Geological Association of Canada Newfoundland and Labrador Section

ABSTRACTS

2016 Spring Technical Meeting

St. John's, Newfoundland and Labrador

The Spring Technical Meeting was held on February 22 and 23, 2016, in the depths of the Newfoundland winter in the Johnson GEO CENTRE on scenic Signal Hill in St. John's, Newfoundland and Labrador. This year the meeting did not feature a special session but instead focused on general sessions that included oral presentations and posters from students and professionals on an eclectic range of topics, as is normally the case at these meetings.

On Tuesday evening the "Public Lecture" series, sponsored by the Canadian Institute of Mining (CIM) and Geological Association of Canada - Newfoundland and Labrador Section (GAC NL), was presented by the CIM Distinguished Lecturer Wilson Pascheto, with a talk entitled "Materials Technology in the Mining Industry: Opportunities and Challenges."

As always, this meeting was organized by volunteer efforts, and would not have been possible without the time and energy of the executive and other members of the Newfoundland and Labrador Section of the Geological Association of Canada. We are also indebted to our partners in this venture, particularly the Alexander Murray Geology Club, the Johnson GEO CENTRE and the Newfoundland and Labrador Department of Natural Resources, Geological Association of Canada, and the Department of Earth Sciences, Memorial University of Newfoundland. We are equally pleased to see the abstracts published in Atlantic Geology. Our thanks are extended to all of the speakers and the editorial staff of the journal.

James Conliffe
Technical Program Chair
GAC Newfoundland and Labrador Section

ATLANTIC GEOLOGY 52, 103-117 (2016) *doi: 10.4138/atlgeol.2016.005*
0843-5561|16|00103-117 $3.25|0

A mineralogical, geochemical, and geochronological study of Marathon Gold Corporation's Valentine Lake Gold Camp, central Dunnage Zone, Newfoundland, Canada

Monica A. Barrington[1], Graham D. Layne[1], Greg R. Dunning[1] and Sherry Dunsworth[2]

1. Department of Earth Sciences, Memorial University of Newfoundland, 300 Prince Philip Drive, St. John's, Newfoundland and Labrador A1B 3X5, Canada ¶
2. Marathon Gold Corporation, Toronto, Ontario M5H 2T7, Canada

Marathon Gold Corporation's Valentine Lake Gold Camp is located in the Exploits Subzone of the Dunnage Terrane of the Newfoundland Appalachians, approximately 20 km east of the main Iapetan suture - the Red Indian Line (RIL). The property contains numerous auriferous zones within a northeast-southwest trending mineralized corridor. Epigenetic gold mineralization is largely hosted within Neoproterozoic (ca. 563 Ma) trondhjemite, but also within quartz monzonite and rhyolite porphyry that are geochemically distinct from the trondhjemite and likely represent a separate arc magmatic event. Gold mineralization occurs primarily within quartz–tourmaline–pyrite ± apatite (QTP) veins, vein stockworks, and adjacent selvedges observed throughout the camp. Minor gold mineralization also occurs within vein networks and late en echelon tension gashes containing varying amounts of carbonate, quartz, tourmaline, pyrite, muscovite, chlorite and rutile, which dominate the Sprite and Victory Gold Deposits – as well as in base-metal-rich quartz veins present in parts of the J. Frank Zone. All vein networks are close to a 30 km long regionally extensive, brittle-ductile shear zone, which defines the eastern contact of the Victoria Lake Intrusive Suite (VLIS) with a Silurian fault-scarp sequence, the Rogerson Lake Conglomerate (RLC). A suite of heterogeneously deformed basaltic and gabbroic dykes, variably transposed toward the penetrative regional foliation, also traverse the property. Detailed ore petrography has identified pre-native gold precious-metal–telluride and post-native gold base-metal–telluride assemblages in all QTP vein networks. Locally, a base-metal assemblage, associated with silicification and pyrite recrystallization, may be consanguineous with a second generation of native gold mineralization. Preliminary trace element microanalyses of native gold also strongly indicate the presence of multiple gold generations, as shown by Te, Ag, Pb, and Bi contents. Sulphur isotopic microanalyses of pyrite collected from each type of silicate vein assemblage display consistent changes in isotopic composition from a corroded core to a recrystallized rim. Together, the sulphur isotopic analyses of pyrite, chalcopyrite, and galena cover a range of negative $\delta^{34}S$ values, likely indicative of a reduced sedimentary sulphur source. Overall, ore petrography, U–Pb geochronology, trace-element analysis of native gold, and sulphur isotopic microanalysis of pyrite are being combined to constrain the timing and nature of gold mineralization at Valentine Lake, and to recognize any correlation between mineralization and distinct events during the Salinic and/or Acadian orogenies.

Significant new Cambrian (Dyeran to Topazan) trilobite faunas of the Labrador Group, Gros Morne National Park, western Newfoundland, Canada

W. Doug Boyce and Ian Knight

Geological Survey, Newfoundland and Labrador Department of Natural Resources, PO Box 8700, St. John's, Newfoundland and Labrador A1B 4J6, Canada

Gros Morne National Park is the newest frontier of Cambrian litho- and biostratigraphic studies in western Newfoundland. Long neglected since the early 20th century investigations of late Early Cambrian faunas by Schuchert, Dunbar, Walcott, Resser and Howell, the Forteau and Hawke Bay formations were recently studied along road-side outcrops and the shoreline of East Arm, Bonne Bay, and have yielded a significant number of new trilobite faunas. The succession spans the late Dyeran to early Topazan stages of the Cambrian of Laurentian North America, and the contact of the Forteau and Hawke Bay formations lies within the latest Early Cambrian (late Dyeran) *Bonnia — Olenellus* Biozone. Olenellid trilobites in the Forteau and basal Hawke Bay formations also correlate with those of the lower *Arcuolenellus arcuatus* to *Nephrolenellus multinodus* biozones of the Mojave Desert (California). Faunas higher in the Hawke Bay Formation are characteristic of the Middle Cambrian, middle Delamaran *Mexicella mexicana* to lowest Topazan *Ehmaniella* biozones. The diverse late Dyeran olenellid trilobites are characteristic of open marine deeper water basin settings, whereas the later low diversity faunas of the higher Hawke Bay Formation reflect shifting shallow water shoreline settings.

The Forteau Formation has yielded the following: *Bonnia columbensis* Resser, *B. senecta* (Billings), *Olenellus clarki* (Resser), *O. thompsoni* (Hall), *O. transitans* (Walcott), *Wanneria walcottana* (Wanner), as well as one undetermined species of *Elliptocephala*, and at least three undetermined *Olenellus* species. *Bonnia columbensis* Resser is known from the Mount Whyte Formation (British Columbia), the Pioche Formation (east–central Nevada), and the upper *Bonnia — Olenellus* Biozone in the Illtyd Formation (Wernecke Mountains, Yukon Terriotory). *Olenellus clarki* provides a faunal link with the late Dyeran zonation of the Mojave Desert, where the taxon ranges from the lower *Arcuolenellus arcuatus* Biozone to the uppermost *Bristolia insolens* Biozone (to possibly the lowermost *Bolbolenellus euryparia* Biozone). *Olenellus thompsoni* is known from the Parker (Slate) Formation (Vermont), and *O. transitans* and *Wanneria walcottana* both occur in the Kinzers Formation (Pennsylvania).

Mesonacis bonnensis (Resser and Howell) and *M. fremonti* (Walcott) occur low in the Hawke Bay Formation; both also occur in the basal shale of the Hawke Bay Formation, on the south shore of Hawkes Bay. *Mesonacis fremonti* is regionally widespread, recognized from the Latham Shale and lower Chambless Limestone (Marble and Providence mountains, Mojave Desert), the Carrara Formation (Death Valley National Park, southwestern Nevada and adjacent California), and the Pioche Formation; it ranges from the middle of the *Arcuolenellus arcuatus* Biozone to the top of the *Nephrolenellus multinodus* Biozone. It therefore indicates a latest Dyeran age for the lowermost Hawke Bay Formation.

