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ABSTRACTS

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THE EDITORS

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Constraining hydrothermal and magmatic processes beneath the Merensky Reef and UG2 Chromitite, Bushveld Complex, RSA

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This thesis takes on a two-part study of late-stage pegmatite veins and pipes which cross-cut stratigraphic units within the Bushveld Complex, South Africa. The compositional evolution of a late magmatic to a hydrothermal system, via a comprehensive fluid and melt inclusion study, is constrained in addition to the thermochemical characterization of the system during pegmatite crystallization.

Quartz and andesine contain primary inclusions of magmatic origin, varying from early, low salinity, two-phase aqueous inclusions to late, nearly anhydrous, NaCl-$CaCl_2$-dominant halide melt inclusions. Silicate melt inclusions (high K and granitic) are also present, and are unambiguously coeval with the halide melt inclusions, demonstrating that the late-stage felsic liquid was saturated in this salt melt. Analyses of melt inclusions by LA-ICP-MS indicate high concentrations of precious metals such as Pd and Au (0.2–0.6 ppm range) at the time of their entrapment. Trace element modeling, using the silicate melt inclusions in conjunction with bulk pegmatite analysis, shows that the formation of the late-stage pegmatite units are by low degrees (~1 vol%) of fractional crystallization of the granitic melt.

SEM (scanning electron microscope) analysis of mineralized cores within the pegmatite veins show pyrrhotite and pentlandite as primary, vug-infilling metals with early inclusions of melonite [(Ni, Pd) Te_2]. Normative abundance patterns are most similar to those from the Bushveld Platreef, showing a marked enrichment in Pd relative to Pt (Pd/Pt > 8), Cu relative to Ni (Cu/Ni > 20) and significant depletion in Ir. Secondary chalcopyrite replacement of pyrrhotite and hessite fracture infill was also observed.

Radiometric $^{40}Ar/^{39}Ar$ dating of biotite (~2022–2044 Ma) indicates the crystallization age of the pegmatite is synchronous with the Bushveld Complex, (~2054 Ma) and disproves previous speculation that the crystallization of the pegmatite was related to the neighboring Pilannesburg Dyke Swarm (~1300 Ma). Mössbauer spectroscopy and EMP (electron microprobe) analyses show direct evidence that slightly oxidizing (within ~1 log unit of the FMQ redox buffer), halide melt-saturated silicate residues were ore metal-bearing during entrapment; therefore, metals at this time were carried via sulfide complexes. Ore/accessory metal ratios in the melt inclusions and pegmatite sulfide assemblages are consistent with the bulk rock metal ratios of pyroxenite cumulates below the Merensky Reef, suggesting that metals were scavenged from those cumulates. Quantitative modeling suggests that the residue melts significantly impacted metal tenor and ratios in the Upper Critical Zone magma.

Estimating a depth of entrapment for three-phase saline aqueous fluid inclusions in the East Bull Lake Intrusion, Ontario, Canada

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Halite-bearing fluid inclusions are present in a vast range of geologic settings and deposits, most commonly porphyry and magmatic-hydrothermal ore deposits, and represent the only evidence of an original fluid composition involved in system evolution. Microthermetric studies on three-phase inclusions that homogenize via halite dissolution (after vapour bubble disappearance) can be useful in determining the minimum pressure of entrapment in a particular system by relating the liquid-vapour homogenization temperature ($Th_{L\text{-}V}$) to the halite dissolution temperature (Tm_{halite}). Once homogenization temperatures for an inclusion are recorded, an isochore can be plotted that intersects the halite liquidus. This point of intersection can then be used to determine a relative depth of entrapment of a deposit.

This method was used on mafic pegmatite samples collected from the East Bull Lake pluton in Ontario, Canada. The area is an exploration prospect for PGE-Cu-Ni sulphide mineralization, as well as a prospective site for safe, long-term disposal of nuclear waste by Atomic Energy of Canada Limited. If applied correctly, this information can be useful in expanding our understanding of current ore distribution and exploration models.

Results from this study conclude (1) the inclusions that report the highest homogenization temperatures, and therefore highest salinity, represent fluids trapped at the highest pressures and minimum depth of entrapment; (2) subsequent inclusions reporting pressures lower than the minimum depth of entrapment represent late stage (post-solidus) magmatic-hydrothermal solutions that circulated through the system after initial mineralization; (3) minimum depth of entrapment of the EBL intrusion is estimated at about 10 km, and corresponds to a minimum trapping pressure of ~300 Mpa for the deepest inclusions.

