The 68th Annual Atlantic Universities Geoscience Conference 2018

1st-3rd November 2018
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Halifax, Nova Scotia
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Letter from the Department Chair of Earth Science

On behalf of the Department of Earth Sciences at Dalhousie University, I’d like to extend a warm welcome to the attendees of the 2018 Atlantic Universities Geoscience Conference (AUGC).

The AUGC was inaugurated in 1950 at Dalhousie University and is still going strong after nearly seven decades. The truly exceptional aspect of this conference is that it is completely organized by you, the students, and you should also take pride in knowing that this is the second oldest geologic Conference in Canada (only bested by the venerable Geologic Association of Canada).

This is an exceptional opportunity for undergraduates from Atlantic Canada to gather and have the opportunity to present their current work, learn about local geology, meet members of the Atlantic geoscience community and enjoy the company of like-minded students. I’d like to thank the members of the Dawson Club who helped to organize this event. They have put together a number of social events, as well as first-rate field trips to see some of the spectacular outcrops of the South Mountain Batholith and local country rock, mine tailings associated with mineral extraction, and the world-class exposures containing Carboniferous to Jurassic flora and fauna along the Fundy shore. I look forward to the student research presentations and also to attending the conference banquet, at which Dalhousie alumni and former astronaut and Director of the U.S. National Oceanic and Atmospheric Administration, Kathryn Sullivan, will be delivering the keynote presentation.

This is a great opportunity to network with your fellow students, meet the professionals attending, as well as professors from the various departments to explore potential graduate school opportunities. I sincerely hope that you enjoy your stay in Halifax!

James M. Brenan
Killam Professor of Earth Sciences and Department Chair
Dalhousie University, Halifax, NS
Letter from the AUGC Planning Committee Co-Chairs

Dear Conference Delegates,

We are very pleased to welcome all of the attendees to the 2018 Atlantic University Geoscience Conference being held here at Dalhousie University.

The 2018 AUGC planning committee and Dawson Geology Club hope that everyone attending enjoys their time spent at Dalhousie University and the various venues we have chosen around Halifax. We especially hope that the undergraduates presenting use this opportunity to demonstrate and enhance their presenting skills, and to make connections with industry representatives, faculty, and fellow students.

To showcase the rich geological history of the region, and the depth of expertise of our field leaders, each field trip varies in discipline and focus. Michael Parsons, Research Scientist at the GSC-Atlantic and Adjunct Professor at Dalhousie, will lead an environmental geochemistry field trip visiting mine tailings in the Halifax area. Dalhousie faculty, Richard Cox and Becky Jamieson will lead a trip to the contact aureole around the South Mountain Batholith in and around Halifax. Finally, Tim Fedak, Curator of Geology at the Nova Scotia Museum and Adjunct Professor at Dalhousie, will lead a paleontological trip to the Fundy Basin near Parrsboro. We are very excited for everyone to experience these trips and learn more about the geological features around Halifax.

Thank you to all our sponsors, field trip leaders, students, and faculty for making this conference a reality. We would like to personally thank Mike Young for mentoring the planning committee and helping us to accomplish great things. We would also like thank Kathy Sullivan for being our Keynote speaker, we cannot express our excitement and gratitude to hear her speak at our banquet.

We look forward to meeting everyone!

Sincerely,

Jordyn Souter & Ryan Taylor
Planning Committee Co-Chairs
Atlantic University Geoscience Conference 2018
Dalhousie University
# Conference Agenda

## THURSDAY NOVEMBER 01

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<th>Event</th>
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<tr>
<td>4:00PM – 8:00PM</td>
<td>Registration</td>
<td>The Atlantica Hotel</td>
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<tr>
<td>8:00PM – 11:00PM</td>
<td>Meet &amp; Greet</td>
<td>The Atlantica Hotel</td>
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## FRIDAY NOVEMBER 02

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<thead>
<tr>
<th>Field Trips</th>
<th>Event</th>
<th>Location</th>
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<tr>
<td>7:30AM – 6:00PM</td>
<td>Triassic/Jurassic Geology and Paleontology – Parrsboro Shore (<em>Dr. Tim Fedak</em>)</td>
<td>The Atlantica Hotel</td>
</tr>
<tr>
<td>9:00AM – 3:30PM</td>
<td>Environmental Impacts of Historical Gold Mining and Acid Rock Drainage in the Halifax Regions (<em>Dr. Michael B. Parsons</em>)</td>
<td>The Atlantica Hotel</td>
</tr>
<tr>
<td>8:00AM – 5:00PM</td>
<td>Geology of the Contact Zone of the South Mountain Batholith, Halifax, NS (<em>Dr. Richard Cox and Dr. Rebecca Jamieson</em>)</td>
<td>The Atlantica Hotel</td>
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<thead>
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<th>Time</th>
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<tr>
<td>7:00PM – 9:00PM</td>
<td>Challenge Bowl</td>
<td>University Club - Great Hall</td>
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<tr>
<td>9:00PM – 12:00PM</td>
<td>Social</td>
<td>University Club - Pub</td>
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<tr>
<td>8:30AM – 4:00PM</td>
<td>Student Presentations – 830AM set up, 9AM presentations commence</td>
<td>Marion McCain - Scotiabank Auditorium</td>
</tr>
<tr>
<td>12:00PM – 1:00PM</td>
<td>Lunch</td>
<td>Marion McCain - Lobby</td>
</tr>
<tr>
<td>12:30PM – 1:00PM</td>
<td>Club Presidents/Executives Meeting</td>
<td>Marion McCain - Classroom</td>
</tr>
<tr>
<td>7:00PM – 11:00PM</td>
<td>Banquet – Awards Presentation &amp; Guest Speaker</td>
<td>The Atlantica Hotel - Guild Hall</td>
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## SUNDAY NOVEMBER 04

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<tr>
<th>Time</th>
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<th>Location</th>
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<tbody>
<tr>
<td>12:00PM</td>
<td>Hotel Checkout</td>
<td></td>
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AUGC 2018 Organizing Committee

Jordyn Souter  Co-Chair
Ryan Taylor  Co-Chair
Mike Young  Faculty Advisor
Catherine Evans  Field Trip Coordinator
Tanner Milne  Judge Coordinator
Max Angel  Registration Coordinator
Kanwar Multani  Treasurer
Bay Berry  Webmaster
Juan Chavez  Venue Coordinator
Aliya Anderson  Secretary
Ben Myrer  Hotel and Banquet Coordinator

Judge Panel

Chelsea Squires, MSc, GIT
Geophysicist, GIT at Painted Pony Energy Ltd.

Matthew Drew, MSc,
Geophysicist I.T

Sally Goodman, MSc, PhD
Chief Geoscientist at Atlantic Gold Corporation

Carson Brown P.Geo.
Production Geologist at Devon Energy Corporation
CSPG Outreach Coordinator

Megan Laracy
Geologist (Petrophysics) at ExxonMobil

Richard Cox, MSc, PhD
Geochemical & Petrology Lecturer/Instructor at Dalhousie University
Kathryn Sullivan graduated from Dalhousie University with a doctorate in geology in 1978. Her research at Dalhousie University included studies of the Mid-Atlantic Ridge, the Newfoundland Basin and fault zones off the Southern California Coast.

In the same year as her graduation from Dalhousie, Dr. Sullivan was selected as an astronaut by the U.S. National Aeronautics and Space Association (NASA). She was part of the inaugural class of women permitted to apply. During her time at NASA she visited space 3 times aboard space shuttle Challenger, Discovery, and Atlantis. She became the first American woman to walk in space and logged over 532 hours in space.

In 1993, Dr. Sullivan was appointed the chief scientist at the National Oceanic and Atmospheric Administration (NOAA). In March of 2014 the U.S senate confirmed Dr. Sullivan as the Under Secretary of Commerce for Oceans and Atmosphere and the Administrator for NOAA, she served in this position until 2017.

Kathy has held many high-ranking positions, she has been nominated for four different presidential positions under four different administrations, and she has received honorary degrees from numerous institutions across North America including Dalhousie University. Dr. Sullivan's achievements are truly inspiring.

We are very excited to meet Kathy and hear her keynote address at our banquet on November 3rd.
# Student Presentation Schedule

**Saturday November 03**  
8:30AM – 4:00PM  
Dalhousie University, Scotiabank Auditorium

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<td>8:30AM – 9:00AM</td>
<td>Setup: Posters and Talks (.pps files to speaker’s podium)</td>
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<tr>
<td>9:00AM – 9:20AM</td>
<td>Sean Freeborne, St. Francis Xavier University</td>
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<tr>
<td>9:20AM – 9:40AM</td>
<td>Melissa Mills, Memorial University</td>
</tr>
<tr>
<td>9:40AM – 10:00AM</td>
<td>Catherine Evans, Dalhousie University</td>
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<tr>
<td>10:00AM – 10:20AM</td>
<td>COFFEE BREAK, 20 MIN</td>
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<tr>
<td>10:20AM – 11:00AM</td>
<td><em>Poster Session</em></td>
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<tr>
<td>11:00AM – 11:20AM</td>
<td>Victoria Currie, Memorial University</td>
</tr>
<tr>
<td>11:20AM – 11:40AM</td>
<td>Alejandro Jaimes, Memorial University</td>
</tr>
<tr>
<td>11:40AM – 12:00AM</td>
<td>Mariah Williams, Saint Mary’s University</td>
</tr>
<tr>
<td>12:00PM – 1:00PM</td>
<td>LUNCH, 1 HR</td>
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<td>12:30 – 1:00PM: Club Presidents/Executive Meeting</td>
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<tr>
<td>1:00PM – 1:20PM</td>
<td>James Cooke, Dalhousie University</td>
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<td>1:20PM – 1:40PM</td>
<td>Liam MacNeil, University of New Brunswick</td>
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<tr>
<td>1:40PM – 2:00PM</td>
<td>Kali Gee, Saint Mary’s University</td>
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<tr>
<td>2:00PM – 2:20PM</td>
<td>COFFEE BREAK, 20 MIN</td>
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<tr>
<td>2:20PM – 2:40PM</td>
<td>Garrett Velkjar, Acadia University</td>
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<tr>
<td>2:40PM – 3:00PM</td>
<td>Juan Chavez, Dalhousie University</td>
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<td>3:00PM – 3:20PM</td>
<td>Brant D. Gaetz, Memorial University</td>
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<td>3:20PM – 4:00PM</td>
<td><em>Poster Session</em></td>
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Redox State of the South Mountain Batholith: A reconnaissance study

Juan Chavez and James Brenan
Department of Earth Sciences, Dalhousie University, 1459 Oxford Street, Halifax, NS, B3H 4R2
Oral Presentation

The late Devonian South Mountain Batholith (SMB) of Southwestern Nova Scotia is the largest plutonic igneous body emplaced during the Appalachian orogeny, with a current surface expression of 73,000 km$^2$. The batholith is composed of 13 distinct plutons that are broadly peraluminous in composition, ranging from tonalite to syenogranite. A parameter that has been particularly difficult to quantify for the SMB is the redox state, as measured by the oxygen fugacity ($f_O^2$), which exerts a profound control on magmatic phase stability, element partitioning, and importantly, the potential for economic mineral deposits. Here we present a redox state survey of mineralised and unmineralised phases of the SMB using the newly-calibrated Ce-in-zircon oxygen barometer. This method combines bulk rock and zircon compositions to calculate apparent zircon/melt partition coefficients for Ce, a parameter which varies with the $Ce^{4+}/Ce^{3+}$ in the melt, and hence oxygen fugacity.

A total of 23 samples were collected and 13 were selected for whole-rock major and trace element analysis and zircon separation based on spatial distribution, mineralogy and preliminary geochemical data acquired by X-Ray Fluorescence Spectroscopy. We obtained 13 samples from the spatially zoned Halifax pluton. From these, 2 samples were taken near the contact with the metasedimentary country rock (Halifax Formation of the Meguma Terrane) to assess how assimilation might influence $f_O^2$. The remaining 11 samples were taken from a contact-to-contact traverse, yielding information on $f_O^2$ evolution during increasing differentiation from contact to core. An additional 7 samples were taken from the adjacent Sandy Lake Pluton from a traverse along Highway 103. The remaining 3 samples were obtained from the New Ross Pluton, which hosts uranium, molybdenum and copper mineralization, and will provide information on the relationship between ore formation and magma redox state. Individual zircon crystals will be selected for trace element analysis by laser ablation ICPMS, following detailed textural characterization. Preliminary results for the New Ross pluton indicate an abundance of euhedral zircons, exhibiting well-developed igneous zoning, but also clear evidence for multiple growth events and the likelihood of inherited cores from older zircon-forming episodes.
History Cast in Stone: The effect of earth on history

James Cooke
Department of Earth Sciences, Dalhousie University, 1459 Oxford Street, Halifax, NS, B3H 4R2
Oral Presentation

I am more of a historian than a geologist so I would like to discuss something more from my wheelhouse. Nowadays we are constantly told about/discuss the influence of people on the earth. For a moment let us discuss times that the earth affected human history, both large and small. Some of the subjects I could touch upon are: war for resources, sudden wealth from resources, and sudden loss of wealth from resources. I’d only do one subject if I have especially limited time.

