Geological Association of Canada

A B S T R A C T S

Newfoundland Section 2010 Spring Technical Meeting
February 22–23, 2010

JOHNSON GEO CENTRE, SIGNAL HILL,

ST. JOHN'S, NEWFOUNDLAND

Following our long-standing tradition, and in keeping with our sense of the absurd, the 2010 Spring Technical Meeting was once again held in the depths of the Newfoundland winter in the Johnson GEO CENTRE on scenic Signal Hill in St. John's.

The meeting featured a special session intended to highlight recent resource developments and the renewed interest in the energy potential of the province, especially as it relates to onshore and offshore petroleum, but also included energy minerals and other resources. A special session featured a series of talks related to the Geological Survey of Canada's Targeted Geoscience Initiative (TGI) program in Newfoundland. For those specifically interested in the TGI Program and the geology of central Newfoundland, a post-conference workshop (organized by Geological Survey of Canada and Geological Survey of Newfoundland and Labrador) was held to discuss outcomes and future plans. In addition, a general session included papers on an eclectic range of topics, as is normally the case at these meetings.

The 2010 meeting featured the third of the "Topical Geoscience Lecture" series, co-sponsored by the Professional Engineers and Geoscientists of Newfoundland and Labrador (PEG-NL). The speaker was Dr. Maurice Tivey of the Woods Hole Oceanographic Institute, who spoke on the scientific, technical, and jurisdictional challenges in the development of seafloor mineral resources.

The Newfoundland and Labrador Section of the Geological Association of Canada is pleased to have once again hosted an interesting and diverse meeting, and we are equally pleased to see the abstracts published in Atlantic Geology. Our thanks are extended to all of the speakers and the editorial staff of the journal.

ANDREW KERR
TECHNICAL PROGRAM CHAIR
GAC NEWFOUNDLAND AND LABRADOR SECTION

Atlantic Geology 46, 76–89 (2010)
0843-5561|08|00076–14$3.10|0

How useful is the Ibexian Series?

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

The Ibexian Series is commonly used as the correlation standard for latest Cambrian–Early Ordovician sedimentary rock sequences developed around the ancient continental margin of Laurentia. It was proposed to replace the previously accepted Canadian Series. It is defined in the Notch Peak, House, Fillmore, and Wah Wah formations of the Great Basin (western United States), originally part of Northern Laurentia. In ascending order, it is subdivided into the following stages: Skullrockian, Stairsian, Tulean, and Blackhillsian. The bases of these stages are defined by the First Appearance Datums (FADs) of individual trilobite species. The stages are further subdivided into zones, again based on trilobites, except for the *Hesperonomiella minor* brachiopod zone at the top of the Ibexian. A subsidiary conodont zonation is also defined within the Ibexian sequence. In most cases, trilobite-based correlations with regions outside the Ibexian type area of Northern Laurentia are difficult, due to a lack of common species. In practice, most correlations are done using the widespread conodonts. In contrast, correlations are easy along the length of the Caledonian–Appalachian–Ouachita orogen in Southern Laurentia, due to the wealth of common trilobites and other macrofossils. It is in this belt of rocks that the Canadian Series was originally developed. Two solutions are possible:

1. Revision of the Ibexian Series. Redefine the four stage bases using conodont species FADs. Relegate the trilobite zonation to a subsidiary role.
2. Two separate zonations: the Ibexian Series (Northern Laurentia) and the Canadian Series (Southern Laurentia).

Prospects for conventional and unconventional hydrocarbon plays for the Winterhouse Formation, Port Au Port Peninsula, Newfoundland

Elliott Burden, Helen Gillespie, and Jennifer Cunningham
Department of Earth Sciences, Memorial University of Newfoundland, St John's, Newfoundland and Labrador A1B 3X5, Canada

Winterhouse Formation, the Newfoundland equivalent to the Utica shale of New York, Ontario and Quebec, lies in a region of western Newfoundland that is thought to contain an active petroleum system. Outcrop studies in 2009 explored sedimentology, paleontology, structural geology, and petroleum prospects for these rocks. Some key findings on source reservoir and seal and relevant to exploration are reported here.

Winterhouse is thought to be well over 800 m of grey calcareous siltstone, punctuated with grey and white sandstone beds, and conglomerates. The base is a flooding event covering the underlying Lourdes Limestone. The top is a conformable succession of redbeds of the Misty Point Formation. In detail, the lower 130 m of Winterhouse strata are darker in colour and presumably a little more organic rich. Throughout this part of the section, acritarch concentrations are normally thousands of grains per gram and *Gloeocapsomorpha*, a key indicator species for source rock, are common. In contrast, the upper part of the formation is lighter grey in colour, he acritarch flora is markedly different in composition, and *Gloeocapsomorpha* are rare.

In total, Winterhouse strata are considered to be storm deposits punctuated by chaotic beds of conglomeratic debris covered with rafted and imbricated clasts. Some sandstone and conglomerate beds are darker in colour and smell of hydrocarbons when cracked. In other places, small joints and fractures are lined with pyrobitumen. The distribution of possible petroliferous beds is not uniform. Coastal outcrops are gently to steeply dipping and overturned. In addition, small faults, parasitic folds, and perhaps also drape folds appear to influence hydrocarbon migration. These aspects are addressed as threats and opportunities for conventional oil and gas and unconventional shale exploration.

Structure and timing of deformation and metamorphism of the Baie Verte Peninsula, Newfoundland Appalachians

Sébastien Castonguay[1], Tom Skulski[2], Cees R. van Staal[3], Vicki McNicoll[2], and Nancy Joyce[2]
1. Geological Survey of Canada, 490 rue de la Couronne, Québec, Québec G1K 9A9, Canada ¶ 2. Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario K1A 0E8, Canada ¶ 3. Geological Survey of Canada, 605 Robson Street, Vancouver, British Columbia V6B 5J3, Canada

On Baie Verte Peninsula (BVP), Newfoundland, the Baie Verte Line (BVL) forms a prominent zone of steep WNW-dipping fabrics separating the Laurentian margin rocks (Fleur de Lys Supergroup; Humber Zone) to the west from ophiolite and arc complexes of the Notre-Dame subzone (Baie Verte Oceanic Track; BVOT), to the east. East of the BVL, the main fabrics in the BVOT and Silurian cover are mainly oriented E-W. This abrupt structural curvature is known as the Baie Verte Flexure and has been interpreted to be inherited from the original geometry of the Laurentian margin.

Numerous published radiometric ages indicate that the predominant amphibolite-facies metamorphism of the Fleur de Lys Supergroup was Salinic (Silurian), not Taconic (Ordovician), whereas east of the BVL, most data in the Notre Dame subzone provided Middle Devonian to Early Carboniferous cooling ages. Correlating fabrics and metamorphic assemblages across the BVL is one of the main challenges to resolve the structural evolution of the peninsula. New $^{40}Ar/^{39}Ar$ and U-Pb geochronologic data allow for better age control on deformation and metamorphic events, which improves correlations across the BVP.

This area has been affected by at least four phases of regional deformation. D_1 fabrics are strongly overprinted west of the BVL and are cryptic east of it. D_1 age constraints from the Fleur de Lys Supergroup range from ca. 468 to 459 Ma, and are interpreted to be related to west-directed obduction of ophiolites, arc-continent collision and burial of the Humber Zone during the Ordovician Taconian Orogeny. D_2 represents the main tectonometamorphic phase. Along the BVL, it is associated with penetrative steep SSW-trending fabrics attributed to east-directed thrusting and sinistral shear, and is dated between ca. 427 and 417 Ma. East of the BVL, the main fabric, correlated to S_2, is mainly west-trending, associated with south-directed thrusting, greenschist to amphibolite facies metamorphism, affecting the Silurian Cape St. John group, and therefore has to be younger than ca. 426 Ma. D_2 is interpreted to be related to transpression during the Silurian Salinic Orogeny. D_3 west of the BVL is associated with a SSW-trending crenulation fabric and shear zones, mainly concentrated along the BVL. Kinematics of D_3 along the BVL mainly suggest dextral motion, with a component of transpression and transtension. East of the BVL, shallowly-inclined F_3 folds have been interpreted to be cogenetic with inversion of shear zones and reverse faults during dextral transtension. D_3 is thought to be contemporaneous with the unroofing of a tectonic window of Humber zone rocks (Ming's Bight Group) east of the BVL, where timing of deformation and cooling range between ca. 405 and 360 Ma. Finally, NE- to NW-trending F_4 cross folds are documented in the central (Rambler Mines area) and northeastern (Cape St. John Group) parts of the peninsula. Their age is unconstrained beyond being post-D_3.