Stratigraphically higher Hawke Bay Formation horizons have yielded: *Mexicella grandoculus* Palmer, *M. mexicana* Lochman, *Glossopleura lodensis* and an undetermined ptychopariid, *Spencella*? sp. nov., and *Olenoides serratus* (Rominger). *Mexicella grandoculus* occurs in the Middle Cambrian (Delamaran Stage) *Mexicella mexicana* Biozone in the Carrara Formation. *Mexicella mexicana* is known from the Los Arrojos Formation (northwest Mexico), the Carrara Formation, the Pioche Formation, and the La Laja Formation (Precordillera, western Argentina). *Glossopleura lodensis* — a characteristic taxon of the *Glossopleura walcotti* Biozone (the uppermost biozone of the Delamaran Stage) — is known from the Pioche Formation, the Carrara Formation, and the La Laja Formation. In the southern Canadian Rocky Mountains, *Olenoides serratus* (Rominger) ranges from the *Pagetia bootes* to *Pagetia walcotti* subzones of the *Bathyuriscus — Ptychoparella* Biozone in the Burgess Shale Formation, correlative with the basal Topazan *Ehmaniella* Biozone.

Differentiating source geochemical contributions in glacial tills in local (deposit-scale) surveys

Heather Campbell

Geological Survey of Newfoundland and Labrador, Department of Natural Resources, P.O. Box 8700, St. John's, Newfoundland and Labrador A1B 4J6, Canada

Geochemical signatures in local (deposit) scale glacial till surveys can be better understood by first examining possible bedrock sources for elemental enrichment and accounting for pre-glacial weathering (mechanical and chemical) of bedrock. Factors such as bedrock competency and tectonic deformation determine which source rocks are weathered, and thus the abundance of certain elements in the clay and silt (<0.063 mm) fraction of till. Pre-glacial chemical concentration can occur when meteoritic processes interact with minerals, resulting in the preferential dissolution and precipitation of elements.

Glacial dispersal patterns from the Mount Fronsac North Pb-Zn-Ag deposit in northern New Brunswick were studied in terms of bedrock environment, pre-glacial bedrock alteration and subsequent glacial transport history. The clay and silt fraction of 236 glacial till samples collected over the deposit were analyzed for 53 elements, using aqua regia digestion and ICP-MS/OES analysis. Results from a 2 km, 25 m-spaced self-potential (SP) transect are also analyzed in the context of the geochemical element profiles. The results of a select suite of elements in the till were compared to geochemical concentrations in unweathered and weathered (mineralized gossan) bedrock, using tin (Sn) as an immobile element, to determine the source and path of element migration from bedrock to till. Elemental abundances were examined with respect to their inter-correlation, bedrock topography and the mechanical characteristics of the underlying bedrock units.

Enrichment of Pb, Bi, Hg, Cu, As, Mo, and Sb was observed in gossan relative to bedrock whereas enrichment of Co, Zn, Sr, Au, Cd, Ba, Hg, and Se was observed in till relative both to bedrock and to mineralized gossan. Dispersal patterns indicate two main glacial transport directions, with possible preconcentration of material at the base of a topographic low directly north of the outcropping deposit by colluvial (slopefall) processes. Enrichment of Cu, As, Mo, Sb, Pb, Bi, and Hg in the gossan is believed to be due to the chemical nature of the gossan, with anionic complexes adhering to mineralogically immature goethite, and formation of sulfosalts under low pH conditions. Additions of Co, Ba, and some Au are thought to originate from surrounding units, i.e., not from the mineralized zone, based on the dispersal patterns and the nature of the bedrock units. Anomalous element dispersal shows an offset pattern reflecting an earlier E to W large-scale glacial transport event, followed by a smaller SW to NE local glacial event. Dispersal patterns of Zn, Cd, and Hg in till are thought to be caused by initial alteration processes, and further enhanced by meteoritic and electrochemical processes in areas of increased porosity. Results of the SP survey support this interpretation as the profile appears as a classic double-peaked anomaly occurring on the boundaries of the deposit, with a trough above it. Thus, elements such as Zn, Cd, and Hg maybe more effective in delineating the extent of this type of deposit in situ, as the distribution of higher concentrations of these elements seems to be independent of large-scale mechanical processes and may reflect the electrochemical interaction of the mineralized body with the surrounding environment.

Predictive mapping using self-organizing maps, Baie Verte Peninsula, Newfoundland, Canada: a case study

Angela Carter-McAuslan
and Colin G. Farquharson

Department of Earth Sciences, Memorial University of Newfoundland, 300 Prince Philip Drive, St. John's, Newfoundland and Labrador, A1B 3X5, Canada

The extraction of usable information from large multi-dimensional geoscience datasets has become a crucial issue as more and more data of different types are collected over the same area. Ideally, interpretation of these large datasets should take into account all types of data during interpretation in order to produce the most coherent interpretation. Visualization and interpretation methods commonly used to interpret geophysical data often rely on visual inspection by the interpreter. This is problematic when the number of datatypes exceeds three as the human brain has difficulty visualizing relationships at high dimensions. As such, new methods for discovering patterns in multi-dimensional geophysical datasets need to be investigated. Self-organizing maps (SOMs) are a class of unsupervised artificial neural network algorithm which are be used to cluster multi-dimensional data while preserving the overall topology of the original dataset. In this project SOMs are employed to cluster multi-dimensional geophysical data. As the geophysical signature of an area is strongly influenced by the local geology these clusters could be used to produced maps showing the similarity between data points which reflects the geology. The Baie Verte Peninsula is a region of complex geology associated with the Taconic orogeny. The area is host to base-metal and gold deposits both historically mined and currently in production. The peninsula has good regional geophysical data coverage (magnetics, gravity, radiometrics, and VLF) presenting a good case study for the application of SOMs to the production of predictive geological maps. Good regional geological maps exist of the Baie Verte Peninsula allowing the predictive maps produced through the SOM process to be evaluated both through visual inspection and quantitatively using a number of measures of clustering quality.

Structural analysis of the Howley Basin, western Newfoundland, Canada

Linden Ernst, Tom Calon, and Alison Leitch

Department of Earth Sciences, Memorial University of Newfoundland, 300 Prince Philip Drive, St. John's, Newfoundland and Labrador, A1B 3X5, Canada

The Howley Basin, part of the Maritimes Basin, is a Carboniferous terrestrial, fault-bounded basin, located in western Newfoundland. High-yielding source rocks, thick reservoir rocks, and occurrences of coal and migrated oil along the basin margins suggest that the Howley Basin is prospective for hydrocarbon exploration. The basin, however, suffers from having only sparse exposure and shallow drilling along its margins, providing few constraints for interpretations of its internal stratigraphy and structure. As part of Nalcor's Petroleum Exploration Enhancement Project, a detailed mapping project was conducted to document structures within the basin.

Major NNE-trending faults, the Grand Lake Fault to the east and the Fisher Hills-Birchy Ridge Fault System to the west, form the primary displacement zones around the Howley Basin. Both of these faults are seldom observed in outcrop, but notably juxtapose rock units of varying age and composition and style and degree of deformation. Locations of the fault traces are defined by sharp linear topographic and magnetic expressions.

On the eastern basin margin mainly alluvial sedimentary rocks of the Howley Formation are in fault contact with the Ordovician–Silurian Topsails Complex along the Grand Lake Fault which is offset along right- and left-stepping high-angle cross faults. Fault-slip data show large variability in fault orientations with a predominance of oblique strike slip with undetermined shear senses. Bedding in the Howley Formation proximal to the fault lies in homoclinal panels which are moderate-steep dipping with normal facing to both the east and west. Fold geometry is only well-constrained in one section showing a close east-verging kink-style fold train. Elsewhere large kink folds are inferred between bed panels with opposite dips. Fold axes show an acute angle with the master fault indicating a phase of dextral transpression syn- to post-Howley deposition.

In the west, Birchy Ridge is a NNE-trending structural high that is cored by Anguille Group and separates the Howley Basin from the Humber Basin to the west. Tight kink-style east-verging folds trend oblique to the bounding Hampden and Birchy Ridge faults suggesting the high formed as a positive flower structure during an (early?) phase of dextral transpression. On its southeastern flank, inferred NE-trending right-stepping splays between the main faults bring panels of Deer Lake Group and Howley Formation to surface. Beds in the Deer Lake Group panels are moderately to steeply tilted, bent, and are truncated by the splays. This part of the strike-slip system is interpreted as a transpressive strike-slip duplex of R Shears requiring a (localized?) phase of sinistral transpression, likely coeval with Rocky Brook Formation deposition. The Howley Formation is deformed along its western margin as shown by moderate to steep dip of beds. Deposition of the formation probably occurred in a dextral transtensional regime with slip concentrated on the Grand Lake Fault. Finally, the young basin was subjected to dextral transpression, presumably post deposition.

