The 60th Annual Atlantic Universities Geological Conference 2010

28-30 October

Acadia University
Wolfville, Nova Scotia

AUGC 2010 would like to thank all our sponsors:

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Letter from the Dean of Science

Dean of Pure and Applied Science

ACADIA
UNIVERSITY

21 October 2010

Dear AUGC Delegates,

I am very pleased to welcome you to Acadia University for the 60th annual Atlantic Universities Geology Conference On behalf of the University and the Faculty of Pure and Applied Science, welcome! I wish you all the best in having a productive and enjoyable conference

I know that this is an important conference for all earth science students from the Atlantic Provinces I trust the competitive presentations and field trips will provide ample opportunity for new and lasting friendships to form. It is my strong belief that these are one of the most important aspects of coming together in conferences Please also take the time to enjoy our campus, and this lovely area in the bright colours of the fall.

The members of the Fletcher Geology Club have worked hard to develop an interesting conference and I thank them for their work. Finally, thanks to all of you for coming and sharing your work.

Sincerely,

Dr. Peter Williams
Dean of Pure and Applied Science

Letter from the Head of Earth and Environmental Science

Department of Earth and Environmental Science
Acadia University
Wolfville, N.S.
B4P 2R6

Tel: 902-585-1323
Fax: 902-585-1816
e-mail: rob.raeside@acadiau.ca
20 October 2010

Dear Delegate,

I am most pleased to welcome you to the 60th annual Atlantic Universities Geological Conference. Over the days of the conference you will have opportunities to meet and interact with students and professors from all the Atlantic region Earth Science programs and with representatives from government and industry. Through the posters and oral presentations you will learn about the current work being done in earth science research, and on the field trips you will have a chance to see the diverse and fascinating geology of this part of Nova Scotia.

I know that the organizing committee has been enthusiastically planning for, and looking forward to, this conference for many months. They have compiled an excellent program of excursions and lectures and now await your participation. The 60th anniversary of the establishment of the AUGC is a remarkable achievement and speaks volumes about the interest in the Earth Sciences and the eagerness that the student body in this region has for their chosen discipline. I hope that the passion for learning excites you as much as it did for the founders of the AUGC in 1950!

I look forward to meeting many of you at the conference. Enjoy your stay in Wolfville, your visit to Acadia, and your learning experience at the AUGC!

Yours sincerely,

Robt P. Raeside

Robert Raeside, Head,
Department of Earth and Environmental Science

AUGC 2010 Co-Chairs

Welcome to the AUGC! We are all very excited to welcome you to this year's conference.

The Acadia geology student body is very proud to be hosting the 60^{th} Atlantic Universities Geological Conference (AUGC). We hope that this year's conference is full of great experiences, events and memories. Hopefully it will give you all a chance to experience what we at Acadia get to experience every day, living in the beautiful Annapolis Valley.

This year we have chosen events that give you a bit of a valley experience and we hope that you enjoy them. We would like to thank our industry sponsors, our professors, our department secretary and many students in our department for all their support and help. Without it, this event would not have been successful.

Sincerely,

Leah Chiste, Graeme Hovey, Dwight DeMerchant and Nor Afiqah Mohamad Radzi
AUGC 2010 Co-Chairs

Schedule

Thursday October 28th

3:00 pm – 7:00 pm	Arrival and Registration at the Old Orchard Inn
7:00 pm – 12:00 pm	Barn Dance and Challenge Bowl Trivia (Nametag, ID and AUGC Shirt required)

Friday October 29th

Field Trips

8:30 am – 5:00 pm	Economic Geology of the Windsor Basin
9:00 am – 5:00 pm	Rocks, mud and scenery: an introduction to the amazing geology of the Wolfville area
9:30 am – 4:30 pm	Stratigraphic and Structural Enigmas of the Noel Shore
6:00 pm – 7:00 pm	Wolfville Ghost Walk *tickets included in registration* (Nametag required)

Saturday October 30th

8:00 am – 9:00 am	President's Meeting at the KC Irving Centre on the Acadia Campus
9:00 am – 5:00 pm	Student Presentations in the KC Irving Centre on the Acadia Campus
6:00 pm – 10:00 pm	Banquet Dinner with awards presentation and guest speaker at the Old Orchard Inn

Sunday October 31st

11:00 am	Hotel checkout

Organizing Committee

Leah Chiste

Dr. Sandra Barr

Graeme Hovey

Dwight DeMerchant

Nor Afiqah Mohamad Radzi

Dr. Robert Raeside

Special Thanks to

Dr. Sandra Barr

Dr. Ian Spooner

Dr. Robert Raeside

Dr. Cliff Stanley

Lynn Graves

Judges

Sarah Trend is a geophysicist with Imperial Oil Resources, currently working in St. John's at ExxonMobil Canada East. She completed her BSc in Earth Sciences at Dalhousie in 2000, and an MSc in Geophysics at University of Calgary in 2003. She has worked for Imperial Oil for over 10 years, working on a variety of projects including both conventional oil and gas as well as heavy oil. The last 6 years have been spent working fields offshore Eastern Canada, including Sable fields, Hibernia, Terra Nova, and Orphan Basin exploration. Her current role at Hibernia includes drillwell planning, production well workover evaluation, stewardship of geophysical projects, and rock property analysis. She is also the Imperial Oil and ExxonMobil Canada recruiting contact for Eastern Canada. When she's not working, Sarah enjoys ultimate frisbee, hiking, camping, foods of all kinds, and playing with her 3-year old daughter.

Chris E. White is a senior geologist in the Geological Services Division at the Nova Scotia Department of Natural Resource. He is also an Adjunct Professor in the Department of Earth and Environment Science at Acadia University and a Honorary Research Associate in the Department of Earth Sciences at Dalhousie University and the Nova Scotia Museum. Chris received his BScH in geology from Acadia University in 1984 and a PhD in Earth Sciences from Dalhousie University in 1996. He then worked as a Post-doctoral Research Associate and Laboratory Instructor in the Geology Department at Acadia University.

Chris is a past president of the Atlantic Geoscience Society and in his spare time is the Production Manager of the journal *Atlantic Geology*. He is active in the earth science community and has served on a number of committees. He is currently a member of Atlantic Geoscience Society (councillor), Mineralogical Association of Canada, Geological Association of Canada (Fellow), Geological Society of America, and the Geological Society of Maine. As senior geologist in the Geological Mapping Program he is responsible for producing geological maps of Nova Scotia and investigating geological evolution of the northern Appalachian orogen.

Mark Graves has an exploration background in varied mineral deposit environments having worked extensively in eastern Canada for the past 30 years with companies that include BP Canada, Billiton Canada and Kidd Creek Mines. His nickel experience began while working for Falconbridge in Greenland, exploring for Noril'sk type nickel deposits. During the 1990's Mr. Graves was a key member of the exploration team working for Archean Resources during the early discovery days of the Voisey's Bay deposit. Mr. Graves then went on to become regional exploration manager for Archean Resources, conducting nickel exploration in the Voisey's Bay district. More recently, Mr. Graves supervised a deep drilling program for Rambler Metals and Mining in preparation for an underground exploration program on the Rambler project. He is currently project manager for Acadian Mining's flag-ship gold property at Fifteen Mile Stream, Nova Scotia.

Guest Speakers

Randall F. Miller, Ph.D., P.Geo.
Research Curator of Geology and Palaeontology
Head, Geology and Palaeontology Section, New Brunswick Museum

Randall Miller studied geology in the Department of Earth Sciences at the University of Waterloo and received his Ph.D. in Environmental Earth Science in 1984. His graduate research dealt with climate change during the last ice age. For his thesis titled "Stable isotopes of carbon and hydrogen in the exoskeleton of insects; developing a tool for palaeoclimatic research", he received the 1985 W.B. Pearson Medal from the University of Waterloo, Faculty of Science for outstanding evidence of creative scholarship in research. Before finishing a Ph.D. he spent a term as a visitor at the California Institute of Technology in the Division of Geological and Planetary Sciences.

In 1986, after two years of contract research for the Geological Survey of Canada and the Canadian Museum of Nature, Dr. Miller moved to Saint John to become the Curator of Geology and Palaeontology at the New Brunswick Museum. The museum traces its history to one of the oldest geological collections in the country, with mineral and fossil specimens collected as far back as the 1820's. Miller's job includes organizing and developing the museum's geology and palaeontology collection and educating the public about the geosciences through exhibitions, lectures, field trips and media stories. Although his research still examines ice age climate and climate change, his job at the New Brunswick Museum encompasses all of New Brunswick's fossil history going back almost one billion years. He has published more than 60 scientific papers on a variety of topics with a focus on fossils or fossil sites. His research has included studies of the world's oldest most complete shark fossil, giant sea scorpions, tiny spider-like trigonotarbids, walrus fossils, ancient lobe-finned fish, some of the world's oldest reptile footprints and the history of geological discoveries in New Brunswick. In January 2004 his work on fossil sharks was described in Discover magazine and featured on the CBC Radio show 'Quirks and Quarks'. He has also written a children's book, *Fossil Hunter - Will and the Giant Trilobite*, to accompany an exhibit of the same name, contributed to a best-selling book about the geology of the Maritimes called *The Last Billion Years*, and coauthored *Rebuilt in Stone: Geology and the Stone Buildings of Saint John, New Brunswick*.

Dr. Miller is also an Adjunct Professor in the Department of Geology at the University of New Brunswick and a Professional Geoscientist with the Association of Professional Engineers and Geoscientists of New Brunswick. Miller is the recipient of the 2010 Distinguished Scientist Award 'Gesner Medal' from the Atlantic Geoscience Society.

Kathryn Welsh
Canadian Society of Exploration Geophysicists

Kathryn Welsh graduated with a BSc in Geophysics from the University of Calgary in 2006. She worked for Talisman Energy in Calgary until December 2009. She is now attending Southern Alberta Institute of Technology getting a Bachelor of Applied Petroleum Engineering Technology. She has volunteered with the CSEG for almost 2 years where she is the University Student Outreach Conference Coordinator as well as Ambassador Coordinator. She spends her free time coaching a competitive swim team.

Student Poster Abstract Index

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   Brandon Boucher

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   Ryan Fearon

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   Nor Afiqah Mohamad Radzi

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

Erin E. Adlakha
Department of Geology, Saint Mary's University
Halifax, Nova Scotia

There are two commonly referenced models describing the origin of metals and mechanisms of metal precipitation in magmatic Ni-Cu-PGE (platinum-group element) reef-type deposits: (i) magmatic mixing and sulfide liquid settling, whereby sulfide liquid saturation and PGE enrichment of the sulfide liquid occurs by silicate melt and sulfide liquid mingling, followed by sulfide settling (Campbell and Naldrett 1983) and (ii) volatile fluid percolation, whereby saline fluids or vapour migrate upward through the lower units of the complex, extracting metals and sulfur, and reprecipitating them higher in the sequence (Nicholson and Mathez 1991, Boudreau 2008). Hydrous silicates, hydrous silicate melt inclusions, and saline aqueous fluids in the Merensky reef pegmatites are spatially associated with PGE-rich base metal sulfides. Characterization of this association is imperative in constraining the mechanism for precious metal transportation and precipitation. The motivation for this study is to constrain i) the chemical conditions and timing of formation of silicate pegmatites and associated volatiles contained within them as fluid inclusions; and, ii) the amount of metal transported by fluids at the time of pegmatite formation. A revised model for the formation of the reef horizons and their associated PGE tenor is proposed that integrates the magmatic and hydrothermal models.

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

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

Brandon Boucher
Mineral Exploration and Ore Fluids Laboratory, Department of Geology, Saint Mary's University

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

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

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

RYAN K. FEARON
Department of Earth Sciences, Memorial University of Newfoundland
St. John's, Newfoundland & Labrador, A1B 3X5

The Wabana and Bell Island Groups of the Avalon Peninsula of Newfoundland contain oolitic hematite beds of Early Ordovician age, with a dip of ~11° north-northwest. The effect of external stress on magnetization of hematite has rarely been studied, although it has been suggested that internal stress in hematite is an important source of its remanence stability.

To study the effect of stress, the hematite ore is cut into cylinders and given a remanence in magnetic fields up to 800mT in strength parallel or perpendicular to the cylinder axis. The samples are loaded and unloaded stepwise increasing the pressure to a maximum compression of about 17.5×10^6 Pa. The changes in remanence as stress is varied will be measured by looking at the changes in magnetic field due to the sample using a fluxgate probe.

Ore sample B6-1 has been collected and is devoid of magnetite and shows that the compression causes both permanent and reversible decreases in the remanence of a magnitude comparable to that of magnetite.

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

JON M. GATES
Department of Earth and Environmental Science, Acadia University, Wolfville, Nova Scotia, B4P 2R6 (075353g@acadiau.ca)

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

The Partial Extraction of Soil Samples across a Pb-Zn Deposit via a Cation Exchange Mechanism

AMANDA M. ISNOR
Department of Chemistry, Acadia University
Wolfville, Nova Scotia B4P 2R6

Most mineral deposits that are exposed at the surface have already been found by mining companies over the last 50 years. The ones that have not been discovered are typically buried by some form of surficial materials such as gravels, tills, or volcanic ash. This material makes mineral deposits difficult to detect and therefore causes difficulties during exploration. However, groundwaters can travel through the deposit and transport metal ions from the mineral deposit to the surface where they can adsorb onto organic matter and Fe-Mn oxy-hydroxides present in the soil. Extracting the labile components of the soil could detect these metal ions, and thereby detect mineralization at depth.

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

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

Petrology and SHRIMP U-Pb Geochronology of Detrital Zircons from the Holly Lake Metamorphic Complex, Leith Ridge, NWT

Newton, L.O.[1], Ootes, L., [2] and Culshaw, N.G.[1]

(1) Dalhousie University, Halifax, NS
(2) NWT Geoscience Office, Yellowknife, NT

The Paleoproterozoic (>1900 Ma) Hottah terrane is the oldest component of the Wopmay orogen and remains poorly understood. Largely overlain by Paleozoic cover and poorly exposed, the Hottah terrane outcrops on the western side of the orogen and is thought to extend as basement underneath much of the Great Bear magmatic zone.