Saturday November 03 1:00PM – 1:20PM
Dalhousie University, Scotiabank Auditorium
Evaluation of Hercynite and Gittinsite as indicator minerals, Voisey's Bay area, Labrador

Victoria Currie and Derek Wilton
Department of Earth Sciences, Memorial University of Newfoundland, St. John's, NL, A1B 3X5
Oral Presentation

The use of indicator mineral surveys has become a standard mineral exploration tool in surficial sediment-covered regions. The concept for this method is that robust minerals exhibiting distinctive physical and chemical features associated with mineralization, or from alteration associated with mineralization, can survive weathering and erosion. Identifying and examining these minerals, with the knowledge of the direction of sediment transport, may provide a vector back towards the source of mineralization. In this study I am examining two potential indicator minerals, Hercynite and Gittinsite in till and stream sediment samples collected around the Voisey's Bay (VB) Ni-Cu-Co deposit in northern Labrador in a previous study. Hercynite has previously been identified as a common spinel phase associated with the country rock assimilation that ultimately led to the formation of the Voisey's Bay (VB) troctolite-hosted massive sulphide deposits. Hence determination of its presence within a surficial sediment might suggest that the sediment was derived from the erosion of a VB-like deposit. The other indicator mineral to be examined in this study, gittinsite, has been identified as the most common Rare Earth Element (REE) phase in the Strange Lake REE deposit over 100 km to the west of the VB deposit. Hence its presence in surficial sediment may point toward potential REE mineralization. The 31 samples for this study have been analysed using Scanning Electron Microscope - Mineral Liberation Analysis (SEM-MLA) techniques to map and identify any examples of these two indicator minerals and to examine any textures or relationships present. These MLA maps will be used to further examine the mineral chemistry of these grains will be analysed using both the Electron Microprobe Analyzer (EPMA) and the Laser Ablation Inductively Coupled Plasma – Mass Spectrometer (LA-ICP-MS). To confirm that these phases mapped by the MLA minerals in the surficial sediment are “indicator” minerals, hercynite in whole rock samples from the VB deposit, and gittinsite in whole rock samples from the Strange Lake REE deposit will be analysed by SEM-MLA, EPMA, and LA-ICP-MS.
Linking Remotely Sensed Reflectance to Suspended Sediment Stratification in Tidal Channels in Southwest Korea

Catherine Evans and Paul Hill
Department of Earth Sciences, Dalhousie University, 1459 Oxford Street, Halifax, NS, B3H 4R2
Oral Presentation

Satellite imagery can provide information on the spatial distribution of surficial suspended sediment over broad scales in coastal environments. An outstanding challenge is to determine the extent to which surficial sediment distributions can be linked to sediment processes occurring near the seabed. Recent research indicates that dense suspended sediment suspensions at the bottom of tidal channels off the southwest coast of South Korea limit upward turbulent mixing of sediment to the sea surface. The goal of this project is to determine whether this sub-surface sediment process is detectable with reflectance at the sea surface measured by the Landsat 8 satellite. My overall hypothesis is that the magnitude and variance of sea-surface reflectance will be lower in channels than in ridges. This is due to the presence of dense suspensions in channels that limit vertical mixing. On the ridges, this process would not occur, because dense suspensions would flow into adjacent channels under the influence of gravity. As a result, reflectances would be higher and more variable. To assess this hypothesis, Acolite processing software was used to perform atmospheric corrections on Landsat 8 images, and sea surface reflectances at 655 nm and 865 nm were used as proxies for suspended sediment concentration in a total of 15 cloud-free images collected over the years 2013-2018. Reflectance in both bands was extracted over a tidal channel and over an adjacent tidal ridge using SeaDAS. The reflectances from these two points were assessed for statistical correlation with depth and with other environmental variables, including sea level, wind speed, recent precipitation levels and stage in the tidal cycle. Results indicate that the depth exerts primary control on mean and standard deviation of the reflectances, consistent with my hypothesis. Secondary controls on reflectance are wind speed and sea level. I propose that higher windspeeds are associated with larger reflectances due to resuspension over fringing tidal flats and that the correlation of higher water levels with reduced reflectances is caused by sediment supply limitation.
Tectonic evolution of the Northern Block Phyllite Quartzite Group, South Portuguese Zone, Spain

Sean Freeborne and Dr. James Braid
Department of Earth Sciences, St. Francis Xavier University, Antigonish, NS, B2G 2W5
Oral Presentation

The evolution of sedimentary rocks associated with orogenic development potentially records changes in regional tectonics and deformation with time. The geology of Southern Iberia is dominated by rocks that record the amalgamation of Pangea, which formed during the late Paleozoic with the collision between Laurussia and Gondwana. The mid to late Devonian Phyllite Quartzite Group, which are the oldest exposed rocks in Southern Iberia, are thought to be continental shelf deposits deformed during Pangean orogenesis. Therefore, the Phyllite Quartzite Group is an ideal candidate to study the relationship of sedimentation to the evolution of the collision. In order to study these processes related to the formation of the Phyllite Quartzite Group, two field sections were studied in detail. The first section is in the core of the Iberian Pyrite Belt, and is considered to represent a classic example of Phyllite Quartzite deposition. The second, is poorly studied and crops out in the Northern section of an un-mineralized part of the Iberian Pyrite Belt. By studying these sections, we hope to: (i) record the final stages of ocean closure and deformation associated with the formation of Pangea; and (ii) provide important insight into the development of the coeval Iberian Pyrite belt (host to some of the world’s largest copper, lead and zinc deposits). Field observations and detailed structural analysis are complemented by detrital zircon geochronology of various samples and clasts to constrain the potential sources of the metasedimentary rocks, and assess potential changes in deposition with time. Preliminary results suggest that the metasedimentary unit of the Northern section is lithologically distinct from the classic Phyllite Quartzite Group, and indeed may have a genetic link to units not exposed in the Iberian Pyrite Belt. Taken together these observations and data may greatly improve our knowledge of one of the most contentious geologic areas in the world.
Continental shelf offshore Newfoundland comprises a collage of fault bound microplates, assembled during the closure of the Iapetus Ocean and the formation of the Pangea Supercontinent during the Mississippian. These inherited terranes and structural fabrics were later reactivated thru the multiphase rifting of the North Atlantic between 237-66 Ma. Rifting along offshore Newfoundland occurred in three to four transtensional phases which increased basin accommodation space and sediment infill. Each rift phase is represented by distinct tectonostratigraphic packages displaying: (1) Basal rift onset unconformities (ROU) underlying syn-tectonic clastic units which thickening into active fault zones; (2) Back-stepping shore proximal deposits formed during tectonic and thermal subsidence; and lastly (3) Waning post-rift basin deepening often associated with capping carbonate marker units e.g., Petrel, Marker-A, Rankin, Iroquois carbonates. These rifting phases were driven by global plate motions including: (1) Late Triassic to Early Jurassic rifting of Africa away from North America; (2) Middle Jurassic rifting away of Iberia; (3) Late Jurassic to Early Cretaceous oblique rifting of Baltica from the margin including Ireland; and (4) Early Cretaceous to Late Cretaceous extension associated with the opening aulacogen between Baffin Island / Labrador and Greenland.

Recent peer-reviewed dynamic tectonic publications modeled in the @GPlates freeware package, led to interest in the development of an original 4-D dynamic micro-plate model for the MAGRiT geophysical group. This thesis project will provide a needed dynamic tectonic model that can simulate the microplate motion, and deformation patterns along the North American borderlands of offshore Newfoundland. The model is constructed to be infinitely expanded upon by future researchers as interpretations become more refined, and future datasets become available. This model will improve visualization and constrain the timing and distribution of structures, providing better control on the spatial-temporal relationships for of hydrocarbon source units, reservoir facies, and evolution of structural & stratigraphic traps, aiding future hydrocarbon exploration along the margin. This study focuses on the deformable North American plate margin with implications for Mesozoic basin evolution and contributes key detailed spatial – temporal tectonic stress information to refine global plate motions across relevant conjugate margin pairs e.g. Ireland and Iberia.
Origin of epithermal-style gold mineralization in the eastern Cobequid Highlands, Nova Scotia: constraints from S isotopes and pyrite trace element chemistry

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Oral Presentation

Within the northeastern Cobequid Highlands, Nova Scotia, recent bedrock mapping, bulk rock geochemistry, and prospecting have identified a potential low-sulphidation epithermal Au system in Late Devonian to Early Carboniferous bimodal, rift-related felsic (Byers Brook formation) and mafic (Diamond Brook formation) volcanics and volcaniclastics. The Warwick Mountain area located in the northwest portion of the Diamond Brook Formation shows the most potential for gold mineralization, with two zones of intense silicified and sulphidized basalt present. Assays show anomalous Au concentrations up to ~660 ppb, as well as anomalous As, Sb, Cd, W, and Hg.

This research aims to (i) characterize the ore mineralogy of the Au occurrences; (ii) determine what generation of pyrite Au mineralization is associated with, and (iii) utilize the trace element and S isotope chemistry of pyrite to establish key events in the paragenesis of the mineralization. Petrographic and scanning electron microscopy (SEM) results document the mineralogy and textural characteristics of pyrite and representative grains of pyrite were investigated further by secondary ion mass spectrometry (SIMS), electron microprobe (EMP), and laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS). SIMS data for Nuttby Mountain showed distinct differences from rim to core with arsenic-poor pyrite cores having a δ34S ranging from -1.8 ‰ to -0.6 ‰ and As-rich rims having a δ34S between -3.0 ‰ and -6.8 ‰. SIMS data from Warwick Mountain showed indistinct differences with arsenic-rich cores having a δ34S ranging from -1.5 ‰ to 0.7 ‰ and As-poor rims had δ34S between -1.9 ‰ and 0.6 ‰. Pyrite from Nuttby Mountains is oscillatory zoned with respect to As, with the highest concentrations of As occurring on the rims of pyrite. Oscillatory zoning is also present in the Warwick Mountain pyrites. Gold maps show some elevated concentrations near and along the rims of pyrite from Nuttby, which together with the S isotope data, suggests that fluid boiling was a key mechanism for gold precipitation. Further additions to this study will include the use of similar methods and techniques to analyze drill core and an additional surface sample from the Cobequid area.
Validation of a recently proposed method for coda wave inversion: A comparison between real and synthetic data

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Oral Presentation

Seismograms and the information that they provide are of crucial importance for understanding the nature of seismic sources and the media through which the waves travel. These waves, in particular coda waves, contain details about the half-space through which they propagate, important for both industry and research purposes. Coda waves make up the tail of seismograms and are typically ignored regarding them as noise as a consequence of unmodelled physics. However, these types of waves are extremely important because they contain information about scattering attenuation which deals with how energy is redistributed when seismic waves interact with heterogeneities within the propagation medium. Understanding this physical phenomenon is fundamental in seismic hazard analysis as well as in the study of rock properties. In addition, they also contain information about intrinsic attenuation which may be used, with other physical measurements, for characterizing important rock properties such as fluid saturation, lithology, permeability or porosity, making attenuation estimation valuable for different areas such as mining or geothermal exploration. Here we apply an inversion linear process, proposed in 2014 by Fielitz & Wegler based on the radiative transfer theory (RTT), to both real and synthetic data to recover parameters related to scattering and attenuation. We show the challenges in the application of this method to a database of hundreds of earthquakes recorded in South-Western Iceland from 2010 to 2011, and how we partly overcome these challenges. We also show how closely we recover the parameters from the synthetic data created by researchers at the MIT Earth Resources Laboratory and the proper changes required to apply the inversion process.
Reconstructing Paleoproductivity in the North Water Polynya Employing Diatom Microfossils

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Oral Presentation

The regional climate of the Arctic and North Atlantic is directly influenced by the properties of ocean water masses. Changes in the sea-surface oceanic conditions can influence marine phytoplankton production, which leaves a biological signature in the underlying seafloor sediments. This project investigates the features of this biological signature through the lens of diatoms; diatoms are the dominant primary producers in many aquatic ecosystems on Earth. Specifically, we are examining this biological signature in the largest and most biologically productive region of the Arctic: the North Water polynya. Polynya's are typically defined by seasonally ice-free conditions in an area bounded by ice. The North Water polynya is recurrently ice-free and in concomitance with its immensity, functions as a refuge for diverse biological communities that have sustained human populations for millennia (e.g. Dorset, Thule, Inuit). Located at the entrance to Nares Strait, between Greenland and the Canadian Arctic Archipelago, the North Water Polynya fosters large seasonal diatom blooms that are the base of the Arctic food web. This project will explore changes in the diatom abundance and species composition during the past 8000 years, using a marine sediment core collected from the region. This project will contribute to estimate temporal changes in primary producer biodiversity, identify tipping points in primary producer communities and infer the parameters under which drastic changes occurred. This project represents the groundwork in understanding how changing climate affects Arctic phytoplankton communities.

