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A B S T R A C T S

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THE EDITORS

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The evolution of late intrusive phases in the Georgeville Granite, Nova Scotia

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New exposures of the post-orogenic Georgeville granite reveal the presence of three distinct late-stage differentiates of the granite. The Neoproterozoic pluton is exposed in Georgeville, Nova Scotia, along the Northumberland Strait. Its intrusive age is inferred from a 579.8 ± 2.2 Ma date obtained by Ar/Ar analysis of muscovite in a related pegmatite (Cormier pegmatite). The new outcrops provide the opportunity to investigate the late-stage evolution of ahighly fractionated A-type granite by examining the temporal, textural and chemical relationships of the different intrusive phases. The different phases can be subdivided based on texture and mineralogy into: (I) coarse-grained pegmatite (pegmatite I) composed almost entirely of quartz and microcline; (II) amazonite-bearing pegmatite-aplite dykes (pegmatite II); and (III) relatively fine-grained green, amazonite-zinnwaldite-bearing granite. The pegmatites occur as dykes and irregular shaped pods. The dykes are generally less than 50 cm in width, whereas the pod-shaped pegmatites may be up to a few meters in their maximum dimension. Pegmatite II crosscuts pegmatite I, but the temporal relationship of the green granite relative to the pegmatites is uncertain due to faulting. Pegmatite II and the green granite have similar major element compositions. However, trace element data show that the green granite is enriched in the rare alkalis Rb and Cs (Rb = 851 ppm, Cs = 41ppm) compared to pegmatite II (Rb = 214 ppm and Cs = 4 ppm). The green granite is also enriched in Pb (113 ppm versus 72 ppm in pegmatite II) and depleted in Ba (52 ppm compared to 166 ppm in pegmatite II). The remainder of trace elements analyzed show similar values for each of the units. Pegmatite I is mainly composed of microcline, quartz, and clinochlore and is the volumetrically dominant pegmatite in the pluton. Thorite, zircon, and pyrite occur as accessory phases. Pegmatite II contains albite, microcline, quartz, and accessory clinochlore, zircon, and pyrite. The green granite is microporphyritic. It contains microcline (var. amazonite), quartz, albite, and accessory zinnwaldite, zircon and pyrite. Microcline in all units exhibits perthitic textures. The green granite is similar in composition to the niobium-, yttrium- and fluorine-enriched Cormier pegmatite that is located several hundred meters north of the study area. However, the granite is not as enriched in Nb and Zr. The highly fractionated green granite is interpreted to be the latest phase in the Georgeville pluton. This study shows that pegmatite-forming melts were generated at different times during the solidification of the Georgeville pluton. Textural variations within the pluton can be attributed to different melt compositions and degrees of undercooling.

The North Group – A newly discovered multiple impact crater site in southwestern Nova Scotia?

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An approximately 0.4 km diameter elliptical structure was identified in southwestern Nova Scotia in 1987 during a regional airphoto survey. The structure was confirmed as an impact crater in 2009, and was named the Bloody Creek structure (BCS). In addition to the main crater, a cluster of discontinuous arcuate scarps located approximately 1 km north of the BCS was identified. These arcuate scarps have been called the North Group. The purpose of this study is to resolve the nature of the North Group in order to determine if this site represents a multiple impact event. This assessment will be achieved through an integrated analysis of geomorphic, geophysical and petrographic data.

A detailed aerial photo analysis of the site reveals several discontinuous arcuate scarps (1 to 2 m high) sharply outlining flat depressed inner floors. Sonar and lake sediment probing across a few of the structures revealed a crater-like morphology beneath the depressed inner floor. The craters are interpreted to be infilled with lacustrine sediment and peat.

Bedrock samples for petrographic analysis have been collected from just outside one of the crater rims. Preliminary petrographic work revealed possible shock-metamorphic effects. They include kink-bands in feldspar and biotite and planar microstructures (PMs) in quartz and feldspar. The PMs consist of planar fractures (PFs) in both quartz and feldspar and possible planar deformation features (PDFs) in quartz. Of these features, the PDFs are considered uniquely diagnostic of shock metamorphism. These features will be further examined using a universal-stage petrographic microscope. A detailed morphometric analysis of the arcuate scarps remains to be completed; this work will determine if the structures exhibit elliptical symmetry.

Fluid and melt evolution during the formation of the Berg copper molybdenum porphyry deposit, British Columbia

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[Poster]

The purpose of this study is to delineate the chemical and physical evolution of hydrothermal fluids and the associated silicate melts in a molybdenum-rich copper porphyry calc-al-

kaline deposit located within the Hazelton Mountains, British Columbia. Within the Berg deposit are two main zones of mineralization: the Northeast zone that contains hypogene, as well as some supergene, mineralization, and the Southeast zone, which contains widespread supergene mineralization. Ore-forming processes are not very well understood in porphyry copper-molybdenum systems compared to porphyry copper-gold systems. This study will focus on determining whether molybdenum gets concentrated in a porphyry environment by the same processes that influence copper and gold.

The fluid and melt inclusions studied are very well preserved and found within quartz phenocrysts of the Eocene-aged monzonite intrusion within the Berg copper-molybdenum deposit. The intrusion, based on bulk rock geochemistry is a typical potassic-altered calc-alkaline arc monzonite with LREE > HREE, a subtle depletion in Nb and Ta (rutile retains these elements in the source region), and a strong depletion in Ni and Cr, also typical of arc magmas. Fluid inclusions are primary or pseudosecondary and are two-phase (at room T) containing aqueous liquid and vapour. Less common are polyphase inclusions containing aqueous liquid, two-phase bubbles composed of CO_2 liquid + vapour, halite and other salt crystals, and occasionally hematite. Melt inclusions are less common but are of primary origin and are recrystallized. Two-phase fluid inclusions and melt inclusions of primary origin were also identified in apatite.