The long-lived non-coaxial nature of deformation has played a major role in defining the Baie Verte Flexure. The structure and evolution of northern Baie Verte Peninsula resemble a large-scale long-lived oblique transfer zone between the BVL and the Green Bay Fault, which acted in transpression during the Salinic Orogeny and was later reactivated as a Devonian–Early Carboniferous dextral transtensional zone.

Dual-frequency acoustic seabed classification on the Scotian Shelf, Canada

Andrew Cuff[1], John Anderson[2], Rodolphe Devilliers [1,3], and Sam Bentley[3]

1. Department of Geography, Memorial University of Newfoundland, St. John's, Newfoundland and Labrador A1B 3X5 Canada ¶ 2. Department of Fisheries and Oceans, St. John's, Newfoundland and Labrador K1A 0E6, Canada ¶ 3. Department of Earth Sciences, Memorial University of Newfoundland, St. John's, Newfoundland and Labrador A1B 3X5, Canada

Understanding surficial seafloor geology is important when mapping marine benthic habitats. Acquiring information on surficial seafloor geology is usually derived from acoustic measurements. Acoustic seabed classification (ASC) aims to objectively classify surficial seafloor substrate types based on acoustic energy reflected by the seabed (i.e., backscatter). The shape and intensity of acoustic backscatter is influenced by the physical properties of seafloor substrate, primarily grain size and roughness. In general, larger particles (e.g., boulder or cobble) reflect more acoustic energy than smaller particles (e.g., sand). Acoustic backscatter will also vary depending on a number of other factors, including the acoustic frequency. Lower frequencies penetrate deeper within the seabed than higher frequencies, whereas higher frequencies exhibit greater resolution than lower ones and therefore can detect smaller features. Therefore, lower frequencies reveal information on seabed substrate that higher frequencies will not, and *vice versa*.

Existing approaches to ASC typically use one acoustic frequency. This paper presents an approach that aims to quantify the variations in backscatter from two acoustic frequencies and to assess the improvement in dual-frequency ASC of surficial substrate. Two acoustic frequencies commonly used in fisheries sciences, 38 kHz and 120 kHz, were collected simultaneously at two study sites of the Scotian Shelf, Canada, using a single beam echo sounder sonar system. The acoustic data were processed for the near nadir (coherent) backscatter component, which emphasizes the contribution of particle size as opposed to surface roughness.

In each of the study sites, both frequencies provided a similar response over large distances (kilometres), but sometimes differed significantly locally (10–100 m). For example, in one study area, the backscatter response generally allowed the identification of two seabed substrate types, sand and gravel, over large distances. For each frequency, backscatter intensities were classified using univariate classification techniques and then compared in order to highlight differences in relative frequency responses that could be related to different substrate types. Analyses revealed that sand substrate generally produced higher relative 38 kHz backscatter as compared to 120 kHz backscatter, while gravel substrate was the opposite. Backscatter responses from each frequency were compared using a Wilcoxon Signed Ranks Test (non-parametric test) for each surficial geological unit to determine whether there are any significant differences in the backscatter response and significant differences were identified for a number of geological units. Finally, multivariate classification techniques were used to classify seabed surficial geology using acoustic backscatter, along with a number of morphology layers (e.g., slope and depth). Results revealed that using backscatter from two frequencies, as opposed to one, improved classification accuracy. These results suggest that combining acoustic frequencies can allow for a more accurate mapping of seabed surficial geology.

High-resolution record of cyclone strikes from the Blue Hole, Lighthouse Reef, Belize

Kathryn Denommee and Samuel J. Bentley
Department of Earth Sciences, Memorial University of Newfoundland, St. John's, Newfoundland and Labrador A1B 3X5, Canada

Sediment cores from the Blue Hole of Lighthouse Reef, Belize, were collected in order to obtain a high-resolution record of storm activity over approximately the past two millennia. The focus of this study is to identify the sedimentary signature (recorded in our cores) produced by storms of known track and intensity. These observations will then be used to evaluate recently posed hypotheses relating North Atlantic cyclone trajectories to 10^2–10^3y shifts in large scale atmospheric circulation. Vibracores (to >6 m length) have been scanned with a multisensor logger equipped with digital camera, gamma densitometer, and photospectrometer, then imaged with a digital X-ray system. The vertical resolution of data gathered ranges from 0.03 mm to 2.0 mm. Radioisotope geochemical analyses (Pb-210, C-14) are underway. Preliminary results show that background sedimentation consists of varved carbonate muds which are interbedded with thicker coarser layers produced by notable sediment-transport events. Depositional event beds are distinguished from background varved laminae based on coarser grain size, normal grading, light colour, and layer thickness >2.5 mm. Documented cyclone landfalls, compared with patterns of bedding and sedimentary fabric, suggest that the high-resolution data record deposition of both direct strikes of intense cyclones, as well as weaker events that are presumably more distant and/or less intense storms, thus providing one of the most complete paleotempestological records for the region to date.

Late Jurassic source rock super-highway in the North Atlantic: proven and possible hydrocarbon systems

Michael Enachescu[1,2], J. Hogg[1], I. Atkinson[3], D. McCallum[4], and P. Einarsson[5]
1. MGM Energy, 4100, 350 – 7th Avenue SW Calgary, Alberta T2P 3N9, Canada ¶ 2. Department of Earth Sciences, Memorial University, St. John's, Newfoundland and Labrador A1B 3X5, Canada ¶ 3. Nalcor Energy, St. John's, Newfoundland and Labrador A1B 0C9, Canada ¶ 4. Energy Branch, Department of Natural Resources, PO Box 8700, St. John's, Newfoundland and Labrador A1B 4J6, Canada ¶ 5. Geological Survey of Ireland, Beggars Bush, Haddington Road Dublin, Ireland

In the past decade, the offshore of Atlantic Canada has become an important petroleum- producing province. The largest hydrocarbon discoveries in this area were made during 1979–1984, when drilling in the high-risk, high-cost North Atlantic waters was stimulated by the Canadian Federal Government's Petroleum Incentive Program (PIP). Currently, 350,000 BOPD are produced from three large oil fields and several smaller satellite fields within the Jeanne d'Arc Basin of the Grand Banks of Newfoundland. A further production of 150,000 BOPD is expected by the end of the decade from the Hebron field. In Offshore Nova Scotia, 450 MMCFGD flow from the five gas fields in the Sable sub-basin, whereas the Deep Panuke field will start producing later this year and is scheduled to reach 300 MMCFGD peak sales gas.

The offshore basins of Newfoundland and Labrador and Nova Scotia had a complex geodynamic evolution including Mesozoic extension, salt tectonism, subsidence, and localized exhumation that have created numerous and varied hydrocarbon trapping styles and play types. However, the main ingredient of the Atlantic Canada's petroleum system is the extensive presence of a rich and thick Late Jurassic (mostly Kimmeridgian), predominantly restricted-marine-origin source rock in the basins off East Newfoundland, and predominantly terrestrial-derived on the Scotian Shelf and slope basins. This difference in source rock origin and quality is due mainly to differences in paleotectonic and paleogeographic conditions.

The presence of Late Jurassic source rocks in less known, deep water Newfoundland offshore basins was initially postulated by correlating the associated seismic markers from the established basins through seismic regional mapping and basin-to-basin correlations. In 2003 their presence was confirmed in the Flemish Pass Basin by drilling of the Mizzen L-11 well. The well intersected Late Jurassic source rock and discovered oil within an Early Cretaceous reservoir. In 2009, the Mizzen O-16, drilled 10 km up-dip, confirmed a larger discovery in the basin. The Great Barasway F-66 well in the East Orphan Basin intersected a Late Jurassic sequence that appears to contain source rocks that can be extrapolated to adjacent mini-basins and troughs.