Saturday November 03 1:20PM – 1:40PM
Dalhousie University, Scotiabank Auditorium
Using sulfur isotopes to determine the sulfur budget of Brothers volcano, Kermadec Arc, New Zealand

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Oral Presentation

Brothers volcano is an active submarine arc volcano on the southernmost section of the Kermadec-Tonga arc, northeast of New Zealand. The volcano caldera hosts hydrothermal systems in a volcanic arc setting that differ from those hosted in mid-ocean ridges in their fluid chemistry and mineralization due to the more felsic host rock and high magmatic volatile content. Brothers volcano hosts two distinct seafloor hydrothermal systems: a seawater dominated system on the caldera flank and a system dominated by magmatic volatiles at the summit of a resurgent volcanic cone within the caldera. Drill cores from Brothers volcano were collected at various sites within the caldera on the International Ocean Discovery Program (IODP) Expedition 376 from May 5-July 5, 2018. The objective of this study is to determine the sulfur budget in a hydrothermally active arc volcano and to understand mixing relationships between seawater, hydrothermal fluid, and magmatic volatiles. Drill sites from the seawater dominated Northwest Caldera were located near actively-venting black smokers, and thus are believed to represent regions of hydrothermal upflow. Sulfur isotopes can be used to identify the source of the sulfur as well as sulphide mineral precipitation processes. Pyrite and anhydrite from drill core at these sites have been analysed for precise measurements of $^{32}$S, $^{33}$S, $^{34}$S, and $^{36}$S using isotope ratio mass-spectrometry in the Stable Isotope Geobiology Laboratory at the Massachusetts Institute of Technology. The isotope data show a clear distinction between the sulfur isotopic composition of sulfate and sulfide minerals. The combination of $\delta^{34}$S and $\Delta^{33}$S values suggest sulfur disproportionation of magmatic SO$_2$ as the primary control on sulfur cycling within this seawater dominated hydrothermal system.
Characterization of three mineralization styles of the Revenue Au Occurrence, Dawson Range, Yukon Territory, Canada: implications for a large-scale, intrusion related system

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Oral Presentation

The Freegold Mountain Project in the Dawson Range of the Tintina Gold Belt hosts multiple gold showings, including the poorly characterized Revenue Au occurrence. At Revenue, three different mineralization styles are hosted in the Cretaceous-aged (ca. 105 Ma) Revenue Granite: i) early, Cu-Au quartz stockwork, named the Blue Sky Porphyry (BSP), locally overprinted by ii) the polymetallic (Cu-Mo-W-Au-Pb-Zn) WAu (wow) Breccia, which is crosscut by iii) a diatreme Cu-W hydrothermal breccia. The ore and alteration mineral assemblages have been characterized with respect to paragenesis and mineral chemistry (including major, minor, and trace elements) in order to discriminate the different mineralizing events, fingerprint their chemical signatures, and interpret the processes that led to their formation. The BSP is characterized by early quartz-pyrrhotite-chalcopyrite-pyrite±gold veins with trace sphalerite and potassically altered (biotite, K-feldspar) margins, and late stage quartz- chalcopyrite-molybdenite±carbonate veins. The WAu breccia consists of clasts of phyllic altered Revenue Granite and coeval quartz-feldspar porphyry (QFP) dykes hosted in a sulfide-quartz matrix. The sulfide matrix contains massive pyrite-chalcopyrite with late pervasive molybdenite and local occurrences of Bi-rich galena, sphalerite, and pyrrhotite, and trace glaucodot and ferberite-scheelite. The diatreme-hosted hydrothermal breccia consists of a fine-grained chalcopyrite-pyrite±scheelite matrix interstitial to weakly phyllic-altered diatreme clasts with diffuse boundaries. Trace element compositions of chalcopyrite, pyrite and pyrrhotite from the early and late Blue Sky Porphyry and WAu Breccia indicate that the sulfides from each location show unique chemical signatures, with respect to relative Co+Ni, Ag+Au+Te, and W+Sn abundances. Major elements of sulfides and sulfarsenides provided a basis to calculate crystallization temperatures: i) sphalerite with pyrite and pyrrhotite from late stage BSP and WAu Breccia yielded high temperatures of 601°C to 613°C and 610°C to 647°C, respectively, ii) glaucodot from the WAu Breccia gave temperatures of 300°C to 465°C, and iii) arsenopyrite in equilibrium with pyrite gave temperatures from 363°C to 491°C for mineralized QFP dykes.The overprinting mineralization styles of the Revenue occurrence were likely the result of an overpressured system due to the emplacement of granitic intrusions at depth. Similar intrusion related mineralization styles in the Freegold Mountain area suggest that the granitic intrusions were part of a large cooling magmatic system at depth.
Decoupling sources of natural and anthropogenic impact using lake sediment archives: An example from Cecil Lake, Fort St. John, B.C.

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Oral Presentation

Lake sediment archives are an established tool for examining environmental change over time. Cecil Lake is a productive shallow lake located in the Peace Region of Northeastern British Columbia and supports a variety of waterbirds, including a significant breeding population of eared grebes (*Podiceps nigricollis*). The Cecil Lake watershed was originally open grass prairie and muskeg and Bison herds fed on the new growth that was maintained through controlled burns by the Dane-Za. The region was first homesteaded in 1928, making this one of the last areas in North America to be populated by traditional European pioneers. These lands are now almost entirely agricultural and used primarily for the farming of canola and hay, conventional oil wells are also scattered across the countryside. Nearby Fort St. John is highly industrialized and supports a variety of Petroleum handling facilities. The environmental impact of these recent changes is unknown but recent study in other northern industrial centers (Fort MacMurray) suggests substantial regional and atmospheric contributions are possible. The bulk geochemistry of the lake sediment archive at Cecil Lake is being investigated to decouple the natural and anthropogenic impacts on the environment. Three sediment cores were collected in July 2018 using a Glew gravity corer. Stratigraphic variations in bulk geochemistry (metals, δ¹⁵N, δ¹⁵C, Total C, N, poly aromatic hydrocarbons) will be determined. X-ray fluorescence will be used to determine metal concentrations. These data will provide insight into change through time and the total Pb curve will provide temporal control. The results of the analysis will provide further insight into the significance of the impacts of long-range atmospheric transportation of contaminants and regional/local environmental changes. These data will be used to determine the risk to both humans and ecologically significant species such as the eared grebe.
Analysis of precious metal mineralization within the Bald Hill Antimony deposit: a portable X-ray fluorescence study

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Poster Presentation

The volcano-sedimentary rocks of the Annidale Group in the Bald Hill area of south-central New Brunswick has been actively explored for base metals and gold in recent years. As a result of this exploration, significant amounts of antimony and anomalous gold has been discovered along a northwest trending fault zone. To better understand the characteristics of the gold mineralization in the Bald Hill area, pXRF analysis and petrographic examination was completed on core samples. Samples were collected from drill core stored at the NB Department of Energy and Resource Development’s core storage facility in Sussex and chosen from intervals that were enriched in gold based on drill hole assay data. These samples were then analyzed using an Olympus Vanta VMR model pXRF spectrometer. Analyses were run with a count time of 120 s to ensure the reliability of the collected data. The certified reference standards CD-1, DS-1, MA-2C, NIST-2710a, NIST-2711a, SY-4, and a silica blank were analysed at the start and end of work sessions to ensure the accuracy and precision of the collected data over multiple days. The data quality assurance and control (QA/QC) was completed on the data to determine a linear correction factor to correct the data. Since accepted concentrations for standards are recorded in databases, the accepted concentrations can be compared with the recorded concentrations to determine the correction factor. This correction factor was then applied to correct the data for each desired element. With the data corrected, further analysis and interpretation of the data can now be completed to attempt to better understand the gold and silver mineralization within the area.
Investigating the potential for economic mineralization in the Jumping Brook Metamorphic Suite, Cape Breton Highlands, Nova Scotia

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Poster Presentation

The Jumping Brook Metamorphic Suite (JBMS) underlies a large part of the western Cape Breton Highlands east of the village of Cheticamp. It consists of the mainly metavolcanic Faribault Brook Formation overlain by the main metasedimentary Dauphinee Brook Formation. Numerous mineral occurrences are known to occur in the JBMS, including native gold, silver and sulphide minerals including chalcopyrite, arsenopyrite, galena, and sphalerite. The rocks are strongly deformed and hence stratigraphic relationships between the formations of the JBMS and the nature of the mineral occurrences that they contain are poorly understood. The purpose of this study is to further investigate these relationships by examining in detail core from two drill holes, GM-08-08 drilled at 45 degrees to a depth of 50 m by Globex Mining Enterprises Limited in 2008, and FB-01-86/08 drilled vertically to 128 m by Selco BP Resources Canada Ltd in1986 and deepened to 277 m Globex Mining in 2008. The cores will be logged and magnetic susceptibility measured. Representative samples will be taken for thin section preparation and petrographic study to enable definitive identification of rock types. A portable XRF instrument will be used to obtain detailed analysis of chemical variations in the core, and igneous samples will be submitted for whole-rock chemical analysis to investigate chemical affinity and tectonic setting in which the rocks formed. Previous studies have suggested that the mineralization is syngenetic polymetallic volcanogenic massive sulphide (VMS) mineralizing event in MORB-type basalt associated with turbiditic sediments in a back-arc basin, but there is also evidence of epigenetic vein-related mineralization. The area will be compared mineralized rocks units of similar Cambrian-Ordovician age in Newfoundland and New Brunswick. Ultimately, the implications of this research may provide new exploration targets and/or genetic models for the Jumping Brook Metamorphic Suite.
Fluid inclusion systematics of the polymetallic (Co-Ni-As-Au) veins of Nictaux Falls Dam Occurrence, Annapolis Valley, Nova Scotia

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Poster Presentation

A polymetallic (Co-Ni-As-Au) vein system is located within the Nictaux Falls Spillway (44°51’12.5"N, 65°02’01.5"W), Annapolis Valley, Nova Scotia. Variably mineralized, fault-hosted quartz veins occur in the late Silurian Kentville Formation (metasediments), near their contact with the Cloud Lake Pluton of the South Mountain Batholith. Field work and sampling was conducted in late August 2018, resulting in a collection of representative vein samples as well as field observations of vein form and orientation. Multiple generations of subparallel and crosscutting veins were observed hosted within the main fault zone of the property, an east-west striking brittle-reactivated shear zone. Mineralization (predominately cobaltite, CoAsS) is restricted to early, laminated quartz veins surrounded by a later thick vein of milky white quartz breccia containing clasts of metasediment.

Now that suitable vein samples have been obtained, the project will characterize the P-T-X-t characteristics of quartz-hosted fluid inclusion assemblages (FIA) within representative vein styles using i) hot cathodoluminescence imaging to determine the relative timing (e.g. primary vs. secondary vs. pseudosecondary) of the FIA, ii) microthermometry to determine minimum entrapment temperatures, bulk salinity, and isochores for P-T modelling, iii) Raman spectroscopy to identify volatile components within fluids, iv) laser ablation inductively-coupled plasma mass spectrometry to quantify major and trace elements (including potentially metals) content in fluids. The results of this study will aim to i) determine the conditions before, during, and after mineralization, ii) constrain the source of fluids (e.g., metamorphic vs. magmatic vs. meteoric waters) and metals, and iii) classify the occurrence through comparison with similar polymetallic deposits worldwide.
Synthetic 3D CSEM Forward Modeling for Hydrocarbon Exploration Applications

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Poster Presentation

The Marine controlled source electromagnetic (CSEM) method is an exploration tool that is occasionally used within the oil and gas industry to help delineate possible hydrocarbon reservoirs. Marine CSEM is a geophysical method which utilizes Faraday’s and Ampere’s laws to induce currents within the subsurface allowing the resistivity of the subsurface to be measured. This is done by deploying receivers on to the seafloor which measure the secondary electric and magnetic fields that are induced due to the currents that are generated in the subsurface by a high current, low voltage oscillatory waveform source being towed above the seafloor. Marine CSEM is an additional de-risking tool that can be used to determine if a possible target reservoir contains gas or hydrocarbons due to different resistivity response between the two. This tool can be helpful as the typical technique used in reservoir mapping is seismic reflection, which is useful for determining possible reservoirs but lacks in determining if the reservoir is hydrocarbon saturated or gas saturated due to similar amplitude response seen in the seismic data.

I will be using 3D EM forward modeling to determine possible CSEM data based on an Earth Model. My primary focus will be building the appropriate Earth model for a hypothetical hydrocarbon reservoir to be able determine a possible resistivity reading for a typical hydrocarbon reservoir. This Earth model will be designed based on similar reservoirs seen in the Jeanne d’Arc Basin offshore Newfoundland and will be built and refined using the FacetModeller software tool.
Characteristics of epithermal-style gold occurrences at the Goldy and Irene showings, Dawson Range, Yukon Territory, Canada: towards a first model

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Poster Presentations

The objective of this study is to characterize and compare epithermal quartz-Au-sulfide vein mineralization that occurs on Triumph Gold Corporation’s Goldy and Irene showings in the Dawson Range, Yukon Territory. Specific goals of the study will be to (i) determine if the two showings constitute part of a single hydrothermal system that had several mineralizing centers along common structures or in relation to a common heat source, (ii) to determine the fluid characteristics and crustal depth of the gold mineralizing process(es), and (iii) to characterize the mineralogy expressed at the showings leading to a classification of the P-T regime of the mineralization.