Methods used to study the inclusions and associated host rocks include optical petrography, photomicrographs, microthermometry, scanning electron microscope (SEM), cathodoluminescence (CL), electron microprobe (EMP), and laser ablation ICPMS. The origin of the inclusions is being constrained by CL; preliminary results show that quartz phenocrysts have a complex zoning pattern related to resorption and regrowth during interaction of the quartz phenocrysts with the surrounding magma. Biotite-apatite thermometry of the host rocks indicate that the monzonite crystallized at relatively low temperature (<650 °C assuming a 2 kbar crystallization P); apatite is end-member fluorapatite, indicating a high F content in the associated melts from which the apatite crystallized. These conditions will be used to help constrain temperature of entrapment for primary inclusions in the apatite and early quartz phenocrysts (apatite and quartz were both early crystallizing phases).

Interpretation of airborne electromagnetic data using 1-D inversion

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[Poster]

The purpose of this honours project is to analyze helicopter-borne electromagnetic survey data acquired over an active exploration site. The goal is to determine firstly if there is indeed a deep ore body as currently hypothesized, and secondly if there are any other ore bodies in the survey area. The AeroQuest IMPULSE airborne system was used to collect the data. This system uses a six channel frequency domain, with three frequencies in each of the horizontal coplanar and vertical coaxial orientations. The area of the survey covers just over 15 km², and flight line spacing varied from 50 to 100 m. There are a number of current mining claims within the survey area, and it is very complex geologically.

The main component of this project is to invert the electromagnetic data at each measurement location to produce a layered Earth structure (1-D model). This will be done using the program EM1DFM from the University of British Columbia. All of the 1-D models in one flight line will be gathered together to produce a 2-D approximate model of the subsurface beneath that line. Upon completion of the 2-D modeling, the entire data set will then be linked to form a 3-D conductivity model of the subsurface of the survey area. The inversion results will be compared with other geophysical data from both the AeroQuest survey and other surveys to give a clearer picture of the subsurface.

Lateral accretion deposits in a sinuous density underflow channel: a study of the channel evolution and rate of sediment accumulation

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The objective of this study is to investigate the continuity and extent of lateral accretion deposits on the western bank of a sinuous density flow channel in the southwestern Black Sea. This channel travels roughly north-northeast from the mouth of the Bosphorous Strait. Across this strait, a strong density contrast of ~12–16‰, causes the saline Mediterranean waters to sink below the lower salinity Black Sea surface waters. Once through the Bosphorous Strait, the saline water flows as a bottom current across the southwestern Black Sea shelf, creating an anastamosed channel network similar in appearance to anastamosed stream channels in terrestrial environments.

Before beginning the analytical component of the study, initial background reading must be done on the topic of density flows and detailed seismic data from the Black Sea channel area must be gathered. This data has been compiled previously and is available to be analysed. It consists of ~1500 km of high-resolution seismic reflection profiles collected using a Huntec deep tow system, which includes an internal hydrophone and a ~6 m-long external hydrophone array, as well as several piston and gravity cores. For the present study, twelve line segments from the MAR05 (2005) and one line segment from the MAR98 (1998) survey plus two gravity cores (MAR08-06G and 07G) were selected.

Seismic profile segments will be interpreted using conventional sequence stratigraphic approaches, with the horizontal and vertical scales being determined using the original seismic profiles. A datum common to all profiles will be established. The positions of the sediment cores will be plotted on the profiles and the core length will be projected into the subsurface. The position of each radiocarbon date will be projected onto the seismic profiles. On the basis of these ^{14}C ages, as well as incorporating grains size analysis data and core X-ray photographs, several key reflections defining the boundaries of distinct prograded lateral accretion deposits will be selected and correlated across all seismic profiles. This process will allow a chronostratigraphy to be determined for the lateral accretion deposits within the study area, providing the basis for the calculations of rates of sedimentation and progradation.

The density contrast between the salinity underflow and the lower salinity surface water is similar to those measured in natural low concentration turbidity currents. Thus, this channel may serve as a field-scale analogue for various aspects of turbidity currents. This project will contribute not only to future studies of density flow channels, but may also help expand knowledge on the behaviour of turbidity flows outside the scale of laboratory experiments.

Mud accumulation on the open coast: a sedimentological puzzle

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Mud accumulation along open coastlines occurs near many major river deltas, yet it remains a sedimentological puzzle, due to the low settling velocities of mud particles, compared to the relatively intense turbulence created by waves and currents on open coasts. The conceptual model for muddy coast sedimentation suggests that high rates of sediment supply may dampen turbulence from waves and currents in the coastal zone, resulting in reduced bed shear stresses and increased deposition. However, the exact interactions among sediment supply, waves, currents, and associated sediment deposition are not quantitatively understood. The goal of this study is to evaluate the sediment supply component of this model, and its impact on long-term accumulation, along a rapidly prograding portion of the western Atchafalaya/Mississippi River delta.

In order to understand the dynamic morphology and sediment accumulation along the inner continental shelf of the Chenier Plain of Louisiana (fed by the Atchafalaya River, a distributary of the Mississippi River), chirp subbottom sonar profiles and piston cores were collected along gridded survey lines. The chirp data and piston cores will be analyzed using seismic visualization tools and $^{210}Pb/^{137}Cs$ geochronological analysis of cores to provide pictures of temporal and spatial variations of sediment accumulation in the study area. Through this, a map of the stratigraphic successions and sedimentation events will be made that will be compared to the known history of river-sediment discharge over the past century. Although the study area is over 100 km west of the Atchafalaya River outlets, we anticipate that periods of most rapid progradation will follow highest river-sediment discharge, and that periods of low sediment discharge may be primarily erosional.

What causes the formation of the Himalayan transverse anticlines? Thermochronology of the Rangit window in the Sikkim Himalaya

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[Poster]

The Gondwana Formation (GF) is a poorly understood lithological unit at the base of the Lesser Himalayan Sequence (LHS), with a poorly constrained Permian age. West of Nepal and East of Bhutan, in the Sikkim region of India, tectonics and perhaps river incision influenced the formation of a double tectonic window revealing micaceous sandstone of the GF in the core. Bounded by the Main Central Thrust (MCT) at the base, and the Ramgarh Thrust in the roof, the area has undergone a great amount of deformation resulting in a transverse antiform of the LHS. Such structures are rare in the Himalayas and one hypothesis states that these structures are the result of interaction between tectonics (Himalayana collision) and focused erosion (incision of the largest Himalayan rivers). Using $^{40}Ar/^{39}Ar$ dating of detrital muscovite grains from GF, the provenance of GF and its thermal and structural history will be interpreted. Combined with a concomitant study using other themochronometers this study will determine exhumation rates in the window and thus help determine the relative importance of focused river incision and localized tectonic deformation. Preliminary ages suggest that the temperatures caused by Tertiary Himalayan metamorphism and tectonic burial were not high enough to reset the $^{40}Ar/^{39}Ar$ ages of the muscovite grains. This puts a constraint on maximal temperatures and therefore burial attained by the GF.