Testing the use of cosmogenic nuclides to determine subglacial bed deformation

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The Hartlen till is an extensive, variably thick (up to 20 m), highly compacted, grey silty diamicton that cores many of the drumlins exposed along the eastern shore of central Nova Sco-

tia. It has been well characterised and due to its apparent homogeneity many of the observations made at specific locations are transferrable to its other outcroppings. Based on ice flow measurements, pebble provenance, and offshore stratigraphy, it has been determined that the till was deposited during the Caledonian glacial phase but its exact age has yet to be determined. As it commonly occurs at the base of the terrestrial stacks of tills, it may comprise material from the Meguma and associated terranes that had been previously weathered. The overlying tills appear more immature (clasts are more angular, and greater abundance of clasts) but have different sources. The unit has been proposed to be a lodgement till. Diamicton pebble fabric data are being collected at Lawrencetown, Nova Scotia, to investigate this interpretation, and software will be used to determine the eigenvalue to characterize the till type based on previous research on glaciogenic sediments. The till provides an ideal means of demonstrating the plausibility of a deformable bed in a drumlin environment.

Although the concept of deformable beds beneath glaciers has been generally accepted, the thickness of a deforming bed at an instant in time is less predictable, and is expected to vary with the material properties of the bed, with flow velocity, and with subglacial hydrological conditions. Thickness of a deforming bed has only been observed under modern glaciers. Is it possible to use a combination of ^{10}Be with other sedimentological data to determine deformable bed thickness? The following experiment is being set up, using a vertical sequence of approximately eight samples of quartz sand from the Hartlen Till matrix. Based on previous measurements of ^{10}Be in till, it is assumed that the Hartlen quartz sand contains inherited ^{10}Be from exposure as regolith prior to deposition. The vertical distribution of the ^{10}Be concentrations will have two basic end member distributions: (i) If the concentration is invariant with depth, then there is either no deformable bed, or the entire Hartlen Till was completely deformed; (ii) if the concentration decreases with height in the till, then there was a deformable bed of thickness less than the total thickness of the Hartlen Till. The data are expected to aid in defining the deformable bed and thereby allow a better understanding of subglacial processes.

An ion microprobe investigation of the trace element chemistry of titanite as a function of magma composition and metamorphic grade

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Titanite ($CaTiSiO_5 \cdot H_2O$) is a common accessory mineral in igneous and metamorphic rocks and occurs as detritus in sedimentary rocks. It accepts many trace elements which substitute for Ca or Ti. They include the important rare earth elements (REE) and high field-strength (HFS) elements such as Nb, Ta, and Y, which are used in tracing the petrogenesis of rocks. Because titanite can be dated using the U-Pb technique, the chemistry of distinctive titanite generations can be linked to processes for which ages can be determined.

The purpose of this study is to document the major and trace element chemistry of previously dated titanite from selected plutonic rocks ranging in composition from gabbro to syenite, and from metamorphic rocks ranging from greenschist to granulite facies. These data will be used to potentially identify characteristic signatures of titanite crystallized in different geological environments.

To establish the analytical technique, a large gem-quality titanite was analyzed by laser ICP-MS, electron microprobe and ion microprobe, and these results cross-calibrated. This crystal is now the internal standard. Samples were mounted in epoxy, polished and coated in gold, and then imaged by BSE using an SEM to identify internal complexities such as cores vs rims, or growth zoning. Analyses were carried out using a Cameca 4f ion microprobe with a primary O^- ion beam. Data were reduced in an Excel spreadsheet and concentrations calculated with reference to the internal standard values. Results are presented of REE and HFS patterns from these selected samples of titanite, as well as an assessment of their potential petrogenetic use.

Reexamining Pleistocene tunnel valleys on the Scotian Shelf and their implications for slope sediment delivery

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Tunnel valleys are a special kind of erosional channel characterized by anastamosing, steep-sided channel systems formed by subglacial, confined meltwater flow. On the Scotian Shelf, partially infilled tunnel valleys are recognized on the sea floor in bathymetric data, but previous workers have also found buried examples. An earlier project by the authors used 2D industry seismic data near Sable Island to better constrain the geometry of tunnel valleys in the area. Our interpretation showed V to U-shaped buried channels north and west of Sable Island averaging 2–5 km wide and 150–400 m deep with a north-south orientation that extensively branch, reconnect, and meander. The buried channels are similar to channels exposed on the sea floor further north. Immediately to the south and west of Sable Island, the channels become narrower (1–1.5 km) and more widely spaced. Contrary to previous interpretations, the orientations remain roughly N-S and there is a gap of 20–30 km between the ends of the detectable tunnel valleys and the shelf edge south of Sable Island. An exception is at the shelf edge at the head of Logan Canyon, but these channels are also disconnected from those further north. The reason for this gap is not clear; however, it could be due to the limited resolution of industry seismic data in the shallow part of the section. Alternatively, if the channels genuinely end just south of Sable Island, then the gap between them and the shelf edge implies

that they were either present but not preserved (i.e. removed by subsequent erosion), or that along this stretch of shelf edge (between The Gully and Logan Canyon) the subglacial meltwater channels did not empty directly at the shelf edge. This situation would have implications for models of sediment delivery to the Scotian Slope during the Pleistocene. Thus, we plan to use single channel and 3-D industry seismic tied with borehole data to investigate the tunnel valleys between Sable Island and the shelf edge. The data will allow us to test relative ages, modes of formation, and the character of the valleys as they become smaller in size.