Late Neoproterozoic epithermal-style Au mineralization of the Burin Peninsula, Newfoundland, Canada: U–Pb geochronology and deposit characteristics

Sarah A. Ferguson[1], Graham D. Layne[1], Greg R. Dunning[1], and Greg W. Sparkes[2]

1. Department of Earth Sciences, Memorial University of Newfoundland, 300 Prince Philip Drive, St. John's, Newfoundland and Labrador, A1B 3X5, Canada ¶
2. Geological Survey of Newfoundland and Labrador, Department of Natural Resources, P.O. Box 8700, St. John's, Newfoundland and Labrador A1B 4J6, Canada

The Burin Peninsula in southeastern Newfoundland lies along the western margin of the Avalon Zone, which makes up the eastern extent of the northern Appalachian orogen. This lithotectonic zone formed in an extensional arc setting along the margin of Gondwana during the Neoproterozoic, and is characterized by low-grade, magmatic-arc-related volcanic, plutonic, and epiclastic sedimentary rocks, which are overlain by a late Neoproterozoic to early Ordovician sedimentary cover sequence. Epithermal-style gold mineralization is present throughout the Avalon Zone in Newfoundland, as well as in the neighbouring, correlative peri-Gondwanan terranes of Ganderia (Gander Zone) to the west, and Carolinia to the south. The most notable deposits include the Hope Brook Mine in southwestern Newfoundland, and the Brewer, Haile, and Ridgeway Mines in South Carolina.

On the Burin Peninsula, both high- and low-sulphidation styles of epithermal mineralization are present within the Neoproterozoic volcanic-arc related stratigraphy. In addition, the potential for related porphyry Au-(Cu) mineralization has also been recognized. The high-sulphidation occurrences are characterized by extensive zones of advanced argillic alteration, and include the Hickey's Pond, Tower, and Stewart prospects, all of which are nominally hosted within Marystown Group volcanic rocks. The low-sulphidation occurrences are characterized by well-preserved epithermal textures that include breccia, blading and colloform banded veins. The most notable prospects include Heritage, Big Easy, and Long Harbour, nominally hosted in Marystown Group volcanic rocks, Musgravetown Group epiclastic rocks, and Long Harbour Group volcanic rocks, respectively.

Here we present an overview of the epithermal-style mineralization found in the region, including new data on the occurrence and distribution of precious metal mineralization at Hickey's Pond, Long Harbour, and Forty Creek (part of the Stewart property), from SEM-EDX analysis. We also report new zircon U-Pb (CA-TIMS) ages for volcanic and plutonic rocks hosting, or associated with, the high- and low-sulphidation epithermal systems at Stewart and Long Harbour, respectively. At Stewart: dacitic quartz-plagioclase crystal tuff, 575.2 ± 2.1 Ma; dacitic quartz crystal tuff host rock, 576.7 ± 2.5 Ma; basaltic-andesitic lapilli tuff, 575.9 ± 2.0 Ma; silicified dacitic feldspar porphyry, 575.6 ± 1.7 Ma; and altered granodiorite, 576.0 ± 2.7 Ma are indistinguishable, and overlap with ages of the proximal, previously dated Swift Current Granite, 577 ± 3 Ma and Burin Knee Granite, 575.5 ± 1 Ma. At Long Harbour, the flow-banded rhyolite hosting the mineralization is 564.6 ± 3.4 Ma, which is currently interpreted as a separate, later mineralizing event from that which occurred at Stewart.

Investigating copper and zinc adsorption to natural sediment using experimental and modelling methods

Leanne Fisher-Power, Tao Cheng, and Zahra Sadat Rastghalam

Department of Earth Sciences, Memorial University of Newfoundland, 300 Prince Philip Drive, St. John's, Newfoundland and Labrador, A1B 3X5, Canada

As a by-product of industrial processes, such as mining, heavy metals are generated in toxic concentrations, and can be environmentally hazardous if not cared for properly. A potential inexpensive and abundant remediation option is the adsorption of aqueous heavy metals by natural sediments, which reduces the bioavailability and transport of heavy metals. The purpose of this study was to (i) investigate the ability of natural sediment to adsorb aqueous copper and zinc; (ii) elucidate the influence of various soil components on adsorption; and (iii) determine the effects of cations and organic matter that leached from the sediment on adsorption. Batch adsorption experiments in the pH range of 3 to 8 were conducted using natural sediment, and surface complexation models were used to simulate copper and zinc adsorption under the experimental conditions. Experimental results showed that substantial quantities of copper and zinc could be adsorbed by the sediment and high concentrations of multivalent cations and organic matter could be leached from the sediment to water. Surface complexation models sufficiently simulated the experimentally observed copper and zinc adsorption and indicated that at pH <6.5, soil organic matter was the dominant adsorbing phase for both copper and zinc, whereas metal oxides were the major adsorbent at pH >6.5. It was also found via surface complexation model calculations that clays were insignificant in adsorbing copper, but important for zinc adsorption at pH <5. Furthermore, surface complexation model results indicated that the leached cations markedly decreased Cu adsorption at pH <6 and Zn adsorption at pH 3–8. Dissolved organic matter (DOM) was found to decrease Cu adsorption at pH >6 due to formation of Cu-DOM aqueous complexes, but increase Zn adsorption at pH 4–7 due to formation of aqueous complexes between DOM and major cations, which reduced competition from these cations against Zn for binding sites on the sediment.

The results of this study demonstrate the capacity of natural sediment to adsorb copper and zinc and could be useful in developing remediation strategies.

A detailed study of magmatic processes in development of part of the Fogo Batholith, Newfoundland, Canada

Ben Graham, Alison Leitch, and Greg Dunning

Department of Earth Sciences, Memorial University of Newfoundland, 300 Prince Philip Drive, St. John's, Newfoundland and Labrador, A1B 3X5, Canada

The geology of Fogo Island, located in north-central Newfoundland, is dominated by a Silurian–Devonian batholith that contains rocks ranging from mafic to felsic in composition. Past work has focused on mapping the different gabbroic and granitic units represented on the island, studies of their chemistry, along with the nature of intrusion of plutonic rocks into the surrounding metasedimentary host rocks of the Fogo Harbour Formation. Our research focuses on spectacular mafic enclave swarms and dykes seen at Wild Cove, on the northeast coast near the town of Tilting. The enclaves are generally gabbroic to dioritic in composition and display mingling relationships with the diorite-granodiorite rocks that host them. Our hypothesis, based on the cuspate texture of the enclaves and the intruding/back-intruding nature of contacts between units, is that multiple felsic and mafic magmas co-existed as crystal-rich "mushes" within the chamber at the time of mingling.

Due to the lack of a base-map at an appropriate scale for this detailed study, aerial imagery specialists CloudBreaker™ were hired to conduct remote drone photography over Wild Cove. A total of 735 high-resolution photos were combined to create an ortho-rectified, GPS-located, photo mosaic base-map of the region. Careful hand-drawn maps were made of particular areas of interest where complex mingling relationships occur between units. Over the course of this investigation, these maps are being thoroughly examined to ascertain the nature and time-frame of magma mingling between the various hosts and intruding units. As an example, at one location evidence is preserved of complex mingling between mush units involving the intrusion of diorite dykes into diorite and granite mushes. The dykes were later pulled apart and subsequently back-intruded by liquid from the host mush. Field relationships such as this yield apparent contradictory evidence for the sequence of intrusion. This research may have implications for magma mingling processes in plutonic rocks seen elsewhere, such as the Vinalhaven intrusion in Maine, as well as provide new ideas for the understanding of the construction of composite intrusive suites.

From experiential tourism to flying drones: the evolving role of the Geological Survey in geoheritage projects

Alana M. Hinchey and Larry Nolan

Geological Survey of Newfoundland and Labrador, Department of Natural Resources, P.O. Box 8700, St. John's, Newfoundland and Labrador A1B 4J6, Canada

The Geological Survey of Newfoundland and Labrador is increasingly active in a wide range of geotourism and geoheritage projects throughout the Province. Many of the geotourism projects are collaborative with colleagues at the Newfoundland and Labrador Department of Business, Tourism, Culture and Rural Development, as well as with local partners and stakeholders, including the Aspiring Discovery Geopark on the Bonavista Peninsula and the Aspiring Cabox Geopark in the Bay of Islands region.

In collaboration with the Aspiring Cabox Geopark, the Geological Survey is involved in the new Northern Peripheries and Arctic Region Project entitled – "Drifting Apart". Over the next 3 years, this project will support the development of new and aspiring Global Geoparks, the promotion of innovative products and services for social and economic prosperity and to continue to build a strong network of geoheritage destinations in the Northern Periphery and Arctic Region.