These new wells prove that both Flemish and Orphan basins are part of the Kimmeridgian-aged source rock "super-highway" that partially follows the Atlantic rift trend connecting the Scotian Shelf to offshore Newfoundland basins and extending into the Porcupine, Rockall Trough and Slyne basins of West of Ireland and from there into the North Sea and Norwegian Sea basins and sub-basins. While not directly proven by drilling at this time, it is hypothesized that arms of the Kimmeridgian Sea may have extended into the present day Labrador Sea's earlier basins and troughs, now situated on the present day shelf slope and within the deep waters of both the Greenland and Labrador margins. The key to further oil and gas discoveries in these and other regions of the North Atlantic lies in identifying through the use of regional seismic grids the Late Jurassic source rock intervals and mapping the source rock super-highway.

Unbioturbated marine mudstones: environmental stress or rapid deposition? A worked example from the Ordovician Beach Formation, Newfoundland, Canada

Dario Harazim, Duncan McIlroy, Joe Macquaker, and Sam Bentley
Department of Earth Sciences, Memorial University of Newfoundland, St. John's, Newfoundland and Labrador A1B 3X5, Canada

Recent research demonstrates that most mudstone successions contain a great deal of evidence of having been deposited by advective sediment transport processes. These processes are commonly difficult to investigate because original sediment fabrics are commonly disrupted by the activity of burrowing organisms. In order to investigate some of the mechanisms of mud dispersal, Lower Ordovician sediments of Bell Island have been studied. These sediments are ideal because the primary sedimentary textures in the mudstones are commonly still preserved. At Freshwater Cove, storm-dominated shoreface sediments are partially bioturbated by trace fossils of a proximal *Cruziana* ichnofacies. The purpose of this study was to examine all possible controls on deposition of intercalated, unbioturbated mudstones in the succession through integration of sedimentological and geochemical datasets at a range of different scales. Previous sedimentological studies interpreted unbioturbated mudstone intervals as being deposited in an anoxic, low-energy paleoenvironment. Our micro-fabric analysis and geochemical studies of these mudstones suggest that anoxia is not the only possible control on intensity of bioturbation. Within thick, unbioturbated siltstones and mudstones, bases are erosive, and rip-up clasts are common. Through micro-fabric studies (i.e., low-power microscopy), a wide range of previously unrecognized sedimentary structures has been described in the unbioturbated mudstones. Those structures include thin (<1 mm), stacked beds with erosional tops and bases and well-developed low-angle cross-stratification. Microscopic bioturbation in the form of very small (<1 mm) *Planolites* burrows is common in mudstone horizons. Mudstones contain 0.5% TOC in average, with peak values of up to 3.4% TOC. Pyrite framboid analyses of unbioturbated intervals reveal that the water column close to the sediment-water interface was fully oxygenated during deposition. Sedimentary provenance of mudstones within distinct facies associations (using Rare Earth Elements, REE) reveals that all examined mudstones are either from the same source, or have undergone the same mixing process before deposition. We have therefore determined that, (1) given the distal location of the exposure with respect to a potential fluvial source, (2) the fully oxygenated state of the water column, and (3) the evidence for bottom currents, that at least some of the unbioturbated muds were deposited as wave-enhanced fluid mud flows. This episodic form of sediment supply is widely recognized from recent, mud-rich coasts but has never been appreciated as a significant depositional process in the lower Palaeozoic. A careful, integrated, study of other ancient mudstone successions is needed in order to assess the importance of fluid mud deposits throughout the sedimentary record. In addition, uncritical interpretation of unbioturbated mudstones as resulting from bottom water anoxia is potentially flawed.

An overview of petroleum exploration activity in Newfoundland and Labrador

Larry Hicks
Energy Branch, Department of Natural Resources, PO Box 8700, St. John's, Newfoundland and Labrador A1B 4J6, Canada

The province of Newfoundland and Labrador lays claim to an offshore area of petroleum potential in excess of 800,000 square kilometers (80 million hectares) and an additional 20,000 square kilometers (2,000,000 hectares) of prospectivity within the onshore basins of western Newfoundland. Currently, less than 10% of this entire acreage is held under exploration licence (offshore) or permit (onshore) by exploration companies. The offshore sector is administered by a joint federal-provincial board, the Canada-Newfoundland and Labrador Offshore Petroleum Board (C-NLOPB), while onshore activity is regulated by the provincial Department of Natural Resources (Energy Branch), Petroleum Development Division. Both entities maintain extensive geoscience data files and core repositories which are available for access by the general public.

In early 2009 the province reached a significant milestone, having produced the first 1 billion barrels of oil from the Hibernia, Terra Nova, and White Rose fields. In addition to this production milestone, offshore exploration wells were drilled in the Flemish Pass basin (StatoilHydro *et al.* Mizzen 0-16) and Jeanne d'Arc basin (Petro Canada *et al.* Ballicatters M-96). Exploration results for both wells remain confidential until 2011, although speculation abounds with respect to the Mizzen well after StatoilHydro applied to the C-NLOPB for a Significant Discovery Licence (SDL). Offshore exploration activity should increase in 2010, with drilling currently underway by ConocoPhillips et al. in the Laurentain basin (East Wolverine G-37) and announcements by Chevron et al. to drill the Lona 0-55 well in the Orphan basin and Husky Energy and partners gearing up to commence the Glenwood H-69 well north of the White Rose field in the Jeanne d'Arc basin. In addition to current and proposed drilling, offshore 2D, 3D and geohazard seismic surveys are slated for the Labrador shelf (by Husky Energy, Investcan Energy and Chevron Canada Resources), Sydney basin (Husky Energy) and Laurentian basin (ConocoPhillips). The NL09-01 (Jeanne d'Arc basin), NL09-02 (Laurentian basin) and NL09-03 (Gulf of St. Lawrence) Call for Bids resulted in a total work commitment of $47,000,211. On the development side, Hebron partners are predicting first oil by 2017 and oil should be flowing from the North Amethyst field (Husky Energy) and Hibernia South Extension, AA block (HMDC) by mid 2010.

For onshore western Newfoundland Vulcan Minerals and

partner Investcan Canada Ltd. were the most active operators in 2009, drilling two shallow stratigraphic holes into oil bearing conglomerates (Fischell's Brook Member, Spout Falls Formation) at Flat Bay in the Bay St. George basin to determine fracture orientations in preparation for a frac/stimulation program. They also completed two wells (Robinsons #1 and Red Brook #2) around the southern periphery of the Flat Bay anticline and upon completion, Vulcan announced that significant gas shows had been achieved during drill stem testing at Red Brook #2. On the Port au Port Peninsula PDI Production Inc. continued with their testing program at Garden Hill and plan to conduct a foam acid frac/stimulation program sometime in 2010. Also in 2010, Nalcor Energy is planning a three well drilling program at Parson's Pond, the first of which, Seamus #1 has been spudded. Further to the east Deer Lake Oil and Gas have targeted a shale gas play in the Deer Lake basin and have just commenced their Werner Hatch #1 well to evaluate this unconventional resource. Elsewhere in the region, Shoal Point Energy and partners continue to examine a shale oil play under Port au Port Bay.

Petroleum discoveries in the Bay St. George Basin of western Newfoundland

Patrick Laracy
Vulcan Minerals, Inc., 333 Duckworth Street, St. John's, Newfoundland and Labrador A1C 1G9, Canada

Vulcan Minerals has been exploring for petroleum in the northern part of the Carboniferous Bay St. George Basin for several years. The company has acquired a significant database of geophysical and geological information as it unravels the geological evolution of the basin. During 2009, two deep wells were drilled, providing new insights into the petroleum system. Both wells encountered a significant thickness of gas-charged sediments suggesting that the petroleum traps are of potentially commercial scale. Production testing of the wells planned for the spring of this year will be required to determine if commercial flow-rates will be attainable. A review of the petroleum geology of the basin will be presented in light of the new gas discovery.

Mud dispersal on continental shelves and predicting shale gas reservoir targets

Joe Macquaker
Department of Earth Sciences, Memorial University of Newfoundland, St John's, Newfoundland and Labrador A1B 3X5, Canada

Successful shale gas exploration requires a subtle appreciation of the sedimentological and petrophysical properties of mudstones that are the reservoir targets. For decades, these rocks have largely been neglected because they are fine-grained and, at first sight, commonly appear laminated. Recent research, however, has demonstrated that mudstones, which are also economic shale gas reservoir plays, are typically enriched in organic carbon and susceptible to hydrofracturing. As a result, geologists seeking to determine a particular units' shale gas potential, have typically investigated:

(a) Their composition (ideally they should contain higher than average silica and carbonate concentrations) – to determine how likely they are to successfully fracture during completion.
(b) Their TOC contents (ideally >2%) – to ensure that economic volumes of gas will be present.
(c) Their maturity (ideally in the gas window) – to ensure that gas has been generated, and to ensure that adequate porosity for economic volumes of are likely to be present.

