn Craton, consists of five distinct petrologic zones. Zoned tourmaline crystals from the Ta-rich "mixed" zone are host to abundant primary and pseudosecondary polyphase inclusions. Petrographic analysis indicates that inclusions occur within a brown pleochroic growth zone that was subsequently overgrown by a blue growth zone devoid of inclusions. Fluid inclusion assemblages (FIA) display a wide range of liquid-vapor-solid phase ratios. Raman spectroscopy was used to identify solid phases within thirty different inclusions, and one representative polyphase inclusion was analyzed using a dual beam focused ion beam-scanning electron microscope (FIB-SEM). Inclusions ranging from 40 to 90 volume % solids contain quartz, pollucite, trilithionite, zabuyelite and an arsenic-antimony rich phase (predominantly native arsenic, senarmontite, paakonenite and/or arsenolite). Inclusions ranging from 5 to 40 volume % solids contain zabuyelite ± an arsenic-bearing phase and inclusions with less than 5 volume % solids typically contain an arsenic-rich solid phase. Rare stibnite, nahcolite, lithiophosphate and triphylite-lithiophilite are also present. The inclusion compositions indicate that tourmaline entrapped a Li-, Cs-, As-, Sb- and carbonate-enriched hydrous silicate liquid. This solute-rich fluid separated from the crystallizing pegmatite melt during crystallization and influenced the distribution of rare elements within the pegmatite and in the surrounding host rocks.

Field, petrographic and chemical characterization of the Neoproterozoic Ohio Pluton, southern Antigonish Highlands, Nova Scotia

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The Antigonish Highlands are located in northeastern mainland Nova Scotia, and are part of a peri-Gondwanan terrane known as Avalon (or Avalonia). In the late Neoproterozoic, the Avalon terrane is widely interpreted to have been a volcanic-arc regime located along the northern margin of Gondwana. Avalonia separated from Gondwana by the Late Cambrian and was accreted to Laurentia during the mid-Paleozoic. The Ohio Pluton is located in the southeastern corner of the Antigonish Highlands. The pluton intrudes Neoproterozoic low-grade volcanic and sedimentary rocks of the Georgeville Group, and is unconformably overlain by undivided Devonian-Carboniferous sediments of the Antigonish Basin to the east. Many faults intersect the pluton in both east-west and north-south trends. The primary exposure of the granite is along the Ohio River and less extensive exposure can be found along the sides of the many roads which cross through the pluton. Petrographic observations of the pluton indicate a mineralogy dominated by quartz, potassium-feldspar, and plagioclase. The feldspars are saussuritized and show intense alteration to sericite. Fractures contain abundant chlorite. There are minor opaque minerals associated with the chlorite mineralization, yet to be identified.

U-Pb geochronological analysis (TIMS, zircon) yields an age of 606 ± 0.6 Ma, an age typical of Neoproterozoic igneous rocks in parts of Avalonia. Geochemical analysis was carried

out to determine the major element, trace element and rare earth element composition of the pluton. The samples collected contain 70–75 wt% SiO_2, approximately 2 wt% FeO, and between 0.5 and 1 wt% MgO. Granite samples also display unusually high levels of the trace element Ba, (up to 3600 ppm). Harker diagrams indicate that alkali and alkali earth elements (Na, K, Rb, Ca, Sr, and Ba) have been mobilized and can no longer be used to make inferences about the original chemistry of the pluton. Plots involving relatively high field strength (HFS) and rare earth elements (REE) are more reliable indicators of original geochemistry. Diagrams which serve as proxies for the alkali content such as Zr/Ti vs. Nb/Y and Ta vs. Yb show the granitoid rocks are subalkalic and were emplaced in a volcanic arc regime. There is a weakly negative light REE slope with one sample showing a significantly positive europium anomaly. This anomaly suggests an accumulation of plagioclase phenocrysts was present in the melt. The heavy REE exhibit a flat pattern. This flat HREE pattern is also seen in other 605 Ma granitoids in the Antigonish Highlands with the exception of the Eden Lake Plutonic Suite, and is generally typical of volcanic-arc granites.