Over the last several years, the Survey has supported the bid for Mistaken Point to become a UNESCO World Heritage Site. This September, the Province and the Mistaken Point Ambassadors Inc. welcomed a representative from the International Union for the Conservation of Nature (IUCN) who conducted the Mistaken Point onsite evaluation mission, which is a critical step in a larger evaluation process that also includes formal desktop reviews of the nomination dossier.

This year also saw the re-branding and grand "Re-opening" of the newly re-designed Fortune Head Geology Center and a new collaboration entitled the "Geological Treasures Network of Eastern Newfoundland" that aims to cross promote sites that are of geological interest.

The Survey has commenced a project utilizing our newly acquired drone (UAV) to capture high-quality imagery of our provincial geoheritage sites. This video and picture data will be used in a variety of ways; from updating our Building Stones of Newfoundland App to creating new digital access to the geology of the province. We plan to add a layer to our digital atlas that allows user to view videos of select geoheritage sites.

Exploring the use of unmanned aerial vehicles (UAVs) to study the evolution of beaches and cliffs in Newfoundland and Labrador, Canada

Melanie Irvine

Geological Survey of Newfoundland and Labrador, Department of Natural Resources, P.O. Box 8700, St. John's, Newfoundland and Labrador A1B 4J6, Canada

In Newfoundland and Labrador, most communities are built near the coast, and thus the geologic stability of these environments has economic, cultural, and environmental importance. Many areas of the province have low vulnerability to coastal issues due to the steep and rocky nature of the coastline; however, certain areas are highly vulnerable to erosion and flooding. Low-lying areas such as the bayhead barriers near Holyrood Pond along the southern Avalon Peninsula, and low-lying beach-ridge complexes in Placentia, are subject to flooding and overwash, especially during storm surges. Landforms at risk to erosion include unconsolidated Quaternary deposits, such as the cliffs along St. George's Bay, Conception Bay, and the Gulf of St. Lawrence in western Newfoundland. This is also the case at Parsons Pond, where a short-term recession rate of the clifftop of 73 cm/annum was measured. Coastal erosion and flooding will continue to have an influence due to rising sea levels and projected climatic changes. Accurate predictions of coastal evolution are important in determining vulnerability to flooding and erosion. Town planners, policy makers, and other stakeholders can utilize this information to prioritize mitigation efforts, to guide planning decisions, and to ensure that the necessary adaptations are made if development close to the coast is necessary.

The use of an Unmanned Aerial Vehicle (UAV) is currently being explored to study coastal environments (beaches and cliffs), in Newfoundland and Labrador. UAV provide an effective tool to understand coastal environments, because they are able to cover a large area in a time-efficient manner, access difficult to reach locations, and collect a significant quantity of accurate data. The UAV operates by flying at a low altitude (maximum of 100 m above the ground) and collecting overlapping aerial images. After the flight, the images are processed using photogrammetric software, and a digital elevation model (DEM) is created based on a point cloud. To increase data accuracy, topographic survey equipment, specifically a Real Time Kinematics (RTK) system, is used to geo-reference the DEM. Repeated surveys provide an understanding of how beaches are evolving: specifically an assessment of sediment accretion, deposition and the net sediment budget. Data collected from the UAV include measurements from the entire cliff face, and will be used to assess volumetric changes over time. These data will provide a more complete dataset of slope stability, compared to traditional data acquisition which has involved only the clifftops and bases of landforms in coastal surveys.

Coupled Ti-in-quartz thermometry and cathodoluminescence imaging: a potential technique for investigating the thermal history of partially melted rocks

Jillian L. Kendrick and Aphrodite Indares

Department of Earth Sciences, Memorial University of Newfoundland, 300 Prince Philip Drive, St. John's, Newfoundland and Labrador, A1B 3X5, Canada

Titanium as a trace element in quartz has become a subject of interest in the fields of metamorphic, igneous, and hydrothermal deposit petrology. The Ti content of quartz has been positively correlated with growth temperature, forming the basis of Ti-in-quartz geothermometers. A relationship has also been found between trace Ti and cathodoluminescence (CL) emissions in quartz, allowing textures such as growth zonation to be recognized in individual crystals. Coupling Ti-in-quartz thermometry with CL imaging therefore creates a potentially powerful tool for interpreting complex geologic histories. As quartz is one of the most robust and common silicate minerals in the crust, the technique has profound potential for a wide variety of rock types. Reliable results are limited, however, to rocks for which the activity of Ti (a_{TiO2}) during quartz growth can be quantified, such as those bearing rutile. A promising yet largely unexplored application of the technique is metamorphic quartz, particularly in migmatites. Quartz may be produced by many retrograde metamorphic reactions, and is most importantly associated with the crystallization of partial melt. Interpreting Ti signatures in quartz using Ti-in-quartz thermometry and CL imaging could provide insight into the thermal history of migmatites.

This project aims to test the coupled Ti-in-quartz thermometry and CL imaging technique using previously studied migmatite samples. Using mineral liberation analysis (MLA) maps, distinct textural varieties of quartz in a thin section can be readily identified and subsequently imaged using CL to create an approximate map of Ti distribution. Trace Ti in quartz can be detected by electron microprobe analyzer (EPMA) using a multi-spectrometer approach, with the advantage of a high spatial resolution. Resulting temperature estimates can then be compared to a P-T framework for the sample previously established through phase equilibria modelling. As rutile is relatively common in migmatites, a_{TiO2} can be quantified in many cases; however, if if rutile is absent or not stable with quartz, a_{TiO2} must be considered carefully. By following this procedure, the details of migmatite metamorphic history recorded in quartz will become apparent, and the effectiveness of the Ti-in-quartz technique can be evaluated.

Serpentinized Archean ultramafic rocks in the Hopedale area, Labrador, Canada: geology and potential for artisanal carving stone

Andrew Kerr

Department of Earth Sciences, Memorial University of Newfoundland, 300 Prince Philip Drive, St. John's, Newfoundland and Labrador, A1B 3X5, Canada

Ultramafic rocks are a widespread but generally minor component of the Archean gneiss complex that forms the southern part of the Nain Province, around Hopedale in coastal Labrador. These ancient rocks are part of the North Atlantic Craton, and originally correlative rocks occur in southwestern Greenland. The ultramafic rocks in the Hopedale area are equated with two 'greenstone belts' known as the Hunt River Group and the Florence Lake Group. In Labrador and Greenland, and also all across Nunavut, altered ultramafic rocks (commonly termed 'soapstone') are the preferred material for artisanal carving, a cultural tradition that dates back for millennia. Past and current exploitation in Labrador involves extraction of loose and easily-moved material from coastal locations on a small scale, and some carvers now use purchased or bartered stone from other areas.

At Tooktoosner Bay, close to Hopedale, several lenses of altered ultramafic rocks up to 1 km in length are interleaved with complex orthogneisses. They are intruded by late Archean granite and pegmatite, and also by Proterozoic diabase dykes. The ultramafic rocks were previously correlated with metavolcanic rocks of the older Hunt River Group, and assumed to be older than surrounding migmatites, but an origin as intrusive bodies equivalent to the younger Florence Lake Group now seems more likely. Coarse-grained harzburgite and lherzolite are preserved locally, but most areas are serpentinized, and zones of intense alteration yield soft, dark-coloured materials that are already harvested by some local carvers. Of particular note is a distinctive bright-green-weathering serpentinite, but other stone types also occur. Investigation of coastal outcrops and closely adjacent inland areas has defined several zones of such material that could yield larger quantities of artisanal stone, but further assessment of stone quality (by test working) is needed for some of the larger sites.

The work to date is almost entirely field-based, and has pragmatic objectives. However, Archean ultramafic rocks are of scientific interest, as are the details of the process of serpentinization. Material from this project has considerable potential for a student research project aimed at mineralogy, petrology, and geochemistry.

Uncertainty in 4-D imaging

Maria Kotsi and Alison Malcolm

Department of Earth Sciences, Memorial University of Newfoundland, 300 Prince Philip Drive, St. John's, Newfoundland and Labrador, A1B 3X5, Canada

Monitoring of an oil field for changes in reservoir parameters during production is important for efficient oil recovery planning. The technique most commonly used to do this is time-lapse (4-D) seismic. Full Waveform Inversion (FWI) is a promising tool for 4-D analysis. The objective of FWI is to deliver a velocity model of the subsurface by iteratively matching modelled and recorded data. FWI iteratively updates the Earth model, and 4-D changes can then be related to changes in elastic properties (e.g., pressure, fluid saturation, density).