Once these data have been obtained, this information is typically incorporated into geological models that are designed to predict the stratigraphic location of "shale gas reservoir sweet spots". On the basis that "target shale gas facies" appear to preserve lamination, are commonly enriched in pyrite, as well as organic matter and predominantly composed of fine-grained detritus, these models typical assume that deposition mainly occurred in low-energy, deepwater anoxic basins, where sediment was being delivered to the basin floor by suspension settling as a continuous rain from buoyant plumes. In these models, facies variability is usually interpreted as being caused by variations in primary production within the water column coupled with rare influxes of sediment linked to turbidite emplacement. Recent research, however, clearly demonstrates that many of these sediments are bioturbated. These fabrics suggest that persistent anoxia cannot have been a prerequisite for organic matter preservation in these settings. The presence of bioturbation in these rocks, however, raises questions as to how unusually large amounts of organic matter were actually preserved, when the most efficient oxidant was present and in theory capable of dramatically downgrading their source potential. In the light of this problem the aim of this research is to investigate how sediment was delivered to the sea floor in these paleoenvironments to determine if there any clues as to how the organic matter was preferentially preserved.

In order to investigate this problem, unusually thin, polished thin sections were manufactured of a variety of mudstones collected from organic-carbon enriched successions, including the Kimmeridge Clay Formation, Jet Rock and Mowry Shale. Textural analyses of the fabrics present in these units combined with geochemical analyses reveal that they are highly heterogeneous, and where not bioturbated, are commonly organized into thin, normally-graded beds organized into "triplets", evidence of erosion, and abundant pellets composed of clay, amorphous organic matter and calcareous nanoplankon even where they contain up to 20% TOC. The presence of these fabrics indicates that sediment was delivered to the sea floor in these basins by a combination of advective currents and suspension settling. Moreover, the characteristic triplet structure of these beds suggests that at least some of the sediment was delivered by newly-recognized wave-en-

hanced sediment gravity flows of fluid mud, whereas much of the rest was being delivered in the form of pellets. The existence of these fluid mud flows is important, as their presence indicates that much of the sediment was actually delivered in episodic pulses to the basin, rather than as a continuous rain. Additionally, the presence of pellets is also significant as they indicate that much of the sediment was likely packaged into larger organo-minerallic aggregates in the water column, prior to settling to the sea floor. The existence of these aggregates means that detritus in the water column likely settled rapidly to the sea floor following its formation, thereby minimizing the effects of oxidation in the water column and maximizing the chances of organic matter preservation.

The combination of episodic sedimentation coupled with rapid transit of sediment through the water column explains the preservation of organic matter in these settings, as local sediment accumulation rates were sufficiently rapid to ensure that at least some of the organic matter was preserved. These factors mean that it is simply not necessary to invoke bottom water anoxia as a pre-requisite for organic matter preservation. Additionally, the requirement for deep-water enclosed basins to preserve organic matter has likely been overstated; consequently mudstones that might have shale gas potential are likely to be much more widespread than most researchers assume.

Oil and gas exploration in northeastern North America: is there a common thread?

John Martin
New York State Energy Research and Development Authority, 17 Columbia Circle, Albany, New York 12203-6399, USA

All sedimentary basins along the Appalachian structural front are seeing increased exploration activity. Though some interest remains in conventional “buoyancy” traps and continuous-accumulation tight sands, the major focus has turned to continuous-accumulation shale deposits. In the United States, the Marcellus Shale, trending all the way from West Virginia to New York, has become the hot topic of conversation; the cross-border Utica Shale in New York and Quebec has also garnered some interest. In Canada, some shale units of interest include the Horton Bluff of Nova Scotia, the Kettle Point and Collingwood in Ontario, the Frederick Brook in New Brunswick, and the Green Point and Rocky Brook of western Newfoundland. Other interesting plays include the Herkimer-Oneida and Galway sandstones of New York, the Hiram Brook of New Brunswick, and the Red Brook and Cambrian-Ordovician carbonates of western Newfoundland. These reservoirs range in age from Cambrian to Mississippian. Any geological similarities seem to exist within defined tectonostratigraphic packages, rather than within specific geographic regions. This presentation will focus on the structural, stratigraphic, thermal, and geochemical similarities and differences among the various plays from West Virginia to western Newfoundland to answer this question: Is there a common thread?

Back to the future: oil from the Green Point Formation, western Newfoundland

Steve Millan
Canadian Imperial Venture Corporation, St. John’s, Newfoundland and Labrador A1C 1B2, Canada

The Green Point Formation has long been recognized as a rich hydrocarbon source rock and the origin of oil found in seeps and early shallow wells from Parson’s Pond in the north to Shoal Point in the south. While significant but low volume production was established from this horizon in Parson’s Pond in the late 1800s and early 1900s, the possibility of obtaining economic production from the Green Point itself has been discounted in the more recent past because it did not fit the classical description of a reservoir. However, the application of new technology to similar shale formations elsewhere has demonstrated that so called unconventional plays can, indeed, be commercial in today’s price environment. This presentation will discuss the current project to test the commerciality of the Green Point in the Port au Port Bay area.

3D modelling and fluid inclusion studies at the Moosehead property, central Newfoundland: a new perspective on mineralizing fluids and controlling structures

Jackie O’Driscoll[1], James Conliffe[2], Derek Wilton[2], Lawrence Winter[1], and Roland Butler[1]
1. Altius Resources Inc., P.O. Box 8263, St. John’s, Newfoundland and Labrador A1B 3N4, Canada ❡ 2. Memorial University of Newfoundland, St. John’s, Newfoundland and Labrador A1B 3X5, Canada

The Moosehead gold property is located in central Newfoundland, approximately 3 kilometres southeast of the town of Bishop’s Falls. The property consists of 90 claims in one license, 9856M, comprising 23km^2. The Moosehead property is currently held under a joint venture between Altius Resources and Agnico Eagle Mines. Previous exploration has identified concentrations of quartz boulders with gold values up to 442 g/t and drill intersections of up to 170.3 g/t and 413.6 g/t over 1.53 and 0.6 m, respectively. One of the main problems encountered in previous programs has been the extent of till and the lack of outcrop exposure, making geological interpretation and drill target identification difficult.

3D modeling provides a powerful tool for viewing the subsurface data and understanding the kinematics of structures related to gold mineralization. Three parallel, north-northwest trending mineralized extensional fault structures have been identified from diamond drilling and geophysical surveys; these structures have been recognized as an important host to gold mineralization. Review of previous data has revealed a series of parallel northeast-trending brittle shear structures that cross cut these structures. Modeling of both series of structures in 3D has allowed an interpretation of their kinematics and suggests that high-grade gold mineralization is concentrated at the intersection of these structure sets. The recognition of such a relationship is significant, and enables a vector for tracing high-grade veins to depth. The property remains largely untested below 100 m depth. A single deep drill hole intersected 278 g/t gold over 0.5 m at 257 m vertical depth.

Gold-bearing quartz veins are texturally complex, with four generations and multistage brecciation recognized. Fluid inclusion studies show that the veins formed from moderate to high temperature (240–400 °C), low- to moderate-salinity (0–10 eq. wt% NaCl) aqueous-carbonic fluids. Gold deposition resulted from the mixing of gold-bearing carbonic fluids with low salinity meteoric fluids. Pressure-temperature modeling of fluid trapping conditions indicates minimum mineralization depths of approximately 5.8 km. Based on the composition of mineralizing fluids and estimated mineralization depths, it can be concluded that the Moosehead property represents an orogenic lode-gold type prospect. Documentation of a deeper, orogenic-style for the Moosehead vein systems, suggests different target vectors for these veins. The combination of these studies has advanced our understanding of the high grade mineralization at the Moosehead property and has proved to be an important tool for identifying new high priority exploration targets.