The oldest units within the Hottah terrane are metasedimentary and metavolcanic rocks of the Holly Lake metamorphic complex (HLMC), a scantly preserved supracrustal sequence. The HLMC has been intruded by numerous, 1940-1930 Ma plutons of the Hottah continental arc. Fieldwork within the HLMC was completed in August of 2010 along Leith Ridge, south of Great Bear Lake and northwest of Hottah Lake, where three outcrops of partially migmatised, interbedded psammitic and pelitic rocks were mapped and sampled. These rocks are characterized by biotite-sillimanite-melt pockets (pods) and have a well-developed foliation, striking along 315 degrees and dipping 45 degrees to the northeast. Numerous porphyritic tourmaline-bearing granitic rocks and 0.5-1m wide granodiorite dykes intrude the metapelite outcrops.

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

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

NOR AFIQAH B. M. RADZI
Department of Earth and Environmental Science, Acadia University, Wolfville, Nova Scotia B4P 2R6 (091014m@acadiau.ca)

The Phetchabun basin is one of at least 30 Tertiary intermontane basins in Thailand formed by regional crustal extension localized by strike-slip faults. Most oil production in Southeast Asia is from these Tertiary basins, and they are primary targets for hydrocarbon exploration. Basins in Thailand contain thick lacustrine strata, in places including coal, lignite and oil shale. This study focuses on the Wichian Buri subbasin, one of the five grabens that comprise the Phetchabun basin. This subbasin is unusual due to the fractured igneous intrusions that apparently form hydrocarbon reservoirs. The stratigraphic units of the Phetchabun basin have been defined by earlier workers and include an upper unit of Pliocene-Pleistocene sediments, underlain by the Miocene Chaliang Lab Formation and Wichian Buri Group, and the Oligocene “basal Tertiary”, which unconformably overlies Mesozoic volcanic and granitoid rocks. The Chaliang Lab Formation consists of claystone with minor sandstone and lignite. The underlying Wichian Buri Group is divided into 4 units: unit 1 has been previously described as reworked basaltic tuff and interbedded coarsening-upward sandstone units. Units2, 3, and 4 contain basaltic flows and gabbroic sills interlayeredwith claystone, sandstone and siltstone. The basal Tertiary is described as claystone with minor interbedded sandstone and altered fine-grained basaltic flows or sills. This project is petrographic study of a suite of thin sections from 150 cuttings samples from 15 drill holes in the Wichian Buri subbasin. The samples are from units 1, 2 3, and 4 of the Wichian Buri Group and were initially logged as tuffaceous. However, low magnetic susceptibility measurements and preliminary petrographic observations indicate that they are sedimentary and in some cases metasedimentary where contact metamorphosed by gabbroic sills. The data obtained in this study will enable comparison between stratigraphic units and also give some information about how the units vary across the area by providing data from drill holes located across a distance of 8 km from south to north across the basin.

Student Presentation Times

9:00 am to 9:20 am – Michael Warren, St. Mary's

9:20 am to 9:40 am – Nathan Corcoran, Memorial

9:40 am to 10:00 am – David Murray, St. Francis Xavier

10:00 am to 10:20 am – Mark Colbourne, Memorial

Break for 20 minutes

10:40 am to 11:00 am – Matthew Vaughan, Dalhousie

11:00 am to 11:20 am – Sarah Gordon, UNB

11:20 am to 11:40 am – Saif Al-Silwadi, Dalhousie

11:40 am to 12:00 pm – Luke Bickerton, St. Francis Xavier

12:00 pm to 12:20 pm – Presentation from Jeff Faulkner from Geoscientists Nova Scotia

Lunch Break for 40 minutes

1:00 pm to 1:20 pm – Khalhela Zoeller, Dalhousie

1:20 pm to 1:40 pm – Anne Belanger, Dalhousie

1:40 pm to 2:00 pm – Leah Chiste, Acadia

2:00 pm to 2:20 pm – Alex Howe, Memorial

2:20 pm to 2:40 pm – Kendra Carrigan, Memorial

2:40 pm to 3:00 pm – Presentation from Kathryn Welsh from CSEG

Break for 20 minutes

3:20 pm to 3:40 pm – Travis McCarron, St. Francis Xavier

3:40 pm to 4:00 pm – Evan Gladney, St. Mary's

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4:20 pm to 4:40 pm – Michael Power, Memorial

4:40 pm to 5:00 pm – Matt Stimson, St. Mary's

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3. Seafloor Records of Sediment Dispersal Patterns in the Nelson River, Hudson Bay
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11. Field, Petrographic and Chemical Characterization of the Neoproterozoic Ohio Pluton of the Antigonish Highlands, Nova Scotia
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13. Early Jurassic Gordondale Member – Shale Gas Potential and XRD, Wire-line Log, and TOC Analysis
Frank Ryan

14. Log jam Deposits in the Boss Point Formation near Joggins
Saif Al-Silwadi

15. New discoveries of tetrapod bearing fossil forests at Joggins Nova Scotia: Implications for tetrapod entombment and ecological persistence.
Matt Stimson

16. High Resolution Seismic Stratigraphy (GPR) of Braided Channel Complexes in the Triassic Wolfville Formation- controls on reservoir heterogeneity
Matthew Vaughan

17. The origin and distribution of platinum group metals in the Mt. Milligan alkalic Cu-Au porphyry deposit, B.C., Canada
Michael Warren

18. IODP Site 1256- Petrological and Textural Variations Down-Core
Khalhela Zoeller

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

Belanger, A.C.[1], Corrigan, D.[2], Jamieson, R.A.[1]

(1) Dalhousie University, Halifax, Nova Scotia
(2) Geological Survey of Canada, Ottawa, Ontario

A suite of highly metamorphosed and hydrothermally altered sedimentary and chemogenic rocks was sampled from an area on the northern flank of Barrow River, Melville Peninsula (N 67º24'08.44", W 82^{0}35'43.23"), Nunavut. The study area resides within the Proterozoic Penryhn Group (Reesor and Henderson, 1972), which is stratigraphically equivalent to the Piling Group of Baffin Island, NU. The Penryhn Group generally consists of alternating layers of pelitic and psammitic gneisses, amphibolites, marbles and calc-silicates, all intruded by continental arc and syn-collisonal plutons and pegmatites.

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

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

THE ORIGIN OF ORDOVICIAN PLUTONIC ROCKS IN THE NORTHERN ANTIGONISH HIGHLANDS

Luke Bickerton
Department of Earth Sciences, St. Francis Xavier University

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

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

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

Geochemical analyses indicate that the syenite is characterized by a SiO_2 content of 57-62 wt. %, an intermediate Fe_2O_3 content (5.3-7.9%) and low MgO (<1%). The pluton contains alkalies that vary in concentrations, such as a relatively high Na_2O content (5.5-6.3 wt%) and a lower K_2O content of 3.5-4.5%. The concentration of CaO is also low (<1.6%).The range in alkalies is consistent with petrographic evidence for intense alteration of feldspar, indicating these elements were mobile during metasomatism. These observations indicate that determining petrogenesis should rely on relatively immobile high field strength (HFS) and rare earth elements

(REE). The syenite has high Nb/Y ratio (4-4.5), indicative of a peralkaline melt. A high degree of fractionation is also indicated by the high Zr (up to 880ppm), Nb (132-175ppm) and Hf (10-13ppm). The REE pattern reveals LREE enrichment, with an average La/Sm ratio of 9.02, and a flat HREE profile with a very subtle europium anomaly. The chemistry of this pluton is similar to other Ordovician plutons in the Antigonish Highlands, indicating that magmatism of this age is more extensive than previously realized.

Seafloor Records of Sediment Dispersal Patterns in the Nelson River, Hudson Bay

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

Two gravity cores were collected from the Nelson River Estuary in 2009, and have been sub-sampled for granulometry and radiochemical analysis during July 2010. Analysis of the particle-bound radioisotopes ^{210}Pb (half-life=22.3y) and ^{137}Cs (half-life=31y), using a low-energy gamma spectrometer, are used to determine sediment flux over ~decadal timescales. Previously processed analysis of box-cores from the same area is used to supplement findings. Multibeam bathymetry and sub-bottom seismic profiles are being analyzed to evaluate seafloor morphology and depositional patterns. The physical data, radiochemical data, and structural images are being integrated to elucidate sediment dispersal patterns. The preliminary results show a region of sediment bypass in the inner estuary, with sediment accumulation rates increasing from 0.4 cm/y to >0.9 cm/y in the middle and outer estuary. The results are consistent with high sediment supply from the river and decreasing tidal current energy in a seaward direction. These observations will be compared with ice-coverage and river-flow data, to explore relationships among spatial deposition patterns, ice extent, and river forcing.

Partial Digestion Geochemistry of Pediment over the Toki Cluster Porphyry Copper Deposits, Atacama Desert, Chile

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

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

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

The Role of Anaximander Seamounts in an Active Transform Fault Zone in the Eastern Mediterranean: Processing and Interpretation of EMED2010 Seismic Reflection Profiles 6-10

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

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

Inversion and Interpretation of Marine Controlled Source Electromagnetic (CSEM) and Magnetotelluric (MT) Data

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The use of the geophysical electromagnetic method in a marine environment has become remarkably attractive, as there have been many advances to applications for hydrocarbon exploration. This project will examine the use of marine Controlled Source Electromagnetics (CSEM) and Magnetotellurics (MT), and will investigate their effectiveness in hydrocarbon exploration. CSEM transmits synthetic electromagnetic signals into the ocean floor and the fixed seafloor receivers then measure the reaction of the earth’s magnetic field. CSEM can be applied to hydrocarbon exploration since layers of rock containing high amounts oil and/or gas will have an electrically resistive signal. Magnetotellurics is an electromagnetic method in which the response to the changes of the earth’s natural time varying magnetic field are measured. MT is less sensitive to layers or structures at shallow depths than CSEM, but can identify conductive units or formations where CSEM would respond to more resistive units.

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

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

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Mafic pegmatites in the platinum-group element (PGE)-mineralized Roby Zone, Lac Des Iles Complex ("LDIC"), NW Ontario, Canada comprise dykes, veins and irregular pods of coarse-grained magnesiohornblende, pyroxene, and labradorite-andesine with minor biotite, apatite, Fe-Ti-oxides and intercumulus quartz that grades into massive quartz or graphic quartz-base metal sulfide-vysotskite [Pd, Ni(S)] intergrowth at their cores. Quartz, apatite and magnesiohornblende host primary and secondary assemblages of one- or two-phase carbonic fluid (CO_2 ± up to ~10% CH_4 ± minor H_2O, N_2) inclusions that contain ore metals (Ni, Cu, Pd, Bi, Te, Fe). Rare trails of late stage, high salinity aqueous fluid inclusions are secondary in origin and therefore unrelated to the crystallization of the pegmatites. Assemblages of primary carbonic fluid inclusions show considerable variation in mode and temperature of homogenization, reflecting large fluctuations in confining pressure at the time of quartz crystallization of up to ~ 1 kbar (in single quartz crystals) and ~2.8 kbar (all data). Independent thermobarometric methods constrain conditions for two stages of pegmatite formation (and carbonic fluid entrapment): (i) the crystallization of magnesiohornblende-plagioclase intergrowth at T ~ 650-850^{o}C, and P ~ 1-3 kbar, and (ii) the crystallization of quartz at T ~ 535-650^{o}C, and P ~ 0.4-3.2 kbar, setting the maximum depth of emplacement of the LDIC North Roby Zone magma at 10-12 km. The results indicate that aqueous-dominant volatile phases were absent during the crystallization of pegmatitic gabbroic rocks at LDIC, and that water-poor, carbonic fluid entrapment persisted to well below solidus conditions. A role played by carbonic fluid as a potential transport medium for ligands involved in the precipitation and remobilization of the PGE and base metals is strongly suggested and warrants further investigation.

The Petrogenesis of Calc-Alkaline Lamprophyres from Mali, West Africa

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

The lamprophyres have been termed calc-alkaline due to their modal mineral content, which is also how the types of lamprophyres were identified. Two variations of lamprophyres occur at the Morila Mine: 1) kersantites (plagioclase > orthoclase) with biotite phenocrysts; 2) minette (orthoclase > plagioclase) with biotite phenocrysts.

The lamprophyres are porphyritic with phenocrysts of biotite and amphibole set in a feldspathic groundmass. The distribution of sulfides is preferential to the phenocrysts and they can be used to infer the original sulphur contents of the magma. Several textures were observed petrographically including glomerocrysts of biotite and amphibole as well as poorly developed sagenitic biotite. The sagenitic biotite consists of sub- to euhedral grains of titanite that have aligned to form three-rod asterisks and equilateral triangles. Pilite recording the breakdown of olivine to Mg-silicates is locally observed. Also contained within these lamprophyres are several REE-rich minerals that are scattered throughout the samples. A metamorphic overprint has also been recognized based on the mantle overgrowths on biotite and amphibole, the pilite and sagenitic textures and zoned titanites. The titanites will be analyzed using the LA-ICP-MS in order to identify the age at which metamorphism occurred.

Mineralogical and Chemical Analysis of Rumuruti (R) Chondrite: Sample NWA 6145

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

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

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

An X-ray Diffraction and Structural Refinement Study of Radiation-Damaged Zircons from Bancroft, Ontario

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

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

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

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

Field, Petrographic and Chemical Characterization of the Neoproterozoic Ohio Pluton of the Antigonish Highlands, Nova Scotia

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The Antigonish Highlands are located in northeastern mainland Nova Scotia, and is part of a peri-Gondwanan terrane known as Avalon (or Avalonia). In the late Neoproterozoic, the Avalon terrane is widely interpreted to have been a volcanic arc regime located along the northern margin of Gondwana. Avalonia separated from Gondwana by the Late Cambrian and was accreted to Laurentia during the mid-Paleozoic.