Uncertainty is a key component of any measurement, especially in 4D monitoring where we are primarily looking for small changes in a localized region. Current methodologies do not provide a measure of the accuracy of the estimated changes, essential to developing effective production. In this research, we aim to develop a framework for uncertainty quantification, in order to improve the monitoring of fluid movement in time-lapse surveys.

Previous work developed preliminary ideas for assessing uncertainty where the background model is improved by exploiting information from both baseline and monitor datasets, and the time-lapse changes are differentiated from the background, also using both data sets. Here, a confidence map is provided to show how reliable the results are. Others demonstrated a method in which they invert for the baseline and monitor model simultaneously, minimizing in this way unwanted model oscillations that may mask useful production- induced changes. Their observed results showed clear advantages compared to traditional FWI methods.

Using these ideas and methodologies, we are working to provide an appropriate framework for assessing uncertainty. Several numerical experiments will be tested and we will begin to put in place a more rigorous uncertainty assessment. The final goal of this research is a realistic measure of uncertainty in velocity changes within the reservoir.

Lithogeochemical and Nd isotopic provenance studies of metalliferous mudstones associated with the Lemarchant volcanogenic massive sulphide deposit, central Newfoundland, Canada

Stefanie Lode[1], Stephen J. Piercey[1], and Jonathan Cloutier[1,2]

1. Department of Earth Sciences, Memorial University of Newfoundland, 300 Prince Philip Drive, St. John's, Newfoundland and Labrador, A1B 3X5, Canada ¶
2. Department of Earth Sciences, University of St. Andrews, St. Andrews, Scotland KY16 9AL, UK

Neodymium isotopic and geochemical data from metalliferous mudstones and tuffs associated with the Cambrian Lemarchant Zn-Pb-Cu-Ba-(Au-Ag) volcanogenic massive sulphide VMS deposit provide insights into the tectonic environment and metallogenic evolution of the Tally Pond volcanic belt, northern Appalachians. The Tally Pond belt represents the oldest (~513–509 Ma) magmatism associated with the construction of the Cambrian to Ordovician Penobscot Arc, and is built upon crustal basement of the Ediacaran Crippleback Intrusive Suite and coeval Sandy Brook Group. The Lemarchant metalliferous mudstones and tuffs yield εNd_{513} between -6.0 and -1.8, whereas the associated Tally Pond belt felsic and mafic volcanic rocks have more juvenile εNd_{513} of +0.4 and +1.4, respectively. The latter are similar to previously reported values for volcanic rocks of the Tally Pond belt. The more evolved values of the exhalative sediments have not been reported previously in this belt; however, they overlap the documented range of εNd for the underlying Neoproterozoic Sandy Brook Group rhyolite (εNd_t = -6.5 to -1.9), and the Crippleback Intrusive Suite (εNd_t = -5.9 to -5.2). Accordingly, it is suggested that the exhalative metalliferous mudstones that precipitated from hydrothermal fluids, represent mixed Nd sources with Nd inherited from the Tally Pond volcanic rocks as well as from the evolved crustal basement sources. Erosion of the Neoproterozoic crustal basement and the Cambrian Tally Pond volcanic rocks, together with coeval eruption that results in direct emanation of material into the water column, releases Nd into the seawater, which is subsequently scavenged onto hydrothermally Fe-oxyhydroxides and thus, archived in the metalliferous mudstones. Combined with lithogeochemical provenance data it is proposed that the Lemarchant sedimentary rocks were deposited in a volcanic basin/caldera setting in a peri-continental rifted arc environment, with evolved continental and juvenile volcanic arc rock sources, which is consistent with the previously reported tectonic environment of formation for the Tally Pond volcanic belt.

Characterizing earthquake source physics with source scanning algorithms

Frédérick Massin and Alison Malcolm

Department of Earth Sciences, Memorial University of Newfoundland, 300 Prince Philip Drive, St. John's, Newfoundland and Labrador, A1B 3X5, Canada

Earthquake swarms that lack a clear main-shock are particularly difficult to explain and characterize for hazard assessment. These events could be triggered in the vicinity of a local perturbation from many sources, natural or not, with implications for our understanding of the rupture characteristics of earthquakes. We tackle the problem of understanding perturbing mechanisms, by investigating the location, mechanism and extent of earthquake ruptures. Shift and stack methodologies (or source scanning algorithm, SSA) are innovative methods for probabilistic analysis of earthquakes sources using continuous seismic records. We investigate the potential of SSA for the probabilistic analysis of focal mechanisms.

SSA for earthquake location is based on three steps: (1) pre-calculation of travel time grids (also defining the hypocenter solution space), (2) calculating a characteristic function of the body-wave arrivals from continuous data, with signal processing methods, and (3) the shifting and summation of the characteristic functions in each grid cell, with shifts defined by the pre-calculated travel times. Ideally, the power recovered by the entire network as a function of time can be used for simultaneous event detection and location. Although the SSA method shows promise for automatic detection and location of events, it is limited by the precision of the pre-defined grid.

We extend this approach to focal mechanism determination with slight modifications. We first pre-calculate the polarity distribution for all double couple orientations. Then polarity corrections are applied to the first motion wavelets (as extracted with SSA) from all possible mechanisms. For the optimal orientation, the wavelets with downward first motions are multiplied by negative polarities and thus all wavelets stack constructively. Finally, the probability of each double couple orientation is estimated by stacking the modified wavelets.

Effects of solid-to-solution ratio on Cu and Zn adsorption onto natural sediment

Kazuhito Mizutani and Tao Cheng

Department of Earth Sciences, Memorial University of Newfoundland, 300 Prince Philip Drive, St. John's, Newfoundland and Labrador, A1B 3X5, Canada

Adsorption of heavy metal ions to natural sediments in the subsurface influences the fate and transport of heavy

metals. Laboratory batch experiments, in which sediment samples are mixed with heavy metal-spiked solution, are frequently used to study adsorption and to determine distribution coefficients (K_D) for heavy metals. However, the solid-to-solution ratio (SSR) in most laboratory experiments is much lower than that of natural sediments in aquifers. Therefore, it is questionable if these experiments can accurately mimic heavy metal adsorption in the natural environment. The objective of this study was to investigate if SSR influences the adsorption of heavy metals onto natural sediment, and if SSR controls the leaching of multivalent cations and dissolved organic carbon (DOC). Cu and Zn adsorption onto a natural sediment and component leaching were examined using batch experiments at SSRs of 25 and 250 g/L. Results showed that Cu and Zn adsorption was SSR dependent under certain conditions, caused by complex interactions between the sediment, leached multivalent cations, and DOC. Leached Al and Fe was found to influence Cu adsorption, while Zn adsorption was influenced by Al and Ca. This study verified that DOC, Al, and Fe leaching is SSR independent and solubility controlled, while Mg and Ca leaching is SSR dependent and cation-exchange controlled. This study demonstrated that the K_D of heavy metals determined by batch experiments could be used for simulating heavy metal adsorption in natural environments under certain conditions, but should be used with caution.

Mountains to sea in the Late Ordovician: sequential synorogenic basins near the Red Indian Line suture in Notre Dame Bay, Newfoundland, Canada

Brian H. O'Brien

Geological Survey of Newfoundland and Labrador, Department of Natural Resources, P.O. Box 8700, St. John's, Newfoundland and Labrador A1B 4J6, Canada

Several unique tracts of inhomogeneously deformed and variably metamorphosed strata ranging from the late Darriwilian to the late Katian comprise the progressively younger submarine fill of three regionally extensive basins in west-central Notre Dame Bay. Different parts of these relict basins have been locally preserved within the regional hanging wall and footwall sequences of the Red Indian Line suture.

The Sops Head basin, the Rocky Brook basin and the Badger basin are dominated by immature quartz wacke turbidites hosting recycled fragments of carbonate-encrusted basalt or flow-banded rhyolite or bioclastic limestone. The transport of extrabasinal plutonic or metamorphic detritus into these basins was achieved by the formation and downslope movement of arenaceous or argillaceous debrites. The late Middle Ordovician Sops Head basin and its alkali gabbro sill complex were initially juxtaposed with the magmatic rocks of composite Laurentia in the latest Darriwilian. Much of the exotic broken formation and pebbly mudstone produced during this period of accretion came from sub-seafloor thrust sheets carrying calc-alkaline rhyolite and normal mid ocean ridge basalt. Tectonosomes and olistostromes distinguished by these types of lava had been mainly, though not exclusively, sourced from within the adjacent early-middle Darriwilian Catamaran Brook succession (a peri-Laurentian Red Indian Lake Group correlative).