Both mineral showings contain economically significant concentrations of gold in quartz-sulfide veins that are focused along fault-modified contacts between the metamorphic rocks of the Yukon Tanana Terrane and intrusive bodies that are Jurassic to Cretaceous in age. The Goldy showing comprises a roughly 160 x 160 metre elliptical area of quartz-carbonate veining at a contact between biotite schist/gneiss and Jurassic syenite. The Irene showing, located 9.5 km NW of Goldy, comprises a greater than 3-metre-thick quartz-sulfide vein exposed over 150 metre strike-length at a contact between biotite schist/gneiss and biotite-hornblende granodiorite to granite of probable mid- to late-Cretaceous age. At both showings, roughly fault/contact-parallel quartz-feldspar-porphyry dykes are present and are interpreted to occur along segments or splays associated with the regionally important Big Creek Fault.

Preliminary petrographic microscopy, BSE-SEM, and electron probe analysis have identified the following key similarities between the two showings, suggesting a genetic kinship: (i) the mineralize assemblage consists of electrum-arsenopyrite-pyrite-boulangerite-tetrahedrite/tennantite-stibnite-galena, reflecting an ambiguous (both low and high) sulfidation epithermal signature; (ii) arsenopyrite thermometry (by electron microprobe) shows a very similar, and high, crystallization temperature for the earliest mineral assemblages in the veins (Irene: 380-430 °C; Goldie: 390-430 °C). This mineralogical work will be complemented by fluid inclusion analyses (petrography and microthermometry) of the vein-hosted minerals, in order to constrain fluid composition and origin, as well as the crustal depth and temperature of the mineralizing event(s). The value of this study will be to ultimately establish robust geochemical criteria to aid in mineral exploration within this under-characterized region.
The mineralogy, paragenesis, and petrogenesis of the polymetallic (Co-Ni-Au-Ag-Bi) veins of the Nictaux Falls Dam Occurrence, Annapolis Valley, Nova Scotia

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Poster Presentation

Mineralization of the Nictaux Falls Dam Occurrence occurs in predominantly fault-hosted quartz veins that crosscut Silurian-aged metasediments of the Kentville Formation, near their contact with the Cloud Lake Pluton of the late Devonian-aged Southern Mountain Batholith (SMB). Fieldwork and mapping conducted in September 2018 indicates that barren quartz veins post-date the SMB; however, no crosscutting relationships were observed between the mineralized (predominantly cobaltite) veins and the SMB or other lithologies exposed on-site (felsic dykes, diabase sills, and gabbroic intrusions). Mineralization is constrained to the middle of the main fault zone where early, laminated quartz-cobaltite veins occur in quartz breccia veins that contain angular metasediment clasts. Drag folds were observed at the eastern (unmineralized) end of the fault, suggesting that the fault may have initiated as a ductile shear zone and was reactivated as a brittle fault zone during hydrothermal, mineralizing activity. The far western end of the fault diffusely disappears near the contact with the SMB. Samples were collected from representative areas (mineralized and barren veins, and exposed lithologies) for petrographic thin sections and bulk rock geochemical analysis, in order to characterize their mineralogy and geochemistry. Using field observations, petrographic methods, bulk rock geochemistry and microanalytical techniques (e.g. electron probe microanalysis for major elements and laser ablation inductively coupled plasma mass spectrometry for trace elements and absolute age dating) this project aims to resolve: i) the mineralogical characteristics and paragenesis (including distribution of Au and relationship to Ni-Co) of mineralization, ii) the timing of veins with respect to the SMB, and iii) conditions (PTxT) of vein formation including the age of mineralization and source(s) of metals.
Comparing CO2 sequestration experimental methods and investigating CO2 sequestration using Type I and Type II serpentine groundwaters

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Poster Presentation

In situ sequestration of CO2 in tectonically exposed mantle peridotite is a potential long-term sink for atmospheric CO2. Atmospheric carbon dioxide is a prominent greenhouse gas that can be sequestered when groundwater reacts with ultramafic rocks during a process known as serpentinization. This hydrothermal alteration occurs naturally in ophiolites; sections of ocean crust and upper mantle that have been emplaced onto a continental plate causing uplift and exposure above sea level. The Tablelands in Gros Morne National Park, Newfoundland is the site of investigation. The objective of this study is to determine the ideal experimental apparatus for CO2 sequestering experiments. The accuracy of the LICOR Flux chamber and CO2 gas analyzer will be compared to similar experiments performed in a sealed glass bottle whereby the concentration of CO2 will be analyzed by a gas chromatograph (GC) with a Flame Ionization Detector (FID). Once the ideal apparatus is determined, CO2 sequestering experiments will be conducted, comparing simulated Type I waters (i.e., Mg-, OH-rich waters with a pH of 10) and Type II waters (i.e., Ca-, OH-rich waters with a pH of 12) that occur at sites of serpentinization. Initial experiments with just Type II waters sequestered 349 ppm of CO2 in 3 hours. The CO2 sequestration rates and the mechanism of CO2 sequestration will be determined using peridotite samples from the Tablelands.
An Experimental Study of Reaction Textures of Volcaniclastic Kimberlites to Determine their Emplacement Process

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Poster Presentation

Some of the most famous diamond deposits are associated with Kimberly-type volcaniclastic kimberlite facies (KPK) located within the diatreme part of the kimberlite pipes. The emplacement process of this type of kimberlite is still highly debated around the world. The two contemporary models suggest either 1) explosive pyroclastic eruption with subsequent welding of the pyroclasts or 2) in-situ magma fragmentation without formation of a pyroclastic deposit. The latter model suggests that a reaction between silicate fragments of the country rock and carbonatitic magma exsolves CO₂ causing the magma fragmentation and freezing. The study will test the two hypotheses by examining the reaction of granitoid and basaltic xenoliths with carbonate-rich kimberlite magma whose composition will be similar to that of Anaconda hypabyssal kimberlite dyke located on Ekati property, Northwest Territories, Canada. Experiments will be conducted at 0.1 MPa in a box furnace to explore the effect of temperature and cooling rate on the textures and the sequence of the reaction minerals. The developed reaction mineral phases, their textures, and the reaction with the xenoliths will be compared to the textures of natural KPK in BK1 kimberlite from Orapa kimberlite cluster, Botswana.
Mineralogy, porosity, and provenance of Upper Jurassic reservoir sandstones in Mizzen F-09 drillcore, Flemish Pass Basin, offshore Newfoundland

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Poster Presentation

The Flemish Pass Basin is located 450km east of St. John’s and is a highly faulted, syn-rift area. The basin is thought to be of similar origin to the producing Jeanne d'Arc Basin, but has been relatively unexplored in comparison. The aim of this thesis is to compare the Flemish Pass Basin to the Jeanne d'Arc Basin by studying the mineralogy, porosity, and provenance of the Mizzen F-09 strata. The evaluation of the Mizzen F-09 well will help to improve our understanding of the stratigraphy and reservoir quality of the Upper Jurassic strata in the Bodhrán formation (informal) located in the Flemish Pass Basin. The goals of this project will be to (1) describe and log the 60 metres of core and to create a stratigraphic section, (2) prepare the samples from the core for further analysis, and (3) analyze the prepared samples using SEM-MLA techniques. The data that will be collected will be used to help evaluate the economic potential of the F-09 well and of the Bodhrán formation sandstones. A comparison will also be made between the Mizzen F-09 well and the K-19 well in the Jeanne d'Arc Basin. It is thought that the sandstone units of the Flemish Pass Basin are correlative with producing reservoirs of the Jeanne d'Arc Basin. The comparison will help to determine if the source areas have predictable mineralogical and porosity characteristics.
Numerical and Experimental Observation of Nonlinear Responses from the Interaction of Two Progressing Waves at an Interface

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Department of Earth Sciences, Memorial University of Newfoundland, St. John's, NL, A1B 3X5
Poster Presentation

The nonlinear response of sedimentary rocks has been an ongoing area of research in recent years due to information it can reveal about reservoir porosity, fractures, and pore fluids. We attempt to observe numerically and physically a nonlinear response, generated at an interface between two different nonlinear media (e.g. reservoir rocks) due to the interaction of two acoustic waves at that interface, proposed theoretically by previous authors. It is thought that this response could be used in the future as a new way of mapping the reservoir properties mentioned previously. We first model two waves interacting at an interface both to see if we can observe the response numerically, and also see what parameters to use in physical experiments. The nonlinear response is demonstrated by numerical modelling and thus the project progressed to physical experiments. In the experimental aspect of the project, we use high-frequency transducers as sources for the waves with an interface made between several different nonlinear materials (e.g. gelatin, water, salt brine). Two different receiving mechanisms were explored, a vertical array of transducers identical to the sources and a Polytec laser vibrometer positioned on a motorized slider, programmed to incrementally traverse across the media. The magnitude of the response varied between different materials, as expected. We have met the objective of the project by observing this response physically, which opens up a new line of work to both characterize these waves when produced from different materials, and also to perform the experiment with sedimentary rocks for a more realistic analogue to hydrocarbon reservoirs.
The illegal mining of lapis lazuli, a bright blue semi-precious mineral aggregate, in Afghanistan is fuelling conflict in the region, with half of illegal mining revenue going to insurgent groups. There are other lapis lazuli deposits located in Chile, Tajikistan, and Russia and, depending on the origin of the sample. The ore contains differing quantities of lazurite, pyrite, and other minerals within the lapis matrix. This study is a pilot project to determine if the origins of the lapis lazuli can be effectively pinpointed using techniques such as transmitted and reflected light microscopy, X-ray diffraction, and electron microprobe. A Chilean sample was characterized and compared to samples sold as Afghan. The results from our X-ray diffractogram confirm our thin section analysis, in which the peaks for Chilean sample indicate the presence of lazurite, wollastonite, and pyrite, and the peaks for the Afghan sample indicate the presence of lazurite and diopside. Electron microprobe analysis of lazurite and pyrite from the two “Afghan” samples indicate they came from different mines within the same region. The lack of wollastonite demonstrates that they are not from Chile. Reflected light microscopy verified that the pyrite samples contain no alteration which is characteristic of Russian lapis lazuli. The nickel content in the pyrite, as analyzed by the electron microprobe, fit into the parameters for potential Afghan provenance; however, copper content was below detection limits, and therefore could not be distinguished as Afghan or Tajik (Lo Giudice et al. 2016). More work is necessary to characterize the pyrite chemistry in order to determine potentially significant conflict origins.
Fluid inclusion and textural evidence of boiling in the epithermal veins in the Cobequid Highland

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Poster Presentation

Low-sulphidation epithermal Au mineralization has been the focus of recent bedrock mapping, geochemical and geochronological studies in the northeastern Cobequid Highlands, Nova Scotia. Mineralization is hosted in Late Devonian to Early Carboniferous bimodal, rift-related felsic (Byers Brook formation) and mafic (Diamond Brook formation) volcanics and volcaniclastics. The Warwick Mountain area located in the northwest portion of the Diamond Brook Formation shows the most potential for gold mineralization, with two zones of intense silicified and sulphidized basalt present. Assays show anomalous Au concentrations up to ~660 ppb, as well as anomalous As, Sb, Cd, W, and Hg. A key question in this epithermal setting is "Has boiling occurred, what is the evidence for this potentially important mechanism for gold mineralization?" To answer this question, representative samples of epithermal veining were obtained from the only two diamond drill holes targeting this mineralization style, (Colchester county, NS; (R and J Drilling Ltd for Sugarloaf Resources Incorporated). The specific goals of the research are to (i) characterize vein textures (quartz-carbonate intergrowths) using established criteria for boiling vs. rapid boiling (flashing) vs. non-boiling systems, and (ii) and utilize fluid inclusions to constrain conditions such depth, fluid salinity, and fluid temperature during, prior to, and after mineralization. Boiling textures are typically associated with the presence of ore elements (Au, Ag, Cu, Pb, Zn, As, Hg and Sb). Mineral and fluid inclusion textures such as colloform and plumose quartz, lattice bladed calcite (± replacement by quartz), as well as coexisting liquid-rich and vapour-rich fluid inclusions are definitive characteristics of boiling. These will be investigated by petrographic microscopy. With fluid inclusion micro-thermometry, the P-T-X characteristics will be determined. This study will help refine ore exploration models in the Cobequid highlands. From initial petrographic analysis, boiling textures have been identified in some areas of the drill core but not all, suggesting that distinct boiling "horizons" existed. The relationship between these and gold mineralization is unknown but will be investigated.
Chemical signatures and cathodoluminescence of multiple generations of apatite within the Mactung W (Cu, Au) skarn deposit, Northwest Territories: implication for the evolution of skarn fluids

