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Geological Association of Canada

ABSTRACTS

Newfoundland Section 2008 Spring Technical Meeting
February 18–19, 2008

JOHNSON GEO CENTRE, SIGNAL HILL, ST. JOHN'S, NEWFOUNDLAND

We are frequently asked why we refer to our annual technical meeting as the "Spring Meeting" when it is held in the depths of the Newfoundland winter, in late February. We have always had a strong sense of the absurd, and we are eternal optimists, but there is a more rational reason. In the past, the meeting was held as late as April, when the weather is truly more spring-like, even in St. John's. But we have for many years adopted a late February slot that coincides with mid-term break at Memorial University.

In 2008, we did actually have some spring-like wet and mild weather, which is certainly better than the mammoth snowstorm that buried us in 2007. This year's meeting was, by all accounts, a success, with over 125 registrants in total. In addition to the technical presentations at the meeting, the Newfoundland and Labrador Chamber of Mineral Resources sponsored a workshop on exploration for volcanogenic massive sulphide deposits.

As has been the case for several years, the meeting was divided into a thematic session and a general session. The choice for the thematic session was driven by strong recent interest in VMS exploration, coupled with the fact that it is now 150 years since the very first discovery of this type in Newfoundland. The Terra Nova mine marked the start of Newfoundland's first mining boom and was in all probability one of the first VMS deposits mined in the territory of modern Canada. To mark these developments, our thematic session was entitled "VMS deposits in Newfoundland - 150 years of discoveries". In the end, it included a variety of talks related to regional geology and VMS metallogeny, and extended beyond Newfoundland, to New Brunswick, northern Québec, offshore western Canada, and even to the South American country of Peru. We believe that variety is indeed the spice of professional meetings, and were happy to see such diverse contributions. The special session was in part supported by the Geological Survey of Canada's Targeted Geoscience Initiative (TGI) program, which is actively engaged in geological studies related to VMS environments in eastern Canada. A workshop related to TGI activities in Newfoundland also formed part of the agenda, and there were many presentations by GSC geologists involved in TGI. The general session this year was fairly short, but included talks on paleontology, Quaternary geology, regional geology and experiments on immiscible liquids applied to magmatic sulphides.

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

ANDREW KERR
TECHNICAL PROGRAM CHAIR
GAC NEWFOUNDLAND AND LABRADOR SECTION

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Late Wisconsinan glacial history of Placentia Bay, Newfoundland, as interpreted from seabed geomorphology and stratigraphy

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This presentation describes the glacial history of Placentia Bay, Newfoundland as interpreted from both seabed and terrestrial glacial records. Multibeam sonar data, augmented by seismic and coring data revealed a range of flow-parallel and flow-transverse glacial landforms on the Placentia Bay seafloor. Flow-parallel landforms identified include drumlins, flutes, megaflutes and crag-and-tails. These landforms show a general trend of convergent flow, interpreted to represent fast-flowing ice which was converging into an ice stream down the axis of Placentia Bay. Flow-parallel landforms and striations from the surrounding land areas demonstrate that the convergent flow can be traced up-ice to regional ice dispersal centres. Flow-transverse landforms include De Geer moraines and grounding-line moraines. De Geer moraines occur in several fields throughout the bay marking the intermittent retreat of grounded ice up the bay. Radiocarbon dates from glaciomarine silt suggest that ice became ungrounded and glaciomarine sedimentation started by at least 16,080 yrs BP.

Ice-flow mapping in Placentia Bay also demonstrated that the largely depositional record preserved on the seabed is incomplete, with the apparent absence of a strong westward flow onto the Burin Peninsula. The mostly erosional ice-flow record on land also appears incomplete because there is no evidence to date, for a northeast-southwest ice-flow that is recorded by a fluted field in southwestern Placentia Bay. Given the incomplete records on both the seabed and on land, the integration of seabed data with onshore glacial records provides a better understanding of the glacial history. This integrated approach also represents an important development in mapping palaeo-ice flows and the understanding of ice sheet behaviour during the transition from largely marine-based to land-based glacial conditions which may reflect the deglacial scenarios in other bays in Newfoundland and elsewhere.