Epizonal commingling and mixing of minette and cordierite-biotite (S-type) magmas, south Quenamari Meseta, Puno Department, southeast Peru

Hamish A. Sandeman[1] and Alan H. Clark[2]
1. Geological Survey of Newfoundland and Labrador, Department of Natural Resources, PO Box 8700, St. John's, Newfoundland and Labrador A1B 4J6, Canada ¶ 2. Department of Geological Sciences, Queen's University, Kingston, Ontario K7L 3N6, Canada

In the Cordillera de Carabaya of southeastern Peru, exposed immediately south of the Quenamari Meseta, upper Oligocene – Lower Miocene (ca. 23.2–23.9 Ma) rocks of the Picotani Group of the Crucero Supergroup preserve evidence of commingling and mixing between diverse minette and cordierite-biotite S-type (PSGS) rhyodacitic-monzogranitic magmas. Three such localities include: (1) the, hypabyssal, porphyritic, cordierite-biotite ± sillimanite rhyodacitic Ninahuiza Stock containing dispersal clouds of "scalloped" mafic micaceous enclaves and widely dispersed phlogopite xenocrysts: (2) the hypabyssal, porphyritic, cordierite-biotite ± sillimanite rhyodacitic Quebrada Centilla stock containing dispersed phlogopite xenocrysts and; (3) the plagioclase-quartz-sanidine xenocryst-bearing, minette lava flows of the Lago Perhuacarca Formation. The mafic micaceous enclaves and the minette lavas contain high proportions of Al-Cr-Ti phlogopite and subhedral serpentine psuedomorphs after Ol ± Cpx along with less abundant Al-Ti biotite, Fe-cordierite, thermally shattered and embayed quartz, rounded and sieve-textured grains of plagioclase and sanidine, and groundmass microlites of Ba-sanidine and rare orthopyroxene. The rhyodacitic intrusions exhibit the inverse mineral proportions and, commonly only preserve fresh phlogopite. Collectively, the inferred xenocrysts in these rocks are compositionally equivalent to the phenocrysts in the opposing suite, although minor variation in mineral chemistry suggests slightly differing S-type anatectic and minette end-member magma compositions were locally involved. These data imply that minette magmas, representing small degree partial melts of a lithospheric mantle source, entered the middle crust, acted as heat sources, fluxed both radiogenic heat-producing and volatile elements, and facilitated the late Oligocene episode of high-*T*, low-*P* upper crustal anatexis. The minettes co-mingled and mixed with the associated PSGS S-type crustal melts, a relationship readily documented because of the favoured stability of the volatile-rich trioctahedral micas during such processes. Extensive evidence for mixing of PSGS with diverse potassic, mantle-derived melts offers an explanation for the anomalously elevated cafemic element (e.g., Mg, Fe, Ca, Cr, and Ni) and radiogenic element (K_2O, Rb, Th, and U) contents of many PSGS "S-type" granites (or rhyodacites) in southeastern Peru, and also in other igneous provinces characterized by comparable low-*P*, high-*T*, PSGS rocks.

The Albert Oil Shale Project – Altius' venture into unconventional petroleum exploration

Carol Seymour, Lawrence Winter, and Roland Butler
Altius Resources Inc., Suite 202, 66 Kenmount Road, St. John's, Newfoundland and Labrador A1B 3V7, Canada

Altius' New Brunswick Oil Shale Project comprises 9,702 hectares of land in southeastern New Brunswick. The project is located within the Moncton Subbasin of the Late Devonian – Carboniferous Maritimes Basin. The kerogen-rich oil shale intervals which are the focus of Altius' exploration program occur within the Albert Formation and are considered to be among some of the most significant unconventional hydrocarbon resources of their kind in Canada. During 2008-2009 Altius completed a 23-hole core drilling program totaling 7,835 m in three target areas, the majority of which was completed in the central target at Albert Mines. In addition to the drill program a three-dimensional geological model of the Albert Mines area was constructed and bench-scale oil shale characterization and processing tests were performed on core samples from Albert Mines, including batch retort testing to produce shale oil and shale gas.

Drill results compare favourably with documented oil shale occurrences worldwide in terms of shale oil yield and thick-

ness. At Albert Mines, the oil shale is interpreted to occur as three stratigraphic horizons (Upper, Middle and Lower oil shale) each separated by approximately thirty-five metres of low-grade oil shale or barren siltstone. The stratiform beds have been regionally deformed into a southwest-plunging, tight antiform offset by several generations and orientations of steeply dipping faults. The average thicknesses and oil yields for each horizon are 20 m @ 52 to 62 litres per tonne (l/t) for the Upper oil shale, 60 m @ 77 to 107 l/t for the Middle oil shale and 210 m @ 39 to 53 l/t for the Lower oil shale horizon. Results of preliminary oil shale characterization tests and shale oil chemical and physical analyses indicate favourable characteristics. Also, preliminary processing tests show that there is apparent potential for production of high quality, light, sweet synthetic crude should appropriate technologies be developed and successfully applied.

Reconciliation? Oil industry data in light of revised Iberia-Newfoundland rift models

Iain K. Sinclair
Husky Energy, Suite 901, Scotia Centre, 235 Water St., St. John's, Newfoundland and Labrador A1C 1B6, Canada

The petroleum industry has a long history of exploring for and producing hydrocarbons in rift basins. Many of the pioneering and persisting concepts of rift development are based on industry-generated data. Structural and stratigraphic features commonly recognized in rift basins are known to be critical elements in the trapping of oil and gas. Such elements include initiation and termination of brittle extension in the upper continental crust (i.e. faulting) and changes in the rate and distribution of extension. In addition to providing the basis for hydrocarbon-play type recognition and quantification of specific prospects, these rift basin data and models have been useful in illuminating specific chapters in the history of global plate tectonics.

Recognition of the start and end of extension are important in distinguishing structural versus stratigraphic traps and in characterizing structural controls on sediment input and deposition within prospective rift basins. Unconformities associated with these two end points of extension have been referred to as "rift onset" and "break-up" unconformities. One assumption has been that the "break-up" unconformity commonly recognized at the termination of extensional faulting was a response to the complete failure of the lithosphere and synchronous initiation of sea-floor-spreading along a newly formed oceanic ridge. Relatively recent compilations of data from ODP drilling of the Iberia and Newfoundland margins, in conjunction with widely uplifted exposures of rift-related strata in the Alps, have called into doubt the validity of this assumption. These non-industry data and models indicate passage of a considerable period of time between the end of extension recognizable in the upper continental crust versus complete separation of tectonic plates with coeval initiation of sea-floor-spreading. Implications of this apparent discrepancy include possible invalidation of models in use by the petroleum industry, revision of previously-coined terminology, and revised understanding of the timing of specific plate-tectonic events. These elements will be addressed using industry data from the Jeanne d'Arc Basin in comparison with current models of the Iberia-Newfoundland rift to drift history.

Early Ordovician island arc formation, arc-continent collision, and syn- to post-accretionary sedimentation, volcanism and mineralization, Baie Verte, Newfoundland Appalachians

Tom Skulski[1], Sebastien Castonguay[2] , Vicki McNicoll[1] , and Cees van Staal[3]
1. Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario K1A 0E8, Canada. ❡ 2. Geological Survey of Canada, 490 rue de la Couronne, Québec, Québec G1K 9A9, Canada. ❡ 3. Geological Survey of Canada, 605 Robson Street, Vancouver, British Columbia V6B 5J3, Canada