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Poster Presentation

In order to understand the evolution of the Mactung deposit, and constrain chemical signatures of mineralizing fluids, multiple generations of apatite were characterized using classical petrographic techniques, hot cathodoluminescence (CL), and laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS). Representative skarn samples were collected from each stratigraphic unit of the deposit and examined for apatite. Apatite occurred in all stratigraphic units and skarn types studied, including pyroxene-pyrrhotite, garnet-pyroxene, pyroxene, pyrrhotite and amphibole skarn. Textural evidence suggests that at least some apatite formed through the recrystallization of detrital collophane, as apatite were commonly distributed around partially dissolved phosphate nodules. Apatite was paragenetically early and coeval with scheelite and titanite. Apatite exhibits five texturally distinct fluorescence colours under CL: i) irregular masses at the cores of oscillatory zoned apatite fluoresced light to dark grey, ii) the interior of oscillatory zoned apatite fluoresced blue, iii) the interior and/or rims of oscillatory zoned apatite fluoresced green, iv) the rims of oscillatory zoned apatite and entire unzoned crystals fluoresced yellow, and v) small patches of altered apatite rims fluoresced orange. Preliminary LA-ICP-MS data show that the different coloured fluorescent apatite have distinct rare earth element (REE) abundances. Dark grey apatite showed relatively low total REE contents (~590 ppm ∑REE, La-Lu), with relatively high LaN/YbN = 33 and negative Eu anomaly (Eu/Eu* = 0.4; where Eu* = \sqrt{Sm*Gd*}). Green apatite contained moderate REE contents (average 1170 ± 180 ppm, 1σ; n = 14), with LaN/YbN = 7 (± 3, 1σ) and Eu/Eu* = 0.6 ± 0.1. Yellow apatite contained high REE contents (average 2130 ± 640, 1σ; n = 23), with LaN/YbN = 4 (± 2, 1σ) and Eu/Eu* = 0.4 ± 0.1. Orange apatite showed the highest concentration of REE (average 4040 ± 130 ppm, 1σ; n = 2), with LaN/YbN = 1.83 (± 1, 1σ) and Eu/Eu* = 0.1 ± 0.0. These preliminary results indicate that the breakdown of collophane likely influenced the HREE abundance of green apatite. As more data is collected, apatite compositions will be used to describe the evolution of skarn fluids.
Investigating the Barra Volcanic Ridge System and overlying Paleogene sills in the Rockall Basin using seismic reprocessing and potential field modelling

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Poster Presentation

The conjugate Irish Atlantic and the Orphan Basin/Flemish Cap margins are both considered non-volcanic margins formed from continental breakup of North America and Europe during the Triassic-Cretaceous, and resulted in the North Atlantic Ocean. The focus of this study is on the Irish Rockall Basin, which is one of several large, deep water sedimentary basins in this region. Although both margins are classified as non-volcanic, they both exhibit significant magmatism formed during late stages of rifting. The Barra Volcanic Ridge System is identified as a young Cretaceous volcanic structure having three large ridges and is suggested to be an important example of the volcanism in the Rockall Basin. These Barra volcanics involve Paleogene sills making it difficult for sub-sill imaging due to the high reflectivity contrast between the sediments and overlying sills. New regional seismic reflection data were provided by the Petroleum Affairs Division of Communications, Climate Action and Environment, Government of Ireland. The reflection line will be seismically reprocessed to produce an enhanced understanding of the BVRS and overlying sills. The line will be seismically interpreted with support from 2-D reflectivity, gravity and magnetic modelling.
The aim of this study is to document the type and abundance of indicator minerals in till at varying distances down ice from the East Kemptville tin deposit, as an aid to tin exploration in glaciated terrain. Southwestern Nova Scotia is covered by a thick, nearly continuous sequence of till deposited by multiple ice-flows during the Wisconsinan glaciation. This sediment cover produced complex geochemical dispersal patterns and represents a challenge to mineral exploration in this region. The greisen-hosted East Kemptville tin deposit is one of many granite- and metasedimentary hosted Sn, W, Mo, Zn, Pb, Cu, Ag and In prospects that comprise the Southwestern Nova Scotia Tin Domain. Detailed knowledge of glacial dispersal patterns is required to effectively plan and implement exploration strategies for mineral occurrences in southwestern Nova Scotia. In this study, indicator mineralogy and surficial geochemistry will be employed together with a re-examination of existing research to evaluate how regional and local ice-flow dynamics have influenced the dispersal of mineralization from the East Kemptville tin deposit. These data can be used to better understand and potentially locate occurrences both locally and elsewhere in similar geological settings.
Cooling history of a failed rift margin – new insights from (U-Th)/He thermochronology along the Labrador passive margin

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Poster Presentation

The Labrador Sea is the result of a failed rift system between Labrador and Greenland. The initiation of rifting has been attributed to the Late Triassic to Jurassic (223–150 Ma) based on Rb-Sr and U-Pb dating of dike emplacements in southwest Greenland. Less magmatic activity from rifting has been found on the Labrador side with the oldest ages determined through fossil evidence of a diatreme yielding Early Jurassic–Early Cretaceous ages (197-145 Ma). There is still ongoing debate on the initiation of spreading, which represents the end of rifting. The oldest undisputed evidence of oceanic crust formation has been dated to 63.0 ± 0.7 Ma correlating to magnetic anomaly polarity Chron C27. Older ages have been attributed to 72.1 Ma (Chron C32) for Southern Labrador and 66.0 Ma (Chron C28) for northern Labrador. Cessation of spreading has been determined stratigraphically to the late Eocene to early Oligocene. The asymmetry of magmatism, bathymetric/topography, sediment distribution and crustal structure along both margins suggests a lithospheric scale simple shear model of rifting. Low temperature thermochronometry includes a range of methods used to retrieve the thermal history of the uppermost crust, allowing to date and identify tectonic, magmatic and/or surface processes that have contributed to this thermal history. In this study, five bedrock samples were collected along a 200 km transect along the Labrador passive margin between Nain (56.5417°N, 61.6969°W) and Hopedale (55.4580°N, 60.2115°W). Samples will be dated using apatite and zircon (U-Th)/He thermochronometry, with closure temperatures of 70°C and 170°C, respectively. We expect to quantify the crustal cooling of the margin and identify the processes driving it. If rifting ages (Jurassic – Early Cretaceous) are obtained from our samples, we expect those to be consistent with diachronous rifting from south to north yielding progressively younger ages northwards. Alternatively, if much younger ages (Quaternary) are obtained, we expect a more uniform distribution along the Labrador margin, which could be attributed to glacial erosion generated by the Laurentide Ice Sheet which covered most of Canada including Labrador.
Awards

1. The Science Presentation and Communication Award
2. The Imperial Oil Best Poster Award
3. The Canadian Society of Petroleum Geologists Award
4. Canadian Society of Exploration Geophysicists Award
5. The Frank S. Shea Memorial Award
6. The Atlantic Geoscience Society Award – Focus on Environmental Geoscience

1. The Science Atlantic Presentation and Communication Award

The Science Atlantic Presentation and Communication Award is given for the best overall student paper on any geoscience topic presented orally at the annual AUGC (Atlantic Universities Geoscience Conference).

Judging

The award is judged primarily on the basis of the scientific quality of the topic, the amount of original work done by the student, and his/her understanding of the subject.

Evaluation criteria include:
- Abstract – Clear statement of problem, objectives, principal findings
- Presentation – Clarity, visual aids, organization
- Scientific merit – Experimental design, innovative approach, and interpretation of data
- Understanding – Overall knowledge and response to questions

The award will be judged by a panel of at least 3 qualified judges with diverse geoscience expertise as described under judging above.

The Award

The award consists of a monetary prize and letter of commendation for the presenter, as well as a plaque that will reside at the winner’s university for one year, after which the winner’s university is responsible for bringing the plaque to the next annual conference. The award is usually presented by a representative of the Science Atlantic Earth Science Committee at the annual banquet of the AUGC.

Sponsor Information

This award (previously known from 2004-2012 as the APICS-NSERC Award) is the AUGC version of the Science Atlantic Undergraduate Research Award and Communication Award offered at all
Science Atlantic-sponsored conferences. The Communication part of the award is sponsored by Canadian Science Publishing. A separate Communication Award is not offered at AUGC.

2. The Imperial Oil Best Poster Award

The **Imperial Oil Best Poster Award** is given to the student presenting the best overall student poster on any topic at the annual AUGC.

**Judging**

The award is judged primarily on the basis of the scientific quality of the topic, the amount of original work done by the student, and his/her understanding of the subject.

Evaluation criteria include:

- **Abstract** – Clear statement of problem, objectives, principal findings
- **Poster design** – Clarity, organization, visual appeal
- **Scientific merit** – Experimental design, innovative approach, and interpretation of data
- **Understanding** – Overall knowledge and response to questions

The award will be judged by a panel of at least 3 qualified judges with diverse geoscience expertise as described under judging above. When a representative of Imperial Oil is present, he/she will take the lead in judging this award.

**The Award**

The award consists of a monetary prize for the student presenter.

**Sponsor Information**

Imperial Oil has sponsored this award since 2007. Imperial Oil recognizes that business success depends on the economic, social, and environmental health of the communities where they operate and views community investment not simply as a responsibility, but as an essential component in building a strong society. Imperial Oil gives back to local communities through financial contributions, in-kind donations and volunteer efforts, and supports scientific research with a number of awards and sponsorship.

3. The Canadian Society of Petroleum Geologists Award

The **Canadian Society of Petroleum Geologists Award** is awarded annually for the best presentation of a petroleum geology-related paper at the annual AUGC. If the winner of the
Science Atlantic Best Paper Award gave a petroleum geology-based presentation, then the CSPG award will go to the petroleum geology-based paper judged to be next best.

**Judging**

The award will be judged by a panel of at least 3 qualified judges with diverse geoscience expertise as described under judging above. When a CSPG representative is present, he/she will take the lead in judging for the award.

**The Award**

A plaque, as well as a monetary prize is presented to the winner at the AUGC banquet, preferably by a CSPG member or representative. The plaque will reside at the winner’s university until the next AUGC, when the winner’s university is responsible for bringing the plaque to the next conference.

**Sponsor**

The Canadian Society of Petroleum Geologists sponsors this award. Founded in 1927, the mission of the Society is to advance the professions of the energy geosciences – as it applies to geology; foster the scientific, technical learning and professional development of its members; and promote the awareness of the profession to industry and the public.

4. Canadian Society of Exploration Geophysicists Award

Established in 2008, the **CSEG Award** is given to the student who presents the best overall geophysics paper at the AUGC conference (typically awarded for an oral presentation; however, poster presentations are also eligible). Geophysics is a diverse discipline with many different areas of study, and this award could be awarded to any student whose work falls under this broad category.

**Judging**

Students will be evaluated on the scientific merit of their work, their general understanding of the material covered and their ability to effectively communicate this to the judges. This award will be judged by the panel of judges chosen by the conference organizers. Ideally one of these judges should have a geophysics background. The CSEG will typically send representatives to attend the conference so if a geophysics judge cannot be found locally then one of these representatives may be asked to judge. The award may not be presented if the judges and the CSEG representatives determine that no presentation fulfills the spirit of the award.
The Award

The award consists of a monetary prize for the student presenter, as well as a plaque that will reside at the winner’s university for one year, after which the winner’s university is responsible for bringing the plaque to the next annual conference. The award is usually presented by CSEG’s representative at the annual banquet of the AUGC. The monetary prize comes from the funds the CSEG commits to the conference. It is a responsibility of the school that hosts the conference to prepare and distribute a cheque for the winning presenter.

Sponsor Information

The Canadian Society of Exploration Geophysicists began in 1949, around the time of the petroleum production boom of the Leduc and Redwater discoveries. As a result of these significant discoveries, there was a need for increased knowledge, skill and professional attributes in the field of geophysics. Today, the CSEG is a thriving organization. CSEG’s mandate is to promote the science of geophysics among its members, especially as it applies to exploration, and to promote fellowship and co-operation among those persons interested in geophysical prospecting.

5. The Frank S. Shea Memorial Award

The Frank S. Shea Memorial Award honours the student making the best presentation regarding an aspect of, or, with implications for economic or applied geology. If the winner of the Science Atlantic Best Paper Award gives an economic or applied geology presentation, then the Shea Award will go to the economic or applied geology presentation judged to be next best.

About Frank Shea

For 27 years, Frank Shea was engaged in mineral resources exploration and development activities in the Atlantic region. For more than 10 years he served as Chief Geologist and division director of the Mineral Resources and Geological Services Division in the former Nova Scotia Department of Mines.

Frank graduated from St. Francis Xavier University in 1954 with a BSc in geology. He continued his studies at Dalhousie University, receiving his Master’s degree in 1958. Frank had a great love for his native province and promoted its welfare by assisting mineral exploration and research projects whenever and wherever he could. He was a strong supporter of educational programs in geology such as the geology field school at Crystal Cliffs near Antigonish and prospector training.

Judging

Student papers are reviewed and judged for content in economic or applied geology or implications for economic/applied geology by a panel of practicing geologists. For practical purposes, this will be done the same panel of judges that evaluates the other awards. If there are
no papers on economic or applied geology deemed worthy during the annual AUGC, the award may not be given.

**The Award**

The award consists of a cheque for the winning student and a $100 cheque for the geoscience club that the student represents.

**Sponsor**

The Mining Society of Nova Scotia sponsors the Frank Shea Memorial Award. Organized in the 1890s to promote the mineral industry, to share technical knowledge, and to encourage fellowship, this Society was one of the founding members of the Canadian Institute of Mining and Metallurgy (CIM), the premier mining organization in Canada.

The Society is pleased to support this award honouring a student, the contributions of Frank Shea, and the economic impact of geology on the Canadian economy.