In tectonic distinction, the Late Ordovician Rocky Brook basin had a more restricted development; its felsic pyroclastic strata and interbedded sulphidic argillites having filled a subsiding graben that was possibly incrementally stretched during volcanic flare ups. Located farther northwest in Notre Dame Bay than the Darriwilian basin, the mainly Sandbian Rocky Brook basin fill accumulated, nevertheless, above the same late Middle Ordovician (Catamaran Brook) volcanic arc and ophiolite sequence that had flanked the Sops Head shortening basin. The depositional substrate of the non-volcanic Badger basin had originated in the peri-Gondwanan realm. During the Late Ordovician, indurated sedimentary strata from the Sop Head basin and the adjacent Exploits arc – back arc complex became re-deposited as clasts in certain conglomerates of the lower Badger Group.

During the Late Ordovician, synorogenic marine sedimentary basins proximal to the Dunnage Zone's Red Indian Line became tectonically incorporated into a developing thrust stack that had retreated from the margin of the Sops Head basin and then advanced past the margin of the Badger basin. They record the successive opening, arching, erosion and closure of discrete subduction zone-related depocentres situated near the hinterland's northwest-dipping Late Taconian mountain front.

U-Pb detrital zircon constraints on the terminal closure of Iapetus

Jeffrey Pollock

Department of Earth and Environmental Sciences, Mount Royal University, 4825 Mount Royal Gate SW, Calgary, Alberta T3E 6K6, Canada

The Dog Bay Line is a major Silurian terrane boundary in the Exploits Subzone of the Appalachian orogen in Newfoundland. Late Ordovician-Early Silurian rocks (Badger and Botwood groups) northwest of the Dog Bay Line contain detritus sourced exclusively from Laurentia. These groups were deposited on peri-Gondwanan volcanic arc terranes that were accreted to Laurentia in the Middle Ordovician. The Davidsville and Indian Islands groups southeast of the Dog Bay Line have stratigraphic links to peri-Gondwanan terranes and were deposited during the Late Ordovician-Early Silurian upon the peri-Gondwanan margin of Iapetus and were accreted to Laurentia in the Silurian.

A change from Paleozoic-dominated to Meso- and Neoproterozoic-dominated detritus in sequences northwest of the Dog Bay Line is attributed to Ordovician collision and rapid exhumation of peri-Laurentian arc terranes of the Notre Dame Subzone. Uplift related to extensional collapse of these accreted arc terranes re-exposed Laurentian basement which eroded and deposited detritus from the latter into the Botwood Group. Salinic orogenesis resulting from the collision of Ganderia with Laurentia resulted in obduction and erosion of the accreted Victoria and Exploits arcs and deposition of the detritus into a fore-arc basin on Laurentia.

The absence of zircon in the ca. 510–550 Ma and 1550–1600 Ma range northwest of the Dog Bay Line and paucity of ca. 1600–1700 Ma zircons southeast of the Dog Bay Line suggest the presence of a Silurian arm of the Iapetus Ocean that separated Laurentia from peri-Gondwanan terranes of Ganderia and Avalonia. The change in Late Ordovician deep marine turbidites to Early Silurian stable-shelf rocks and non-marine, subaerial sediments east of the Dog Bay Line parallels that on the Laurentian margin and indicates the destruction and subsequent closure of Iapetus. The upper formations of the Botwood Group contain ca. 700–800 Ma zircons that are atypical of Laurentia, but are common in peri-Gondwanan terranes, and suggest that the youngest rocks of the Botwood Group may postdate closure of the Dog Bay Line and transgress the suture as an overlap sequence.

The presence of Silurian orogenesis on both the Laurentian and peri-Gondwanan margins of Iapetus is consistent with the closure of the Tetagouche–Exploits basin and Iapetus Ocean by the Late Silurian. Laurentia and Ganderia subsequently collided, suggesting that rocks along the Dog Bay Line represent the last known occurrence of Iapetus Ocean in the northern Appalachian orogen.

GEM-2 Hudson-Ungava: modern constraints on historical correlations in the Kaniapiskau Supergroup, Labrador Trough, Canada

Nicole Rayner, Mary Sanborn-Barrie, and Vicki McNicol

Geological Survey of Canada, Natural Resources Canada, 601 Booth Street, Ottawa, Ontario K1A 0E8, Canada

Integrated mapping of the southern New Québec Orogen - Core Zone, as part of the second phase of NRCan's Geomapping for Energy and Minerals (GEM-2) program, is providing insight into the collisional orogen between the Superior and North Atlantic cratons by investigating the composition, age and architecture of intervening crust at a scale that bridges the Quebec - Labrador border. Although there has been a long history of bedrock mapping, exploration activities and mining in this region, quantitative data on the age and provenance of many key map units is lacking. Targeted mapping and geochronology sampling was undertaken with the aim of strengthening the geological context under which mineral exploration can continue. This presentation provides new results from the Kaniapiskau Supergroup in the southern part of the New Québec Orogen and highlights activities to the north near Kuujjuaq. Collectively, these are being integrated with new results from the Core Zone.

The Kaniapiskau Supergroup has long been recognized as recording cratonic rifting and incipient development of an ocean basin. Three samples from its southeastern margin were analysed for geochronology, in order to explore their provenance and provide quantitative pins on the stratigraphic correlations assigned to them. Pink-grey weathering quartz arenite with well-developed cross stratification was investigated to test its long-held correlation with the lower Seward Group. Quartzite, exposed at Quartzite Lake, has variably been interpreted as part of the Seward Group (basal Cycle I), a basal transgressive sequence (Cycle 2, Wishart Formation) or a transgressive sequence at the top of Cycle 2 (Menihek Formation). An intermediate pyroclastic volcanic unit exposed at Galena Lake was analysed in order to directly date the Nimish Formation, whose inferred age of ca. 1878 Ma comes from a syenitic cobble in associated conglomerate.

Complementary detrital zircon studies to compare provenance profiles of samples from both the Kaniapiskau Supergroup and the Rachel-Laporte domain extend this tectonostratigraphic research to the north, near Kuujjuaq. Also in the north, mafic and ultramafic sills historically assigned to the Montagnais suite despite textural and compositional differences, are the subject of high-precision geochronological investigations. This new information will aid comparisons between the magmatic history of the Labrador Trough and other Paleoproterozoic Ni-Cu-PGE districts, such as Cape Smith in Quebec and Thompson in Manitoba. Collectively, geochronological calibration of key plutonic and volcano-sedimentary rock packages will allow historical correlations to be assessed, strengthened and revised.

Kilometre-scale cross-folding in the Ottawa River Gneiss Complex, western Grenville Province – signal of transtensional collapse of overthickened hot crust

Toby Rivers[1] and Fried Schwerdtner[2]

1. Department of Earth Sciences, Memorial University of Newfoundland, 300 Prince Philip Drive, St. John's, Newfoundland and Labrador, A1B 3X5, Canada ¶
2. Department of Earth Sciences, University of Toronto, 22 Russell Street, Toronto, Ontario M5S 3B1, Canada

Recent 2D and 3D analogue and numerical experiments have shown that transtensional folds form in constrictional regimes in which extension (stretching) of the fold hinge

is coeval with buckling (shortening and rotation) of the fold limbs. In ductile extension-dominated regimes, transtensional folds are characterised by the presence of L>>S mineral elongation lineations parallel to the fold hinges, and can exhibit a range of axial surface orientations from upright to recumbent depending on the original orientation of the folded surface. We have used these criteria to identify a system of transtensional cross-folds (also known as transverse folds) with NW- to NNW-trending hinge lines at high angle to the NE-SW orogenic grain of the Grenville Province within the Ottawa River Gneiss Complex (ORGC), a giant metamorphic core complex in the western Grenville Province. The amplitudes of individual cross-folds range from metre- to 10s-of-km-scales and the hinge lines of the larger examples can be traced along strike for more than 50 km.