The Ohio Pluton is located in the southeastern corner of the Antigonish Highlands. The pluton intrudes Neoproterozoic low grade volcanic and sedimentary rocks of the Georgeville Group, and is unconformably overlain by undivided Devono-Carboniferous sediments of the Antigonish Basin to the east. Many faults intersect the pluton in both east-west and north-south trends. The primary exposure of the granite is along the Ohio River and less extensive exposure can be found along the sides of the many roads which cross through the pluton.

Petrographic observations of the pluton indicate a mineralogy dominated by quartz, potassium-feldspar, and plagioclase. The feldspars are saussuritized and show intense alteration to sericite. Fractures contain abundant chlorite. There are minor opaques associated with the chlorite mineralization, yet to be identified.

U-Pb geochronological analysis (TIMS, zircon) yields an age of 606 ± 0.6 Ma, an age typical of Neoproterozoic igneous rocks in Avalonia. Geochemical analysis was carried out to determine the major element, trace element and rare earth element composition of the pluton. The samples collected contain 70-75 wt% SiO_2, approximately 2 wt% FeO, and between 0.5 and 1 wt% MgO. Granite samples also display unusually high levels of the trace element Ba, (up to 3600 ppm). Harker diagrams indicate that alkali and alkali earth elements (Na, K, Rb, Ca, Sr, and Ba) have been mobilized and can no longer be used to make inferences about the original chemistry of the pluton. Plots involving relatively high field strength (HFS) and rare earth elements (REE) are more reliable indicators of original geochemistry. Diagrams which serve as proxies for the alkali content such as Zr/Ti vs. Nb/Y and Ta vs. Yb show the granitoid rocks are subalkalic and were emplaced in a volcanic arc regime. There is a weakly negative light REE slope with one sample showing a significantly positive europium anomaly. This anomaly suggests an accumulation of plagioclase phenocrysts were present in the melt. The heavy REE exhibit a flat pattern. This flat HREE pattern is also seen in other 605 Ma granitoids in the Antigonish Highlands with the exception of the Eden Lake Plutonic Suite, and is generally typical of volcanic arc granites.

Early Jurassic Gordondale Member –

Shale Gas Potential and XRD, Wire-line Log, and TOC Analysis

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

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

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

Log jam Deposits in the Boss Point Formation near Joggins

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

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

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

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

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

High Resolution Seismic Stratigraphy (GPR) of Braided Channel Complexes in the Triassic Wolfville Formation- controls on reservoir heterogeneity

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The Triassic Wolfville Formation crops out along the shoreline of the Minas Basin of the Bay of Fundy, Nova Scotia. Cambridge Cove contains an exceptionally well preserved outcrop which presents 2D and 3D exposures of the braided channel depositional environment of the Wolfville Formation. These outcrops demonstrate the stratigraphic complexities associated with the depositional environment.

This study aims to: 1) Use Ground Penetrating Radar survey techniques to image braided channel deposit architecture in the subsurface for correlation to outcrop LiDAR data. 2) Provide 3D, hi-resolution stratigraphic and structural information about braided channel deposits and their characteristic as petroleum reservoirs. 3) Improve understanding of fluid connectivity and emplacement in these deposits and the influence of these factors on petroleum production.

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

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Porphyry Cu±Au±Mo deposits associated with alkaline to calc-alkaline rocks represent significant sources of platinum group elements. Unfortunately, the current understanding of the controls of PGE enrichment in porphyry systems is poorly understood. Recent discoveries have identified PGE-enriched porphyry deposits within the Canadian Cordillera. The purpose of this study is to investigate the occurrence of PGE in one of these systems, in order to better understand PGE enrichment in alkalic porphyry systems.

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

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

IODP Site 1256- Petrological and Textural Variations Down-Core

Khalhela Zoeller
Department of Earth Science/Oceanography, Dalhousie University
Halifax, Nova Scotia

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

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

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

Awards

APICS – NSERC Award

This award is for the best paper presented at the conference. It is judged primarily on the basis of the scientific quality and the relevance to the topic, the amount of original work done by the student, and his/her understanding of the subject. Secondary consideration is given to the organization and the presentation of the talk. The award consists of $500 to the presenter along with a plaque, which resides at the winner's university for one year. The award is usually presented by a representative of the APICS Earth Science Committee at the annual banquet of the AUGC.

The APICS Earth Science Committee will usually suggest an appropriate judge.

The award is part of the financial support given to the conference by APICS and NSERC. Application for support is made through the chairman of the APICS Earth Science Committee.

Poster Award

Supported by the hosting University Geology Club.

An award provided by Imperial Oil will be given to the student with the best poster.

Challenge Bowl Award

Trip for two to Calgary to compete at the CSEG Challenge Bowl

CSEG Award for Best Geophysical Presentation

The CSEG Award for the Best Geophysical Presentation was established by the Canadian Society of Exploration Geophysicists in 2008 and will be presented annually at the AUGC. The recipient of the Best Geophysical Presentation Award will be provided with a $300 cheque to assist in his/her development as a geophysicist.

The Canadian Society of Exploration Geophysicists began in 1949 at 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 fellowship and co-operation among those persons interested in geophysical prospecting.

The Canadian Society of Petroleum Geologists Award

This award is for the best presentation of a paper. A paper that is read should be given a lower rating. A trophy is presented to the winner at the AUGC banquet, preferably by a member or representative of the CSPG. The trophy will reside at the winner's university for one year. Additionally, the winner will be awarded a choice of CSPG publications to a maximum value of $100.

The CSPG has usually asked the conference to choose an appropriate judge.

The Frank Shea Memorial Award

The award was established by the Mining Society of Nova Scotia at its annual meeting in June 1981 and is presented annually, if appropriate, at the AUGC conference, for the best paper dealing with Economic Geology (or any paper that has implications for use in Economic Geology). The award consists of a certificate and a cheque to the presenter, and a cheque to the Geology Club he or she represents. During some twenty-seven years, Frank Shea was engaged in activities related to the mineral resources of the Atlantic Region. He was involved with base mineral exploration for New Jersey Zinc, with engineering geology for Boylan Engineering, with barite investigations of Magnet Cove Barium, and in the geological activities of the Nova Scotia Department of Natural Resources Mines and Energy division, as its Chief Geologist and Director of Mineral Resources and Geological Surveys for many years. Frank graduated from St. Francis Xavier in 1954 with a B.Sc. in Geology, after which he continued his studies at Dalhousie University, receiving his Master's degree in 1958. Frank Shea 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 also encouraged educational programs in geology, as shown by his involvement with university field camps. The Mining Society of Nova Scotia is pleased that through this award it can honour a long time member and one of its first presidents, and give recognition to his many contributions to the field of geology in Nova Scotia.

Mrs. Mary Shea and/or a representative of the Mining Society of Nova Scotia present the award at the AUGC banquet.

The Mining Society of Nova Scotia usually asks the conference organizers to choose an appropriate judge.

Field Trips

AUGC – 2010 – Field Trip #1

Rocks, mud, and scenery: An introduction to the amazing geology of the Wolfville area

Leaders: Sandra Barr and Ian Spooner
Department of Earth and Environmental Science, Acadia University

Stop 1: ROSS CREEK (basalt, chert, zeolite minerals, agate, and amethyst)

North Mountain Basalt formed as a result of fissure eruptions about 200 million years ago as Africa and North America began to rift apart. The basalt is well exposed in bluffs along the Bay of Fundy shoreline. In synclinal bays, sedimentary rocks of the overlying Scots Bay Formation are also preserved. The calcareous sedimentary rocks of the Scots Bay Formation were deposited in lakes and hot springs on top of the basalt, and reach thickness of several kilometres under the Bay of Fundy.

North Mountain Basalt is composed of up to 18 basaltic flows, ranging in thickness from a couple of m to 60 m, with a total thickness of about 250 m. At Ross Creek, we will look at the uppermost flow of the sequence. As you walk from Ross Creek to the southwest along the shore you are seeing a section through this flow from near the bottom to the top. Because of this, you will notice an obvious change in texture. The lower part of the flow shows columnar jointing, and is cut by veins containing chalcedony (agate) and zeolite minerals. Toward the top, the flow becomes highly amygdaloidal, and the amygdales contain the same minerals as the veins. You can walk through the top of the flow into the overlying Scots Bay Formation.

The Scots Bay Formation is mainly well bedded limestone, but contains abundant large **chert** nodules (which may represent algal structures or silicified tree remains?). Cavities in the chert nodules commonly contain well developed quartz crystals, in places with purple colour (amethyst). The chert was popular with and widely traded by native people in the area who used it to make arrow heads and other tools.

Stop 2: THE LOOK-OFF - more than just scenery!

The view from the Look-off shows how geology controls topography and land use in the Wolfville area. The North Mountain Basalt "caps" North Mountain between Cape Blomidon and

Brier Island, a distance of more than 180 km, and forms a protective barrier from the cold winds of the Bay of Fundy. The basalt is underlain by the Blomidon and Wolfville formations, which are less resistant to erosion and underlie the Annapolis Valley. The sandstone and mudstone of the Blomidon and Wolfville formations erode to form the fertile red soils of the valley, and the red mud of Minas Basin. On the south side, the valley is protected by South Mountain, underlain by resistant metamorphic and plutonic rocks that we will see later. These rocks are unconformably overlain by the Wolfville and Blomidon formations. Carboniferous sedimentary rocks underlie the Avon River area to the east - if it is a clear day, you may be able to see outcrops of these rocks around the lighthouse at Horton Bluff and on the Cheverie shoreline. We may see some of these Carboniferous rocks later today.

On top of the bedrock, varied effects of glacial and post-glacial erosion and deposition and post-glacial erosion and deposition have produced the detailed topography of river valleys, gentle rolling hills, and the Minas Basin itself. We will have a closer look at some of these glacial deposits later today.

Stop 3: BLOMIDON FORMATION, HOUSTON BEACH

A walk along Houston Beach brings us to outcrops of the Blomidon Formation, composed of shale and siltstone deposited in a mainly lacustrine (playa lake) environment. What evidence can you find in these rocks for the type of climate in this area back in the Triassic?

The bedrock is overlain by thick glacial sediments. Together, the two are eroding to produce a great beach (when the tide is high!).

Stop 4: WOLFVILLE FORMATION, KINGSPORT

Along the beach at Kingsport, we can see the effects of coastal erosion, and what land-owners are trying to do to stop it. We can also see very well the rocks which form the Wolfville Formation, easily eroded fluvial sandstone and conglomerate deposited more than 200 million years ago. The rate of erosion here is as much as 1 m/year one hundred years ago, the rocky bluffs were 100 m farther out in the basin. "The Canada", one of the largest sailing ships ever built in Canada, was constructed here at the wharf in Kingsport more than 100 years ago. Try to imagine what this place must have looked like then (1891).

Stop 5: CORNWALLIS RIVER

The Cornwallis River at this location is still part of a tide-dominated estuarine system. If the tide is low, it may be possible to see large current dunes developed on the river floor, an indication that the current has sufficient strength to both transport and deposit appreciable amounts of sand. Similar deposits to these are prolific oil producers in western Canada. Dykes protect these farmlands from flooding.

Stop 6: PENNY BEACH AND HORTON BLUFF

(a) Penny Beach

At this site you can see excellent examples of coastal erosion and local strategies to mitigate the process. Coastal erosion in the Minas Basin can be as much as 30 cm/year, and locally rates greater than 1 m/year have been noted. Most erosion occurs during the winter months, as storms are frequent and often accompanied by northwesterly winds allowing waves to build up over a maximum distance (fetch) of 30 km. Storms that coincide with the highest tides are especially damaging. Local strategies for dealing with erosion are varied. Property owners with money have used North Mountain basalt, South Mountain granite, and other local rocks as armour. Some have used (with much less success) coarse fill and brush. In many cases the placement of armour has exacerbated the problem or, worse yet, transferred the problem down the coastline.

Penny Beach is migrating landward. The migration is over salt-marsh peat that is up to 2.5 m thick and is accumulating in the basin landward of the present beach. This basin was formerly more extensive and the peat underlies the present sand beach, in places cropping out on the beach face.

(b) Horton Bluff

In addition to observing the effects of present-day and recent-past beach and shorelines processes, we will also walk along the shore to look at outcrops of sedimentary rocks of the Horton Group. The Horton Group is a major rock unit in Nova Scotia; it is over 1200 m in thickness and of early Carboniferous age (about 350 million years old).

The rocks of the Horton Group display a variety of sedimentary features, which can be used to interpret the environment in which the original sediments were deposited. These features include fossil footprints made by a large labyrinthodont amphibian. William Logan first discovered these (or similar) tracks in this area in 1841. In 1979, a team from the Nova Scotia Museum examined this trackway in detail and made casts of the footprints in fibreglass for permanent display at the museum. They measured a total of 27 footprints from a trackway 30 m long. The largest track was 30 cm in length. Few tracks remain now because of continued erosion. The animal that made the tracks was four-footed, had four toes on each foot, and looked a bit like a huge salamander! In addition to these tracks, other indicators of the environment of sediment deposition preserved in these rocks include ripple marks, raindrop imprints, mudcracks, bi-lobed trace fossils, fish scales, and plant fossils.

Stop 7: GASPEREAU RIVER VALLEY

At this stop you will see a classic example of a Gilbert-style delta, a coarse-grained delta most commonly associated with deglaciation. Gilbert deltas develop when sediment-laden meltwater enters a standing body of water. This delta is now perched above sea level as land has rebounded from the weight of the glaciers, resulting in a relative sea level drop. Notice the clay balls that are incorporated in the coarse sediment, an indication that the source of the sediment was ice and that the transport distances were very short.

Stop 8: WHITE ROCK FORMATION

The Silurian White Rock Formation in the Wolfville area consists mainly of quartzite. The original quartz sands were likely deposited on a beach. The quartzite weathers light grey (hence the name of the small community after which the formation is named) but shows a lot of iron oxide staining as a result of groundwater movement along joints and fractures.

The quartzite is a popular building stone in the Wolfville area, and was used, for example, in the construction of the gymnasium/arena complex at Acadia University.

From this stop one can also see the highly incised upper portion of the Gaspereau River. This incision is about 70 m deep and could not be formed by the river in its present condition. The incision was almost certainly formed by subglacial meltwater erosion during the waning stages of deglaciation. It is a classic example of a tunnel valley.