Stratigraphy of the Siwalik Group in the Eastern Himalaya: An oxygen and hydrogen isotope record in authigenic clays

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The Indian summer monsoon was established by 12 Ma, creating some of the wettest regions on earth because of orographic precipitations along the Himalayan foothills. There is growing evidence for the correlation between the recent rate of precipitation, rate of surface erosion, and the rate of deformation along some of the active major faults, therefore indicating a coupling between erosion, climate and tectonics. However the field evidence for the rate of change of these feedbacks with time is lacking.

The Shillong Plateau is located directly south of Bhutan, along the pathway of the monsoonal circulation presenting a 1600 m orographic barrier to the northward-circulating moist air and condensing high amounts of precipitation at its southern front, while creating a rain shadow to the north. It has been suggested that the surface uplift of the plateau occurred at the Miocene-Pliocene transition after the monsoon had been established. Consequently, it is plausible that the Himalayan mountain front in Eastern Bhutan receives less rainfall now than before the uplift of the Shillong plateau. Along the southern border of the Himalaya lie the deformed foreland basin sediments. The youngest member, the Siwalik Group, was deposited through the middle Miocene- Pliocene and is exposed in Eastern Bhutan. As the sediment age covers the period of interest, the Siwalik sediments may carry information on precipitation pattern changes towards the Pliocene uplifting of the Shillong Plateau diverting the monsoonal precipitation away from the Himalayan front.

A river section in Eastern Bhutan offers a ~1100 m stratigraphic outcrop section of the Siwaliks. In this study, measurements of oxygen and hydrogen isotopes in authigenic clays from 80 paleosol horizons were used to estimate the precipitation pattern within the Himalayan foreland basin at the time of the uplift of the Shillong Plateau. Preliminary results indicate cyclic variations of oxygen isotopes until the upper Siwaliks where the data present a steep incline. The hydrogen isotopes also indicate cyclic change throughout the section after a steep increase in the lower Siwaliks. Detailed magnetostratigraphy of the Siwaliks sediments will allow precise dating of the sediments and the final interpretation of the isotopic data.

Tracking late-Holocene environmental change at Long Lake, New Brunswick-Nova Scotia border region, Canada

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The Missaguash Bog and Amherst Marsh represent an area with a long history of anthropogenic influence, situated along the border of Nova Scotia and New Brunswick at the head of the Bay of Fundy. Long Lake is a small, shallow lake in the middle of this marsh system affected by a number of human-induced changes including water control structures to keep saltwater out of the Amherst Marsh, dredging of channels to drain the Amherst Marsh for farmland, construction of an impoundment for waterfowl, and increased use through recreation, construction, and forestry. The impact of this activity on Long Lake can be resolved using paleolimnological methods to link changes in organic content, metals concentrations, and other proxies observed in sediment cores to the known history of the lake basin, leading to a better understanding of how small shallow lakes react to anthropogenic influence. The importance of the Missaguash and greater Tantramar Marshes as an iconic Canadian landscape and important waterfowl habitat also lends importance to understanding environmental change in a shallow lake/marsh ecosystem.

An investigation of the solubility of eskolaite at supercritical conditions; experimentation with a Hydrothermal Diamond Anvil Cell (HDAC)

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The solubility of pure synthetic eskolaite (Cr_2O_3) was investigated in 1 M H_2O_2 aqueous solution via experimentation in a Hydrothermal Diamond Anvil Cell (HDAC) apparatus at supercritical conditions. Crystals synthesized from potassium dichromate ($K_2Cr_2O_7$) were characterized with X-Ray Diffraction (XRD), microRaman spectroscopy, and a Scanning Electron Microscope (SEM). A single crystal of eskolaite (volume ~ 3.25×10^{-4} m³) and a drop of aqueous solution were loaded into the sample chamber of the HDAC. The density of the solution was determined from the temperature at which the vapour bubble disappeared. All samples were held at temperatures ranging between 500 °C and 650 °C and at pressures between 100 and 300 MPa. The degree of eskolaite

dissolution was visually monitored during the experiment and the crystal was inspected using scanning electron microscopy after hydrothermal treatment. These preliminary experiments provide qualitative data on the behaviour of eskolaite in various aqueous solutions. These results are used for the selection of compositions to be analyzed by in situ spectroscopic methods. Knowledge of the solubility of eskolaite is requisite to understanding its distribution in nature and the interaction of supercritical water with different steel alloys.