**6. The Atlantic Geoscience Society Award**

The Atlantic Geoscience Society Award was established in 2015 by the Atlantic Geoscience Society to recognize the best project (talk or poster) at the annual AUGC involving a significant component of environmental geoscience.

**Judging**

Student papers are reviewed and judged for content in environmental geoscience or implications for environmental geoscience by the same panel of judges as evaluates the other awards.

**The Award**

The award consists of a monetary prize to the winning student and a plaque that will reside at that student’s university until the next AUGC.

**Sponsor**

The Atlantic Geoscience Society exists to promote a better and wider understanding of the geology of Atlantic Canada, both to its members and to the public. An entirely volunteer association, the AGS brings together earth scientists from universities, government institutions, the environmental, mining and petroleum industries, and consultants in the Atlantic Province.
Field Trip Guide #1

Triassic / Jurassic Geology and Paleontology – Parrsboro Shore

Atlantic Universities Geoscience Conference, Field Trip Guide
Friday November 2, 2018
Dr. Tim Fedak, Nova Scotia Museum tim.fedak@novascotia.ca
Adjunct Professor, Dalhousie Department of Earth Science

During this field trip, we will be visiting Wasson Bluff, a site with stunning exposures of complex tectonics, sedimentation and important vertebrate fossils spanning the geologically significant Triassic Jurassic boundary. Diverse assemblages of vertebrates, including the oldest dinosaurs in Canada, continue to be found in this active research site of the Fundy Geological Museum. The field trip will include a brief visit to the Museum as well as a visit to the Carrs Brook fossil site. The field trip will also incorporate the use of online maps in order to explore new options for using online maps during guided field trips.

**NOTE:** The timing of trips to the Bay of Fundy requires careful attention to the tides. The Bay of Fundy tides along the Parrsboro shore expose vast intertidal areas (up to 1 km) at low tide, however, high tide can block passages along beach headlands. The field site we are visiting is usually only accessible until 2.5 hours before and after high tide.

**Friday, Nov. 2:** Tide in Parrsboro will be high (11.9 m) at 8:26 am, low (1.7 m) at 2:30 pm.

Bring your cameras! October and November are the most beautiful times to visit the Bay of Fundy. The fall colours may still be vibrant, and the clear skies of the fall weather can provide excellent visibility across the Minas Basin. This trip will include sites within the Cliffs of Fundy Aspiring Global Geopark, ([http://fundygeopark.ca](http://fundygeopark.ca)) and include some of the most stunning geology landscapes in the world.

**Cautions:**
- Caution should be observed when approaching cliffs, with active erosion posing dangers of falling rocks or debris. Hard hats are recommended when near cliff exposures.
- Beach areas include slippery cobbles. Sturdy footwear is recommended.
- It is always cooler along the coast. Prepare for cool wind and chance of rain (or snow).

**Schedule and Stops**

<table>
<thead>
<tr>
<th>Time</th>
<th>Activity</th>
</tr>
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<tbody>
<tr>
<td>7:30</td>
<td>Depart - Life Sciences Centre parking lot</td>
</tr>
<tr>
<td>8:45</td>
<td>(15 min) Stop at Masstown</td>
</tr>
<tr>
<td>10:00</td>
<td>Arrive Fundy Geological Museum, Parrsboro</td>
</tr>
<tr>
<td>11:30</td>
<td>Arrive at Wasson Bluff site</td>
</tr>
<tr>
<td>1:45</td>
<td>Leave Wasson Bluff</td>
</tr>
<tr>
<td>2:15</td>
<td>Leave Fundy Geological Museum</td>
</tr>
<tr>
<td>3:00</td>
<td>Arrive at Carrs Brook fossil site</td>
</tr>
<tr>
<td>4:15</td>
<td>Depart from Carrs Brook fossil site</td>
</tr>
<tr>
<td>6:00</td>
<td>Arrive back - Life Sciences Centre parking lot</td>
</tr>
</tbody>
</table>

**Special Places Protection Act**

Collecting fossils anywhere in Nova Scotia without a permit is prohibited. Learn more by searching for Special Places at [http://novascotia.ca](http://novascotia.ca)
Geological Context

This field guide is provided to convey features that will be observed on the field trip to the Parrsboro shore. The guide is intended to provide context and compliment field observations. For those interested in learning more about the geological and palaeontology of the Triassic and Jurassic deposits of the Bay of Fundy, please consult Sues and Olsen (2015).


The Fundy Basin, Newark Supergroup

During this field trip we will be visiting the rich fossil outcrops of the Early Jurassic, McCoy Brook Formation, Fundy Rift Basin. The Fundy Basin is the most northern and largest exposed of the Newark Supergroup series of rift basins formed during the break up of Pangaea (Figure 1).

![Figure 1](Previous Page): Paleo-reconstruction of the Central Atlantic and syn-rift basin distribution at approximately earliest Jurassic time prior to breakup. The dashed line indicates the approximate limits of the early Jurassic tropical region (Olsen & Kent 1996; Whiteside et al. 2011). Modified from Olsen & Et Touhami (2008).

During the past forty years, the rift basins of the Newark Supergroup have played an important role in the establishment of the Early Mesozoic terrestrial timescale. Olsen and colleagues have established a finely tuned astronomically based sedimentary timescale by documenting cyclical changes in sedimentation occurring in the rift basins attributed to planetary changes in orbit,
procession and precession. Stratigraphic correlations are also achieved through analysis of paleomagnetism (chrons), as well as radiometric and geochemical analyses of the basalts that occur in are found across the Newark Supergroup.

The basalts within the Newark Supergroup and related basalts along the margins of the Atlantic, represent the rapid emplacement of the Central Atlantic Magmatic Province (CAMP), during the break up of Pangaea (Figure 1 Insert). The CAMP basalts represent the largest (by area) igneous province in the geological record. During the emplacement of the basalts in the Late Triassic and Early Jurassic, the flood basalts covered an area estimated at 11 million km$^2$. The end-Triassic mass extinction event has been linked to the rapid global climate change resulting from the CO2 released from this large igneous province.

Within the Fundy Basin there are several interconnected rift basins units, including the main Fundy Basin, the Chignecto Subbasin, and the Minas Subbasin that we will be visiting (Figure 2). The main (Fundy Decollement) rift fault is located parallel to the New Brunswick shoreline. Along this NE-SW striking fault, the eastern edge dropped during repeated tectonic extensional events throughout the early Mesozoic, forming the deepest part of the Fundy Basin sediments. Elsewhere in the Fundy rift basin, especially along the northern shore of the Minas Basin, we see a series of left-lateral fault displacements due to this same extensional fault system.

Similar to the rift basin in East Africa today, the Mesozoic rift basins formed deep lowland valleys where high sediment accumulation rates provide opportunities for preservation of trace and body fossils. Faulting along the margins of the rift basin occurred throughout the Triassic and Jurassic, as Pangaea continued to break apart. The deepest portion of the Fundy rift basin exceeds 3000 m based on seismic profiles from the middle of the Bay of Fundy off the coast of New Brunswick (Wade et al., 1996).

Within the Fundy rift basin, the deposition of Mesozoic strata was controlled by tectonic intervals that caused abrupt changes in sedimentary regimes otherwise driven by climate. There are four tectono-stratigraphic (TS) units defined within the Fundy Basin (Figure 3; Olsen, 1997), including the lowermost Early Triassic Wolfville Formation (TS II), the Late Triassic Blomidon Formation (TS III), the North Mountain Basalt, and overlying McCoy Brook Formation (TS IV). We will not see any of the Wolfville Formation during this trip, but there are very interesting outcrops that we drive on the way to Parrsboro at Carrs Brook of possible Middle Triassic age.
Figure 2. Fundy Basin and related subbasins. Modified from Brown and Grantham, 1992.

Figure 3: Tectonostratigraphic (TS) architecture of the Newark Supergroup basins, Eastern North America. Olsen (1997); Olsen & Et Touhami (2008).
We will be visiting Wasson Bluff, where there are several small micro-basins separated by large faulted horst blocks (Figure 4). The tectonic features at Wasson Bluff are very complex, and the site has become a popular destination for petroleum geologists as the site allows shoreline exposures of the complex fault architecture. The focus of our trip will be on the lower portion of the McCoy Brook Formation, the lacustrine Scots Bay Member, which is also referred to as the “fish bed” unit and a third site where sandstone is among basalt boulders.

Blomidon Formation

A small portion of the Late Triassic Blomidon Formation will be seen in the field at Wasson Bluff, but we will not spend a lot of time looking at this section. The palynologically-defined end-Triassic Extinction can be delineated in other areas where the uppermost section of the Blomidon Formation is well exposed (Five Islands and Partridge Island). Within 20-30 centimeters below the contact with the overlying North Mountain Basalt, there is a palynological fern spike. The presence of the palynologically-defined end-Triassic Extinction 20 cm below the North Mountain Basalt had been problematic in establishing a causal link between the emplacement of the CAMP and the end-Triassic extinction. The cause could not occur after the event. However, the puzzle has recently been resolved by using very high-resolution stratigraphy techniques that combine astrochronology, geochemical and radiometric (Zircon U-Pb) techniques (Blackburn et al. 2013). The CAMP basalts were deposited in four pulses over an approximate 600,000 year period. The oldest CAMP flood basalts occur in Morocco, and the emplacement of the North Mountain Basalt began several thousand (3-10k) years afterwards.

North Mountain Basalt Formation

The North Mountain Formation is a fissure-erupted tholeiitic basalt that occurs across the entire Fundy Basin, and represents the Fundy Basin portion of the CAMP. Outcrops of the North Mountain Basalt can be seen around much of the Bay of Fundy shoreline; Grand Manan Island (NB), south-shore from Digby to Scots Bay, Cape Split, and along the northern shore of the Minas Basin at Five Islands, Wasson Bluff, and further west at Cape d’Or. Its maximum thickness onshore (near Digby) is 300 metres, though it is about 1000 metres just east of Grand Manan Island as determined from seismic data (Wade et al., 1996).

McCoy Brook Formation

Directly overlying the North Mountain basalt, the McCoy Brook Formation represents over 200 m of earliest Jurassic lacustrine, fluvial, and aeolian sandstones (Tanner, 1996), and offshore is at least 3000 m thick (Wade et al., 1996). The lowermost portion of the McCoy Brook Formation is the Scots Bay Member, named by the type section at Scots Bay. The Scots Bay Member represents lacustrine facies and at Wasson Bluff it is referred to as the “fish-bed”. Scots Bay Member sediments are in direct contact with the upper surface of the North Mountain Basalt at Wasson Bluff.
Stratigraphically above the Scots Bay Member, the McCoy Brook Formation includes thick +1m mudstone and sandstone facies, and progressing to aeolian dunes higher in the section. The Fundy Rift Basin continued to remain tectonically active during and after the emplacement of the McCoy Brook Formation. The active tectonics created sheer cliffs of North Mountain Basalt that defined the boundaries of the McCoy Brook Formation deposits. We will see evidence of this active tectonics in large basalt piles.

Figure 4. Aerial schematic diagram of Wasson Bluff, showing stops, faults and geological units. Modified significantly from Brown and Grantham 1992.
Wasson Bluff Site

During this field trip, the **Google Map App** will be used to convey some features and information. The benefits and challenges of using these online tools for enhancing guided beach tours will be explored.

You can access the interactive Google Map at [http://edinos.ca/augc](http://edinos.ca/augc)

NOTE: For optimal mobile performance please ensure **Google Maps App** is installed.

Carrs Brook Fossil Site

The Economy Member is the oldest section (Anisian) of the Late Triassic Wolfville Formation and is exposed on the northern shore of the Minas Basin at Carrs Brook (Sues Olsen 2015). These sandstones are much harder than at Wasson Bluff, with extensive calcite cementation and abundant large (pebble) clast fabric. The large clasts demonstrate the sandstone units represented high flow fluvial regimes, but also fit well within the interpretation of the basin fill model (…). Large clasts are located near margins of fault bound basins, representing the zone of rapid flow decrease as the material is deposited in the lowland basin.