Petrology and SHRIMP U-Pb geochronology of detrital zircons from the Holly Lake Metamorphic Complex, Leith Ridge, Northwest Territories

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The Paleoproterozoic (>1900 Ma) Hottah terrane is the oldest component of the Wopmay orogen and remains poorly understood. Largely overlain by Paleozoic cover and poorly exposed, the Hottah terrane outcrops on the western side of the orogen and is thought to extend as basement underneath much of the Great Bear magmatic zone. The oldest units within the Hottah terrane are metasedimentary and metavolcanic rocks of the Holly Lake metamorphic complex (HLMC), a scantly preserved supracrustal sequence. The HLMC has been intruded by numerous, 1940–1930 Ma plutons of the Hottah continental arc. Fieldwork within the HLMC was completed in August of 2010 along Leith Ridge, south of Great Bear Lake and northwest of Hottah Lake, where three outcrops of partially migmatised, interbedded psammitic and pelitic rocks were mapped and sampled. These rocks are characterized by biotite-sillimanite-melt pockets (pods) and have a well-developed foliation, striking along 315 degrees and dipping 45 degrees to the northeast. Numerous porphyritic tourmaline-bearing granitic rocks and 0.5–1 m- wide granodiorite dykes intrude the metapelite outcrops.

Detrital zircons from a psammitic rock will be dated using the U-Pb isotope systematic by ion microprobe technique (SHRIMP II) to clarify the provenance of the Hottah terrane metasedimentary rocks. This age data will provide the first direct evidence of the older Hottah terrane components, and may clarify its relationship with the Archean Slave craton. Moreover, the dating may help determine if Archean components exist within the Hottah terrane, an invaluable piece of knowledge for further exploration of diamondiferous kimberlites found in the Paleozoic cover sequence to the west. Core-rim relationships, if present within the detrital zircons, will indicate the timing of metamorphism of the psammite, which will significantly further the understanding of the Hottah terrane and its tectonic evolution within the Wopmay orogen. Detailed petrology on metamorphic assemblages and their relation to deformational fabrics will also be a major component of this study from Leith Ridge and selected drill core samples.

An X-ray diffraction and structural refinement study of radiation-damaged zircons from Bancroft, Ontario

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Powder X-ray diffraction (XRD) is one of the most fundamental analytical tools used to characterize materials. Minerals, rocks, high-temperature superconductors, fullerenes, and magnetoresistance devices are examples of materials for which powder XRD has had a major impact in understanding their structures and in their technological development. The main objective of this study is to investigate using powder XRD what happens to extremely metamict (i.e., extremely radiation damaged) zircon ($ZrSiO_4$) crystals from Bancroft, Ontario, when subjected to high temperature (e.g., 800–1200°C) annealing over extended periods of time (up to 36 hours) and what materials are made as part of that process. The X-ray data collected will be compared to known structures of zircon, monoclinic and tetragonal ZrO_2, polymorphs of SiO_2, and potential U, Th, and Pb phases that might be part of the breakdown of zircon during metamictization and that may form during the recrystallization process.

The main reason this study was undertaken was to obtain a better understanding of what physically happens to zircon in the CA-TIMS (chemical abrasion - thermal ionization mass spectrometry) method for treating single zircon crystals before U-Pb TIMS isotopic age measurements are made. So-called waterfall plots of the XRD data have been made using the JADE software program, and further detailed plots will be made in IgorPro, a scientific graphing program, to show the effects of the annealing and recrystallization as a function of time and temperature. The data suggest that during the annealing process, zircon recrystallizes and also tetragonal ZrO_2 and SiO_2 phases are formed. These phases will be further quantified using transmission election microscopy (TEM) to determine the structure of the SiO_2 phase and to determine if the ZrO_2 is only tetragonal ZrO_2 or if monoclinic ZrO_2 (baddeleyite) is also present.