X-Ray diffraction results from the weathering zone above the Bisha volcanic-hosted massive sulphide deposit, Eritrea

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Weathering of the Bisha volcanic-hosted massive sulphide (VHMS) deposit has produced: (i) a gossanous oxide Au zone above (ii) a supergene zone of chalcocite replacement of sulphide minerals, over (iii) hypogene sphalerite-chalcopyrite-bearing massive sulphide. These enrichment zones differ from those developed over other VHMS deposits (Ladysmith, Wisconsin; Caribou, New Brunswick; Las Cruces, Spain; Golden Grove, Western Australia) in that supergene Pb mineralization (galena, siderite) occurs immediately above the Cu-enrichment zone, and oxide Au grades are ten times that of hypogene mineralization (in contrast to the two-fold Au enrichment typically observed at other deposits). To understand how these anomalous zones developed, X-ray diffraction analyses were undertaken on samples from two cross-sections to gain insight into the mineralogical changes that took place during weathering. Lithologies within the weathering zone consist of: (i) gossan (principally in situ and transported Fe-oxy-hydroxide minerals), (ii) acid leached rocks (mostly silica), (iii) saprolite (quartz and clay minerals), (iv) supergene sulphide mineralization (chalcocite replacing pyrite, sphalerite, and chalcopyrite), and (v) hypogene massive sulphide (pyrite, sphalerite, and chalcopyrite). Using lithogeochemical compositions of these rocks, ordinary least squares regression methods were used to obtain 'best fit' mineral modes for each weathering zone. These data have been plotted on cross-sections to define the weathering patterns present in these rocks, and indicate that lateral groundwater flow is likely responsible for an asymmetric distribution of these zones. With these mineralogical constraints, chemical reactions have also been identified that explain the bulk material transfers that occurred to create each weathering zone.

The effect of short-duration rainfall on the surface water quality of Thomas Brook, Kings County, Nova Scotia

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The surface water quality of freshwater systems is an indicator of the overall health of an ecosystem. Nitrogen and phosphorus are limiting nutrients in freshwater systems, so slight increases in either nutrient can negatively affect surface water quality. Agricultural practices dominate approximately 50% of the Thomas Brook Watershed, located within the Annapolis Valley of Nova Scotia. Climatic data indicate that there have been increases in the frequency and duration of rainfall events in the Annapolis Valley. In addition, research indicates that over 90% of nutrients move from agricultural land into watercourses during times of precipitation. This research project focuses on the movement of artificial nutrients from agricultural land into the watercourse during periods of precipitation and its effect on the health of the watershed. An analysis of the surface water quality of Thomas Brook during three rainfall events exceeding 20 mm of precipitation in the spring of 2011 will determine the increase in nutrient concentrations as a result of excess water and soil input from overland flow and throughflow. Results from this study will be used to determine the susceptibility of the watershed to eutrophication during these events and will aid local agricultural producers in managing nutrient application on crops within the watershed.

Aqueous geochemistry and substrate utilization by microorganisms at active sites of serpentinization, Tablelands Ophiolite, Newfoundland

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The Tablelands in Gros Morne National Park, Newfoundland, is an ophiolite thought to have been obducted during the closing of the Iapetus Ocean, several hundred million years ago. This site is barren due to its lack in usual nutrients, low in calcium, high in magnesium and toxic amounts of heavy metals. It contains the extreme environment of active serpentinization, low-temperature oxidization and hydrolization of ultramafic rocks into serpentine, with its anoxic conditions that include elevated pH and low redox potential (Eh) values. Serpentinization provides an environment amendable to abiogenic and biogenic production of methane. Serpentinization is suspected on Mars and more prevalent on early Earth, which is why this site is a Mars and early Earth analog site, supported by the Canadian Space Agency.

The geochemistry of the water will be analysed at various sites within the ophiolite. Concentrations of anions such as sulfate, phosphate and nitrate along with organic acids such as propionate, acetate, valerate and formate will be determined. Total organic nitrogen, total inorganic nitrogen, dissolved organic carbon and dissolved inorganic carbon will all be examined. These compounds will help determine possible substrate sources for microbes at these sites, along with understanding the overall community within the high pH, low Eh groundwater produced by serpentinization.

Microcosms, simplified ecosystems that are used to simulate and predict the behaviour of natural ecosystems under controlled conditions, have been sampled. The microcosms of this study have ^{13}C labeled organic acids and bicarbonate added to determine carbon source in methanogenic microbial pathways. Measuring $d^{13}C$ of methane and carbon dioxide, after microcosm experiment is complete, will determine if labeled substrate was metabolized for methanogenesis. Examining the results between the live bottles and the killed controls will help determine if the methane was produced abiotically or biotically.

Examining possible life in Tablelands serpentinization sites and their energy source will help better understand the carbon cycling in serpentinization environments. As well as, this information can be used to compare to possible Martian communities and/or physical reactions occurring on Mars.