Trends and architecture of Meguma Group turbidites in Point Pleasant Park

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In the Meguma Group a series of clastic and shaly intervals formed in a range of depositional environments from deltaic to deepwater. The area of interest for this thesis is the Bluestone

member in the Halifax Formation formed during the lower Ordovician. This member comprises turbidites containing T_{a-e} and is part of a prograding wedge complex. The area of investigation is Point Pleasant Park located on the Halifax peninsula. A number of outcrops exhibit the classic Bouma sequence. The goal of this project is to understand the distribution and architecture of these turbidites and determine measure the trend through paleocurrent measurements from such features as tool marks and current ripples. Data collection will include measuring and logging sections, petrographic analysis, scintillometer measurements to create synthetic gamma logs of the successions, LiDar to develop 3-D models to investigate the geometry and architecture of the studied outcrop section. These measurements will be completed at outcrops located at Cable Rock, Black Rock Beach, the Battery, and Sailors Memorial.

Microbially mediated sedimentary structures and siliciclastic stromatolites in the Upper Devonian to Lower Carboniferous Horton Bluff Formation, Nova Scotia

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Over the past decade, microbial mats have been identified as major players in sedimentology. They are thin crusts of bacteria and form rubbery mats on sediment surfaces, protecting these surfaces from erosion. Domal stromatolites, which are also microbial in origin, are often linked to the algal mats that are on the bedding surfaces. These features have been recognized as far back as 3.5 billion years. Until recently, they have been difficult to identify and have been overlooked. These features were discovered at Blue Beach, Horton Bluff last summer by Dr. Martin Gibling. To confirm that these features are correctly identified, an honours project has been set up. Understanding the physical sedimentary parameters that control the formation and preservation of microbial structures in siliciclastic regimes can facilitate exploration for biological signatures in early sedimentary rocks on Earth.

Through field work and lab work the outcrop will be examined in detail by accurately locating each occurrence with GPS and get the specific measurements. Samples will be collected for future lab work where thin sections will be made to determine if there is any organic material actually preserved and what the internal structure looks like. By completing this work, the goals of this project are to: (1) determine how they formed and contributed to the Horton Bluff strata; (2) determine the specific environment that controlled the growth of these algae mats and stromatolites; and (3) how the growth of algal mats stabilize sediments.

Carbonic fluid inclusions in the Lac Des Iles (Ontario) and Greendale (Nova Scotia) complexes: constraints on mafic pegmatite crystallization and platinum-group element (PGE) mineralization

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[Poster]

The study aims to constrain the conditions of mafic pegmatite formation in the Lac Des Iles (LDI) and Greendale (GC) complexes in order to understand better the processes responsible for the precipitation and redistribution of associated platinum-group elements (PGE). The main ore zone at LDI, the Roby Zone, is hosted within heterolithic gabbro breccia or varitextured gabbro, with high grade PGE mineralization occurring in gabbro pegmatite dikes (up to 37 ppm Pt + Pd + Au). Mafic pegmatites in the Roby Zone consist of primary magnesiohornblende, pyroxene, plagioclase (labradorite-bytownite), and secondary chlorite and actinolite. Disseminated sulfides and oxides, and interstitial quartz are also present. PGE minerals documented at LDI include: braggite, kotulskite, isomertieite, merenskyite, sperrylite, moncheite, stillwaterite, palladoarsenide, and vysotskite. The GC in Nova Scotia consists of porphyritic hornblende gabbro and diorite, with minor gabbroic pegmatite composed of actinolite, plagioclase (oligoclase-andesine), and quartz. PGE mineralization in the GC is sub-economic and contains grains of Pt-Sb (genkinite) hosted in pyrite and pyrrhotite within the pegmatite.

Intercumulus quartz at LDI hosts primary and pseudosecondary assemblages of pure CO_2 inclusions (two phase L + V at room T) and secondary, late aqueous fluid inclusions. The GC quartz hosts primary, pure CH_4 inclusions (two phase L + V at room T) and secondary, late aqueous inclusions. Microthermometric measurements show that the carbonic fluid inclusions in the coarse-grained LDI pegmatitic quartz homogenize one of three ways: (i) to L between 28.5 and 31.1 °C (n = 31); (ii) to V between 27.6 and 30.9 °C (n = 9); or (iii) by supercritical behaviour between 30.9 and 31.2 °C (n = 14). Carbonic fluid inclusions from fine-grained LDI pegmatitic quartz homogenize only to L between 9.9 and 26.4 °C (n = 37). Methane fluid inclusions from the Greendale complex homogenize either to L between -88.2 and -84.9 °C (n = 25), or rarely by supercritical homogenization at -83.9 °C (n = 4). A variety of thermobarometers were used in conjunction with microthermometrically-derived carbonic fluid isochores to obtain P-T conditions of pegmatite formation. Quartz hosting the inclusions at LDI crystallized between ~550 and 630 °C, with P varying between 460 and 1660 bars. Quartz hosting the inclusions at GC crystallized at very similar T between ~510 °C and 550 °C, with P varying between 470 and 1930 bars.

The results indicate that (i) the primary fluid involved in pegmatite formation in both locations was not aqueous but anhydrous carbonic in composition; (ii) CO_2 or CH_4 entrap-

ment at both LDI and GC occurred over a very similar and relatively large range in P consistent with the transition from lithostatic to nearly hydrostatic conditions.