Petrography of stratigraphic units in the subsurface in the Phetchabun Basin, Thailand

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The Phetchabun Basin is one of at least 30 Tertiary intermontane basins in Thailand formed by regional crustal extension localized by strike-slip faults. Most oil production in Southeast Asia is from these Tertiary basins, and they are primary targets for hydrocarbon exploration. Basins in Thailand contain thick lacustrine strata, in places including coal, lignite and oil shale. This study focuses on the Wichian Buri subbasin, one of the five grabens that comprise the Phetchabun Basin. This subbasin is unusual due to the fractured igneous intrusions that apparently form hydrocarbon reservoirs. The stratigraphic units of the Phetchabun Basin have been defined by earlier workers and include an upper unit of Pliocene-Pleistocene sediments, underlain by the Miocene Chaliang Lab Formation and Wichian Buri Group, and the Oligocene "basal Tertiary", which unconformably overlies Mesozoic volcanic and granitoid rocks. The Chaliang Lab Formation consists of claystone with minor sandstone and lignite. The underlying Wichian Buri Group is divided into 4 units: unit 1 has been previously described as reworked basaltic tuff and interbedded coarsening-upward sandstone units. Units 2, 3, and 4 contain basaltic flows and gabbroic sills interlayered with claystone, sandstone, and siltstone. The basal Tertiary is described as claystone with minor interbedded sandstone and altered fine-grained basaltic flows or sills. This project is petrographic study of a suite of thin sections from 150 cuttings samples from 15 drill holes in the Wichian Buri subbasin. The samples are from units 1, 2, 3, and 4 of the Wichian Buri Group and were initially logged as tuffaceous. However, low magnetic susceptibility measurements and preliminary petrographic observations indicate that they are sedimentary and in some cases metasedimentary where contact metamorphosed by gabbroic sills. The data obtained in this study will enable comparison between stratigraphic units and also give some information about how the units vary across the area by providing data from drill holes located across a distance of 8 km from south to north across the basin.

Early Jurassic Gordondale Member – shale gas potential and XRD, wire-line log, and TOC analysis

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Shales are fine-grained sedimentary rocks (particles <0.062 mm) with either detrital or production source, and termed gas shales when gas is self-sourced and some of the gas is stored in the adsorbed state. The permeability is extremely low and is measured in fractions of nanodarcies with fluid flow paths occupying pores in the 30–120 nanometre range. The Gordondale Member is a shale unit in northeastern British Columbia, and overlies the Triassic-Jurassic unconformity.

The variables affecting shale gas reservoirs are known to include porosity, permeability, thickness and lateral extent, initial total organic carbon, thermal maturity, lithology/rock properties, exhumation, reservoir pressure, stress environment, and gas quality/composition. The level of heterogeneity in fine- and very fine-grained sedimentary rocks, however, makes it difficult to use a general rubric for evaluating individual plays based on analogous plays, as has been done in conventional reservoirs for years. This heterogeneity is an obstacle that is poorly understood, and complicates what variables are most important for each play.

Many of the data collected on the Gordondale Member, however, are speculative and sparse, so further thin section and total organic carbon analysis, as well as X-ray diffraction (XRD) work, is needed to find out what the key drivers are to both source rock quality and what affects the logs. In doing so, hopefully we can see on logs what is deemed sub-resolution in today's research and industry world. If successful, it will make log analysis much more useful for shale gas, as in many cases no core is available.

Log jam deposits in the Boss Point Formation near Joggins Nova Scotia

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The Boss Point Formation, part of the Cumberland Group, consists mostly of sandy braidplain and muddy lacustrine facies. The braidplain facies mainly comprises stacked, trough cross-bedded channel deposits, which contain accumulations of woody material, logs, and in some cases, thin coal seams. The geology of one outcrop towards the base of the formation was studied in detail due to its particularly good exposure of the wood debris, which is present in abundance through about 3 m of sandstone at the top of a channel body. The size of wood fragments was measured, along with the proportion of wood to sediment and the thickness of the log-rinds. From these data, the original thickness of the log jam was estimated, before compaction took place. Stratigraphic analysis shows that the debris is associated with flooding events, and the log jams may have contributed to the abandonment of the channels. The Boss Point Formation was deposited in the early Pennsylvanian. The deposits in this area are similar to other Pennsylvanian log jam deposits in the Sydney Basin of Nova Scotia, but are

considerably older. Log jams became possible on Earth after large trees evolved in the Middle Devonian, and the log jams in the Boss Point Formation appear to be the oldest currently documented.