Petrology of the Indian Lake pluton, Antigonish Highlands, Nova Scotia

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The Indian Lake pluton in the Antigonish Highlands of northern mainland Nova Scotia is not reliably dated but is interpreted to have formed at about 605 Ma like some other plutons in the Avalonian Antigonish Highlands. The purpose of this study is to describe the petrography and geochemistry of the Indian Lake pluton, and based on those data, to investigate whether or not it is likely to have been comagmatic with those other dated suites. The Indian Lake pluton will also be compared to the undated Leadbetter Road pluton, from which it is separated by the West Barneys River plutonic suite, a large composite pluton of Ordovician age (ca. 470 Ma). It is unclear whether the Leadbetter Road pluton is part of the West Barneys River suite or not, and this study will contribute to resolving that question. The Indian Lake pluton consists of medium-grained granodiorite gradational to monzogranite and medium-grained quartz diorite and diorite. Both the granodiorite/monzogranite and quartz diorite/diorite contain abundant dioritic inclusions. In contrast, the Leadbetter Road pluton consists of coarse-grained alkali-feldspar granite and is similar to syenogranitic parts of some ca. 605 Ma plutons elsewhere in the Antigonish Highlands. Preliminary chemical data from the Indian Lake pluton show that SiO_2 content ranges from about 56% to 74% and reveal trends consistent with crystal fractionation of plagioclase and mafic minerals. The petrographic and chemical characteristics are similar to those of I-type granitoid suites formed in subduction zone settings at active continental margins.

The depositional regime of Early Triassic sedimentation in the Bjorne Formation on the eastern margin of the Sverdrup Basin, Ellesmere Island, Nunavut, Canada

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The Bjorne Formation of the Canadian Arctic is a poorly understood, dominantly sandstone unit that occurs in the Sverdrup sedimentary basin in the northern part of the Arctic Islands. The aim of researching this formation is to unravel an important part of Sverdrup Basin evolution. The thickness of the Bjorne Formation nears 2000 m in the depocentres and 1000 m along the margins. The outcrop on Ellesmere Island was deposited on the eastern margin of the basin during three phases in the Early Triassic. Three sandstone members are separated by mudstone members. These mudstones are tongues of the stratigraphically equivalent Blind Fiord Formation in the deep basin that represent basin-wide transgression. The sediment was derived from the east and south of the basin and was sourced mainly from Devonian siliciclastic strata that flanked the basin and extended over the craton. Lithological and sedimentological features were observed and correlated to create facies associations for the lower member. Facies associations help create a depositional model for the entirety of the Bjorne Formation. This enables the understanding of the shifting basinal environment and dominant depositional regime during rapid sedimentation during the Early Triassic.

In the lower member, there are hundreds of metres of stacked sandstones with red siltstone interbeds with planar stratification and primary current lineation. Shallow scours and mud rip-up clasts are present with potential antidune deposits. The red siltstone beds have climbing ripples, desiccation cracks, and slight bioturbation. These associations of sedimentary features give an indication of episodic and rapid sedimentation similar to a fluvial environment within the spectrum of braided rivers. There is also a marine association with interbedded sandstone and siltstone with hummocky cross stratification and intensive bioturbation.

Deposition took place immediately following the Permian-Triassic boundary. Extinction of many vegetational taxa at that boundary could have influenced fluvial styles because vegetation helps stabilize banks. The lack of meandering river deposits in the marine/non-marine transitional zone of the Bjorne Formation in the early Triassic could be in part the result of the extinction event.

Petrographic information will be used to formulate a model for burial history by looking at compaction, cementation and

alteration. Potential reservoirs, source rocks, seals and traps will be analyzed to interpret the hydrocarbon potential within this unit. Sandstone reservoirs are relatively continuous with limited low permeability barriers. Shale above and within the Bjorne Formation provides a seal, and potential source rocks in the Carboniferous and Permian have a high level of thermal maturity in this area.

Investigation of the form and age of the Bloody Creek Crater, southwestern Nova Scotia

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Virtually all terrestrial impact craters exhibit a circular geometry in plan-form; only three impact sites exhibiting non-circular, elongate forms have been identified on Earth. One of these exceptional sites is the Bloody Creek Crater located in southwestern Nova Scotia, an approximately 0.42 km long-axis elliptical crater first identified in 1987 during a regional air photo survey. It was confirmed as an impact crater in 2009 through integrated geomorphic, geophysical, and petrographic data. The structure's rare ellipticity, pristine definition, preservation through shock metamorphic features of anomalously high pressures at the rim, low depth-to-diameter ratio, as well as age remain ambiguous and complicate the interpretation of the origin and evolution of the crater.