Stop 9: HALIFAX GROUP

Interbedded slate and metasiltstone of the Halifax GROUP are almost vertical in this outcrop. Axial planar slaty cleavage (formed during regional greenschist-facies metamorphism associated with the Neo-Acadian orogeny at ca. 400 - 380 Ma) is approximately parallel to bedding. Some beds contain cross-laminations which you can use to interpret younging direction - are younger beds to the north or to the south?

The outcrop is intruded by a large gabbro sheet with well developed chilled margins. Is this intrusion a sill or a dyke?

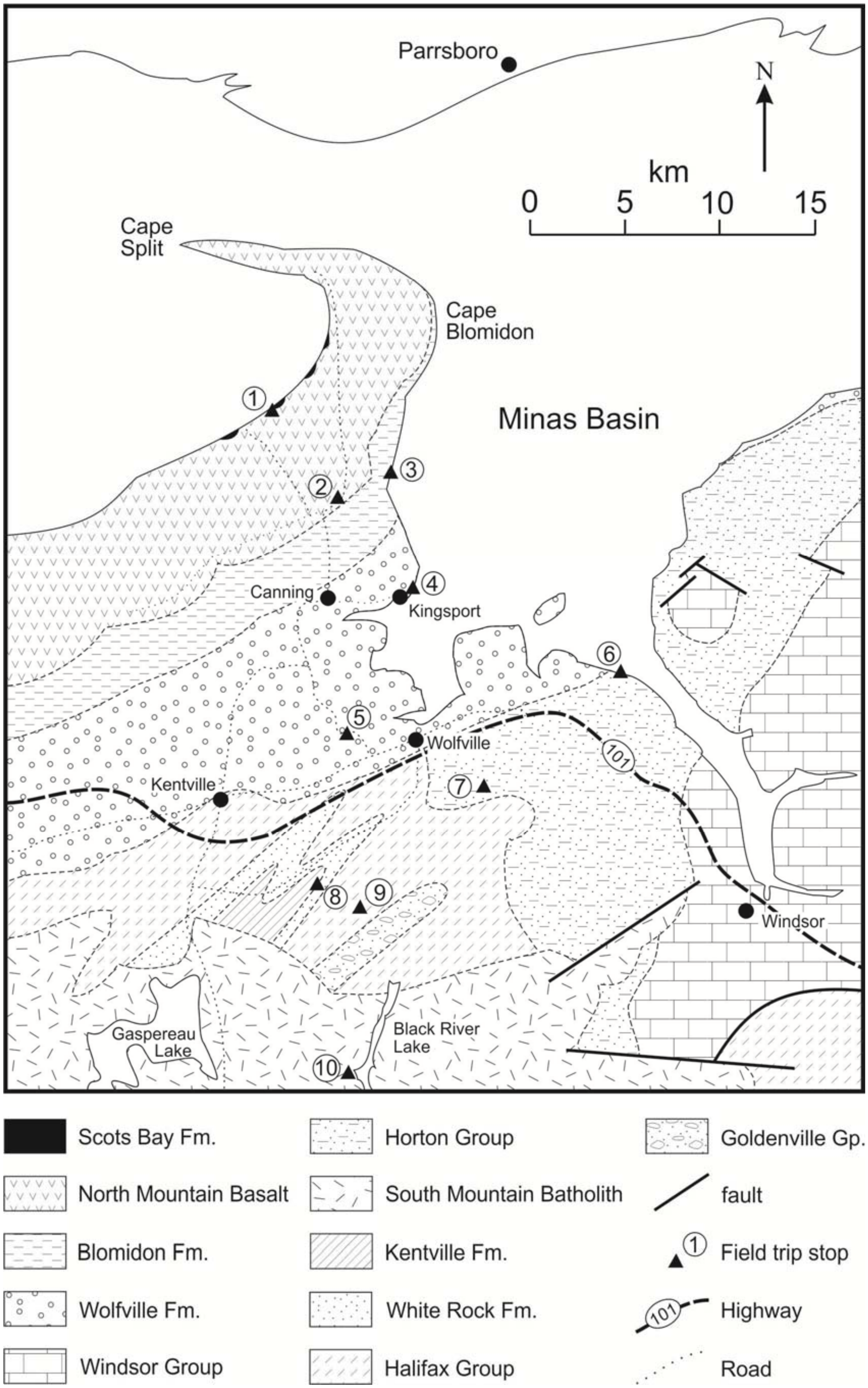
Stop 10: SOUTH MOUNTAIN BATHOLITH AT BLACK RIVER LAKE

South Mountain Batholith underlies much of southern Nova Scotia and forms a topographic feature known as South Mountain (maximum elevation ca. 250 m). The South Mountain Batholith consists of ca. 380-370 Ma granodiorite and granite which have been divided into many mappable units based on often-subtle differences in texture and mineralogy. All units of the South Mountain Batholith are peraluminous, meaning that they contain high Al_2O_3 relative to CaO, Na_2O, and K_2O. This chemical characteristic is reflected in the mineralogy, which is dominated by quartz, plagioclase, K-feldspar, and biotite, with accessory aluminum-rich minerals such as muscovite, cordierite, and andalusite. No hornblende is present.

At this location near Black River Lake, we are in a major biotite monzogranite unit that forms much of the northern part of the batholith. Large phenocrysts of K-feldspar show some alignment due to flow during magma emplacement. Xenoliths of metasedimentary rocks indicate that stoping may have played a major role in magma emplacement in this part of the batholith.

The rocky, uneven topography produced by weathering of the granite demonstrates why most areas of Nova Scotia underlain by South Mountain Batholith are sparsely populated!

End of Trip and Return to Old Orchard Inn



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Gaspereau Lake
Black River Lake
10
Scots Bay Fm.
North Mountain Basalt
Blomidon Fm.
Wolfville Fm.
Windsor Group
Horton Group
South Mountain Batholith
Kentville Fm.
White Rock Fm.
Halifax Group
Goldenville Gp.
fault
Field trip stop
Highway
Road

AUGC – 2010 – Field Trip #2

Stratigraphic and Structural Enigmas of the Noel Shore

Leaders: Rob Raeside and Peir Pufahl
Department of Earth and Environmental Science, Acadia University

October 29, 2010; 9:30 a.m. – 4:30 p.m. Bagged lunch provided.

In this trip, we will visit the Triassic and Carboniferous rocks of the south side of the Minas Basin, where superb coastal outcrops provide text-book quality examples of an angular unconformity, wildly folded sedimentary rocks, the transition from the Horton Group to the Windsor Group, and a rare coastal outcrop of gypsum.

The "Noel Shore" of Nova Scotia is the southern side of the Minas Basin, extending from the Avon River estuary to Truro. Much of the shore is underlain by a narrow coastal plain of sandstone, part of the Triassic Fundy Group. East of Walton, almost all coastal outcrops are of this Wolfville Sandstone. West from Walton, however, some headlands preserve the overlying sandstone, but the bays and inlets provide excellent outcrops of the underlying Carboniferous rocks.

Many outcrops along the Noel Shore are cliffs, which are actively being eroded. People should not stand or walk under the cliffs, as material is constantly falling from them. Any visit to these sections must take careful note of the state and time of the tides – on the flat shoreline sections, the tide rises faster than you can comfortably walk.

Stop 1. Horton Group: Horton Bluff Formation, Blue Beach.

Access: from Highway 101, exit 9 at Avonport, follow Bluff Road 3 km to Blue Beach Road and Museum. Park near the railway bridge, and walk down to the shore (to the right).

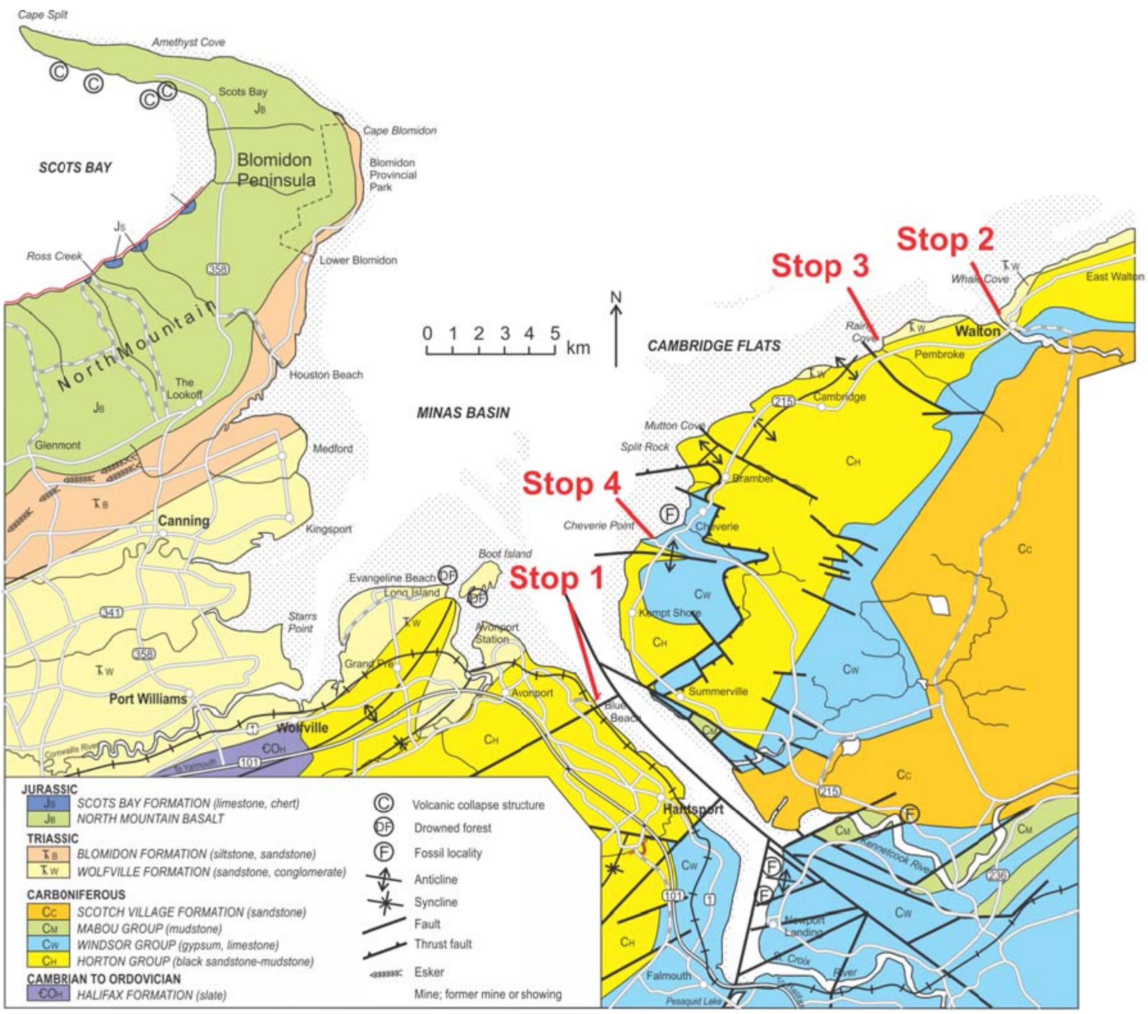
The Horton Bluff Formation is characterized by interbedded shale, sandstone, and impure dolomitic carbonate rocks that probably represent paleosol horizons. The section has been interpreted as a classic lacustrine succession, dominated by successive shallowing upward cycles representing the filling of the lake following each subsidence episode. Although relatively undeformed (at least compared with later stops) the succession contains a number of soft-sediment features. Most notably, synsedimentary dykes are common, and several feed upward into conspicuously thickened, lenticular units of overlying sandstone. These have been interpreted as feeders overlain by sand volcanoes or as sand lenses in hummocky cross-strata formed by storm waves; the underlying sedimentary dykes were interpreted as products of transient pressures generated by waves impinging on a lake shore.

Stop 2. Horton Group: folded Horton Bluff Formation

Access: From Highway 101 at Windsor, take highway 236 to highway 215, and proceed to Walton village. Follow signs to Walton lighthouse, and park where the road bends away from the coast, by a pile of barite tailings.

Outcrops at the base of the track to the shore, beside the large granite boulders, are part of the same unit seen in Stop 1. Here they have been extensively deformed into a series of box and chevron folds. Begin by determining the right way up in the rocks at the start of the beach, and try to follow the layering around to determine which parts are overturned. Watch for sedimentary features such as cross-laminations, syneresis cracks (produced when water is expelled from a gel-like mud), and feeding traces of bottom-dwelling organisms, which resemble fronds on the muddy bottom.

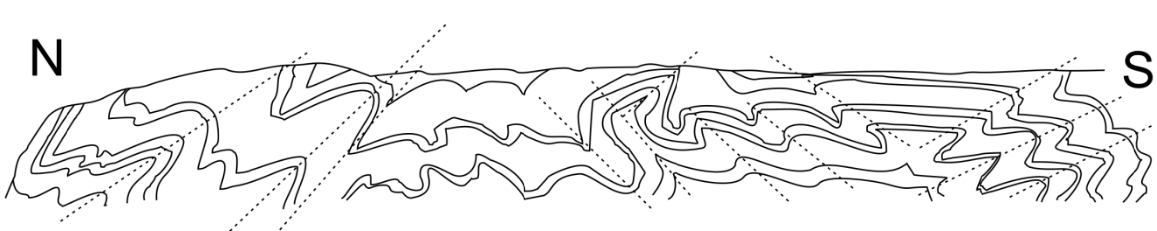
Continue north along the shoreline, following individual layers. It soon becomes apparent that the units are wildly folded into a series of box folds (folds with two axial planes),



Geological map of the Wolfville-Walton area, showing the locations of stops in Trip 2.

with sharp (chevron-style) hinges. Tracing individual layers from the cliffs across the foreshore reveals that even over short distances the folding is strongly disharmonic. The box folds exhibit clear room problems – it is not mechanically possible to fold rocks into these structures without either extension of some layers, or slip along the layers. Detailed examination of the corners of the box folds shows some of the room problem has been accommodated by kink band deformation.