On the Baie Verte Peninsula, Early Ordovician ophiolites and their volcano-sedimentary cover are host to a number of important ore deposits. New geological and geophysical data help constrain the tectonic and metallogenic setting of the various volcanic packages. In the east, the Betts Cove ophiolite complex comprises ultramafic cumulates, layered and massive ca. 489 Ma gabbro and cogenetic, sheeted boninite dykes and overlying pillowed lavas. Overlying island-arc tholeiitic pillow basalts are interbedded with intermediate TiO_2 boninites and represent the final stage in the development of a juvenile, submarine volcanic arc. Stringer-type copper and gold mineralization occurs in the Betts Cove Mine at the transition between boninitic sheeted dykes and pillow lavas. Copper-rich ore is associated with island-arc tholeiitic basalt pillow breccias at Tilt Cove. In south-central Baie Verte, pillowed boninites and thin, felsic tuffs and flows are overlain by the ca. 487 Ma Rambler rhyolite and associated volcanogenic massive sulphide (VMS) mineralization. To the north, the Point Rousse ophiolite comprises mantle peridotite, layered ultramafic and mafic boninitic cumulates, ca. 488 Ma trondhjemite, and overlying sheeted boninitic and island-arc tholeiitic dykes and lavas. A small showing of VMS mineralization is associated with boninitic intermediate volcanic rocks at Mud Pond. The Advocate Complex to the west is separated from the continental margin by the Baie Verte Line (BVL), and comprises a tectonically-thinned and eroded sequence of mantle harzburgite overlain by layered cumulates, boninitic dykes, and erosional remnants of boninitic and island arc tholeiitic lavas. The latter are host to VMS mineralization at the Terra Nova Mine and at small showings along the Baie Verte highway. In summary, the development of island arc crust was accompanied by VMS mineralization as epigenetic ore in underlying boninites, associated with arc basalts, and locally at ca. 487 Ma within submarine felsic volcanic rocks. The overlying ophiolite cover was deposited between ca. 476 and 467 Ma. In the west, it comprises a proximal ophiolite- and platform-derived conglomerate (younger than ca. 479 Ma) overlain by ca. 476 Ma rhyolite, iron formation, and tholeiitic, pillowed basalts and tuffs. In the east, the conglomerate thins and gives way to basinal-facies iron-formation, mafic tuffs, pillowed tholeiitic basalts, calc-alkaline basalt and ca. 470 Ma felsic tuff, volcanic turbidites, and ca. 467 Ma rhyolite and tholeiitic basalts. Ophiolite obduction was accompanied by erosion, deposition of conglomerates (ca. 479–476 Ma), followed by trench migration, episodic arc volcanism (ca. 470 Ma) and arc-rift-related tholeiitic volcanism. Iron formation near the base of the cover sequence was host to later epigentic gold + pyrite mineralization associated with quartz-albite-carbonate alteration at both Nugget Pond and in the Goldenville horizon. Orogenic gold mineralization is associated with polydeformed, hydrothermally-altered ophiolite and cover rocks near the BVL. The host rocks to gold mineralization include serpentinized ultramafic rocks along the Baie Verte Highway, thrust-repeated panels of island arc tholeiitic basalts at Deer Cove, and hydrothermally-altered tholeiitic gabbro and basalt at Stoger Tight and Pine Cove.

Structure of the Rambler Dome, Baie Verte Peninsula, Newfoundland: inversions using UBC-GIF GRAV3D and Mag3D

Bill Spicer[1], Bill Morris[1], Hernan Ugalde[1], Tom Skulski[2], and Sébastien Castonguay[3]

1. MAGGIC, Department of Earth and Environmental Science, McMaster University, 1280 Main St. W, Hamilton, Ontario L8S 4L8, Canada ¶ 2. Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario K1A 0E8, Canada ¶ 3. Geological Survey of Canada, 490 rue de la Couronne, Québec, Québec G1K 9A9, Canada

The Rambler rhyolite dome is hosted within the Pacquet Harbour Group (PHG) on the Baie Verte Peninsula of north-central Newfoundland. The PHG is one of several ophiolite and island-arc-related volcanic packages within the Baie Verte Oceanic Tract of the Dunnage Zone. The lower PHG comprises a fragmented ophiolite including pillowed boninites and felsic volcanic rocks in the south, and the larger Rambler rhyolite to the north. The Rambler rhyolite is ca 487 Ma felsic dome of felsic tuffs, flows and subvolcanic felsic intrusive rocks. The upper footwall of the rhyolite dome hosts Cu ± Au volcanogenic massive sulphide deposits (e.g., Rambler and Ming mines). The upper PHG, and immediate hanging-wall to the ore deposits, is an ophiolite cover sequence consisting of a lower black chert, magnetite iron-formation and magnetic tuffs. These are overlain by a thick sequence of calc-alkaline basalts, volcaniclastic and epiclastic rocks, pillowed tholeiitic basalts and interbedded thin felsic volcanic rocks dated at ca. 470 Ma. Abundant tholeiitic gabbro sills and dykes, likely feeders to overlying flows, cut the Rambler rhyolite and VMS mineralization.

The PHG is affected by multiple phases of deformation, two of which are well-displayed in the Rambler area. The earliest phase (D_2) is associated with south-directed thrusting of the Rambler rhyolite onto its cover along the Rambler Brook fault, and thrusting of lower ophiolite crust onto the upper PHG along the Scrape thrust to the north. As a result of this deformation, the Rambler rhyolite and VMS mineralization plunge roughly 35° to the northeast. Broad, northeast plunging upright cross folds (D_4) fold the Rambler rhyolite and its ore. The ore bodies lie in the hinge zone of an F_4 synform, whereas the Ming ore body lies in the hinge of an adjacent F_4 antiform; both ore bodies occur in the same, upper part of the rhyolite dome.

Geophysical inversions utilizing recently acquired high resolution gravity and magnetic data have been implemented to determine the extent of the dome at depth. Potential field data such as gravity and magnetics, however, are mired by an inherent non-uniqueness. The inclusion of a geophysical reference model incorporating all known geologic constraints can greatly improve the quality of inversion output. A physical property database from drill-holes and surface maps of the Rambler property has been produced for use in reference model development. Employing University of British Columbia Geophysical Inversion Facility software, constrained inversions have been carried out depicting the rambler dome in 3D. The rhyolite is imaged dipping roughly 40° to the northeast as a series of voxels with density values ranging from 2.71–2.75 g/cm^3. While current ore models parallel this structure in the near surface, results from these inversions suggest deeper exploration may be favourable. Magnetic inversion modeling does not provide any insight into dome morphology; however, it does serve to outline the distribution of gabbroic dykes surrounding the dome.

The "E" Surface casting project at Mistaken Point Ecological Reserve, Newfoundland, Canada

Richard Thomas

Department of Parks and Natural Areas, PO Box 12, Site 13, RR 1, Portugal Cove South, Newfoundland and Labrador AOA 4BO, Canada

Located on the southeast coast of the Avalon Peninsula, Mistaken Point Ecological Reserve (MPER) is a globally significant palaeontological site because it contains fossils of the oldest- and largest-known complex, multicellular organisms, and the earliest macroscopic traces of locomotion in the fossil record. The world famous, 565 million-year old bedding plane known as the "E" Surface is unique and unsurpassed in terms of both the abundance (>4100 large life-forms) and diversity (15 + species) of its Ediacaran fossil assemblage. It has been described as "perhaps the finest exposure of an Ediacaran ecosystem available anywhere". This Surface is one cornerstone of the Reserve's ability to demonstrate the "Outstanding Universal Value" criterion demanded by UNESCO's World Heritage Committee.

Currently, the "E" Surface is showing evidence of erosion (due to both natural processes and visitor foot traffic) and the scientific value of its fossils will inevitably deteriorate over time. To preserve an exact record of these important fossils in perpetuity, the Newfoundland and Labrador Government's Department of Environment and Conservation, in partnership with the Royal Ontario Museum, Oxford and Queen's universities and the Johnson Geo Centre, contracted Research Casting International to make a 900 sq. ft. mould (and subsequently a master cast) of the best-preserved portion of the Surface. Both the moulding fieldwork and manufacture of the master cast were filmed for the Discovery Channel's "Daily Planet" show and these films can be viewed at: <www.watch.discoverychannel.ca – clips 223723 and 247576>, respectively. As well as discussing the details and benefits of this project, a new, 12-minute long film (commissioned by Cape Race-PCS Heritage Inc.) introducing the Reserve and the casting project will be shown.

Coastal erosion at Mistaken Point Ecological Reserve, Newfoundland, Canada

Sheridan Thompson-Graham
Department of Geography, Memorial University, St. John's, Newfoundland and Labrador A1B 3X5 Canada

The project location is at Mistaken Point Ecological Reserve (MPER), on the southeastern shores of the Avalon Peninsula. Research began in March, 2009. The purpose of the project is to analyze coastal erosion affecting the integrity of this coastline, as well as to create a comprehensive map exhibiting these processes. The assessment includes analysis of processes and causes of erosion, measurement of the rates of erosion, and evaluation of the roles of climate variation and climate change. MPER encompasses 5.7 km^2 of coastline extending from the town of Portugal Cove South to Cape Race. MPER is deemed globally significant in that it represents a portion of the Ediacaran Fossil Record (565 Ma) exhibiting some of the first complex multi-cellular organisms on Earth.