The use of Sr isotopes in apatite as a tracer of iron ore apatite (IOA) mineralization processes

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The samples selected for this thesis project are from the Adirondack Mountains in New York State and are part of a larger project involving apatite [$Ca_5(PO_4)_3(OH, F, Cl)$] trace elements and geochronology currently being undertaken by Dr. John Hanchar and his students. The main objective of this project is to explore the utility of Sr isotopes ($^{87}Sr/^{86}Sr$) in apatite, which contains Sr as a trace element, as a isotopic tracer of the geochemical processes which led to the production of so-called IOA-type (iron oxide, apatite) mineral deposits in the Adirondacks. A secondary objective is to use Sr isotopes to acquire a better understanding of the temporal and spatial relationship(s) between the respective K- and Na-metasomatically altered host rocks and the IOA ores. Sr isotopes in apatite have successfully been used to "fingerprint" Devonian ash beds in the Appalachians in the United States and to do stratigraphic correlations throughout the Appalachian Basin from New York to Tennessee.

The analytical technique used in this thesis is TIMS (thermal ionization mass spectrometry). Measurements will be taken from individual apatite mineral grains from six IOA ore samples and their respective host rocks, and will be analyzed for the isotopic ratios of Sr. The measured Sr isotopic ratios and the interpretation of those results will allow us, along with other apatite trace element and U-Pb data previously acquired in the area and from some of the same samples, to better understand the development of IOA mineralization in the Adirondacks and hopefully provide insights on IOA mineralization in general. The understanding of the Sr isotopes in apatite in this area will allow further understanding of Sr as a tracer element and will progress the understanding of ore mineralization in IOA-type mineral deposits.

A petrological study of carbonatite intrusions from the Lofdal Farm area, Namibia

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[Poster]

Unusually high total REE and high ratios of HREE to LREE ratios have been discovered in a carbonatite dyke swarm in the Lofdal Farm area near the town of Khorixas in Damaraland, Namibia. Most of the carbonatite dykes range in width from 0.5 cm to 5 m but can reach widths of 25 m and extend over several kilometres. Carbonatite also occurs in plugs with diameters up to several hundred meters, although these bodies appear to lack elevated REE and REE ratios. The carbonatite dykes and plugs occur in association with syenite and nepheline syenite intrusions that combined form an alkaline intrusive complex in an area of over 125 km², of which Etruscan Resources Inc. has prospected 25 km². The complex is hosted by 1.7 Ga metasedimentary rocks, including gneiss and schist, called the Huab Basement Complex.

For this study, Etruscan Resources Inc. provided 18 carbonatite samples, representing 6 of the dykes and 2 of the plugs, as well as the host rocks. Etruscan Resources Inc. also provided a database of REE and some other trace element data for 1400 samples from the dykes and plugs. The objectives of this study are: (i) to determine the petrological and chemical characteristics of the suite of carbonatite samples, including a comparison of the dykes and plugs; (ii) to use the geochemical database to investigate chemical trends and spatial variations in rare-earth elements in the study area; and (iii) to try to gain a better understanding of the origin of this carbonatite suite. Previous work is limited but SEM/BSE analyses of four of the dykes showed a varying abundance of two REE minerals, bastnäsite ($(Ce, La)(Co_3)F$) and sychysite ($Ca, Ce(CO_3)2F$). The abundance of these two minerals varied from minor to ~20–25%. Besides these two REE minerals, the REE-bearing silicate mineral allanite was observed in one of the samples. As expected in carbonatite, minerals such as apatite, fluorite and calcite are abundant in the samples. Xenotime, an accessory mineral containing yttrium, also was identified in previous studies. This mineral had overgrown and/or replaced zircon in the carbonatite that had been used by previous researchers to determine the approximate age of the dykes (~765 ± 15 Ma).

Onshore-offshore correlation of the transform fault zone separating the Cyprus and Hellenic arcs in the eastern Mediterranean Sea

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The Rhodes Basin is an active depocentre located in the eastern Mediterranean Sea between the countries of Greece and Turkey. It is bound to the north by the Anatolian continental margin, to the south by the Mediterranean ridge, to the west by the Hellenic arc and to the east by the Anaximander Mountains. This area consists of very complicated geology, at the junction of two arcs. The Hellenic Arc to the west lies above the actively subducting African plate as it moves northwards. The Cyprus Arc to the east has now stopped subducting and is transitioning to continental collision. The two arcs are offset along a north-northeast-trending transform fault zone.

The Rhodes Basin lies along the transform but is anomalously deep due to rapid subsidence in the Pliocene-Quaternary. In addition, it contains a northeast-southwest thrust system that has been extensively mapped in seismic sections. In southwest Turkey, an area of extensive faulting known as the Fethiye-Burdur Fault Zone also trends northeast-southwest. This fault zone reaches the coastline and is thought to run into the Rhodes Basin. The two fault zones are approximately collinear and from extrapolation to the southwest, they appear to form part of the transform fault zone that separates the Cyprus and Hellenic arcs.

Multi-channel seismic reflection data were collected in 2007 in an attempt to further map the sea floor of the Rhodes Basin and areas to the east. This seismic survey included 200 km of seismic lines running parallel to the Turkish coastline to fill the gap between land geology and previous seismic mapping of the Rhodes Basin. The purpose of this thesis is to process this seismic data and interpret the structural geology of the area in an attempt to link the Fethiye-Burdur Fault Zone with the faulting in the sea floor of the Rhodes Basin.

Pliocene exhumation of the Trumsing La area (Eastern Himalaya, Kingdom of Bhutan) as documented by apatite (U-Th-Sm)/He thermochronology