The purpose of this study is to quantify the form of the feature as well as to develop better constraints on its age. To achieve this objective, an extensive review of the literature was performed to understand the controls on crater formation as well as to synthesize a model for the geological evolution of the site which would aid in the interpretation of the age of the structure. The Bloody Creek Crater provides a unique opportunity to study resultant structures and shock deformation associated with low-angle impact into a homogeneous crystalline target. Such research will supplement our knowledge of how target geology influences the nature of observed shock effects, which may facilitate future identification of potential impact structures in similar geological environments. Moreover, continued identification of terrestrial impact craters contributes to the statistical data base for estimating past impact rates on Earth. The identification of low-angle impact craters in particular will contribute to discussions of the statistical probability of their occurrence on Earth, as well as the role of the terrestrial atmosphere in filtering such impact events.

An evaluation of awaruite in the Atlantic Lake area of the Pipestone Pond Complex, Newfoundland

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Newfoundland hosts several well exposed ultramafic complexes that have been central to mineral exploration and mining activities for decades. These ultramafic bodies have undergone variable degrees of serpentinization: a low grade, retrograde metamorphic reaction in which minerals such as olivine and pyroxene break down to form one of the serpentine family of minerals and magnetite. Strongly reducing conditions caused by the release of H_2 during the formation of magnetite provide conditions amenable to the formation of Ni-rich mineral phases such as awaruite (Ni_3Fe). The nature of these Ni-bearing minerals is further defined by the available sulphur content of the system. Awaruite is formed under reduced conditions in the absence of sulphur and represents hydrous-metamorphic remobilization of nickel from its silicate residence in olivine.

The scope of this project is i) to document awaruite and associated nickel mineralization in the Pipestone Pond Complex in central Newfoundland and ii) to constrain the geological conditions under which Ni-Fe alloy mineralization formed. Detailed mapping, core logging, polished petrographic thin sections, and the SEM-MLA will be utilized to investigate awaruite and associated minerals. The results of this research will be used to help guide exploration for Ni-Fe alloy minerals by identifying rock types which host the most significant awaruite, as well as provide some insight on the controls of mineralization.

Structural geometry and kinematic evolution of the Latakia – Tartus Ridge system of the Cyprian Arc, East Mediterranean Sea

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The Cyprian Arc defines the active tectonic boundary between the African Plate to the south, the Arabian microplate to the east, and the Anatolian microplate to the north. This plate boundary has evolved from north-south contraction related to subduction of the African plate below the forearc region of the Anatolian Plate to strike slip in transpression related to the collision of the Arabian and Eurasian/Anatolian plates. The morphological expression of the front of the Cyprian arc is a narrow east-west trending ridge situated southeast of Cyprus and known as the Latakia Ridge, and the broad system of northeast-southwest trending ridges situated to the west of the coast of the Arabian Plate.

The structural geometry and evolution of the plate boundary has been under discussion since publications starting in the early 1990's based on regional marine seismic surveys. Previous work by the East Mediterranean Research Group at MUN (2005) in the region of the Cyprus Arc has presented new interpretations based on analysis of a somewhat limited set of high-resolution seismic profiles. These interpretations lacked a solid underpinning of the assumed lateral continuity of the structures along strike based on the morphotectonic expression of the ridge system. Recently, a high-resolution side-scan sonar

map of the seabed morphology in this deep-water region has become available for detailed analysis. This new morphotectonic map clearly shows that the ridges are segmented across lineaments striking NE – SW, and that the structural elements underlying the ridges are discontinuous and offset in apparent strike separation.

This Honours thesis study proposes to execute a detailed morphological and structural analysis of the seabed map to identify the plan view pattern of the active faults that control the architecture of the ridge system. Following this analytical phase, the stratigraphy and structure of the ridge segments will be analyzed in a set of high-resolution marine seismic profiles collected by the MUN research group. This part of the study will also utilize available seismic profiles collected by other consortia. It is expected that the proposed study will yield a more refined and accurate interpretation of the geometry and kinematic evolution of this complicated plate boundary region.

Quantitative mapping in the Parry Sound Domain for structural analysis.

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The Parry Sound domain (PSD), a granulite nappe in the Central Gneiss Belt of the ca 1.1 Ga Grenville Province gives insight into structural processes in mid-crust of a doubly thickened orogen. The Twelve Mile Bay Shear Zone forms a boundary of the PSD along which interior granulite-facies PSD structures are transposed at amphibolite facies. The focus of the study is to create a quantitative map so that measurements can be obtained for further structural analysis, for a better understanding of how the lower crust deforms. In the summer of 2011 a Dalhousie team set about creating this unique map by using a camera on a pole to shoot very low aerial photographs of a few islands. The islands were selected being transitional from foliated granulite-facies rocks to transposed sheared amhibolite-facies rocks of the same composition, with the intention of understanding how these shear zones form and propagate. Leica DGPS system was used to set up a grid of points in combination with the pole-camera to shoot the grid systematically. Photos are now in the process of being merged to create the map through experimenting with several different photo software suites. Once the map is complete, data such as change in thickness of a layer as it enters a shear zone and layer displacement across a shear zone can be collected. These data can be used to quantify the shear strain and tell us how the islands have changed shape over time.