The stratigraphic section contained within MPER is ~2.5 km thick, exposed as rock platforms and cliffs along an indented and morphologically variable coastline 24 km in length. As many as 100 fossil-bearing horizons are present within the Reserve. Under the Province's Wilderness and Ecological Reserves Act, MPER is protected as an internationally significant Precambrian fossil zone. In March 2004, the Reserve was added to the official Canadian Tentative List as a potential World Heritage site. Aside from field observations, and photographs of individual fossil sites within the last 10–30 years, there has been no quantitative data acquired with respect to the erosion issues at MPER. In response to this knowledge gap, the following research has been initiated:

(a) Measurement of coastline of MPER
(b) Assessment of current processes and rates of erosion
(c) Analysis of jointing, bedding, and faulting patterns which condition coastal erosion
(d) Measurement of mass movement of Quaternary gravel deposits, and
(e) Assessment of human impacts due to trail usage.

Research completed as of December 2009 includes:

(a) Identification and measurement of attitudes of bedding planes, jointing, and faulting of two sites at Pigeon Cove (western MPER) and Mistaken Point (central MPER)
(b) Repetitive measurements to bluff line, to record bluff erosion
(c) Repetitive measurements of wave characteristics and dynamics

The goal is to provide mapping and analysis that will contribute to effective management of coastal erosion issues at MPER.

The new gold rush: seafloor hydrothermal research and marine mining

Maurice Tivey
Department of Geology and Geophysics, Woods Hole Oceanographic Institution, Woods Hole, Massachusetts 02543, USA

Once the sole purview of research scientists, deep-sea hydrothermal vent systems are now attracting considerable interest from commercial mining companies. Hydrothermal vent systems precipitate metal-rich seafloor massive sulfide (SMS) deposits in the form of chimneys many meters tall, collapsed edifices, and mounds tens to hundreds of meters across with a stockwork zone that penetrates several tens of meters beneath the seafloor. These deposits are rich in copper, zinc, gold and silver and are typically found in a mid-ocean ridge spreading environment as well as in back-arc spreading systems and associated with active seamount volcanism. Commercial and political interest in SMS deposits in the deep sea has been encouraged by several factors. The offshore oil and gas industry has pushed into deeper waters (>3000 m depth) over the past decade and technologies for accessing and exploiting SMS deposits have emerged. Furthermore, the infrastructure costs of mine development and ore extraction are likely to be much less than conventional terrestrial projects. Similarly, geophysical and geological exploration of the deep sea has become more efficient with the use of Remotely-Operated vehicles (ROVs) and autonomous underwater vehicle (AUV) mapping technology. Perhaps the most important factor, however, has been the dramatic rise in the price of metals such as copper, zinc, gold, and silver over the past few years. In the past decade, several start-up companies were formed to specialize in the exploration and possible development of SMS deposits, seeking mining claims with countries such as Papua New Guinea, Tonga, and New Zealand.

While the economic news of recent times has seen a decline in metal prices and perhaps a cooling of activity on the commercial side, the political side of the equation is continuing. The deep sea resources of the ocean floor beyond the national jurisdictions of the EEZs and continental shelves is under the purview of the International Seabed Authority (ISA), a body created by the treaty of the United Nations Convention on the Law of the Sea (UNCLOS) in 1982. ISA recently announced plans to divide the global mid-ocean ridge into segments for exploratory licenses, similar to areas already claimed by national interests for polymetallic nodule mining in the central Pacific. In 2007, the ISA published its first "Draft regulations on prospecting and exploration for polymetallic sulphides in the Area," which includes block sizes (10km x 10km, not to exceed 100 contiguous blocks) and annual fees. It is unknown what the effects of nationalizing or privatizing these areas might have on continued free access to the High Seas and the Area for marine scientific research; however, it may offer opportunities too. Woods Hole Oceanographic Institution (WHOI) has a long-standing interest in the study of hydrothermal vents on the mid-ocean ridge, with research towards a understanding the geological, chemical and biological processes that create the Earth's crust and sustain life adapted to the extreme environment of the deep sea. Recently, WHOI scientists collaborated with a commercial mining company to characterize and quantify the mineral resource of hydrothermal vent fields in the Bismarck Sea of Papua New Guinea. WHOI's approach to fast, high-resolution, multi-parameter mapping and precision measurements along with sampling and analysis contribute to a framework for discovery and exploration in the new frontier of deep sea mining.

Does bioturbation enhance reservoir quality? A case study from the Cretaceous Ben Nevis Formation, Jeanne d' Arc Basin, offshore Newfoundland, Canada

Nicola S. Tonkin[1], Duncan McIlroy[1], Rudi Meyer[2], and Allison Moore-Turpin[1]
1. Department of Earth Sciences, Memorial University of Newfoundland, St John's, Newfoundland and Labrador A1B 3X5, Canada ❡ 2. Department of Geoscience, University of Calgary, Calgary, Alberta T2N 1N4, Canada

The delineation well Ben Nevis L-55 located in the Hebron/ Ben Nevis Field of offshore Newfoundland, targets the Ben Nevis Formation in the petroleum-rich Jeanne d' Arc Basin. This case study focuses on the bioturbated net pay horizons, with the objective to understand the importance of animal sediment interactions in controlling the porosity and permeability of sandstone reservoir intervals. The net-pay interval is dominated by persistent and conspicuous *Ophiomorpha* burrows, which upon initial hypothesis (without laboratory analyses) have a direct relationship to enhancement of porosity and permeability. Results reveal this is not the case; *Ophiomorpha* burrows reduce permeability relative to the host sediment. Conversely, less conspicuous unlined burrows of *Thalassinoides* show enhancement of permeability.

Sorting is a fundamental control on primary porosity and biogenic sediment reworking can modify grain size sorting. Results demonstrate that intra-burrow porosity increases in open burrows such as *Thalassinoides*, where burrow fill is commonly coarser than matrix, although the converse relationship is true when the burrow-fill is mud-rich. Intra-burrow porosity is low in *Ophiomorpha* burrows, where thick mud and organic rich burrow fills and linings exist. Inter-burrow (matrix) porosity is commonly enhanced in highly bioturbated fabrics, where mud-grade material is removed from the matrix and incorporated into burrow linings and fills. In sparsely bioturbated facies, mud-rich inter-burrow porosity can be highly dependent on the behavior of the trace-making organisms and intensity of bioturbation.

Complex relationships exist between bioturbation and petrophysical properties in the studied material. Bioturbation can enhance or reduce porosity/permeability, dependent on trace fossil morphology, composition of burrow linings/fills, burrow size and bioturbation intensity. Our data should be compared with other studies of similar reservoir intervals to establish general models for the effects of bioturbation on petroleum reservoirs.

Volcanology and lithogeochemistry of the Lundberg volcanogenic massive sulphide zone, Buchans, Newfoundland

Greg van Hees[1], Alex Zagorevski[2], and Mark Hannington[1]
1. University of Ottawa, 335-150 Louis Pasteur, Ottawa, Ontario K1N 6N5, Canada ❡ 2. Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario K1A 0E8, Canada

The Buchans mining camp is characterized by a number of unusually high-grade low-tonnage volcanogenic massive sulphide (VMS) deposits hosted by a bimodal calc-alkaline continental arc sequence. The mining camp produced a total of 16.2 Mt of ore at an average grade of 14.5% zinc, 7.6% lead, 1.3% copper, 126 g/t Ag, and 1.37 g/t Au. Four volcanic units and one volcano-sedimentary unit have been identified including basalt, dacite, two different rhyolites (both geochemical and textural constraint) and a varying succession of sandstone, siltstone, and volcanogenic mass-flow breccias. These units can be correlated across the entire Lundberg zone and provide an excellent testable stratigraphy.