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The ongoing convergence between India and Eurasia since continent-continent collision ~55 Ma ago has formed the Himalayan orogen, the highest mountain range on Earth. Remarkably continuous tectonostratigraphic units and structures along the strike characterize its 2000 km-long range front. The topographic uplift of the range has induced perturbations of atmospheric circulations patterns sometime between ~20–35 Ma and led to the establishment of the Indian Summer Monsoon (ISM) along the southern flank of the Himalaya. The monsoon is responsible for about 80% of the annual rainfall along the range front and results from the condensation of wet air derived from the Bay of Bengal to the South and travelling northward before being blocked by the Himalayan Mountains. Consequently, strong interactions between tectonic and climatic processes have likely conditioned the exhumational and landscape evolution of the range in the Late Tertiary. Furthermore, the only raised topography outboard the Himalayan range front, the Shillong plateau, is located south of Bhutan on the ISM trajectory and was uplifted in the Pliocene. The Shillong plateau concentrates 30–40% on monsoonal rainfall along its southern slope and consequently central and eastern Bhutan receives about half of the rainfall as the Sikkim Himalaya situated further west. The object of this study is to quantify Late Tertiary potential changes of exhumation rate in the Trumsing La area (central Bhutan) located in the rain shadow of the Shillong plateau. Four bedrock samples collected along a vertical profile will be dated using (U-Th-Sm)/He thermochronology on apatite crystals (AHe). The effective closure temperature of this thermochronometric system is about 70 °C and will help to derive exhumation rates of the upper 1–2 km of the crust. Published apatite fission-track results, a method providing information on the exhumation of deeper crustal levels (closure temperature is 120 °C), obtained from the same samples yielded an exhumation rate of 1.6 ± 0.6 mm/year in the Late Miocene. We anticipate obtaining Pliocene AHe ages with exhumation rates that may either decrease or increase during this period of time. A decrease in exhumation rates could be attributed either to (i) reduced erosion due to the rain shadow effect induced by the orographic barrier or to (ii) partitioning of the India-Eurasia horizontal convergence into the Shillong plateau that would decrease rock uplift rates along the southern Himalayan front in Bhutan. Conversely, in case of an increase of Pliocene exhumation rates the effects of the uplift of the Plateau may have being overshadowed by more powerful climactic and erosional effects from the documented onset of glaciations in the late Pliocene. Other explanations include renewed tectonic activity in the orogenic wedge, although as of yet, this is undocumented.

Lateral permeability differences in the Elgol Sandstone Formation

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[Poster]

There is significant variation in permeability in the Elgol Sandstone from the Middle Jurassic, an onshore analog of some North Sea reservoirs. The purpose of this thesis is to determine the factors influencing permeability variability. Initial data suggests there is an increase in the proportion of clay, associated with evolution into a lagoonal system. Reported permeabilities range between less than 0.001 millidarcys (mD) to greater than 300 mD. In order to investigate this problem, thin sections obtained from outcrops will be analyzed in order to correlate these thin section descriptions with porosity, permeability and petrophysical data. To determine depositional environments, detailed descriptions will be published and integrated with unpublished log data. The final goal will be to produce a thorough reservoir description incorporating conclusions based on the applications mentioned.

Permeability variabilities will be investigated by petrographic analysis. Samples selected from two locations within the reservoir, were based on corresponding porosity and permeability data. Thin sections will be made from outcrop samples and impregnated with dye resin. This will cause the interconnected porosity to become visible upon analysis using

a petrographic microscope. Depositional environments within the reservoir will be confirmed by correlating petrophysical data and sedimentary structures seen in the outcrop.

Fluid inclusion evidence for an epithermal-porphyry link at the Mount Milligan porphyry Cu-Au system, Quesnel Terrane, British Columbia, Canada

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Based on detailed field studies, genetic links have been made between high sulfidation epithermal Au and porphyry Cu-Au systems but a connection between low sulfidation epithermal and porphyry systems is less clear, owing partly to the lack of preservation of fluid inclusions in the transitional environment between these two deposit styles. Recent studies have demonstrated that epithermal mineralization may be precipitated by the cooled, aqueous vapour phase that is produced by boiling of metal-rich intermediate density fluids in the porphyry environment.

At the Mount Milligan porphyry system of central British Columbia, Canada, mineralized andesitic and trachytic volcanic rocks occurring distally to the main Cu-Au porphyry zones contain abundant alteration veins that form narrow stockworks. The veins are comprised of quartz ± carbonate ± pyrite ± chlorite ± tourmaline and are younger than the porphyry stage mineralization based on cross-cutting relations. Bulk analyses of mineralized rock have yielded two distinct trends of mineralization.

Primary and pseudosecondary fluid inclusions in massive quartz and freestanding quartz crystals lining the walls of the alteration veins occurring in the volcanic host rocks to the porphyry system. The inclusions contain a two-phase aqueous fluid (L + V) at room temperature.

Microthermometric analysis of 60 inclusions from 6 different veins indicate fluid salinities ranging from 4.2–14.6 NaCl wt% eq (n = 60) and homogenization temperatures (to liquid) between 117 and 270 °C. Individual assemblages representing single veins show much narrower ranges in salinity and homogenization temperature. The homogenization temperatures in individual veins are consistent with the temperatures of chlorite crystallization in the veins determined by Al-in-chlorite compositional thermometry (by electron microprobe). Analyses of single inclusions from the veins by LA-ICPMS (ETH Zurich) show that the low to moderate salinity fluids contained extremely high dissolved concentrations of B, As, and Sb. Ratios of As/Sb in the inclusions overlap closely with bulk ratios in the associated epithermal mineralization in the volcanic rocks. However, the inclusions contain unusually low concentrations of metals expected to be mobile as chloride complexes in hydrothermal solutions (e.g., Pb, Zn, Fe, and Ag) compared to saline fluids documented in other Cu-Au porphyry systems. The inclusions may represent a condensed vapour phase resulting from early boiling since boiling is a viable mechanism to fractionate chloride-complexed metals (into brine) from bisulfide-complexed metals (into vapour).

Fluid inclusion assemblages in alteration veins at the Mount Milligan porphyry system preserve evidence of the transport of a low- to moderate-salinity, aqueous fluid with chemical characteristics consistent with a contracted magmatic vapour phase that may have mixed at a shallow level with meteoric water causing the precipitation of pyrite-rich low sulfidation epithermal veins. Considering the distinct metal concentrations in the fluid inclusions, the tourmaline and anomalous As and Sb contents in bulk rocks, or elevated B, As, and Sb in fluid inclusions in apparently barren alteration veins in prospective volcanic terranes in the Canadian Cordillera may indicate proximity to alkalic porphyry-style mineralization or associated epithermal systems.