The site we are going is another area of ongoing research, where fossils are opportunistically collected as they erode from the cliff. We will be exploring the area briefly and using an online interactive map while visiting the beach. You can access the interactive Google Map at [http://edinos.ca/augc](http://edinos.ca/augc)

Over the past fifteen years, regular visits to the beach by Museum staff and volunteers has resulted in the identification and collection of important vertebrate fossils. The specimens are always disarticulated (not full skeletons), and often are just fragments of bone, consistent with the high flow sediment regime. Although fragmentary, the vertebrate fossil material is important to collect in order to identify taxa that may be stratigraphically informative. The age of this section is considered Anisian (247-242 mya), but additional specimens can be used to confirm or clarify the age of this section.
References


Previous Dalhousie Honours Projects at Wasson Bluff


Field Trip Guide #2

Environmental Impacts of Historical Gold Mining and Acid Rock Drainage in the Halifax Region

Atlantic Universities Geoscience Conference, Field Trip Guide
Friday November 2, 2018
Dr. Michael B. Parsons, Geological Survey of Canada (Atlantic), Natural Resources Canada
Research Scientist, Environmental Geochemistry
Phone: (902) 426-7363 / Email: Michael.Parsons@Canada.ca
FIELD TRIP ITINERARY

<table>
<thead>
<tr>
<th>Time</th>
<th>Event</th>
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<tbody>
<tr>
<td>9:00 am</td>
<td>Board vans at Dalhousie University</td>
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<tr>
<td>9:30 - 12:15 am</td>
<td>Stop #1: Montague Gold Mines</td>
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<tr>
<td>12:30 - 1:30 pm</td>
<td>Lunch (Bedford Institute of Oceanography)</td>
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<tr>
<td>2:00 - 3:00 pm</td>
<td>Stop #2: Bayers Lake Business Park</td>
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<tr>
<td>3:30 pm</td>
<td>Return to Dalhousie campus</td>
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ACKNOWLEDGMENTS

Parts of this field guide dealing with acid rock drainage in the Halifax Region were written by Terry Goodwin (formerly Senior Geologist with the Nova Scotia Dept. of Natural Resources, now with Enbridge). Information on the regional geology of Nova Scotia was kindly provided by Rob Fensome and Graham Williams, Geological Survey of Canada-Atlantic.
Introduction

Most of the rocks we will be seeing during this field trip belong to the Cambro-Ordovician Meguma Supergroup (Fig. 1). This supergroup consists of the lower metasandstone-dominated Goldenville Group and the overlying slate-dominated Halifax Group, with a combined vertical thickness of at least 11 km. Rocks of the Meguma Terrane are interpreted as a continuous sequence of deep-water turbidites (deep sea sediments), which were deformed and regionally metamorphosed to greenschist to upper amphibolite facies during the mid- to late Devonian Acadian Orogeny, then intruded by large volumes of granitoid rocks at ca. 385–357 Ma.

STOP #1: MONTAGUE GOLD MINES

SAFETY WARNING: Montague Gold Mine contains numerous deep shafts, open pits and trenches that are now overgrown and can be very dangerous. Please stay with the group and do not venture too close to the historical mine workings. This site also contains abundant tailings with high concentrations of both arsenic and mercury. Please be careful not to place food on the tailings, and wash your hands thoroughly before eating.

There are over 300 documented gold occurrences throughout mainland Nova Scotia, most of which are located within 64 formal gold districts that were defined by the provincial government in the late 1800s and early 1900s for claiming purposes (Fig. 2). The gold deposits can be divided into three main types: (1) high-grade (~15 g/t Au), narrow gold-bearing quartz veins; (2) low-grade (0.5–4 g/t Au) slate-argillite hosted; and (3) low-grade (0.5–5.5 g/t Au) meta-sandstone hosted. Almost all historical production has come from high-grade quartz veins located within 200 m of the surface. These veins are primarily hosted by meta-sandstones and slate of the Cambro-Ordovician Meguma Supergroup. Arsenopyrite is the predominant sulfide, with variable amounts of pyrrhotite, pyrite, chalcopyrite, galena and rare sphalerite and molybdenite.

Bedrock gold mineralization in Nova Scotia was first discovered in 1858 in quartz outcrops near Mooseland along the Tangier River. Mining has since been carried out at 64 formal gold districts, resulting in a total production of approximately 1.2 million troy ounces of gold. The majority of this production took place between 1862 and the mid-1940s, and there has been only limited mining of gold deposits until October 2017, when Atlantic Gold’s Touquoy Gold Mine opened near the former village of Moose River Gold Mines about 70 minutes’ drive north-east of Halifax. A resurgence in the price of gold over the last 15 years or so [from US$260/oz. (2001) to >US$1200/oz. (2018)] has led to renewed interest in Nova Scotian deposits, and there are now numerous exploration programs underway, and several new gold mines in development.

From 1861 to the mid-1940s, stamp milling at lode gold mines in Nova Scotia generated more than 3,000,000 tonnes of tailings. Most of the mined gold was recovered using mercury (Hg) amalgamation, and an estimated 10–25% of the Hg used was lost to the tailings and to the atmosphere. Arsenic (As) also occurs naturally in the ore, and is present at high concentrations in the mine wastes. Tailings from these operations were generally slurried into local rivers, swamps, lakes and the ocean. Recent land-use changes (e.g. residential development, recreational activities, shellfish harvesting) in some historical mining districts are increasing the likelihood of human exposure to these tailings. From 2003 to 2012, Natural Resources Canada and its partners carried out multi-disciplinary investigations of the dispersion, speciation and fate of metal(loid)s in terrestrial and shallow marine environments surrounding 14 abandoned gold mines in Nova Scotia. Results from this study led to the formation of a Provincial-Federal Historic Gold Mines Advisory Committee in 2005, which has evaluated the ecological and human health risks associated with gold mines throughout Nova Scotia and developed recommendations for management of these tailings sites. The results of this research are now being used to help minimize the environmental impacts associated with past, present, and future gold extraction and to inform land-use decisions.
Stop #1a: Shafts along Skerry Lead, Montague Gold Mines

The Montague district operated from 1863 to 1940 and produced 68,139 troy ounces of gold from 132,158 tonnes of crushed ore. Most of this gold was mined from narrow quartz veins that occur along the southern limb of a large anticline in the underlying Goldenville Formation. In general, miners used surface trenches to locate these steeply dipping quartz veins, then sunk multiple shafts all along the vein to access the gold ore (Fig. 3). In most cases, horizontal tunnels called ‘drifts’ were driven between these shafts underground to mine out as much of the gold as possible.

Figure 2: Generalized geological map of southern Nova Scotia, showing the Goldenville (white) and Halifax (grey) groups of the Meguma Supergroup, and the location of the Montague gold district.

Figure 3: Surface plant of the New Albion gold mine at Montague Gold Mines in 1911, showing headframes over parallel shafts along a quartz vein.
Stop #1b: Mine tailings at Montague Gold Mines

Mine tailings from the stamp mills at Montague Gold Mines were discharged into various swampy areas around the district, and were transported by Mitchell Brook for more than 1.5 km to Lake Charles. For decades, the sandy tailings areas at Montague have been a favourite recreational spot for local off-road vehicle enthusiasts, who frequently race their ATVs, motorbikes, and 4X4 trucks on the tailings (Fig. 4). Unfortunately, the tailings at Montague also contain very high concentrations of arsenic and mercury. The arsenic is of particular concern to human health, as it is both toxic and carcinogenic if ingested in sufficient quantities.

![Children racing dirt bikes on the tailings at Montague Gold Mines in August 2004.](image)

**Figure 4**: Children racing dirt bikes on the tailings at Montague Gold Mines in August 2004. The equipment on the right was used to collect airborne particulates and measure wind speed and direction as part of a study of arsenic-rich dusts at the site.

**Selected References**


Near the city of Halifax, the Halifax Group consists of slates of various colours and lesser amounts of metasandstones, metasiltstones, and calcareous units. Unfortunately, the sulphide-bearing Cunard unit of the Halifax Group underlies much of the Halifax region, and is frequently disturbed during construction activities. From a planning perspective, how should we deal with this unit with respect to subdivision development, road construction, and destruction of infrastructure?

Otter Lake Court and Washmill Lake Court in the Bayers Lake Business Park contain exposures of the Cunard unit slates and metasiltstones that have been intruded by granodiorite (Fig. 5). The Cunard unit is sulphide-bearing (pyrrhotite \([\text{Fe}_{1-x}\text{S}]\), pyrite \([\text{FeS}_2]\), and arsenopyrite \([\text{FeAsS}]\)) and intense oxidation of the sulphides has occurred. The variably altered rocks are iron-stained and exhibit a characteristic red to orange-brown staining. Locally, particularly along bedding and cleavage planes, the yellow-green colors are characteristic of the oxidation of arsenopyrite. Fresh sulphide mineralization is common as veinlets and clots while casts of sulphides (that are now completely weathered) are also present. Bedding in the area is sub-vertical and abundant slickensides are indicators of shearing along bedding planes.

![Figure 5: Iron-stained Cunard unit slates (right) intruded by granite (left)](image)

The Cunard unit typically contains pyrrhotite, pyrite and arsenopyrite. At this particular location, however, arsenopyrite is abundant and occurs in cleavage and secondary joint spaces.

Obvious oxidation of sulphides occurs throughout the Halifax area particularly where the Cunard unit has been exposed (Fig. 6). This has led to fish kills and lake acidification throughout the Halifax area (White and Goodwin, 2011). The main effort to mitigate acid rock drainage (ARD) in the business park was to divert most runoff to the storm water collection systems that ultimately
transport surface water to the ocean. Some areas that were producing ARD have been paved to limit the amount of water in contact with ARD-generating slates and fill material.

Figure 6: Simplified geological map of the metropolitan Halifax (from White and Goodwin, 2011)

The granodiorite is equigranular and medium grained with 12% to 15% biotite that gives the rock a medium gray color. Locally, the rock is very siliceous (high SiO$_2$ content) imparting a lighter color. Quartz veins are often found in the siliceous zones. Xenoliths of metasediments are ubiquitous throughout the granodiorite. The granodiorite is also very well jointed and locally faulted. Cross-cutting and bedding parallel “granitic” dykes can be seen within the Cunard unit.

This stop is characterized by thin (typically <2 m), locally derived till that mantles outcrops of slate or granodiorite. These materials have very little buffering capacity with respect to ARD production and continued exposure to the oxidizing environment remains an immediate concern.

Reference

White, C. E. and Goodwin, T. A. 2011: Lithogeochemistry, petrology, and the acid-generating potential of the Goldenville and Halifax groups and associated granitoid rocks in metropolitan Halifax Regional Municipality, Nova Scotia, Canada; Atlantic Geology; v. 47, p. 15
Field Trip Guide #3

Geology of the contact zone of the South Mountain Batholith, Halifax, NS

Atlantic Universities Geoscience Conference, Field Trip Guide
Friday November 2, 2018
Richard Cox and Rebecca Jamieson, Dalhousie University

The purpose of this field trip is to investigate features formed in the South Mountain Batholith and its host rocks during intrusion and cooling of the pluton. We will make up to 5 stops, 3 in the pluton and 2 in the country rocks at/near the contact. Most of the stops involve short to moderate walks over rough terrane and rocky shorelines. As noted below, some of the stops are weather-dependent.

Date and time: Friday, 2 November, 9:00 departure, 4:00 return (approximately)
Meeting place: Parking lot between Life Sciences Centre and King's University
What to wear: Warm and/or rain-resistant clothing suitable for outdoor conditions; light-weight hiking boots or similar slip-proof footwear.
What to bring: This field guide, hand lens, notebook, lunch; hammers are not recommended unless you have eye protection. Some stops are in parks where sample collecting is not allowed.

Geological Setting

The eastern part of the Halifax Regional Municipality (HRM) is underlain by metasedimentary rocks of the Goldenville and Halifax Groups of the Meguma Supergroup (e.g., White et al. 2008, White 2010; Fig. 1, 2). These rocks were folded into regional-scale, NE-SW-trending, upright folds (e.g., Horne and Culshaw 2001) and subjected to regional metamorphism during the Acadian Orogeny (ca. 400-380 Ma; Hicks et al. 1999). In contrast, the western part of HRM is underlain mainly by granitoid rocks of the ca. 380 Ma South Mountain Batholith (e.g. MacDonald and Horne 1988), which is the largest igneous body in the northern Appalachians. The contact between the batholith and its host rocks runs roughly parallel to and west of Halifax Harbour and the Northwest Arm (Fig. 1, 2). Intrusion of the magma heated the surrounding country rocks, producing a contact aureole that underlies much of the Halifax Peninsula.

South Mountain Batholith in HRM: The middle Devonian South Mountain Batholith is a large plutonic complex that ranges from granodiorite to leucogranite (e.g., MacDonald and Horne 1988; MacDonald 2001; MacDonald and Clarke 2017). The granite is enriched in aluminum (peraluminous), and contains a variety of Al-rich minerals (e.g., garnet, cordierite, muscovite) in
addition to variable proportions of K-feldspar, plagioclase, quartz, and biotite. The eastern part of the batholith in HRM includes several plutonic phases including the Halifax and Peggy’s Cove plutons (Fig. 1; Lackey et al. 2011). Close to its eastern contact it consists mainly of granodiorite (Fig. 1), with monzogranite, leucomonzogranite, and other more evolved phases of the pluton further away from the contact zone.

**Meguma Supergroup in HRM:** At the present level of exposure, the South Mountain Batholith is hosted by late Neoproterozoic to Ordovician metasandstones, metasiltstones, and slates of the Meguma Supergroup (White et al. 2008; White 2010). Stratigraphic units in HRM include the Taylors Head Formation and overlying, highly manganiferous, Beaverbank Formation (Fig. 1; White et al. 2008) of the Goldenville Group, and immediately overlying Cunard and Bluestone Quarry formations of the Halifax Group (White et al. 2008; Jamieson et al. 2012; Waldron et al. 2015). The finer-grained metasediments are characterised by a strong slaty cleavage and abundant sulphides, whereas coarser-grained units display cross-bedding, graded bedding, ripple marks, and a variety of other sedimentary structures. Within the contact aureole primary sedimentary features are variably overprinted by contact metamorphism, including growth of metamorphic porphyroblasts such as cordierite and andalusite. Slaty cleavage is progressively annealed, transforming the slate into massive hornfels, and evidence of partial melting can be observed adjacent to the pluton contact. Mineral assemblages in the contact aureole indicate that the SMB in this area was emplaced at a depth of ca. 7.5-8.5 km at 800-850°C (Jamieson et al. 2012; Hilchie and Jamieson 2014).