The stratigraphy of the Lundberg zone is characterized by lowermost massive basalt with local hyaloclastite and mafic tuff. Overlying the basalt is a volcano-sedimentary unit consisting of a rhyolite, dacite, siltstone, and basalt framework breccia with a pyritic sandstone matrix, plus rare sphalerite, galena, and pyrite xenocrysts (up to 1 cm long) and isolated massive sulphide clasts (up to 20 cm long). At the upper contact of the volcano-sedimentary unit lies a discontinuous barite horizon that locally contains high metal grades (e.g., 4.52% combined Zn-Pb-Cu, 102.77 g/t Ag, and nearly 1 g/t Au over 3.92 m). Within the volcanogenic breccia unit lies a highly altered and locally sheared dacitic tuff with the same lithic fragment assemblage as the breccia that surrounds it. This volcano-sedimentary unit is structurally or stratigraphically overlain by a feldspar>>quartz-phyric, green to pale yellow or red, variably flow-banded, coherent rhyolite, and then by quartz>feldspar-phyric, pale beige to red or dark green rhyolite with large quartz phenocrysts, and is intruded by late diabase sills. The basalt is extensively altered and cut by stockwork chlorite-pyrite, polymetallic and chalcopyrite-rich veins which may form the stockwork to the overlying massive and transported sulphides. Some of the polymetallic veins contain extensive bladed calcite and quartz psuedomorphs, suggesting that local boiling occurred. Understanding of the detailed volcanic stratigraphy, lithogeochemistry and mineralization characteristics of the Lundberg zone provides a predictive stratigraphy that can be applied to focus exploration in this mining camp. On a broader scale, the presence of epithermal characteristics in the Buchans VMS camp provides clues to the origin of these very high-grade deposits.

Edicarian-Early Ordovician tectonic evolution of the peri-Laurentian domain in the northern Appalachians and British Caledonides

Cees van Staal[1], D. M. Chew[2], Alex Zagorevski[3], Tom Skulski[3], Sebastien Castonguay[4], Vicki McNicoll[3], and Nancy Joyce[3]

1. Geological survey of Canada, 625 Robson Street, Vancouver, British Columbia V6B 5J3, Canada ¶ 2. Department of Geology, Trinity College Dublin, Dublin 2, Ireland ¶ 3. Geological Survey of Canada, 601 Booth St., Ottawa, Ontario K1A 0E8, Canada ¶ 4. Geological Survey of Canada, 490 de la Couronne, Quebec, Quebec G1K 9A9, Canada

The tectonic setting and evolution of the Cambrian to Early Ordovician Lushs Bight and Baie Verte oceanic tracts (LBOT and BVOT) in the northern Appalachians, and their correlatives in the British Caledonides (e.g., Cambrian Highland Border and Deer Park complexes) is still a matter of intense debate, and in need of a tectonic model capable of explaining all of the geological constraints along this critical segment of the orogen. Crucial in the debate is whether a peri-Laurentian microcontinent comprising the Chain Lakes massif (Quebec/Maine), Dashwoods (NL), Tyrone (Ireland), and Midland Valley (Scotland), that was separated from the Laurentian margin by a wide oceanic Taconic/Grampian seaway, ever existed. Potential evidence for the opening of this seaway is preserved in the ca. 555 Ma rift-related mafic magmatic rocks in the Birchy Complex that postdate the paleomagnetically constrained opening of Iapetus by at least 20 my. The composition of the Birchy Complex, particularly the presence of large serpentinite knockers, fuchsite bands and single crystals in the black shale mélange, suggests that these rocks are direct correlatives of the rift-related Dalradian succession of South Achill in western Ireland.

The basement of the postulated ribbon microcontinent(s) has not been observed and is consistently inferred from inherited zircons and/or isotopic data in Tremadocian and younger arc volcanic or plutonic rocks. Since there is no evidence for any tectonism on the autochthonous Laurentian margin between ca. 500 and 490 Ma, amalgamation of the LBOT with an outboard peri-Laurentian ribbon explains the complex Cambrian dynamothermal history (ca. 515–492 Ma) of the LBOT, which predates formation of the BVOT (490–484 Ma). In Newfoundland, parts of the LBOT (e.g., the ca. 505 Ma Coastal complex) formed basement to subsequent BVOT-related ophiolitic magmatism (e.g., ca. 484 Ma Bay of Islands ophiolite complex) in the Taconic Seaway. In contrast with the previously proposed outboard south-directed subduction model, we propose that north-directed subduction initiated at ca. 515 Ma in the Taconic/Grampian seaway, possibly using old detachments related to its opening. After partial obduction of the LBOT onto the ribbon continent between ca. 500 and 490 Ma, subduction flipped and was directed to the south. This culminated in the closure of the Taconic Seaway and the onset of obduction of the remnants of the LBOT, BVOT, Deer Park complex and elements of the Lough Nafooey arc between ca. 484 and 480 Ma onto the Laurentian margin, and hard collision with the trailing ribbon microcontinent and its arc suprastructure shortly thereafter (475–460 Ma).

Evolution of the Maritimes Basin: transtension, transpression, and salt tectonics

John Waldron

Department of Earth Sciences, University of Alberta, Edmonton, Alberta T6G 2E3, Canada

The Maritimes Basin is an enormous sedimentary basin that ranges in age from Devonian to latest Carboniferous or Early Permian. Beneath the Gulf of St. Lawrence, it contains over 12 km of sediment, and accounts for one third of the thickness of the crust. What caused this massive subsidence? The deepest parts of the basin are framed by strike-slip faults, mostly dextral, but convergent and extensional structures also occur, suggesting episodes of transpression and transtension. However, any explanation involving strike-slip has to account for the paradox that most of the subsidence occurred much later than most of the faulting. Outcrop and subsurface data in selected well-explored sub-basins (Stellarton, Cumberland, and Kennetcook) suggest that strike-slip motion on two dominant trends alternated through the Carboniferous, inverting early-formed structures; complexities of the subsidence history can be explained by withdrawal of thick evaporites during the filling of the basin.

Timing of mineralization and distribution of VMS in accreted peri-Laurentian terranes, central Newfoundland Appalachians

Alex Zagorevski[1], Neil Rogers[1], Cees van Staal[2], Vicki McNicoll[1], and Nancy Joyce[1]
1. Geological Survey of Canada, 601 Booth St., Ottawa, Ontario K1A 0E8, Canada 2. Geological Survey of Canada, 625 Robson St., Vancouver, British Columbia V6B 5J3, Canada

The tectonic history of the central mobile belt in the Newfoundland Appalachians (Dunnage Zone) is paramount to understanding the distribution and tectonic setting of mineral deposits and, by extension, to determining the prospectivity of the various terranes. On a broad scale, the distinction between the coeval peri-Laurentian and peri-Gondwanan arc complexes in the Dunnage Zone has been well constrained in previous studies on the basis of stratigraphic, isotopic and structural contrasts. This eventually led to the recognition of multiple volcanic terranes developed by several accretionary episodes, with a complexity similar to that of the modern Southwest Pacific. On a finer scale, the along-strike variability within terranes has not been well constrained, as the resolution of the data was generally insufficient.

Recent detailed mapping and sampling allowed recognition of two distinct, but coeval and kinematically-related Darriwilian arc sequences in the Annieopsquotch Accretionary Tract of central Newfoundland, namely the Buchans (ca. 467–462 Ma) and Red Indian Lake (ca. 466–460 Ma) groups. The Buchans Group likely represents an incipient rift, while the Red Indian Lake Group preserves a much more advanced stage of arc rifting, locally indicated by eruption of non-arc volcanic rocks similar to modern advanced backarc systems. The majority of the VMS mineralization in the Buchans-Robert's Arm belt occurs in the ca. 465 Ma volcanic rocks (i.e., Buchans Group and Crescent Lake formation, Roberts Arm Group). The Darriwilian volcanic rocks are locally built on sporadically exposed Early to pre-Darriwilian arc basement comprised of plutonic and volcano-sedimentary rocks (ca. 467 to 473 Ma) that also locally host important VMS mineralization. The Red Indian Lake and Buchans groups are interpreted as along-strike equivalents, formed upon distinct peri-Laurentian basement blocks. The current arrangement of these terranes is likely due to lateral juxtaposition during the middle Ordovician closure of the main tract of the Iapetus Ocean and the Early Silurian closure of the Exploits-Tetagouche back-arc basin. The recognition of significant strike-slip displacements in this and previous studies allows an improved understanding of how the Laurentian margin responded laterally both during its development and subsequent accretion of the peri-Gondwanan terranes.