Melt inclusions in the ~2.68–2.69 Ga porphyry intrusions, Timmins and Hemlo, Ontario: constraints on magmatism in Archean greenstone belts containing giant mesothermal gold deposits

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[Poster]

Melt inclusions are primary bubbles of magma that attach to surface imperfections on growing crystals. The mineral host grows around the bubble forming the melt inclusion. Some melt inclusions are recrystallized as a result of either slow cooling of the melt after entrapment or due to post-entrapment modifications. For old melt inclusions hosted in rocks that have undergone significant modification via metamorphism and hydrothermal alteration, post-entrapment modifications can involve changes in the bulk chemistry of the melt inclusions rendering them useless for modeling petrogenetic processes. Rarely are melt inclusions adequately preserved in ancient igneous rocks.

In this study, primary melt inclusions were analyzed from the Paymaster porphyry in Timmins, Ontario, where inclusions are well preserved within growth zones in quartz phenocrysts and do not show evidence of post-entrapment modifications despite recrystallization. The presence of inclusions in the Crown Lake (Timmins), Pearl Lake (Timmins), and Moose Lake (Hemlo) porphyries is yet to be confirmed. The Timmins and Hemlo districts contain substantial gold deposits that are not related to the intrusion of the porphyries or magmatic-hydrothermal processes related to porphyry crystallization. However, their chemical characteristics may reflect the source region that ultimately sourced both the porphyry rocks and the spatially related gold deposits in both districts. The deposits in both cases occur in greenstone belts, charac-

terized by collages of oceanic plateaus, oceanic island arcs, and trench turbidites, which were tectonically assembled in a large subduction–accretion complex.

Major and trace element analyses of the melt inclusions from the Paymaster porphyry at Timmins are being compared to melt inclusions analyzed in younger granites and porphyries within modern arc environments. The Paymaster melt inclusions have bulk chemistry consistent with a calc-alkaline to high K calc-alkaline volcanic arc granite. Primitive mantle-normalized abundance patterns show that the melts are enriched in LILE, HFSE, and LREE relative to primitive mantle whereas HREE and the transition metals show comparable concentrations or are depleted relative to primitive mantle. Notable anomalies that are being investigated are minor depletions in Nb and Sr, and significant depletions in Y, the HREE, Sc, and Ni. However, enrichments and depletions are not extreme, suggesting that the intrusive rocks are not highly evolved (or fractionated). The bulk chemistry of the melts is being assessed to determine if this method of analysis is applicable for the study of very old granites.

Characterization of shock metamorphosed $ZrSiO_4$ in the Chesapeake Bay impact crater

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The 80–95 km diameter Chesapeake Bay impact structure (CBIS) formed in the late Eocene on the continental margin of what is now Virginia, U.S.A. The marine impact involved a target with a water depth of 0–340 m above 400–1500 m of unconsolidated siliciclastic sediments overlying a Neoproterozoic crystalline basement. A 1.76 km deep scientific drilling in the annular moat of the crater, ~9 km from its centre recovered a unique section of well preserved impactites, including rare high pressure mineral polymorphs.

High-pressure polymorphs generated in impact events as a result of the interaction of materials with the shock wave can provide constraints for shock pressures and post-shock temperatures. Zircon has the potential to be especially useful because it is refractory, and can be used for dating. Its high-pressure polymorph reidite was synthesized and found naturally in the distal ejecta from the CBIS, and subsequently in the Ries crater in Germany. The zircon-reidite transition has been studied with shock experiments, but Chesapeake Bay offers the rare opportunity to study its natural occurrence.

A detailed shock petrographic study on a polymict impact breccia sample from a depth of 1481.37 m in the Eyreville drilling was completed. Each of the clasts >1 mm in size was assigned a shock stage based on indicative shock pressure features in its associated rock-forming minerals. Some 69% indicate shock stage IA (~10–20 GPa), while 28% are unshocked and 3% were not determined.

Twenty-seven $ZrSiO_4$ grains were identified and Raman spectroscopy revealed the occurrence of one zoned zircon-reidite grain among them. This grain is associated with an aphanitic <1 mm-size clast with a partly melted (shock stage III-IV, >45 GPa) appearance. In the zircon-reidite grain, electron microprobe data and Raman spectroscopy indicate an outer domain that is disordered and non-stoichiometric. This outer domain has a texture of radiating acicular crystals (0.5–2.0 μm long) oriented inward from the outer rim. These "spongy" textures are similar to those seen in zircon crystals that have decomposed to ZrO_2 and SiO_2 components. HfO_2 concentrations in this domain appear mostly uniform, while ZrO_2 and SiO_2 and trace elements exhibit strong concentration excursions.

These observations will be compared with zircon-reidite grains from an additional sample that contains zircon-reidite grains. The textures in these zircon-reidite grains will allow me to further evaluate this recently discovered natural polymorphic transition and how it relates to shock intensity during hypervelocity impact.

Architecture and geometry of a braided channel complex in the Wolfville Formation, Nova Scotia

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The Wolfville Formation outcrops along the shoreline of the Minas Basin of the Bay of Fundy of Nova Scotia. Cambridge Cove contains an exceptionally well preserved outcrop section in 2- and 3-D exposures of the braided channel depositional environment of the Wolfville Formation. These outcrops demonstrate the stratigraphic complexities associated with this environment. The aim of this study is two fold: (1) to investigate heterogeneity of a braided channel complex including fluid migration baffles, interconnectivity between channel bodies, and barriers of fluid flow within stratigraphic packages; and (2) to discern the potential of these outcrops for other early Mesozoic syn-rift and post-rift reservoirs in the subsurface. Geological modeling of the study area is planned using data collected from the outcrop in Cambridge Cove. Using LIDAR, stratigraphic descriptions, ground penetrating radar, and scintillometer and permeameter logs, data will be incorporated into geological modeling software to demonstrate how minor changes in deposition can effect commercial reservoir depletion.

Stratigraphic analysis of the Cheverie Formation type section, Cheverie Nova Scotia

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Early Carboniferous strata of the Horton Group are excellently exposed in the Cheverie shoreline along the Bay of Fundy,

Nova Scotia. The type section of the Tournaisian Cheverie Formation, which disconformably overlies the Horton Bluff Formation, has yet to be formally measured at Cheverie since its identification by Bell in 1913. The author has undergone field work to illustrate the stratigraphic characteristics of the Cheverie Formation, to produce both a generalized stratigraphic column in addition to a series of detailed subsections. Particulars pertaining to lithology, paleoflow, paleobotany, and sedimentary structures have been observed and recorded. The information will provide evidence to support interpretation of the paleoenvironment and sedimentation regimes.