New discoveries of tetrapod bearing fossil forests at Joggins Nova Scotia: implications for tetrapod entombment and ecological persistence

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The classic Carboniferous section at Joggins is most famous for the discovery of standing fossil lycopsid trees that bear a terrestrial fauna within their once hollowed out stumps. The first discovery of this diverse entombed fauna was made by Sir John William Dawson and Sir Charles Lyell in 1852. Dawson's extensive explorations of a single fossil forest at Coal Mine Point continued throughout the latter half of the nineteenth century. Eighteen productive trees were documented which yielded 12 species of tetrapods and 6 species of terrestrial arthropods. Among the disarticulated skeletal remains was the world's oldest known reptile (oldest amniote) named *Hylonomous lyelli.* Only two other tetrapod-bearing trees have been discovered between Dawson's death in 1899 until recent work (1994-present). Walter Bell noted two tetrapod-bearing stumps during the early twentieth century, however, the stratigraphic horizons and the specimens' whereabouts remain unknown.

The development of a search strategy informed by Dawson's writings, and study of his specimens in London and Montreal, has resulted in the discovery of eight additional tetrapod-bearing trees from six new stratigraphic horizons other than Dawson's Coal Mine Point fossil forest since 1994. Most of the fossiliferous trees discovered in recent years conform to the general model described by Dawson, with tetrapods occurring near the basal mineral charcoal infill which records evidence of wildfires. Three of these productive trees derive from a sequence of upright lycopsids underlying the Forty Brine coal seam. The Forty Brine tetrapod-bearing trees demonstrate persistence of ecological conditions in successive lycopsid forests, wherein entire forest stands were charred by repeated wildfire disturbance, and in at least one case, resulting in the formation of an unequivocal basal fire scar. These, in addition to the other five tetrapod-bearing forests, confirm that Dawson and Lyell's forest was not unique or unusual but that similar paleoecological conditions recurred. It is also unlikely that these conditions were exclusive to Joggins, and as yet undiscovered tetrapod-bearing forests doubtless occurred in wetlands of the tropical biome where seasonality promoted disturbance and wildfire.

Experimental computed tomography (CT) scanning shows promise in revealing the distribution of bone material within the tree fills, most of which is concentrated in the basal 15 cm in association with charred plant material. Tetrapod bones from the trees are presently being analyzed by electron microprobe to determine whether their CaO/P_2O_5 ratios record details of their thermal history and consequently about the chronology of their entombment as it relates to wildfire events and tree burial. The ability to study the taphonomy of the tree hollow fauna also permits evaluation of various scenarios of their entombment, in particular the long held pitfall theory and the newer perception of a hollow tree guild (denning). Our recent discoveries not only provide a clearer understanding of the role of wildfires in the development of the ecological niche inhabited by the earliest amniotes, but also unveil a rich new source of tetrapod skeletal material from this pivotal moment in vertebrate evolution.

High resolution seismic stratigraphy (GPR) of braided channel complexes in the Triassic Wolfville Formation- controls on reservoir heterogeneity

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The Triassic Wolfville Formation crops out along the shoreline of the Minas Basin of the Bay of Fundy, Nova Scotia. Cambridge Cove contains an exceptionally well preserved outcrop which presents 2-D and 3-D exposures of the braided channel depositional environment of the Wolfville Formation. These outcrops demonstrate the stratigraphic complexities associated with the depositional environment. This study aims to: (1) use Ground Penetrating Radar survey techniques to image braided channel deposit architecture in the subsurface for correlation to outcrop LiDAR data, (2) provide 3-D, high-resolution stratigraphic and structural information about braided channel deposits and their characteristic as petroleum reservoirs, and (3) improve understanding of fluid connectivity and emplacement in these deposits and the influence of these factors on petroleum production.