What caused such extreme deformation? The Cobequid-Chedabucto Fault lies on the north side of the Minas Basin. Late Carboniferous motion along it affected the rocks we have examined at Walton.



Sketch of the cliff section at Walton, showing the nature of folding and generation of box folds.

Beyond the headland where the cliff line turns east, a gravelly tombolo connects the folded shoreline outcrops with low-lying outcrops of conglomerate, 50 m beyond. Depending on the accumulation of sand and mud, sometimes it is possible to pin down the contact between the black sandstone of the Horton Bluff Formation with the red conglomerate of the Wolfville Formation to within 5 m.

Visit the conglomerate outcrops only if there is plenty of time before the rising tide. It is easy to get stranded on these outcrops! What is the nature of this contact? (Hint: look to your left and right – the same contact can be seen on the cliffs across the river, or in Whale Cove, to the east.)

On your way back to the road, watch for marcasite disks in the black sandstone along the foreshore – these sulphide nodules presumably were deposited around clumps of organic material. Pinkish grey cobbles with unusually high specific gravity are also scattered on the beach – these are pieces of barite, which used to be mined 5 km southwest of Walton, and shipped out of the harbour.

Stop 3: Rainy Cove. Triassic unconformity on folded Horton Bluff sandstone.

Access: proceed west on highway 215 about 3 km from Walton River, to the Rainy Cove road. Parking is available on the gravel road near the shore.

Rocks exposed in the Rainy Cove section are of the same units as at Walton Harbour, although the folding (at first glance) is not quite so wild here. It is easier to follow the stratigraphy through a series of folds. Walking north along the shore, near the track, you can see non-marine sandstone and mudstone, and in places plant fossils. About 50 m from the end of the track, near a prominent mud-cracked bedding plane, you can find oval fossil tree stumps, evidence that these rocks have undergone some homogeneous strain as well as disharmonic folding. The last major fold is a cliff-high antiform, plunging toward the beach. The layering can be traced out on to the beach as resistant ridges of sandstone. Examine it carefully on the beach for way-up indicators – the strata to the north, although nearly vertical, are overturned, and the younging direction is toward the centre of the fold. Thus the beds in the centre of the antiform are upside down, and the structure is a downward-facing (or overturned) antiformal syncline.

North of the overturned syncline the strata continue with a near-vertical orientation, and are overlain by the reddish conglomerate. (Don't get too close – this cliff is not too stable!) Notice that the Horton Bluff Formation rocks are also reddened and weathered by erosion that occurred in the Triassic Period. Clasts near the unconformity are mainly of the Horton Group, although a few metres up in the cliff, the clasts appear to be mainly quartzite, derived from the Goldenville Formation, now only known several kilometres inland.

Stand back from the cliffs and look for dune-scale cross-bedding. What sort of current energy would be needed to form these dunes? What environment of deposition does that represent?

Stop 4: Horton-Windsor Group contact, Cheverie.

Access: Drive west on Highway 215 to Cheverie village, and north on the Leander Macumber road to the end of pavement.

In this bay, outcrops of three (or possibly four) formations in the Mississippian Horton and Windsor Groups are found. From the bay on the east to the headland to the north are exposed the following units:

White Quarry Fm. "Pembroke Fm." Macumber Fm.	– Windsor Group
Cheverie Fm.	– Horton Group

East along the shore are white outcrops of gypsum of the White Quarry Formation. This unit was formerly quarried in the area in front of the church (it looks like a rubble pile from the beach), and was shipped off the wharf at Cheverie (although this is now only a line of boulders with wooden pilings exposed, extending out from the shore).

Features to watch out for include porphyroblasts of beige anhydrite in the white gypsum, veins of satin-spar, bedding planes marked by calcitic muddy layers, and, in the large flat outcrops well down the shore, black tarry patches, naturally seeping petroleum.

Notice that the gypsum is intensely folded into a series of chevron-style folds, exposed on the large flat outcrops on the shore, indicating this unit has been deformed almost as severely as the rocks at Walton.

Return to the road, and proceed north along the low cliffs to encounter the next unit down in the Windsor Group. The first outcrops you reach are of limestone breccia, with dog-tooth calcite and pyrolusite filling in void spaces. This unit is the "Pembroke formation", and is controversial on account of its variability, origin(s) and time(s) of origin. Farther east it hosts the Walton barite deposit, with accessory lead and silver. The clasts appear to be limestone of the underlying Macumber Formation, but it has been interpreted as a tectonic breccia, a solution breccia, and as a primary depositional breccia.

The bottom unit of the Windsor Group, the Macumber Formation, is well exposed north of the breccia. Here it is a basal laminated peloidal limestone, and records the initial Early Mississippian marine transgression in Nova Scotia. It is widespread across the Maritime Provinces and represents a shallow subtidal to supratidal deposit. The section exposed in this area is the stratotype.

The very bottom of the Windsor Group is probably best placed at the first appearance of the Macumber Formation limestone, although technically it is defined by the appearance of the marine pelecypod *Schidozus*, and imprints of this fossil have been found in the underlying arenite up to 6 m below bottom of the limestone.

The lowermost unit exposed here is the Cheverie Formation, at the top of the Horton Group. It is well exposed to the west around the headland and consists of an alternating continental sequence of maroon fine-grained sandstone, siltstone and shale.

AUGC – 2010 – Field Trip #3

Economic Geology of the Windsor Sub-Basin

Leader: Cliff Stanley
Department of Earth and Environmental Science, Acadia University

Abstract

This field trip will investigate several mineral deposits and a petroleum play hosted by the sedimentary rocks within and immediately outside of the Windsor sub-basin of the Maritimes Basin. The day will include a visit to the Fundy Gypsum Mine, the (closed) Walton barite mine, the Three Mile Plains uranium deposit, a bivalve bioherm that in the subsurface could be a porous host to significant petroleum or water resources, possibly a paleoplacer gold prospect hosted in a basal conglomerate over an angular unconformity, and a gravel quarry in the Goldenville Group basement rocks.

Overview

The 2010 Atlantic Universities Geologic Conference at Acadia University presents a field trip that will visit a number of places of geo-economic importance hosted by rocks of the Windsor sub-basin of the Maritimes Basin. The trip takes place on Friday, October 29, 2010. Departure will be at 8:30 AM from the Old Orchard Inn parking lot, we will have a box lunch at an appropriate time during the trip, and participants will be returned to the Old Orchard Inn by 5:00 PM.

The field trip will involve five extended stops that traverse upward through the basement and Windsor sub-basin stratigraphy:

1.) the Panuke Lake Gravel Quarry in Five Mile Plains,
2.) the Fall Brook exposures in Three Mile Plains,
3.) a Kennetcook limestone bioherm along the Hebert River,
4.) the Walton Barite Mine in Walton, and
5.) the Fundy Gypsum Mine in Wentworth.

In the section below, the stratigraphy of the Maritimes Basin and relevant geological background of the Windsor area are described.

Stratigraphy

In the Windsor, Nova Scotia area, Precambrian to Ordovician meta-greywackes and slates of the Goldenville and Halifax Groups (Meguma Supergroup) comprise the basement to the Windsor sub-basin of the Maritimes Basin (Figure 1). Unconformably overlying these rocks are continental clastic rocks of the Horton Group (Tournaisian; Lower Mississippian; Figure 2), deposited during a marine transgression into this restricted basin. Above these lie Lower Carboniferous limestones and evaporite deposits (gypsum and anhydrite) of the Windsor Group (Visean – Middle Mississippian; Figure 3).

Meguma Supergroup

The Meguma Supergroup stratigraphy is dominated by a thick (>10 km) turbidite succession of the Late Neoproterozoic to Early Ordovician sedimentary rocks deposited in a submarine fan system comparable to those observed in modern rift margins. Primary lithologies within the supergroup include metamorphosed mudstone, siltstone, quartz and feldspathic arenite, and greywacke. The supergroup is divided into two groups. The Goldenville Group comprises the base of the succession, consisting of the Church Point Formation (mainly thickly bedded metasandstones with minor metasiltstone and slate) below, and the Tupper Lake Formation (green, grey-green, and purple metasiltstone and slate that is locally Mn-rich and contains coticules) above.

Overlying this sequence is the Halifax Group, which, from bottom to top, consists of the Cunard Formation (black slate and metasiltstone interbedded with cross-laminated metasandstone that locally contains abundant pyrite, pyrrhotite, and arsenopyrite), the Lumsden Dam Formation (grey metasiltstone and metasandstone interbedded with slate, with metasandstone bed tops locally containing graptolite fossils), the Elderkin Brook Formation (grey to red-brown slate and metasiltstone, with local trace fossils and bioturbation), and the Hellsgate Formation (dark grey slate and metasiltstone interbedded with metasandstone that contains common trace fossils, is bioturbated, and locally is overlain by black slate).

The Horton Group

The Horton Group is a sequence of continental conglomerate, sandstone, siltstone and shale, with minor interbedded carbonate rocks, that were deposited in a large graben that later became the Windsor sub-basin of the Maritimes Basin. In the Windsor area, the Horton Group wedges out to the south against folded, metamorphosed basement rocks of the 'Meguma Platform' (Figure 1). This platform was intruded by the South Mountain batholith and other granitoid rocks during the Devonian.

The Horton Group is divided into two formations: the Horton Bluff and Cheverie Formations, which are in turn further divided into lower, middle and upper, and lower and upper members, respectively (Figure 2).

The Horton Bluff Formation Lower Member consists of chemically immature, cross-bedded quartz arenite and sub-litharenite, conglomerate and minor siltstone that is variably micaceous and carbonaceous. The basal part of this unit contains abundant kaolinite, and ripple marks are common in the upper part of this unit. These rocks were largely deposited in a continental setting during the early stages of basin formation.

In the Windsor area, the base of this formation commonly contains a quartz-pebble conglomerate that contains pebbles of different genesis depending on location. Close to South Mountain batholith basement rocks, the conglomerate contains albite and orthoclase feldspar and mono-crystalline quartz pebbles, indicating derivation from granite, whereas close to Meguma Supergroup basement rocks, the conglomerate contains only poly-crystalline quartz pebbles, indicating derivation from metamorphic quartz veins, likely derived from saddle-reef gold deposits in the Meguma Supergroup.

The Horton Bluff Formation Middle Member consists predominantly of grey shale and interbedded dolostone that occurs as nodules, lenses, concretions and thin beds. Ostracods and palaeoniscid scales, teeth and spines are common. Minor interbedded sandstone exhibits ripple, cross-lamination, lenticular and flaser bedding. Paleosols are common within this unit, which was largely deposited in a lacustrine setting that probably developed within the basin as a result of local normal faulting.

The Horton Bluff Formation Upper Member consists of several thick quartz arenite units interbedded with siltstones and shales, and contains kunkur horizons (concretionary horizons containing calcite and gypsum) and minor conglomerate. Plant fossils, ostracods and palaeoniscid scales are common within the shale units. This member was deposited in a continental setting that prograded across the underlying lacustrine sediments of the Middle Member.

Unconformably overlying the Horton Bluff Formation is the Cheverie Formation. Its Lower Member contains of coarse clastics consisting predominantly of arkose that exhibit festoon cross-bedding and channel structures. At the base of this unit, sandstone and minor conglomerate contain kaolinite, but higher up within the unit, fresh feldspar exists. Interbedded siltstones exhibit green, red and purplish colors reflecting different valence states of iron within the sediments. This unit was deposited in a continental braidplain environment that probably prograded across the Horton Bluff Formation sediments.

The Upper Member of the Cheverie Formation is finer grained than the Lower Member, and consists predominantly of quartz arenite and subarkose. These are well laminated and cross-bedded. Interbedded siltstones contain estheroid shells and *Triletes cheverensis*. These sediments are generally red in color, and contain kunkur horizons and paleosols with preserved rootlets. This unit was also deposited in a continental environment but reflects sedimentation that occurred more distal from the source clastics than the Lower Member.

The Windsor Group

The Windsor Group was deposited in a restricted basin after marine transgression into the basin introduced seawater. Evaporitic processes led to the deposition of limestone, dolomite, gypsum, anhydrite and salt. These evaporitic units are sometimes interbedded by fine grained clastics (siltstones) that occur in the middle and upper part of the Windsor Group stratigraphy.

The basal part of the Windsor Group is marked by the Macumber Limestone/Gays River Formation. The Macumber Limestone consists of cryptalgal laminated limestone where it unconformably overlies Horton Group red bed sediments.

Immediately beneath the Macumber Limestone in underlying reduced intervals of Horton Group red beds, minor pre-existing disseminated chalcopyrite mineralization occurs. These 'red-bed-type copper' occurrences probably formed by replacement of disseminated pyrite in the reduced clastics in the upper part of the Horton Group by Cu-chloride-bearing, low temperature basinal brines that migrated through these relatively permeable strata during basin dewatering. A likely reaction describing the formation of these Cu showings is:

$$2\ CuCl_2^o + 2\ FeS_2 + 2\ H_2O \Rightarrow 2\ CuFeS_2 + O_2 + 4\ H^+ + 4\ Cl^-.$$

The original Cu source may have been mafic minerals within arkosic sandstones of the Horton Group that broke down when they interacted with oxidized basin waters.

In addition, massive barite and minor galena-sphalerite mineralization occurs at a number of places just above the Horton/Windsor contact in proximity to Windsor and post-Windsor faults within carbonaceous parts of the Macumber Formation. The Walton deposit, which contains massive barite, galena and sphalerite, represents one of these deposits. These massive bodies probably formed through replacement of limestone by similar low temperature brines migrating up these faults during basin dewatering. The sulphate and sulphide required by the reactions that formed these massive bodies were probably derived from the overlying evaporites, and reduction of the sulphate to sulphide probably occurred as a result of the oxidation of organic matter in the Macumber Limestone, possibly via the reaction:

$$PbCl_2^o + 2\ CH_2O_{(organic\ matter)} + SO_4^{-2} \Rightarrow PbS_{(galena)} + 2\ Cl^- + 2\ CO_2 + 2\ H_2O.$$

A similar reaction can be formulated to describe the precipitation of sphalerite from a zinc-chloride complex ($ZnCl_2^o$). Dissolution of the resulting CO_2 into water would result in the formation of carbonic acid, which would dissociate to produce H^+ by the reaction:

$$CO_2 + H_2O \Rightarrow H_2CO_3^o \Rightarrow HCO_3^- + H^+.$$

This would cause a drop in pH, and may be responsible for the dissolution of calcite within the Macumber Formation to provide the open space for the massive mineralization (and contribute to the production of the Pembroke Formation breccias; see below).