Nature and distribution of copper mineralization in the Hinds Lake spillway, Howley area, central Newfoundland

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Central Newfoundland contains a collage of Ordovician and Silurian arc and non-arc volcanic rocks that are host to numerous base metal (Cu-Pb-Zn) deposits, most notably the volcanogenic massive sulphide mineralization, such as in the Buchans Group. However, other types of mineralization also occur throughout the region, in a variety of different tectonic settings. This study is focused on an area of copper sulphide mineralization adjacent to the north-west side of Hinds Lake, which was uncovered during the construction of the Hinds Lake emergency spillway in 1980, but has not been studied in detail. The study area is underlain by volcano-sedimentary rocks that are presumed to be Silurian in age, which have been tilted and displaced by normal faults. The exposed stratigraphic sequence consists of columnar-jointed basalt, which is unconformably to disconformably overlain by a siltstone/shale sedimentary sequence and then polymictic conglomerate. The topmost unit present a series of thickly-bedded, columnar-jointed to massive, rhyolitic volcanoclastic rocks.

Preliminary data indicate that the mineralization is both structurally and stratigraphically controlled. Mineralization is hosted by carbonate-quartz veins, with the Cu occurring predominantly within bornite, chalcopyrite and covellite. The mineralized veins have a strong preferred orientation and appear to be restricted to the upper portions of the columnar jointed basalt. As this horizon is only exposed within a section of the floor of the spillway, it is possible that the mineralized zone could extend laterally over a much larger aerial extent, buried beneath a felsic volcanic and sedimentary cover sequence only a few metres to tens of metres thick.

Future work will include (i) a determination of the paragenesis of the sulphide mineralization and the associated alteration; (ii) the geochemical analysis of representative whole-rock samples from the volcanic rocks; and (iii) the integration of field, petrographic, and geochemical data to produce a unified model for Cu mineralization.

New insights on the structural geology of the Pacquet Harbour Group and Pointe Rousse Complex, Baie Verte Peninsula, Newfoundland: implications for mineral exploration

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In the Newfoundland Appalachians, the Baie Verte Peninsula represents one of the classical areas to study the structural evolution of ophiolite and arc complexes. We present new regional structural data focused on ophiolitic and cover rocks of the Pacquet Harbour Group (PHG) and Pointe Rousse Complex (PRC). A better understanding of regional structural geology

is important in establishing guidelines for mineral exploration programs, especially in such a complexly deformed area.

This area has been affected by at least four phases of regional deformation. D_1 fabrics are poorly preserved and strongly overprinted. The D_1 phase is interpreted to be related to the obduction of ophiolites during the Ordovician Taconian Orogeny. D_2 represents the main tectonometamorphic phase. In the PRC, D_2 fabrics are mostly parallel and associated with south-directed reverse faults. These culminate with the Scrape fault, a ductile shear zone that juxtaposes serpentinized mantle on basalts of the PHG. The intensity of D_2 fabrics and accompanying metamorphism decreases southwards across the PHG, culminating in a series of open folds in low grade mafic volcanic rocks. D_2 is interpreted to be related to transpression and crustal thickening during the Silurian Salinic Orogeny. In the northern PHG, D_2 fabrics are progressively affected by shallowly-inclined to recumbent folds, culminating in a structural window into the underlying continental margin metasedimentary rocks of the Ming's Bight Group. These folds have been interpreted to be cogenetic with extensional shear zones and inversion of reverse faults in an overall dextral, locally transtensional regime during the Early to Middle Devonian. An alternative interpretation considers that D_2 and D_3 structures are composite and originated from a protracted Salinic deformational event that involved overthrusting of the Ming's Bight Group on Ordovician and Silurian volcanic rocks. This interpretation implies that extension is post D_{2-3} and unrelated to recumbent folding. Two other set of folds affect the regional S_2 fabric. A map-scale E-W-trending fold apparently bisects most of the eastern peninsula. Its timing relative to extension remains uncertain. Finally, a set of open NNE to NNW trending late cross folds are observed.