The origin and distribution of platinum group metals in the Mt. Milligan alkalic Cu-Au porphyry deposit, British Columbia, Canada

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Porphyry Cu±Au±Mo deposits associated with alkaline to calc-alkaline rocks represent significant sources of platinum

group elements. Unfortunately, the current understanding of the controls of PGE enrichment in porphyry systems is poorly understood. Recent discoveries have identified PGE-enriched porphyry deposits within the Canadian Cordillera. The purpose of this study is to investigate the occurrence of PGE in one of these systems, in order to better understand PGE enrichment in alkalic porphyry systems.

The Mt. Milligan deposit lies 155 km northwest of Prince George, British Columbia, within the Quesnel Terrane of the Canadian Cordillera. Locally Late Triassic to Early Jurassic volcanics of basaltic, andesitic, latitic, tephriponolitic and trachytic compositions overlay and are sometimes are interbedded with Late Triassic sediments. These rocks, known as the Talka group, are intruded by Early Jurassic monzonite to monzodiorite hypabyssal stocks and dikes which are spatially and genetically related to the Cu-Au porphyry deposit. These rocks have been extensively altered through widespread potassic, sericitic, and propylitic alteration. The reserves at the Mt. Milligan porphyry deposit are estimated to be 299 Mt of 0.22 wt% copper and 0.45 ppm gold. In 2002, PGE concentrations of 0.69–0.62g/t Pd were discovered in two concentrate samples, however no further investigation into the PGE potential of Mt. Milligan was made.

In this study a collection of diamond drill hole (DDH) cores from Mt. Milligan were assayed for PGE as well as other possible pathfinder elements (Au, Cu, Co, Ni, and S). The results of this data showed strong positive correlations between Pd-Au and Pd-Cu which suggests that these precious and base metals were transported as chloride complexes in the hydrothermal system. Scanning electron microprobe, along with transmitted and reflected light microscopy, identified sulphide mineralization (most notably pyrite) as the host phase for PGE and that the principal PGE-bearing phase is merenskyite. An analysis of sulphur isotopes from these samples produced $\delta^{34}S‰_{(CDT)}$ values of -0.7 to 3.4 (0.6 average) for pyrite and 0.4 to -4.1 (-1.2 average) for chalcopyrite, fingerprinting the mantle as the source for the PGE. Furthermore, DDH data provided by Terrane Metals was augmented with the bulk rock and isotopic data from this study to produce a 3-D model of the deposit with the latest Leapfrog © 3-D modeling software. The results show two precious metal-enriched regions in the MBX and Southern Star zones.

IODP Site 1256- petrological and textural variations down-core

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An intact core from IODP (Integrated Ocean Drilling Program) Site 1256, located in the eastern equatorial pacific (Cocos Plate), was collected on three different legs (legs 206, 309, and 312). This is the fourth deepest hole that IODP has drilled since 1968, and is the first hole to reach the uppermost portion of *in situ* gabbroic oceanic layer 3. The purpose of this study is to examine down-hole petrological and textural trends, including variations in hydrothermal alteration products.

Fifty thin sections were cut at specific depths down-core and point counts of primary and secondary minerals were done on all samples. Some systematic trends can be inferred from the modal analyses concerning the dominant minerals and alteration products. Trends include a change from possible anthophyllite to chlorite at 1050 mbsf, concentrations of quartz at varying depths, and changes in opaque-oxide minerals at 1230 mbsf. Preliminary electron microprobe analysis was done on six representative thin sections to identify some unknown minerals, including amphiboles, opaque-oxide minerals, and possible clay minerals, suggested by previous work that showed clays to be present in the upper part of the core. Back-scattered electron images were also collected in order to determine the mineralogy and texture of the fine-grained groundmass present in most of the upper core. Results to date have shown the presence of minimal sulphide minerals, orthopyroxene and olivine, and an abundance of possible anthophyllite. Amphiboles minerals were determined to be hornblende and actinolite.

Future work will include a study of samples from a core collected from the Kane Fracture Zone on the Mid-Atlantic Ridge. Point-counts and electron microprobe analyses will be used to supplement data obtained from the Site 1256 core, in particular whether the observed variations in textural and alteration minerals are unusual. Results from both cores will assist in understanding spatial variations in igneous and hydrothermal processes at mid-ocean ridges.