*Fig. 1. Simplified map of the Halifax Pluton section of the South Mountain Batholith (after Lackey et al. 2011), showing the distribution of the main granitoid lithologies and host rocks. The locations of stops 1-3 are also shown; stops 4-5 are shown in Fig. 2.*
Stop Descriptions

**Stop 1: Peggy’s Cove.** This first stop is on the coast by the village of Peggy’s Cove. The rounded outcrops of a porphyritic monzogranite, upon which the famous lighthouse sits, extend along the shore from just south of the Halifax Peninsula to the hamlet of East River by Chester. This section of the Halifax Pluton, a phase of the South Mountain Batholith (SMB), is known as the Peggy’s Cove Granite (MacDonald 2001). The Peggy’s Cove Granite is also the youngest section of the
Halifax Pluton. At this first location we are a significant distance from the nearest contact with the Meguma metasedimentary country rocks. The granitic rocks here are therefore quite “clean” in that they have few xenoliths which are small and sparsely distributed. Here the monzogranite is porphyritic. However, the K-feldspar megacrysts show a wide range in textures from tabular (euhedral) to highly rounded. Note this for comparison with the next two stops by the village of Prospect. Also note the lack of mafic enclaves in these outcrops which again can be compared with the outcrops and the next set of stops. One of the most striking features of these rocks are the spectacular cross-cutting pegmatite dykes (Fig. 3a). These are typically 20-50 cm wide and comprise tourmaline-bearing pegmatitic cores with fine grained, aplitic patches. The development of these contrasting grain sizes can be explained by considering the crystallization of the pegmatite in a fluid-rich system whereby the liquidus-solidus transition is greatly lowered. Therefore, the granitic mineral assemblage is able to crystallize at much lower temperatures than would otherwise be possible. The presence of incompatible- and volatile-element rich minerals such as tourmaline also supports a fluid-rich, late-stage crystallization history for these rocks. Once volatile components are lost, via crystallization of volatile-rich minerals and/or volatile escape through fractures, etc., the remaining melt is far below the solidus for this melt composition and therefore crystallizes rapidly to produce the fine-grained aplitic present.

**Stop 2: Hages Lane shoreline (near Prospect):** This stop comprises approximately 300 m of shoreline section with exposures of two main granitic rock types and the contact between them. The first rock type is the same porphyritic monzogranite as at Stop 1, i.e. the Peggy’s Cove Granite. The K-feldspar megacrysts (phenocrysts) here are significantly more abundant and are typically euhedral. These are the key to understanding the origin of a number of features at this locality. In particular, we can use the megacrysts to see flow directions, cumulate textures, and to determine the origin of enclaves versus autoliths and xenoliths. The megacrysts allow us to determine the relative timing of emplacement of the two main granitic rocks in this section. Autoliths (Fig. 3b) are thought to represent material that crystallized in the magma chamber and was later broken up and reworked into the magma. They typically have similar mineral assemblages to the main granititic host albeit they are slightly more mafic (Fig. 3b). Megacrysts should not be found within autoliths as they would have been largely solid when they were broken up. On the other hand, they may contain megacrysts which were crystallizing as part of their mineral assemblage, or where they have been trapped as accidentals. In addition, they may also contain xenoliths or mafic enclaves (Fig. 3b). Mafic enclaves (Fig. 3c) are typically assumed to represent incompletely mixed mafic magma injected into the still partially molten granitic magma chamber. Thus, they record textures that suggest the interaction between two immiscible liquids of different densities and compositions. One result of incomplete mixing is that the enclaves may pick up megacrysts (Fig. 3c). The enclaves themselves can vary in shape from rather irregular to more rounded. At this stop there are a number of enclaves that clearly show the flow direction, with a rounded front and more irregular tail. Megacrysts are concentrated around the “blob” of mafic material as it flowed into, and through, the granitic host magma. The
next question to be asked is, “Can we see evidence for these mafic intrusions?” In one section of this stop we see a broad vertical schlieren, a concentration of mafic minerals, in this case biotite (Fig. 3d). Although we cannot be certain that this is in fact the remains of a mafic dyke it certainly is a plausible explanation for the origin of this texture. The only mafic dyke known to have injected the Halifax Pluton is found at Sambro Head (e.g. MacDonald and Clarke 2017), where it has a very similar composition and mineral assemblage to the enclaves and schlieren seen here. Several smaller, satellite granitic plutons of the same age as the SMB, also show abundant evidence for magma mixing and hybridization (e.g. Tate et al. 1997; Clarke et al. 2000).

Megacrysts occasionally show coarse oscillatory zones (Fig. 3e) which, when analyzed using an electron microprobe, show 1-2% increases in barium content. This is found in similar crystals as a result of magma mixing (e.g. Cox et al. 1996). So it is likely that this has also happened in the Peggy’s Cove Granite. An explanation for why the megacrysts here are more euhedral versus those at Peggy’s Cove might be that the mixing at Peggy’s Cove was more complete, and therefore resorption of the megacrysts was more pronounced. The preliminary results of an ongoing study, using X-ray mapping of individual crystals, suggests strong textural and micro-chemical evidence to support this theory (Cox et al. in prep). The megacrysts also allow us to determine the relative order of intrusion at the contact between the Peggy’s Cove Granite and a coarse-grained leuco-monzogranite, an older component of the Halifax Pluton. The difference between these two rock-types is clear as the latter is much lighter colored and equigranular. At the contact there is a concentration of megacrysts, essentially forming a wall-rock cumulate (Fig. 3f). This clearly shows that Peggy’s Cove Granite was intruded later. A final feature to be seen at this stop is another tourmaline-bearing pegmatite close to the contact. The tourmaline crystals are quite large, black and show a euhedral, hexagonal, prismatic form and cleavage striations parallel to the long axis.

**Stop 3: Indian Point, by Prospect:** Large shoreline section of 100% exposed granitic rock by Indian Point, near the village of Prospect, Nova Scotia. Despite being several kilometers from the contact there are large numbers of xenoliths (Fig. 3e). These have a gneissic appearance and show variable degrees of partial melting. The abundance of these, and the peraluminous nature of the SMB, has led to the widely accepted theory that source of the SMB is the metasedimentary rocks of Megma supergroup (Clarke et al. 2004). Some of the xenoliths in this section contain garnet which was formed as a result of the reaction between the xenolith and the granitic magma (Erdmann et al. 2009). These can be hard to find and involve a hand lens and strong knees! The K-feldspar megacrysts show strong east-west alignment, suggesting flow of a megacryst-rich, viscous melt during emplacement. Another interesting feature is the presence of magmatic structures called ring-schlieren. As the name suggests these are mafic layers (biotite-rich) which are ring-shaped. At this locality we see a series of them which interconnected to form what is known as a ladder dyke (Fig. 3g). A simple description of the origin of these structures is that a bubble of less dense material rises up through a mafic layer which gets concentrated around the edge of this bubble. If we have a series of these bubbles they will each rise and undergo some
horizontal displacement rather like the bubbles rising in a fish tank. This creates a series of ring schlieren that form the ladder-dyke.
Stop 4: Contact zone, Bear Cove, Ketch Harbour Road: The southwestern shoreline of the approaches to Halifax Harbour is underlain mainly by granitoid rocks of the Halifax Pluton (South Mountain Batholith), with local exposures of the contact zone between the pluton and its country rocks (Fig. 2). Stop 4 is on the coast in a small municipal park (Lookoff Park) at Bear Cove. This outcrop lies in the roof zone of South Mountain Batholith where it has intruded country rocks of the Halifax Group. The contact between the pluton and its country rocks is well exposed along the shoreline.

Park in the parking area near the main road and walk down to the shoreline along the path. There are private homes on either side of the park – NO TRESPASSING!!

This stop is weather-dependent and will be cancelled at the discretion of the field trip leaders if conditions are poor.

HAZARDS: Wet slippery rocks, unstable rocks, steep drops, waves, irate property owners.

a) At the end of the path bear left (north) to the foreshore outcrops in front of large house; we will work our way south along the shoreline from here. At this location both metasedimentary host rocks and cross-cutting granitic rocks are exposed. Make sure you can distinguish between them, and note their characteristic features.

The host rocks are probably part of the Bluestone Quarry Formation (also seen at Point Pleasant Park). Outside the contact aureole, this unit consists of metasiltstones and slates with well-
preserved cross-bedding, some relatively thick metasandstone layers, and calcareous concretions. Can you find any of these features in these outcrops?

Compare the texture and composition of the igneous material in the cross-cutting bodies to the granitoid rocks seen at stops 1-3 – are they similar? Is this material granite, pegmatite, aplite, or something else? Are these dykes, veins, apophyses, or something else?

b) Head back to where the path emerges from the woods and observe the rocks exposed in the low outcrops on the shoreline. Are these rocks granite, hornfels, metasandstone, or something else? The answer may not be obvious - list pros and cons for each.

c) Follow the path south to the high outcrops between the woods and the water line. Be very careful on these outcrops – there are some steep drops! Observe the mineralogy and texture of the rocks - is this granite, slate, hornfels, or something else? If these are metasediments, is the bedding orientation consistent or variable? If it is variable, what does this suggest about the structure at this location? Can you see any evidence of slaty cleavage? See if you can find any larger-scale structures in the outcrops between the park bench and the waterline. In addition, look for calcareous concretions, and veins or other cross-cutting features.

**Stop 5: Contact zone, York Redoubt.** York Redoubt is a National Historic Site that marked the outer fortifications of Halifax Harbour between 1793 and 1956 (Fig. 4). It also happens to be conveniently situated on the contact between the Halifax Pluton and the Meguma Supergroup. As it is a popular recreational spot, a number of trails have been constructed through the park (Fig. 5). We will follow one of these from the main fort down to the shoreline, looking at exposures of the pluton and its country rocks along the way.

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*Fig. 4. York Redoubt in 1882 (sketch by A. Lindsay, reproduced by Potter and Goodwin, 2013).*
Park in the main parking lot at the fort. Inside the gate, bear left (north) and follow the trail that emerges from the north-east corner of the cleared area at "S" (Sally Port) on Fig. 5. If this gate is closed, make a short detour to the left (north) to find the trail on the other side. To avoid confusion, the following stop numbers are as they appear on Fig. 5.

**#6:** The wall near the Sally Port was made from slate quarried at nearby Purcell's Cove. These rocks were transformed into massive hornfels by contact metamorphism, but retained vestiges of their original bedding and cleavage. As a result, the rock was easily broken into resistant, roughly rectangular blocks that made an excellent building material (also widely used in the city of Halifax, including the Dalhousie campus). Note the extremely rusty appearance of the slate - this is
caused by weathering of pyrrhotite, the dominant iron-sulphide mineral in the Halifax Group in this area.

From #6, follow the road to the right (south) for about 300 metres, until you come to a small bridge with a prominent outcrop on the right.

**#10:** The granite-country rock contact can be observed in the outcrop at the bridge. What features distinguish the country rocks from the granite? How do they compare with those seen at previous stops today? Can you see bedding and/or cleavage in the metasediments, and any igneous features in the granite? What does the contact look like? How does it differ from the contact at Bear Cove?

Retrace your steps to the point where the path branches to the right (downhill). Follow the downhill branch, keeping your eyes open for small outcrops and noting whether these are granite or country rock. Stop where the path meets a small stream near a prominent switchback.

**#8:** The outcrops on the far side of the stream can be traced downhill to the switchback. The prominent layering in this outcrop indicates that it is a metasedimentary rock. Does it resemble the host rock outcrops seen at the top of the hill (#10)? If not, what is different? What is the orientation of the layering? Look for other sedimentary structures, cleavage, and/or cross-cutting veins or dykes.

Continue along the path to the switchback, cross the stream, and walk 10-15 m along the path to the right. Describe the outcrop on the steep bank to your right. Does this look familiar? Retrace your steps to the main path, follow it parallel to the shoreline, and take the small path to the right that leads to the beach. **Watch your footing – the rocks are slippery and unstable.**

**#7:** The beach outcrops consist of layered metasedimentary rocks with prominent pinkish-purple bands. The colour indicates the presence of spessartine garnet associated with Mn-rich sediments of the Beaverbank Formation. Spessartine-quartz aggregates like these are commonly referred to as "coticules" (e.g., Zentilli et al. 1986), and may have formed in a similar way to manganese nodules on modern deep-sea abyssal plains. Have you seen these rocks at any of the previous stops? What is the orientation of the layering? Can you see any other sedimentary structures or cleavage in these outcrops?

Facing the water, look along the shoreline to the right (south), noting where an obvious change in the colour of the rocks marks the granite contact. **Do not attempt to walk along the shoreline to the contact – the rocks here are treacherous.** To the left (north), you can see the York Shore Battery, which marked the western end of the anti-submarine net that stretched from here to McNab’s Island during World War II.

**This is the end of the field trip – return to the bus.**
References

Thank you for attending AUGC 2018!

Dalhousie University
Halifax, Nova Scotia