Radon soil gas in Halifax Regional Municipality

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Naturally occurring radon is located in measurable quantities in soil gas across Nova Scotia. All soil types contain variable amounts of uranium, the decay of which produces radon (which has a half-life of 3.8 days) and other radiogenic daughter products. Next to smoking, radon exposure is the leading cause of lung cancer. Several tested buildings within Halifax Regional Municipality (HRM) contained elevated indoor radon gas, and research elsewhere has established a positive correlation between radon soil gas and indoor radon gas concentrations. While the production of radon is an important precondition for its presence in surficial soils, the permeability and rate of transport are important controls on the surface expression of radon. The objective of this study is to identify relationships between the permeability of the soils through which radon passes, the composition of the overlying surficial soils, and the geology of the respective bedrock types within HRM. Over 200 radon soil gas samples from 40 sites were collected and analyzed during the 2009 field season using protocols developed for the North American Soil Geochemical Landscapes Project. Radon soil gas concentrations were determined on site with the RM-2 portable soil radon monitoring system. The study focused on soil developed over the three major bedrock types in HRM: the Cambrian-Ordovician Goldenville and Halifax groups, and granite of the Devonian-Carboniferous South Mountain Batholith. The granite was further subdivided, based on its cooling history, into the primitive monzogranite, the middle stage coarse-grained leucomonzogranite, and the evolved fine-grained leucomonzogranite bodies. All of the soils sampled contained radon soil gas. The average values range from 19.1 kBq/m^3 in metasandstone of the Goldenville Group, to 36.1 kBq/m^3 in the Halifax Group slate, and 44.3 kBq/m^3, 50.2 kBq/m^3, and 51.0 kBq/m^3 respectively for the primitive, middle, and evolved granites. The highest concentrations are associated with the granite, then slate, and the lowest in the metasandstone. The permeability of the surficial soils also plays an important role in the surface expression of radon, as coarser tills tend to have higher permeability relative to clay-rich tills. On-going analysis of the permeability readings with respect to HRM's four major till types (granite, metasandstone, and slate facies of the Beaver River Till, and the Lawrencetown Till) may solidify an important relationship between radon soil gas, and overlying till within HRM. The soil radon potential index (SRP) has been used to correlate the soil gas and permeability readings with the indoor radon potential, and will be applied to data collected this field season. This study should be beneficial in understanding radon soil gas in HRM where over 40% of Nova Scotia's population resides.

Provenance of sedimentary rocks of the Seal Lake Group, central Labrador

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[Poster]

The Seal Lake Group is located in central Labrador and is Mesoproterozoic (ca. 1.25 Ga) in age, and lies close the Grenville Front in the Grenville Province, Labrador. It is comprised of argillaceous and arenaceous sedimentary rocks, basalt flows and intruded by gabbro sills folded into an east-trending syncline. The group is the youngest volcanic-sedimentary succession in the Central Mineral Belt (CMB), which is known to host significant uranium occurrences. Understanding basement cover relationships in the CMB is important to understanding the tectonic history of the belt and the geological setting for uranium mineralization.

This thesis project involves the study of provenance of the sedimentary rocks in a number of the formations of the Seal Lake Group. The study will focus on the Wuchusk Lake Formation that is characterized by arenaceous sedimentary rocks with shale, slate and gabbro sills, and is thought to be in the lower part of the stratigraphy. The main purpose of this study is to determine the source of sediments based on the age distribution of detrital zircons and constrain age of deposition based on the age of the youngest detrital zircon. Most models purpose that the Seal Lake Group has been thrust over rocks of the 1.65 Ga Trans Labrador Batholith (TLB), during the Grenville collision. If this were the case, we would expect a significant population of detrital zircons with ages of 1.65 Ga. If instead the Seal Lake Group overlies basement significantly older or younger than the TLB, we would expect most detrital zircons to have ages other than 1.65 Ga.

During the months of July and August 2009 ten samples of the Wuchusk Lake Formation were collected. The field study concentrated on the area covered by the NTS map areas 13K/5 and 6. Thin sections from the samples will be prepared for petrographic study. Detrital zircons will be separated from three to four samples for dating purposes. These samples will be dis-

aggregated and put through heavy liquid separation to concentrate the zircons. The zircons will then be picked out and mounted, followed by imaging them on the SEM and dating by LA-ICPMS using the U-Pb method.

Evidence of fossil horseshoe crabs from the Joggins Fossil Cliffs – paleoichnology and paleonvironmental implications

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The Joggins Fossil Cliffs were inscribed as a UNESCO World Heritage Site in July 2008 and represent the world's finest example of a Coal Age ecosystem. This 15 km-long coastal cliff section displays multiple horizons of fossilized Carboniferous (310–325 Ma) forests. The Joggins fossil cliffs have yielded more than 200 different species of plants and animals, including the fossil record's earliest known amniote (*Hylonomous lyelli*) and the earliest land snail (*Dendropupa vetusa*),which are found entombed within the erect fossil lycopsid trees. Body fossils of terrestrial biota are not the only evidence of life preserved in Joggins; a diverse trace fossil assemblage of trackways from both vertebrate and invertebrate life is also found at this site. The trace fossil record at Joggins is as impressive as the creatures themselves and adds an important piece to the puzzle of life during the Coal Age. Although sometimes regarded as less important than body fossils, trace fossils provide important information about the locomotion and behaviour of prehistoric fauna and in some cases are the only evidence of a creature's existence. The existence of horseshoe crab activity within the Joggins Formation is well known; however, it remains a poorly studied part of the Coal Age ecosystem.

We present here an overview of the paleoichnology of Carboniferous limulids from the Joggins Fossil Cliffs and their paleoenviromental implications of a possible coastal connection. Unquestionable undertracks of these limulids have been discovered, examined, and identified as the morphological equivalent to small-scale specimens of the ichnogenus *Diplichnites*. The ichnogenus *Diplichnites* is currently assigned to myriapods, including the colossal two metre long, half metre wide *Arthropleura*. The similarity between the two ichnofossils poses problems for the taxonomy of an already confusing ichnotaxa. On the other hand, it also explains the close proximity of both *Koupichnium* (limulid) and small-scale *Diplichnites* (myriapod) trackways within the same paleoenvironment, which is an unlikely association. This issue is reviewed and possible solutions proposed.