When the Macumber Limestone unconformably overlies pre-Carboniferous basement highs consisting of Meguma Group sedimentary rocks, it is referred to as the Gays River Formation, and consists of fossiliferous carbonate bank limestone that hosts important manto-type Pb-Zn-Ag mineralization. These deposits also may have formed by fluids that were slightly warmer than those responsible for the formation of red-bed-type Cu occurrences in the Cheverie Formation, and Ba-Pb-Zn deposits in the Macumber Formation, perhaps because they were sourced from deeper in the basin or were produced during later stages of basin de-watering. The most important manto-type deposit discovered to date in this environment is the Gays River deposit in eastern Hants County. In some places, dissolution processes have facilitated karst development in the Gays River Formation, transforming it into a collapse breccia, referred to as the 'Pembroke Formation'.

Overlying the Macumber Formation/Gays River Formation/'Pembroke Formation' is the White Quarry Formation, which comprises a thick sequence (up to ~400 m) of largely evaporitic rocks. The lower portion of this unit consists of massive gypsum and/or anhydrite with a few small, discontinuous intervals of limestone. The upper portion of this unit consists of salt (mostly halite with minor potash – sylvite). The White Quarry Formation is mined in open pits for gypsum and anhydrite at the Fundy Gypsum Mine and at several other places within Hants County. This unit formed as a result of basin restriction, and subsequent evaporite deposition, probably as one evaporitic sequence. With progressive amounts of evaporation, the seawater became hypersaline, and sequentially deposited calcite, dolomite, gypsum, anhydrite and, ultimately, halite and sylvite. This evaporite precipitation sequence is a consequence of the composition of seawater (in terms of Ca^{+2}, Mg^{+2}, SO_4^{-2}, Cl^-, Na^+ and K^+), and the relative solubilities of the evaporite minerals. Where karst development has formed collapse breccia in the underlying 'Pembroke Formation', the evaporites in the White Quarry Formation have been dissolved, presumably as a result of the same dissolution process.

Overlying the White Quarry Formation is a thick sequence of siltstones of the Tennycape Formation. In the Musquodoboit Valley to the east, a facies change causes these siltstones to occupy the same stratigraphic position as the White Quarry Formation elsewhere. In the Windsor area, this unit is reddish with green and grey streaks that sometimes contain coal fragments. The actual thickness of the Tennycape Formation is not well constrained as it tends to occur within the cores of folds where its thickness has been distorted by deformation. The Tennycape Formation was deposited under subareal (mudflat) conditions, and probably occurred synchronously with karst development in the underlying 'Pembroke' and White Quarry Formations.

Overlying the Tennycape Formation is a sequence of interbedded limestones, and gypsum and/or anhydrite beds that belong to the Miller Creek and Wentworth Station Formations. In the Windsor area, these two units are mined by Fundy Gypsum when in close proximity to evaporites in the White Quarry Formation. These represent a series of evaporative cycles that probably formed as a result of multiple basin restrictions (gypsum beds up to ~20 m thick) and marine incursions (interbedded limestone units) over time.

The Miller Creek and Wentworth Station Formations are overlain by the Pesaquid Lake and Murphy Road Formations. These consist of interbedded fine-grained clastics and limestones of 20 to 40 m thicknesses, and contain only minor amounts of gypsum and/or anhydrite intervals. As a result, these deposits probably represent multiple transgressions and regressions in a basin that was restricted only ephemerally during this time interval.

Overall, evaporite and clastic sedimentation in the Windsor Group changed from deposition under deep water conditions, where basin topography exerted influence on local sedimentary facies and units exhibit substantial vertical continuity (the Macumber Limestone, and White Quarry and Tennycape Formations), to shallow water conditions, where multiple transgression-regression sequences and basin restriction and marine incursion episodes occurred (the Miller Creek, Wentworth Station, Pesaquid Lake and Murphy Road Formations). As a result, these deposits represent the equivalent evaporitic facies to 'rift' and 'sag' style sediments observed in classic rift sequences, respectively.

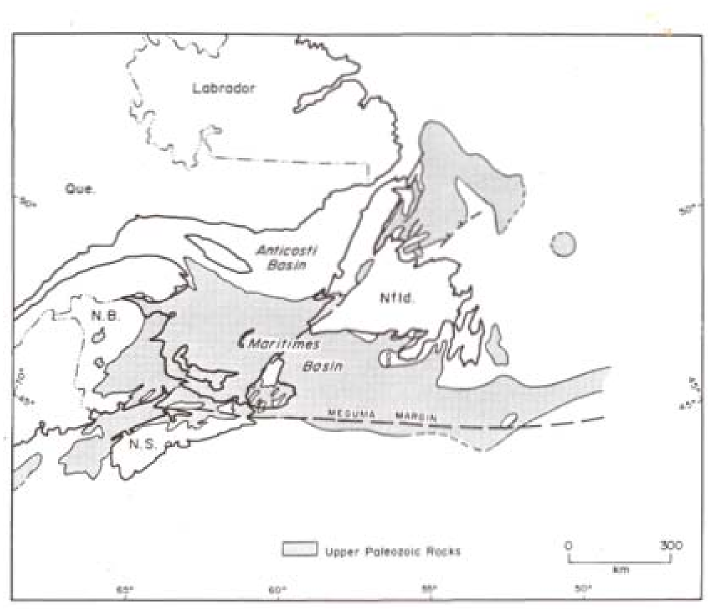


Figure 1 – Map illustrating the areal extent of the Maritimes Basin.

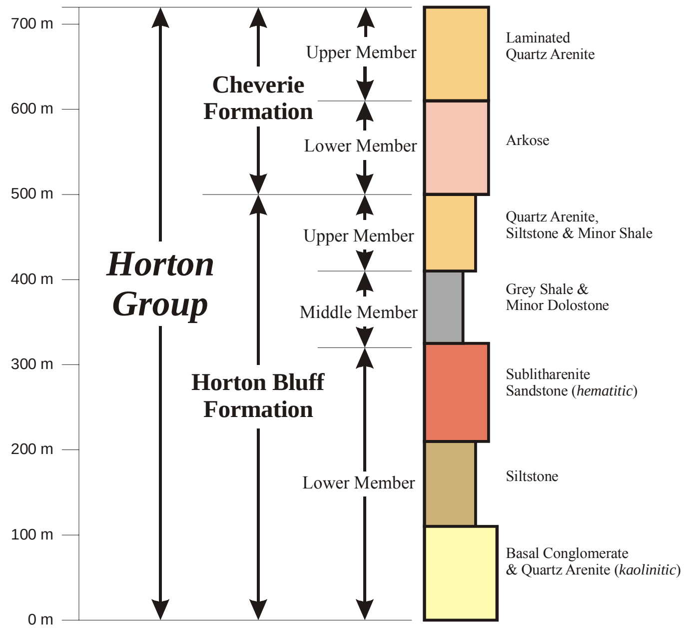


Figure 2 – Stratigraphic Units of the Lower Carboniferous Horton Group, a sequence of largely continental clastic rocks that filled the proto-Maritimes Basin.

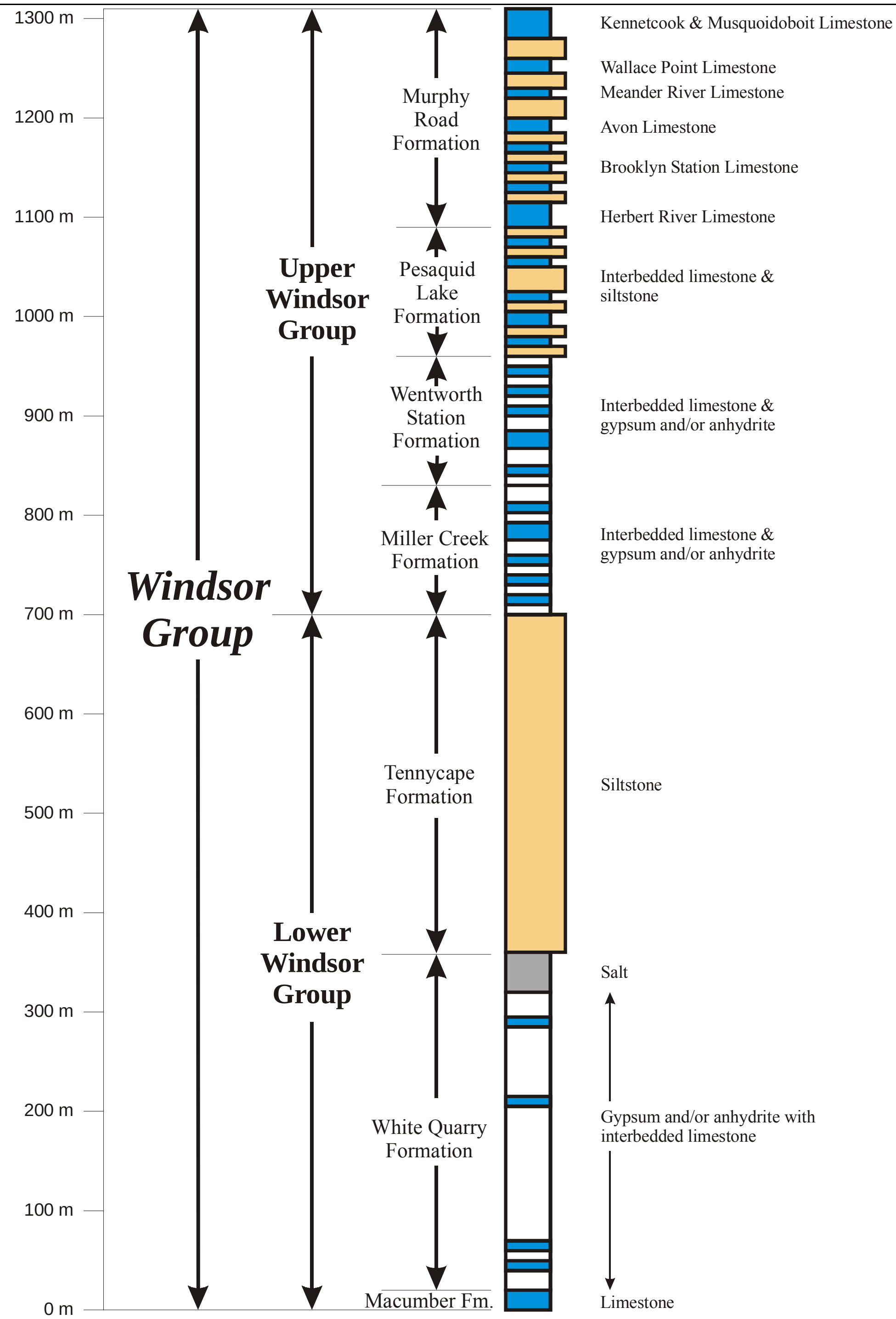


Figure 3 – Stratigraphic Units of the Lower Carboniferous Windsor Group, a sequence of largely evaporitic rocks deposited in the restricted Maritimes Basin after marine transgression into the basin.

Itinerary

8:30 AM – Departure from Old Orchard Inn

From the Old Orchard Inn (Wolfville), turn left (north) on NS Hwy 358, proceed for 1200 m to Greenwich, and then turn right (east) onto NS Hwy 1. Proceed 2.6 km to Acadia University to pick up additional student attendees. Continue east on NS Hwy 1 for 6.8 km through Wolfville and Grand Pre to Exit # 10 and turn left (southeast) onto NS Highway 101. Proceed to Exit # 5 and turn right on NS Hwy 14 (west) for 700 m to Garlands Crossing. Turn left (east) on NS Hwy 1, and proceed 2.4 km to Panuke Road (in Five Mile Plains). Turn right (south), and proceed 3 km to the Panuke Lake Road Quarry (on the right).

9:15 AM – Stop # 1 – Panuke Lake Gravel Quarry [*the quarry is large and flat enough to turn a bus around in*]

Turn left (north) out of the Panuke Lake Road Quarry and proceed 3 km back to NS Hwy 1. Turn left (west) and proceed 800 m to the Windsor Back Road. Bear left (west) and proceed a further 1 km to an intersection with Three Mile Plains Cross Road on the right and Mountain Road on the left (Three Mile Plains). Continue 300 m past this intersection, and turn left (south) on a dirt road that appears to be a driveway at first (just past a white house and barn with green roofs). Proceed approximately 1 km up this dirt road to steepest part of the hill. Park and walk 100 m into woods on the left to the Glass Sand Quarry and nearby outcrops adjacent to Fall Brook.

10:15 AM – Stop # 2 – Fall Brook [*busses can turn around in the Windsor Water Treatment Plant yard located 800 m further up the road; to confirm they are open, call: 798-0144*]

Proceed north 1 km back down the dirt road to the Windsor Water Treatment Plant, and turn right (east) onto the Windsor Back Road. Proceed 1.3 km to NS Hwy 1. Bear right (east) and continue another 3.2 km through Five Mile Plains to Newport Station. There, turn left (north) on Wentworth Road and proceed 2.8 km to Sweets Corner and NS Hwy 14. Turn right (east) onto NS Hwy 14 and proceed to Brooklyn (4.3 km). There, turn left (north), following NS Hwy 14 and County Hwy 215, and proceed 800 m to an intersection with a PetroCanada station on the corner. Turn right (east), staying on NS Hwy 14 to Scotch Village Station Road (4.9 km). Turn left (north) and proceed 1.5 km, crossing the Herbert River, and parking below the bluffs just north of the river on the west side of the road (as it starts to climb up the hill).