The highest structural level of the ORGC is known as the Muskoka domain, a ductile amphibolite-facies detachment surface with abundant leucosome that is up to 7 km thick and separates the underlying granulite-facies core (the Algonquin—Lac Dumoine domain) from the overlying greenschist- to amphibolite-facies carapace (Composite Arc Belt). The transtensional folds are especially well developed in the Muskoka domain, and on the basis of petrological evidence they formed after the peak of metamorphism during amphibolite-facies retrogression of granulite-facies precursors in a tectonic setting of orogenic collapse. To our knowledge, this is the first record of transtensional, as opposed to extensional, gravitationally-driven collapse of a large hot orogen.

GEM-2 Hudson-Ungava: modern constraints from the Core Zone to decipher terrane architecture

Mary Sanborn-Barrie, Nicole Rayner, Natasha Wodicka, and David Corrigan

Geological Survey of Canada, Natural Resources Canada, 601 Booth Street, Ottawa, Ontario K1A 0E8, Canada

The Core Zone is a composite Precambrian lithotectonic terrane that forms the easternmost part of the Canadian Shield in western Labrador and eastern Quebec. Long considered the south-eastern extension of the Archean Rae Province, the Core Zone comprises Archean rocks, Paleoproterozoic supracrustal rocks and variable age plutons extensively reworked during ca. 1.9–1.8 Ga collision of Superior and North Atlantic (or Nain) cratons.

Bedrock mapping of this relatively poorly known lithotectonic terrane is a component of the second phase of the Geomapping for Energy and Minerals (GEM-2) Program, to strengthen the geological foundation for sustainable economic development in this region. Building on previous work, with an aim to bridge understanding across provincial boundaries, our focus is directed at several outstanding problems, including: (1) The character, age, and affinity of the Laporte Domain, west of the De Pas Batholith, where fine-grained clastic metasedimentary rocks, amphibolite and plutonic rocks have variably been interpreted as allochthonous Archean basement, or part of the ca. 1.88–1.87 Ga Cycle II rocks of the Kaniapiskau Supergroup; (2) The depositional age, provenance and tectonic significance of conglomerate and associated coarse clastic rocks, known to occur east (Hutte Sauvage) of the De Pas Batholith and to its west; (3) The age, provance and tectonic affinity of a collage of volcano-sedimentary rocks east of the De Pas Batholith (Zeni, Atshakash and Ntshuku assemblages).

Early results indicate significant involvement of ca. 2.5–2.0 Ga crust in the evolution of the Core Zone. Plutonic rocks of this age include ca. 2.37 Ga feldspar porphyry (Pallatin suite), ca. 2.32 Ga monzogranite, and 2.35 or 2.05 Ga granophyre related to a gabbroic complex. Metasedimentary rocks both east and west of the De Pas Batholith yield detrital zircon modes at 2.5 Ga, 2.3 Ga, and ca. 2.0 Ga, with deposition after ca. 2.0 Ga for clastic rocks east of De Pas (Hutte Sauvage-Atshakash), and after ca. 1.85 Ga for fine-grained clastic rocks west of De Pas (Deborah Lake formation, Laporte Domain). These ages highlight crustal source(s) distinct from the Archean Superior and North Atlantic cratons, and even from the Rae craton which is dominated by ca. 2.99–2.58 Ga rocks. Our age data point to the presence and involvement of Meta Incognita terrane, a cryptic terrane believed to have played a role in an early (ca. 1.87 Ga) stage of collision in the Baffin segment of the Trans-Hudson Orogen. Given its distance from the Ungava promontory, the Core Zone may better preserve some common lithotectonic elements (i.e., Meta Incognita basement, cover units, and ca. 1.83 Ga Narsajuaq suite) compared to its more strongly shortened counterpart on Baffin Island, thereby allowing broader stages of evolution of the Baffin segment of the Trans-Hudson Orogen to be deciphered.

Old and new gravity reference stations in St. John's, Newfoundland, Canada

Jillian Thistle and Alison Leitch

Department of Earth Sciences, Memorial University of Newfoundland, 300 Prince Philip Drive, St. John's, Newfoundland and Labrador, A1B 3X5, Canada

The Canadian Gravity Standardized Network (CGSN) is a series of absolute gravity reference stations maintained by Natural Resources Canada. Incorporating one of these stations into a gravity survey allows relative gravity measurements to be converted to absolute gravity. On the island of Newfoundland there are 2 primary stations and 82 secondary stations which are all tied to a primary station. In the St. John's area 18 stations are located around the harbor. The first part of this study was conducted to determine

which of the 18 stations are still accessible. It turns out that all of the stations are either built over, on private property, or behind security fences. The second part of this study was to set up new replacement gravity stations for the convenience of researchers. Three locations were chosen: outside the Johnson Geo Center on Signal Hill; indoors in the lower level of the Johnson Geo Centre; and next to the statue of Terry Fox outside of the St. John's Port Authority building. These stations were chosen because they are in flat, stable areas sheltered from the wind, they are easy to find and access; and they are not likely to be built over or changed in the foreseeable future. These stations were then tied into a fourth station located in the basement of the Earth Sciences building at Memorial University. This fourth station was in turn tied into the only primary station in the area, which is inconveniently located in a locked vault in the basement of the Science building at Memorial University, and therefore difficult to access.

Analysis of seismic and gravity data collected from the Howley Basin, Howley, Newfoundland, Canada

Oscar E. Vasquez and Charles A. Hurich

Department of Earth Sciences, Memorial University of Newfoundland, 300 Prince Philip Drive, St. John's, Newfoundland and Labrador, A1B 3X5, Canada

Little is known of the Carboniferous Howley basin, a lateral basin that is part of the Deer Lake Basin in between western Newfoundland's Humber and Dunnage zones. Shallow seismic reflection and high-resolution gravity data have been collected in the area with the purpose of imaging the basin. The results of this data can lead to a better understanding of the tectonic evolution of the Deer Lake area.

The Deer Lake Basin is a late Paleozoic, non-marine sedimentary basin located in western Newfoundland. It trends northeast-southwest lying parallel to the Cabot Fault Zone and is composed of two lateral basins separated by a positive flower structure. The eastern portion of the basin has been labeled the Cormack basin, whereas the western portion has been deemed the Howley basin. Because of petroliferous units found within the Deer Lake Basin's lacustrine facies there has been an interest in oil exploration within the area. This interest has led to extensive geological and geophysical studies performed in the Cormack leading to a characterization of its stratigraphy and structure, as well as an uneasy consensus on the development of the greater Deer Lake Basin. In contrast, there has been little geophysical exploration in the Howley basin. This can be attributed to the lack of visible outcrop within the Howley basin, which is largely covered by water, or Quaternary glacial till. This absence in data limits interpretation of the Howley basin's subsurface and structures within, and also makes any stratigraphic interpretations and correlations made with the Cormack basin subject to heavy speculation.

As part of the Petroleum Exploration Enhancement Program (PEEP) and with funding from NALCOR Energy, Memorial University has gathered seismic data on the Howley Basin from shallow reflection seismic surveys performed using a MUN-designed prototype source, and gravity data using a Scintrex CG-5 gravimeter. A major objective of this research is to characterize the stratigraphic and structural character of the Howley basin to provide an improved understanding of the tectonic evolution of the greater Deer Lake Basin and the nature of the eastern bounding Grand Lake fault.

Reassessment of Port au Port Peninsula paleomagnetism, with new preliminary results

Halima S. Warsame[1], Phil J.A. Mccausland[1], and John W.F. Waldron[2]

1. Department of Earth Sciences, University of Western Ontario, London, Ontario N6A 5B7, Canada ¶
2. Department of Earth and Atmospheric Sciences, University of Alberta, Edmonton, Alberta T6G 2E3, Canada

The Port au Port Peninsula in western Newfoundland provides excellent exposures of Early Cambrian through Carboniferous sedimentary rocks, representing a record of post-rift clastic sedimentation and platform carbonates of Laurentia's Early Paleozoic passive margin and its subsequent foundering, deformation and karsting related to successive Paleozoic orogenic events. Following early paleomagnetic work over 50 years ago, a number of studies in the 1980s and early 1990s sought to determine and test primary paleomagnetic results for the platformal rocks in the Port au Port Peninsula, to help define Laurentia's Paleozoic drift history. In a recent reassessment of the global paleomagnetic database for the Phanerozoic, Ordovician results from four studies in the St. George and Table Head Groups have been combined to contribute two Early Ordovician paleomagnetic poles from the peninsula. Here, we report preliminary paleomagnetic results from 21 sites in carbonate and red siltstone from the Cambrian Port au Port Group and Hawke Bay Formation in an effort to assess the autochthoniety of the Ordovician results and possible subsequent rigid block deformation history of the peninsula. The 21 sites produced 198 specimens, with 15 of those sites producing interpretable results. Demagnetization of the specimens revealed very weak magnetizations that were nevertheless resolvable as three recognizable magnetic components: *V*, *I*, and *M*. The *V* component is interpreted to be a Viscous Remanent Magnetization typically removed by 20 mT, showing a steep down, northerly direction that is similar to the present-day field direction. Leftover magnetization was coercively hard and was removed by thermal demagnetization. The *I* component unblocked over an intermediate temperature range up to 450°C,

with a southeasterly shallow down or up direction. The *M* component was defined over a higher temperature range up to 580°C, in which magnetite unblocked and a shallow down, southeastern direction. A fold test on the 15 reporting sites was inconclusive, largely because the fold axis is similar to the ancient remanence direction, so it cannot be concluded whether the remanence was acquired before or after deformation. A preliminary paleopole was calculated (40° N; 151 E) and, when compared to the known apparent polar wander path of Laurentia, the paleopole falls approximately 30° east longitude off of the ~310 Ma portion of the path, implying that the study area may have experienced minor counterclockwise rotation since remanence was acquired. The specimens have not yet been fully demagnetized and require further thermal demagnetization steps at higher temperatures to unblock hematite, providing additional directional information.