Alteration of the Neoproterozoic Morar Brook Formation in the aureole of the Georgeville Pluton, Antigonish Highlands, Nova Scotia

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In the Antigonish Highlands of Nova Scotia, extensive metasomatic alteration in the aureole of the Neoproterozoic post-tectonic Georgeville Granite is well exposed along the Northumberland Strait. The Georgeville Granite, dated at 579.8 ± 2.2 Ma, is an A-type granite that intruded low grade metasedimentary rocks of the Morar Brook Formation of the Georgeville Group, during the waning stages of regional Andean-style arc magmatism within the Avalon Composite Terrane. The depositional age of the Morar Brook Formation is constrained between ca. 612 Ma and 607 Ma by U-Pb age data obtained from the coeval Livingstone Cove Formation and by the syn- to late-kinematic 607 Ma plutons to the southwest of the study area.

Outside the contact aureole, the Morar Brook Formation is composed of turbiditic mudstone and siltstone with occasional thin interbeds of chert and limestone. The mudstone is fine grained and iron-rich, with quartz, albite, and minor rutile in a matrix of clay minerals, sericite, chlorite, and minor biotite. Elongate pyrite crystals are visible in the darker laminae. The siltstone is coarser grained and contains variable amounts of lithic fragments, commonly slate or epidote-bearing volcanic rocks. Intrusive contacts between the Morar Brook Formation and the Georgeville Granite are steep, sharply defined, and, together with the lower greenschist-facies metamorphism of the host rock, indicate epizonal emplacement of the pluton. The aureole is characterized by hornfelsic spotting, a high degree of silicification, and color changes in the host rock, as well as local growth of skarn minerals such as grossular. Taken together, these features indicate extensive metasomatism coeval with intrusion of the Georgeville Granite.

In comparison to the unaltered host rock, aureole rocks exhibit diminishing amounts of albite, rutile, and chlorite with proximity to the contact. There is a corresponding increase of relatively large allotriomorphic quartz crystals, pyrite, and small books of mica within a fine-grained sericitic matrix. Thin section observations also reveal narrow quartz veins cutting across pre-existing fabrics. Major and trace element analyses indicate that, compared to the unaltered host rock, the aureole rocks are moderately enriched in Si, and extensively enriched in Zn, Pb, Ba and in light rare earth elements (LREE, e.g., La, Ce, and Nd). The mobility of LREE is enhanced in chloride-bearing hydrothermal fluids. The Georgeville Granite itself is anomalously depleted in LREE, suggesting transport of LREE from the pluton into the host rock during hydrothermal alteration.

Platinum-group element distribution in the Mt. Milligan alkalic Cu-Au porphyry deposit, Quesnel Terrane, British Columbia

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[Poster]

Elevated concentrations of platinum-group elements (PGE), particularly the elements palladium and platinum, have been recognized within alkalic Cu-Au porphyry systems in the Cordillera of British Columbia. Currently, processes of PGE mineralization in porphyry systems are poorly understood. The purpose of this project is to investigate the occurrence of PGE in an alkalic porphyry system in order to improve exploration models for alkalic porphyry PGE deposits. The Mt. Milligan deposit lies 155 km northwest of Prince George, B.C., within the Quesnel Terrane of the Canadian Cordillera. Locally, late Triassic to early Jurassic volcanic rocks overlie and are in places interlayered with Late Triassic sedimentary rocks. These rocks, known as the Talka Group, are intruded by early Jurassic monzonite to monzodiorite stocks and dikes which are spatially and genetically related to the Cu-Au porphyry deposit. 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 this investigation, PGE bulk rock data collected from all varieties of porphyry mineralization will be assessed for correlations between PGE and an array of possible pathfinder elements (Co, Ni, Sb, As, etc.). A petrographic study will be conducted to look for further correlations between PGE and mineralization/alteration assemblages. A 3-D model of the borehole data using new PGE data and existing data from the Terrane Metals Corp. borehole database will be generated using RockWorks© to demonstrate the spatial distribution of PGE at Mt. Milligan, augmented with the petrographic and bulk rock data.

Inverted metamorphic gradient across the Lesser Himalayan Sequence in eastern Bhutan: Raman spectroscopy on carbonaceous material

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[Poster]

One of the confusing features of the Himalayan Orogen is the inverted metamorphic temperature gradient. Along the orogen the dominant foliation, the lithotectonic units, and the main structures separating them dip dominantly to the north. Therefore, from south to north, one advances into progressively higher structural levels. However, from lowest structural levels of the Lesser Himalayan sequence (LHS) in the south, to the top of the Greater Himalayan sequence (GHS) in the north, the peak metamorphic temperatures increase rather than opposite. In the LHS, this consists dominantly of slates and quartzites, the metamorphic grade ranges from lower to upper greenschist facies conditions. Index metamorphic minerals show this but quantitative thermobarometry is lacking and difficult to do because of absence of suitable mineral assemblages

In this study we apply Raman spectroscopy on carbonaceous material from samples of slates collected from the LHS in the eastern Bhutan. The 18 samples are evenly distributed between the Main Boundary thrust (MBT) at the base, and the Main Central thrust (MCT) at the top. The preliminary results indicate a progressive increase of temperature from south to north. In addition, we observe two jumps in temperature. One in the middle of the LHS is probably due to a younger thrust within the LHS, the Ramgarh thrust. Second temperature jump is across the MCT separating the LHS and the GHS. The latter jump is determined by combining the Raman spectroscopy data and the published data based on thermobarometry.

These are the first quantitative temperature data for the LHS in the eastern Himalaya; only one equivalent study exists in the central Nepal. In the forthcoming study the temperature gradient across the LHS will be calculated, and the throw along the Ramgarh thrust and MCT estimated. These data combined will be compared to the field data from Nepal and to the predictions of numerical models and will thus help elucidate the most likely mechanism of the formation of the inverted metamorphic gradient of the Himalaya.