Rare-earth element-niobium mineralized carbonatite, Clay Howells Alkalic Complex, Kapuskasing, Ontario: significance of magnetite saturation and fractionation

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The Clay Howells Alkalic Complex is located 40 km north-northeast of Kapuskasing in central Ontario. It is a 110 km² layered syenite – nepheline syenite – carbonatite ring dyke complex, with a parabolic ring structure for the carbonatite deposit, as defined by an airborne magnetic and radiometric geophysical survey completed by Rare Earth Metals Inc. in January 2010. Monazites have been dated using Laser Ablation – ICPMS (Pb/Pb and U/Pb ratios), returning an age of 1056.1 ± 3.9 Ma making it the youngest in that group of middle Proterozoic carbonatites. The Clay Howells REE-Nb deposit is magnetite rich and has been recently estimated at 8.5 million tonnes averaging 0.73% TREO and 0.14% Nb_2O_5 with 44.5% Fe_2O_{3T}, with 10% of the TREO being HREO. Two arcuate carbonatitic lenses within the alkali complex have been identified with an average width of 67 m. In these magnetite cumulates, higher grades of Nb-REO have been measured, represented by 2.7% TREO (with 10% as HREO) over 4.9 m.

The (auto-) oxidation of ferrocarbonatite (ankerite) magma to crystallize magnetite during emplacement with migration to shallow depth seems to involve volatile exsolution (H_2O, CO_2, H_2). This process may also be used to explain the crystallization of these large magnesian calcite and dolomite bodies that were an extremely fractionated Fe-Mg-rich carbonatite magma with high RE and Nb oxides at low temperature and pressure, with increasing O_2 fugacity. Carbonatite magmas have extremely low viscosities and liquidus temperatures that enable emplacement to shallow levels and possibly even erupt. H_2O exsolution from the crystallizing ferroan carbonatite magma, possibly released $H_{2\,(gas)}$ by the reaction:

$$6(Ca^{2+}, Mg^{2+}, Fe^{2+})CO_3 + H_2O \dashrightarrow Fe^{3+}{}_2Fe^{2+}O_4 + 3(Ca^{2+}, Mg^{2+})CO_3 + 3CO_2 + H_{2\,(gas)}$$

As the carbonatite melt becomes depleted in ferrous iron with oxidation, calcite and dolomite begin to crystallize with magnetite; this cogenetic crystallization relationship between calcite and dolomite grains is manifested as euhedral dolomite within calcite phenocrysts all within a dolomite host. Areas where large amounts of dolomite and calcite have crystallized also contain fractionated euhedral niobates (chiefly columbite, but locally as exsolution lamellae in pyrochlore). The euhedral and anhedral crystals form along crystal boundaries, and pyrochlore (grain size ~ 50 m) also occurs as inclusions within magnetite. Magnetite saturation also initiates the nucleation of anhedral late-stage monazites (~ 200 m) at crystal boundaries. General rheological properties of carbonatites below the

decarbonation threshold of 1 bar have been estimated to have a viscosity of 5×10^{-2} poise, density of 2.2 g/cm^3, thermal conductivity of 1.65×10^{-2}, thermal diffusivity of 4.2×10^{-3}, heat of fusion of 125, heat capacity of 2, and a thermal expansion of 2.3×10^{-4}. These characteristics have been used to estimate settling velocities for magnetite with diameters ranging from 0.2 to 4 mm within the range of 10–30 cm/s. The calculated settling velocities of magnetite, columbite-pyrochlore, and monazite crystals in the magnesian carbonatite are relatively similar; this produces dynamically interlayered massive magnetite and magnetite-carbonate layers, with REE and Nb abundances most enriched with the magnetite cumulates.

Provenance identification of detrital quartz using the hot-cathode cathodoluminscence (CL) microscope: a study of quartz sandstones of the Scotian Basin

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Determining the source of sedimentary detritus of the Lower Cretaceous deltas of the Scotian Basin is important for understanding the distribution of reservoir sandstones and their subsequent diagenesis. It thus contributes to both exploration models and to understanding reservoir quality. Quartz is the principal mineral in reservoir sandstones, but most quartz grains have few characteristics that are diagnostic of provenance. The technique of hot-cathode cathodoluminescence (CL) provides a method of identifying quartz from different sorts of igneous, hydrothermal, and metamorphic rocks.