Hydrothermal influences on zircon from the Kiruna iron apatite ore district in the Norrbotten region of northern Sweden: a comprehensive geochemical study

Anne Westhues[1], John M. Hanchar[1], Christopher M. Voisey[1], Martin J. Whitehouse[2], George R. Rossman[3], and Richard Wirth[4]

1. Department of Earth Sciences, Memorial University of Newfoundland, 300 Prince Philip Drive, St. John's, Newfoundland and Labrador, A1B 3X5, Canada ¶ 2.Department of Geoscience, Swedish Museum of Natural History, Stockholm, Sweden ¶ 3. Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena 91125, USA ¶ 4. GFZ German Research Centre for Geosciences, Potsdam 14473, Germany

The iron oxide apatite (IOA) deposits of Kiruna are the type locality for this kind of deposit, but the ore genesis is poorly understood and suggested to be either magmatic or hydrothermal. Zircon crystals separated from these highly debated iron deposits located in northern Sweden show several distinct characteristics compared to zircon from adjacent metavolcanic and intrusive rocks. Detailed zircon imaging by BSE and CL revealed complex textures in several samples. Zircon from the iron ores shows xenocrystic cores that are overgrown by "spongy", inclusion-rich rims. In contrast, zircon from the host rocks and a granite intrusion exhibit typical igneous growth zoning.

Selected zircon crystals were analysed for major and trace elements using EPMA and LA-ICPMS. While zircon grains from the volcanic host rock and granite are of near stoichiometric composition, zircon crystals from the ore contained elevated Fe, P, and LREE concentrations and low analytical totals. EPMA elemental X-ray maps reveal Fe-rich inclusions, veins and/or zones in zircon crystals from the ore and syenite. FTIR spectroscopy done on selected zircon grains from the ore revealed that they contained up to several weight percent of H_2O. TEM analyses show no evidence of micro- or nano- inclusions of a LREE-rich phase such as monazite within high REE-zircon, suggesting LREE occur within the zircon structure. Combined with zircon texture and their water content, it is proposed that these zircon grains experienced hydrothermal fluid alteration.

The complex nature of the zircon crystals required analyses with a high spatial resolution: U–Pb data (SIMS) suggest that the metavolcanic host rocks were emplaced and intruded by a syenite (ca. 1884 to 1880 Ma), before the ore was formed (ca. 1877 to 1874 Ma), close to the emplacement of the granite intrusion. In situ oxygen (SIMS) and Hf (LA-ICPMS) isotopic composition show clear contrasts between ore zircon ($\delta^{18}O$ ~7‰, and εHf_i = -5 to + 3) on the one hand, and zircon grains from metavolcanic host rocks and from intrusions ($\delta^{18}O$ ~3‰, and εHf_i = -6 to -10) on the other hand. The oxygen isotopic signature suggests the involvement of high-T hydrothermal fluids and the Hf isotopic compositions indicate a source region for the ore that is different from its host rocks. To explain all observations, a high temperature (~600–700°C) magmatic fluid(s), at the magmatic to hydrothermal transition, seems the most likely heat and fluid source to have remobilised the iron and concentrated it in the massive iron oxide deposits located at Kiirunavaara and smaller deposits in the vicinity.

A geological, geochemical, and mineralogical study of the Heritage gold–silver prospect, Point May, Newfoundland, Canada

Greg C. Woodland and Graham D. Layne

Department of Earth Sciences, Memorial University of Newfoundland, 300 Prince Philip Drive, St. John's, Newfoundland and Labrador, A1B 3X5, Canada

The Heritage Project is located on the southern shore of the Burin Peninsula, a part of the Avalonian terrane increasingly recognized for its potential to host epithermal precious-metal deposits. In addition to the Heritage Project, several other significant prospects have been identified on the Peninsula (including Big Easy, Hickey's Pond, and Stewart). First discovered in 2011, the Point May Epithermal System (PMES) contains both multi-episode vein breccias and massive veins (Eagle Zone). The PMES is 4.5 km long and up to 2 km wide and trends in a north-northeast direction. The system has yielded widespread anomalous Au (up to 3.5 oz/ton) and Ag (up to 89 oz/ton), with minor Cu, Pb, and Zn throughout this area.

A previously unmapped geological unit, termed the High Beach Andesites (HBA), is the exclusive host of the PMES. It consists of a large succession of intermediate crystal tuff, crystal lapilli tuff, and tuff breccia, as well as coarse pyroclastic rocks. These rocks are broadly indicative of an arc-type volcanic environment formed during a protracted period of active magmatism. A large flow-banded rhyolite unit in the center of the mapped area indicates the presence of a paleo-caldera positioned on the 'toe' of the peninsula.

The abundance of jasperoidal fragments and fracture filings implies a shallow subaqueous paleoenvironment during emplacement.

Shear zones located along the western margin of the HBA may have acted as a structural control on the emplacement of the large irregular quartz vein found at the Eagle Zone. It has been suggested that these shear zones and similar structures on the eastern margin could be attributed to extensional forces during back-arc rifting, which is further supported by the presence of a horst-like structure recently identified on the property.

The PMES is a low-sulphidation epithermal system, which is indicated by the presence of banded veins and bladed silica, along with diagnostic clay-chlorite-adularia alteration. Alteration, as mapped on surface, is characterized by an extensive outer silica–phengite (low temperature clay) zone, which surrounds an inner alteration zone consisting of chalcedony–adularia–illite. Surface sampling of the PMES has identified two discreet NNE-trending mineralized zones located on the eastern and western boundaries of the inner alteration zone, now known as the Eagle and Pinnacle Zones, respectively. These zones are characterized by the presence of large veins and pronounced multi-episode hydrothermal breccias, which contain Au–Ag and base-metal mineralization. There appears to be two distinctive mineralizing events: the first event is characterized by higher Au/Ag ratios and the second event by the lower Au/Ag ratios. Mineralized veins are easily identifiable by the presence of ginguro-style mineralization (GSM), as characterized by black 'sooty' stringers and fragments with a fairly simple polymetallic mineral assemblage comprised of native silver and acanthite with lesser amounts of naumannite, electrum, galena, clausthalite, chalcopyrite, and sphalerite.

CABOX – Newfoundland's highest point and an aspiring UNESCO Global Geopark

Paul Wylezol

International Appalachian Trail, Newfoundland and Labrador Chapter, 24-9 Montgomerie Street, Corner Brook, Newfoundland and Labrador A2H 2P8, Canada

From extending one of the world's most famous trails across the Appalachian-Caledonian Orogen to linking UNESCO Global Geoparks and Aspiring Geoparks, this presentation discusses the establishment of a showcase UNESCO Geopark spanning the Bay of Islands Ophiolite Complex and surrounding areas in Western Newfoundland. The Cabox Aspiring Geopark is a partner in the 'Drifting Apart' project, which explores the links between diverse geological terranes now separated by the Atlantic Ocean. The 'Drifting Apart' project is funded by the European Union, but its scope extends beyond Europe. The Cabox project hopes to eventually shine an international spotlight on the province's diverse and unique geological landscapes and the supporting role they played as the "Galapagos of Plate Tectonics". Some important milestones required for consideration as a global geopark have now been achieved, but much work remains towards this objective.