11:30 AM – Stop # 3 – Herbert River

Proceed north on Scotch Village Station Road for 4.2 km until reaching County Hwy 236 (at Scotch Village). Cross County Hwy 236 and continue another 800 m, crossing the Kennetcook River, and turning left (west) on Walton Woods Road. Proceed past Comagun River (5.2 km), the Walton River (20.4 km), to Walton (22.4) and County Hwy 215. Turn left (west), and proceed 1.8 km to an improved dirt road on the left. Turn left onto that road and proceed 2.5 km to the Walton barite mine.

12:30 PM – Stop # 4 – Walton Barite Mine [*note that there is a flat space to turn busses around just to the SW of the open pit*]

Return to Scotch Village via the dirt road to the Walton barite mine, County Hwy 215, the Walton Woods Road, and the Scotch Village Station Road, and turn right (west) onto County Hwy 236. Proceed 4.8 km to the intersection of County Hwy 215, turn left (east) and proceed 1 km to NS Hwy 14, proceed straight through that intersection for an additional 700 and follow NS Hwy 14 as it turns sharply right (west) in Brooklyn. Continue on NS Hwy 14 for 4.2 km to Sweets Corner, and turn right (north) on Wentworth Road. Proceed 4 km to the Fundy Gypsum Mine (on the right). Meet company engineer and mine manager Heather Gatza at the white building in front of concentrator.

2:30 PM – Stop # 5 – Fundy Gypsum Mine

Turn right (west) after leaving the Fundy Gypsum Mine, and proceed on Wentworth Road for 1.8 km. Turn right (north) onto NS Highway 101, and proceed to Greenwich at Exit 11, turning left (south) onto County Hwy 238, and proceeding 400 m to the Old Orchard Inn on the right.

5:00 PM – Return to Old Orchard Inn

Field Trip Stop Descriptions

1 – Panuke Lake Gravel Quarry

The Panuke Lake gravel operation is owned by Municipal Enterprises Ltd. (MEL) and has been in operation since 1995. It quarries thickly bedded sandstone, likely from the Church Point Formation of the Goldenville Group, Meguma Supergroup, and produces a variety of construction products. Beds dip steeply to moderately north, and the rocks are prepared for market using portable crushers and sorters that are shared with other quarries owned by MEL, and brought into the Panuke Lake quarry as needed. Gavin Isenor, development geologist for MEL, will lead us on a tour through the open pit and answer any questions.

Below is a list of products made at this and many other gravel quarries and a description of what these products are typically used for:

1.) ‘Quarry Run’ – blasted rock of various sizes typically used for fill at constructions sites;

2.) unsorted ¾” and 2” crushed rock – used as backfill to underground municipal sewer pipes, etc.;

3.) washed sand – used as a major component in ‘hot mix’ asphalt;

4.) ‘Crusher Dust’ – commonly used as foundation for paving stone patios and driveways;

5.) ¼” to ¾” sorted stone – used in rural septic systems and for house foundation backfill;

6.) ‘Armour Rock’ – large angular rocks used to protect piers and shorelines, and create safe harbours;

7.) 4” to 8” sorted rock – used as facings on steep slopes to enhance stability; and

8.) 1” to 4” sorted stone – mostly used as upper foundations to roads (coarse below, fine above).

In addition to the above products, this quarry also produces asphalt, and a portable asphalt plant is brought in for this purpose. This plant mixes high atomic number ‘waste’ petroleum created during the refining process, with gravel and sand to produce asphalt for roads. A critical factor in this process is the stone used to make the asphalt, as some stone doesn’t adhere well to the petroleum molecules, and this causes the asphalt to break down prematurely. The reason some stones don’t adhere to petroleum molecules is not well understood, so the process of identifying whether a rock will adhere to petroleum molecules is typically of ‘hit-and-miss’. As a result, if you happen upon a rock that will adhere to petroleum, a lot of money can be made producing high quality asphalt.

 # 2 – Fall Brook Outcrops

The Fall Brook area has exposures of Horton Group rocks that provide an understanding of the basal units filling the Windsor sub-basin of the Maritimes Basin. Horton Bluff Formation is exposed at an angular unconformity with Meguma Supergroup rocks in the upper quarry along Fall Brook (Figure 4). Within it are thin coal measures, quartz arenite bodies (including a highly sorted unit called ‘the glass sand’ because of its quartz purity, once used to make glass in the olden days), interbedded siltstones and shales containing abundant fossil of a variety of types, and a basal quartz pebble conglomerate. ***See if you can identify these fossils***.

The underlying rocks are moderately deformed and part of the Meguma Supergroup, but this area has not been mapped in detail using the latest lower Paleozoic stratigraphic column developed for this part of Nova Scotia. As a result, ***see if you can identify what formation the rocks beneath the unconformity are from.***

Above the Horton Bluff Formation is the Cheverie Formation, a sequence of thick arkosic sandstones with abundant cross-bedding. This unit is clearly derived from the uraniferous South Mountain batholith, and so it is no surprise that U mineralization has been discovered within it (back in 1979). This deposit, called the Three Mile Plains Uranium Deposit, is located down-dip from this location, approximately underneath Exit # 5 of Highway # 101, at depths between 360 and 425 m. It is likely a classic, roll-front uranium deposit, formed by the successive dissolution and re-precipitation of uranium by oxidized groundwaters flowing downward within the permeable Cheverie Formation arkoses. Mineralization consists predominantly of uraninite, but this deposit cannot be mined, or further explored, because of the uranium mining and exploration bans imposed by the provincial government. Nevertheless, the uranium in this deposit does pose a risk to human health and the environment, as circulating groundwaters can dissolve and transport this uranium, creating possible exposure opportunities. A municipal water supply has been developed in the largely rural Three Mile Plains area so that residents are sure to have access to a water supply that does not contain anomalous concentrations of uranium. ***We will have a gamma ray spectrometer on this field trip to see if there is any uranium mineralization located within the Cheverie Formation up-dip from the deposit.***

Interestingly, because: (*i*) saddle reef gold vein deposits exist in the Meguma Supergroup, (*ii*) these rocks weathered and eroded to provide the sediments deposited in the Horton Bluff Formation, (iii) these sediments were deposited in high energy rivers that incised relatively deep canyons in the Meguma/South Mountain Batholith landscape, potential exists for the existence of paleo-placer gold deposits at the bottom of the Horton Bluff Formation (associated with the basal quartz pebble conglomerate). In fact, over the past several years, True Metallic Explorations has been drilling this target in the Martock-Three Mile Plains-Windsor area and drilling may be ongoing nearby during our fieldtrip. If so, we will be making an ad hoc stop at their drill site to see what a diamond drill looks like and learn from geologist Larry Riteman how their exploration program is progressing.

3 – Kennetcook Limestone Bioherm

At this stop, two exposures of the Late Visean (Middle Mississippian) Kennetcook Limestone member of the Murphy Road Formation are worth visiting. The Murphy Road Formation consists of six major limestone units separated by recessive siltstone beds that sometimes grade laterally into gypsum (Figure 5). The Kennetcook unit is the top limestone member, and here dips north, on the south side of a regional syncline.

About 100 m west along the river is an exposure of thin-bedded fossiliferous limestone. This section is approximately 20 m thick and contains various fossil facies comprising solitary rugose corals, bryozoans, brachiopods, echinoids and fusilinids (Figure 6). These fossils are exclusively filter-feeders, suggesting that a mesotrophic lagoonal environment predominated in this area.

West of the road is a large bluff containing a massive coquina bioherm up to 10 m thick composed mostly of interlocking bivalve fossils that is stratigraphically equivalent to the compact, thin bedded outcrops along the river. ***Note that this exposure is an excellent fossil collecting locality, so feel free to pick up a dead critter or two.*** These rocks exhibit extraordinary porosity (and permeability), and overlie 10 m of thin bedded limestone, interbedded with shale and containing crinoids, bryozoans, bryozoans and brachiopods. As a result, this exposure represents a, likely, small patch-reef within a vast lagoonal environment responsible for the deposition of the Kennetcook Limestone.

Although most petroleum targets in the Windsor sub-basin of the Maritimes Basin are structural traps produced by thrusting or salt tectonics, bioherms similar to this one but buried at depth could be stratigraphic traps for petroleum or natural gas, or even reservoirs for CO_2 storage. Although small, their very high porosity would allow them to host significant petroleum reserve If buried at only shallow levels, these rocks could also host abundant groundwater reserves.

4 – Walton Barite Mine

The Walton Barite Mine, presently owned by Halliburton Oil Services Company (HOSC) and also known as the Magnet Cove Mine, produced 4 M tonnes of barite and 363,000 tonnes of Cu-Pb-Zn-Ag sulphide ore during operations between 1941 and 1978. Mining was by open pit methods until 1956, after which underground developments were used to access the ore. Massive replacement ore occurs in the Pembroke Formation breccia and underlying Macumber Formation in a pipe-like geometry associated with a drag-folded zone between intersecting east- and northwest-striking faults (Figure 7). Subjacent coarse-grained Cheverie Formation arkoses contain stratabound, disseminated barite replacing the sandstone matrix.

Mineralization is thought to have been formed when cool (100 to 150^{o}C), oxidized, saline basinal fluids derived from dewatering processes operating elsewhere in the Windsor sub-basin inundated the Walton area, dissolving carbonate and replacing it with barite, chalcopyrite, sphalerite, tennantite, and galena. These basinal brines likely carried their metals as chloride complexes, and when they encountered reducing conditions in the Walton area (possibly due to the presence of organic debris or petroleum), underwent reduction that changed some of the sulphate into sulphide. This caused the precipitation of sulphide minerals, in addition to barite. Gangue minerals that also formed from this process include siderite, pyrite, hematite, pyrolusite, calcite and ferroan dolomite (ankerite; Figure 8).

Other barite and manganese showings with anomalous base metal concentrations exist in the Walton area at the same stratigraphic level, notably at the former Tomlinson Mine (6.4 km to the south), and the Log Cabin Brook prospect (19.3 km southwest; Figure 7). However, these mineralizations are predominantly stratabound, occurring within the Macumber Limestone, and with barite exhibiting ‘chicken-wire’ and nodular replacement textures, features normally associated with diagenetic replacement of gypsum in a coastal sabhka environment, and manganese occurring as pyrolusite veins.

During the early mining of the barite and sulphide minerals, tailings were stored in two locations: those derived from barite ore were deposited northwest of the open pit immediately adjacent to Rainy Cove Brook (1 M tonnes), and those derived from sulphide ore were deposited south of the open pit (0.5 M tones; Figure 9). These tailings are contained by berms up to 15 m high, and are filled with mainly re-brown, interstratified sandy and muddy sediments. Later re-processing of the barite tailings took place between 1971 and 1978, and the tailings from this effort were dumped into the open pit, which by that time had closed down.

Unfortunately, partly because little vegetation has taken root on the tailings impoundments over the years, and because the berms surrounding them were not maintained, erosion has breached the berms in several places, allowing tailings to flow into Rainy Cove Brook. This has led to the deposition of essentially raw tailings in the floodplain of Rainy Cove Brook adjacent to the Minas Basin (Figure 10). Enriched concentrations of Ba (40 times background), Mn (10 times background), and Cu, Pb and Zn (5 times background) exist in the stream sediments located there. Other minor enrichments in Ag, As, Sb, Co and Ni also exist in these sediments. Fortunately, the barite, which contains virtually all of the Ba, is highly refractory, and thus has low solubility, and low bio- availability, so its high enrichments do not pose a significant environmental problem. The other enriched metals are far more soluble, and evidence of environmental damage caused by these metals does exist.

In contrast, the stream waters within Rainy Cove Brook are enriched only in As and U (two elements that have high background concentrations in much of Nova), probably because flocculating Fe- and Mn-oxy-hydroxide minerals have adsorbed the other more soluble metals in the deposit, and then have precipitated on the bed of the stream, thereby removing these more hazardous elements from these surface waters. These oxy-hydroxide minerals probably formed when dissolved Fe and Mn in the reduced open pit and tailing waters mixed with upstream waters, a process that caused their oxidation to Fe^{+3} and Mn^{+4}, and the immediate precipitation of limonite and wad. As a result, these poorly crystalline precipitates have essentially acted as sponges to remove many dissolved contaminants from the stream.

Upstream from the minesite, waters have pH’s of 5.7 to 6.7, but downstream from the mine, these pH’s rise to between 6.8 and 7.6. This trend is in contrast to many mines containing sulphide minerals, as oxidation of sulphide minerals usually lowers the pH of streams draining such deposits. This opposite behavior is probably caused by the buffering effect of calcite within the Macumber and Pembroke Formations that host the deposit. Interestingly, the observed increase in pH also enhances to the precipitation of limonite and wad, and the adsorption of metals to their surfaces, and thus assists in the natural remediation of Rainy Cove Brook waters.

Recent reclamation of the Walton Barite Mine minesite has taken place over the past several years, funded by a bond provided by HOSC and held by the province to ensure the environmental hazards on the site have been eliminated and any environmental damage caused by the mining operation has been mitigated and/or remediated. These efforts have resulted in significant changes to the site (*e.g.*, the tailings impoundment berms have been restored and armoured against erosion, the site topography has been smoothed out to minimize erosion, top soil has been distributed to enhance the ability of plants to take hold on the tailings impoundments and waste dumps, and streams have been re-directed around these waste piles to prevent further erosion of their foundations). Consequently, the environmental condition of the minesite has been substantially improved. At present, only a couple more remediations need to be completed (planned for next year) before the environmental status of the minesite can be considered acceptable. As a result, the Walton barite minesite provides an excellent example of how a mine should be closed.

 # 5 – Fundy Gypsum Mine

The Fundy Gypsum Mine is operated by the Fundy Gypsum Company, which is a subsidiary of USG Canadian Mining Ltd. The Fundy Gypsum Company purchased the mine from the Wentworth Gypsum Company in 1926. Wentworth Gypsum started mining the deposits in 1892, after purchasing the property from William Dimock. Starting about 1882, William Dimock and several other local residents purchased a land package containing gypsum, funded development of a railroad, and started small scale mining operations.