Quartz of different origins shows different colors after the first few seconds of exposure to the CL beam and after the color shift has completed. Representative bedrock samples of possible source rocks from the Appalachian orogen were collected and the CL characteristics of quartz of known origin were determined. CL criteria were established for the following six types of quartz: plutonic and hypabyssal, volcanic, aplite and vein, low-grade metamorphic, medium-high-grade metamorphic and high-pressure metamorphic quartz. Once quartz grains have been exposed to the electron beam, the initial CL color cannot be reproduced. We have developed a protocol that records which areas of thin sections have been exposed to the CL beam in order to ensure that true initial CL colors are captured in photomicrographs. Colours are captured by digital photography at three and twelve seconds exposure to the CL beam. The origin of individual detrital quartz grains is then interpreted from the CL photomicrographs, and petrographic features.

In order to test the developed protocol for determining quartz provenance, 890 quartz grains from a sample of the Logan Canyon Formation in the Peskowesk A-99 well were analyzed. Provenance results using this method were reasonably consistent with results of provenance studies involving the same samples using both lithic clast and zircon geochronology, although some important differences were noted. Provenance data collected using lithic clasts reported no vein quartz and a higher abundance of igneous quartz. This is probably because sand-sized vein quartz would normally be indistinguishable from monocrystalline quartz of other origins and because the lithic clast data tend to overestimate the overall supply from igneous rocks since igneous quartz tends to be coarser grained than metamorphic quartz. Also, the reported proportion of volcanic quartz by CL is slightly lower than from detrital zircon geochronology. It is probable that there was a bias towards dating nice-looking euhedral volcanic zircon grains which explains this discrepancy. The developed protocol has since been employed to determine provenance of quartz grains in sandstones from various depths in wells Alma K-85, Venture B-13, and Thebaud I93. Our results so far thus suggest that hot-cathode CL imaging is a powerful method for determining the provenance of quartz grains in Scotian Basin sandstones.

Three-dimensional morphological characterization and petrography of the trace fossil *Rosselia*

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The ichnogenus Rosselia is recognized as a vertically oriented burrow that consists of a cone- or funnel-shaped portion with a central shaft with meniscate backfill. The conical portion of Rosselia has been inferred to consist of either imbricate concentric layers of matrix surrounding a cylindrical shaft, or helicoidal swirls, both tapering downwards. Rosselia can be found in strata from the Lower Cambrian to Pleistocene. Most often, it is found in shallow sub-littoral near-shore environments, but has also been observed in deep water. In the tide-dominated Jurassic Ile Formation off shore Norway, Rosselia was found to occur only in sub-tidal settings, supporting observations found in the tide-dominated Lajas and Tilje Formations that Rosselia is a good indicator of sub-tidal depositional environments. A sample collected from Bell Island, Newfoundland, contains several well-preserved vertical burrows that have been identified as the trace fossil Rosselia. The purpose of this honors project is to construct a high-resolution three dimensional morphological model of the ichnogenus Rosselia based on pre-established serial grinding methodology. The serial images through the specimen will allow complete three-dimensional morphological reconstruction of this trace fossil for the first time. The three-dimensional model will be used to assess hypotheses for the formation of the trace fossil Rosselia. Through this project it will be possible to apply the techniques of three-dimensional morphological modeling to better understand the trace fossil Rosselia, which is a common trace fossil routinely used as a paleo-environmental indicator.

The occurrence and origin of ring schlieren in the South Mountain Batholith, Nova Scotia

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Ring schlieren are alternating melanocratic and leucocratic bands in granites forming open to closed, nested, circular to elliptical, concentric to eccentric, prolate to oblate structures with cross-cutting relationships indicating younging direction toward the centre. The late Devonian South Mountain Batholith (SMB) underlies much of the southern mainland of Nova Scotia and, along a coastal transect between Aspotogan Point and Portuguese Cove, is host to 161 ring schlieren structures. Measured features include location, number of rings, length, width, aspect ratio, orientation, presence or absence of xenoliths, and regional foliation in the peraluminous granitoid host. Image analysis of vertical photographs provides field data verification or correction. For each structure, the melanocratic sharp contact of the outer ring with the granitoid host grades into a leucocratic interior. Outer ring long axes lengths range from 0.14 m to 17.12 m, and short axes range from 0.15 m to 5.07 m. Aspect ratio varies between 1.24 and 1.92 for the 20 single-ring structures, and between 1.04 and 2.41 for the 141 multi-ring structures. Rare three-dimensional exposures reveal a vertical cylindrical nature of these ring schlieren structures. The ring schlieren map pattern in the SMB shows a clustered distribution. Groups of rings occur near Aspotogan Point (n = 7), near Peggys Cove (n = 81), near West Dover (n = 13) near Prospect (n =5) and near Pennant Point (n =41). Within the study area, isolated rings are rare, although 12 do occur. The ring schlieren structures, which are nested vertical pipe-like features in three dimensions, cut flow foliations in the host granite and therefore, represent late features in the crystallization of the batholith. One working hypothesis is that ring schlieren form by ascending bubble trains created by the degassing of magma at greater depths.