The mine presently produces gypsum and anhydrite concentrates in a variety of grades. These are primarily used to produce wallboard, cement hardening retarders, plaster, and soil conditioners. The ore is mined and undergoes primary purification on site. Most product is shipped via rail to Hantsport and by ship to wallboard factories all along the eastern coast of North America. Due to the extreme tides in the Minas Basin, the bulk tonnage ore ships must navigate upstream to the Avon River terminal, be loaded and return to deeper waters within one tidal cycle (otherwise they would be stranded by low tide). As a result, the Hantsport loading terminal is the fastest bulk loading terminal in the world!

During our visit to Fundy Gypsum, Ms. Heather Gatza (mine manager) will provide a geological and mining overview of the evaporite deposit and Fundy Gypsum operation. She will then lead us on a tour of the Wentworth open pit currently under production, as well as the processing facility. During this tour, participants will have an opportunity to visit several fossil and mineral collection sites.

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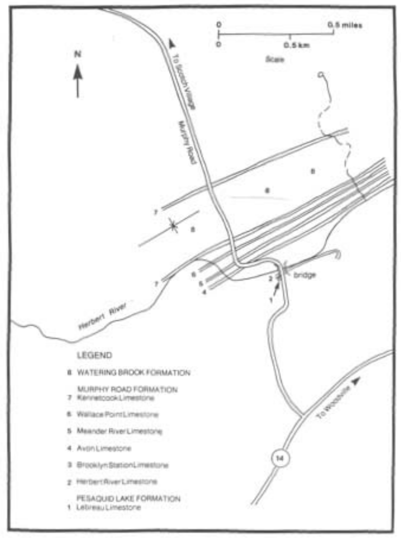

Figure 5 – Geological map of Stop # 3 – Kennetcook Limestone Bioherm; 'Economic Geology of the Windsor Sub-Basin' Field Trip, Atlantic Universities Geological Conference, October 2010.

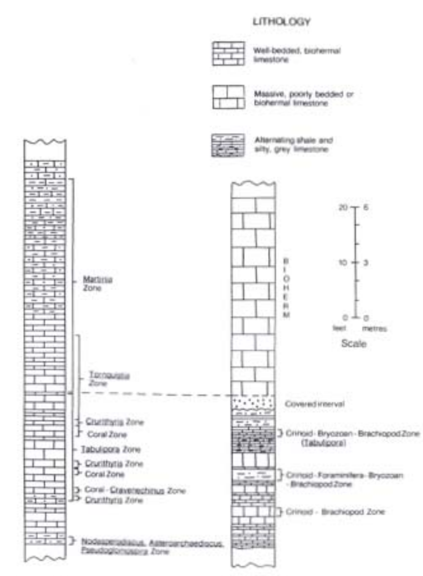

Figure 6 – Detailed stratigraphy of Stop # 3 – Kennetcook Limestone Bioherm; 'Economic Geology of the Windsor Sub-Basin' Field Trip, Atlantic Universities Geological Conference, October 2010.

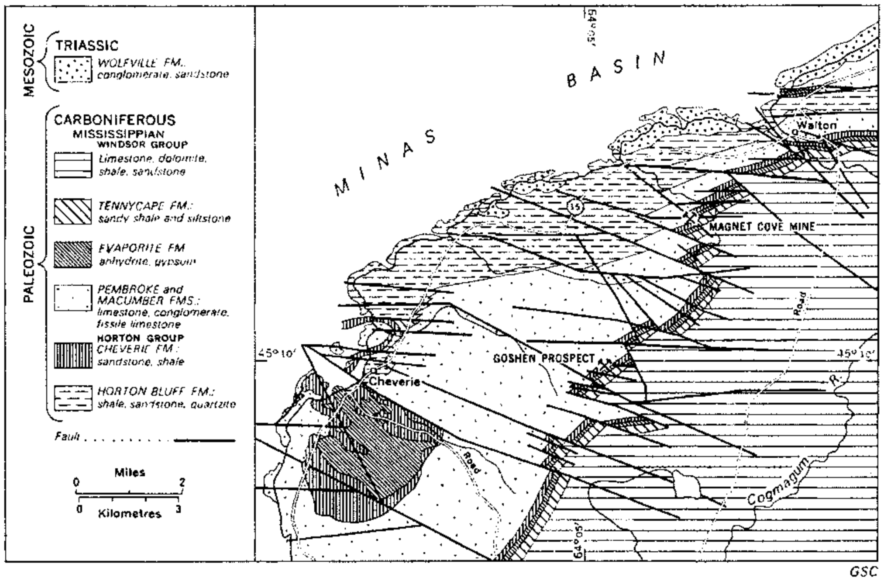

Figure 7 – Geological map of Stop # 4 – Walton Barite Mine; 'Economic Geology of the Windsor Sub-Basin' Field Trip, Atlantic Universities Geological Conference, October 2010.

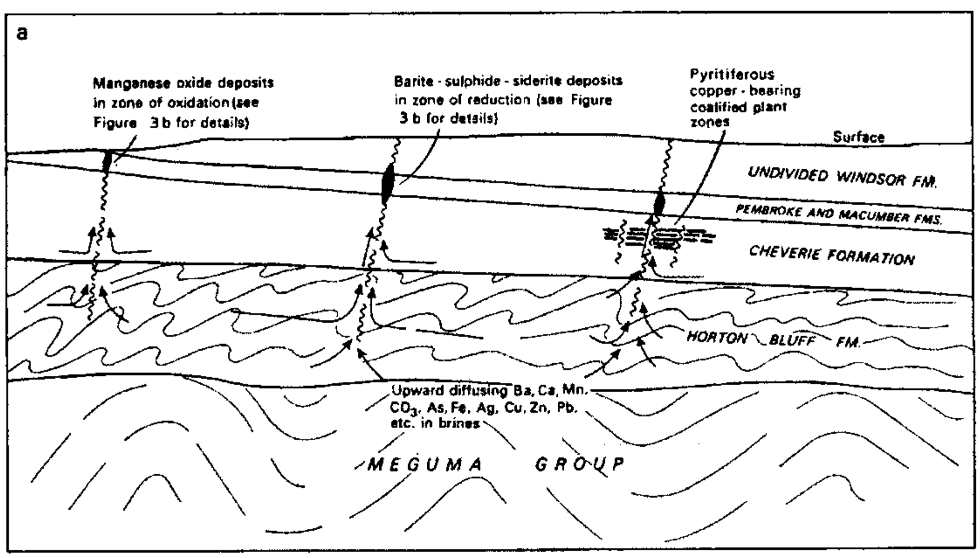

Figure 8 – Ore Deposit Model for the Walton Barite Mine: Stop # 4; 'Economic Geology of the Windsor Sub-Basin' Field Trip, Atlantic Universities Geological Conference, October 2010.

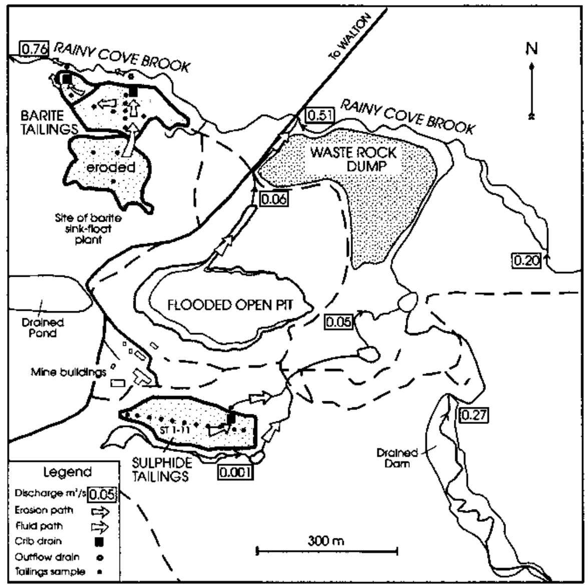

Figure 9 – Mining Operations at the Walton Barite Mine: Stop # 4; 'Economic Geology of the Windsor Sub-Basin' Field Trip, Atlantic Universities Geological Conference, October 2010.

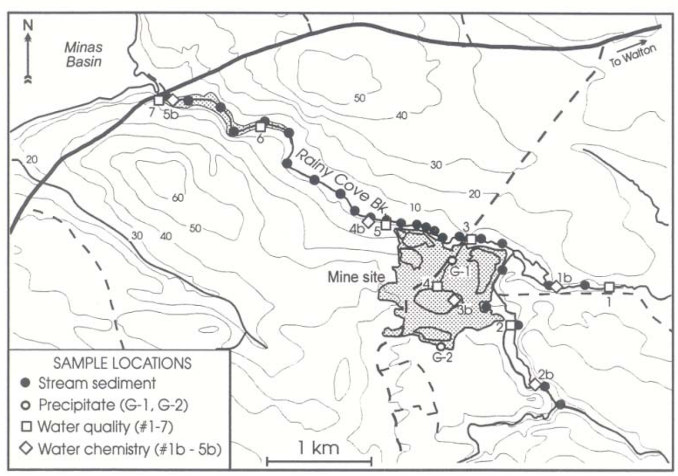

Figure 10 – Samples illustrating the environmentally impacted area around the Walton Barite Mine: Stop # 4; 'Economic Geology of the Windsor Sub-Basin' Field Trip, Atlantic Universities Geological Conference, October 2010.

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1. Beveridge Arts Centre / Art Gallery
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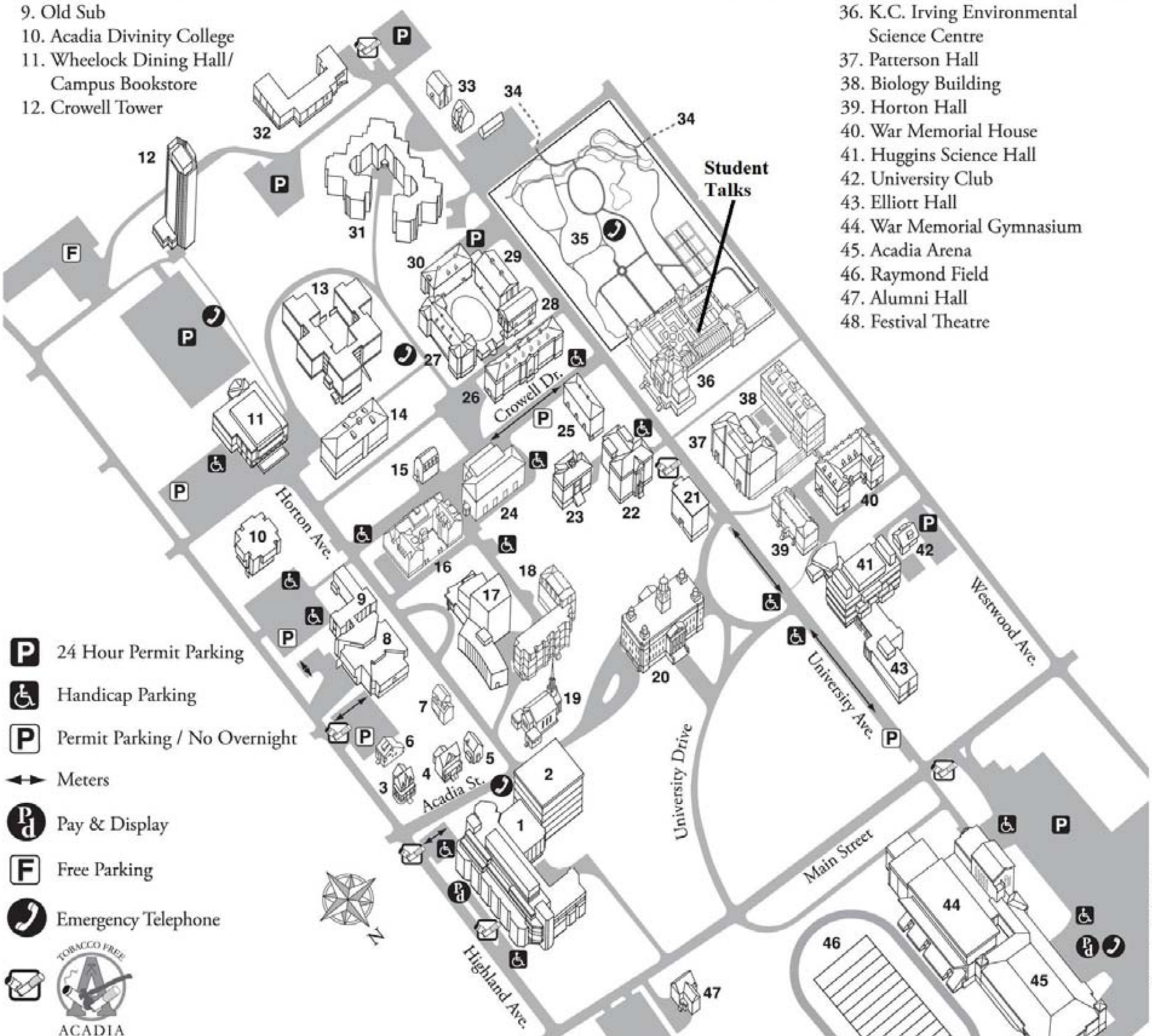
8. Acadia Students' Union Centre
9. Old Sub
10. Acadia Divinity College
11. Wheelock Dining Hall/ Campus Bookstore
12. Crowell Tower
13. Chase Court
14. Dennis House
15. Raymond House
16. Whitman House
17. Harvey Denton Hall
18. Seminary House
19. Manning Memorial Chapel
20. University Hall
21. Rhodes Hall
22. Carnegie Hall
23. Emmerson Hall
24. Fountain Commons
25. Willett House
26. Chipman House
27. Roy Jodrey Hall
28. Clark Commons
29. Christofor Hall
30. Eaton House
31. Cutten House
32. Robie Roscoe Services Building
33. 52 University Avenue and French House
34. Woodland Trails
35. Harriet Irving Botanical Gardens
36. K.C. Irving Environmental Science Centre
37. Patterson Hall
38. Biology Building
39. Horton Hall
40. War Memorial House
41. Huggins Science Hall
42. University Club
43. Elliott Hall
44. War Memorial Gymnasium
45. Acadia Arena
46. Raymond Field
47. Alumni Hall
48. Festival Theatre



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As per: April 2007