Base metal deposits such as the Ming and Rambler deposits have been greatly affected by these deformational events. The second phase was the most significant giving ore bodies an overall north to northeast plunge, sub-parallel to the L_2 lineation and colinear folds axes. Recognition and mapping of D_2 high strain zones are also important as they may have displaced or structurally thickened or thinned the ore bodies. Although less intense, post D_2 deformation is locally significant, producing large to regional-scale open folds that may have also affected the orientation and geometry of prospective horizons and ore deposits. Ongoing structural analysis including geochronology will be critical in further refining the structural and deformational history of Baie Verte Peninsula.

The South Tally Pond project: a high-grade, polymetallic VMS discovery

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The South Tally Pond VMS Project is located approximately 20 kilometres southwest of the Duck Pond Mine. The property is underlain by Cambrian to Ordovician bi-modal volcanic and sedimentary rocks of the Tally Pond Volcanic Belt. The property is host to the Lemarchant Zone which is currently defined via surface geological mapping and geophysics over a strike length of 1.5 kilometres and has been tested by broad spaced reconnaissance style drilling (15 holes) by Noranda from 1988 to 1993. The Lemarchant Zone is centred within the larger Lemarchant alteration zone that extends for greater than 5 kilometres and is up to 700 metres wide. The zone comprises precious-metal rich massive, semi-massive and stringer sulphide mineralization that lies at a gently to moderately east dipping, north-south striking mafic (hangingwall) – felsic (footwall) volcanic contact. Base and precious metal mineralization is marked by an exhalative zone exhibiting increased concentrations of barium and barite deposition. Historic diamond drilling has returned values that include 7.4% Zn, 6.3% Pb, 0.6% Cu, 11.4 g/t gold, and 1515.0 g/t silver over 0.6 metres (LM91-01); 1.53% Zn, 59.8 g/t Ag, and 6.1 g/t Au over 3.8 metres (LM92-08); 4.5% Cu, 5.70% Zn, 0.33% Pb, 272.5 g/t Ag, and 1.06 g/t Au over 0.3 metres (LM92-07), and up to 18.7% Ba. At the time it was interpreted that the down-dip extent of the mineralization was limited due to offset along the shallow west dipping Lemarchant Fault.

Paragon commenced drilling (6 holes for 2,848 metres) in August 2007 with the objective of tracking mineralization down dip of the previous shallow drilling, to understand the geometry and offset along the inferred Lemarchant Fault, and track the mineralized felsic stratigraphy at depth along the zone. Drilling by Paragon has outlined high grade precious metal-rich massive sulphides that assay as follows: 7.49% Zn, 0.77% Cu, 0.07% Pb, 40.29 g/t Ag, and 1.21 Au over 5.05 metres from 164.5 to 169.55 metres (LM07-13); 5.26% Zn, 1.06% Cu, 1.52% Pb, 92.56 g/t Ag, and 0.85 g/t Au over 5.40 metres from 203.5 to 208.9 metres (LM07-14); 9.46% Zn, 0.81% Cu, 2.13% Pb, 73.44 g/t Ag, and 1.85 g/t Au over 14.60 metres from 219.0 to 233.6 metres (LM07-15); and 12.38% Zn, 0.45% Cu, 2.61% Pb, 50.32 g/t Ag, and 0.74 g/t Au over 14.6 metres from 236.0 to 250.6 metres (LM07-17).

The Bent Hill and ODP massive sulphide deposits, Middle Valley, Juan de Fuca Ridge: hydrothermal architecture, fluid evolution and sulphide formation in a sedimented rift environment

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Middle Valley is a hydrothermally active rift near the northern extremity of the Juan de Fuca Ridge, northeast Pacific Ocean. The rift is covered by hemipelagic and turbiditic sediments that thicken from nil at the margins to > 1000 m near the centre of the rift. At depths > 500 m, basaltic sills intrude hydrothermally altered sedimentary rocks and comprise 20–30% of the sequence. This sill-sediment complex represents a hydrothermal reaction zone that is composed of fractured, brecciated, veined and lithified sediments containing quartz + wairakite + epidote + chlorite between 450 and 926 m below seafloor; current temperatures exceed 250 °C. Elements that are markedly depleted in this reaction zone include K, Ba, Na, CO_2, Rb, total organic carbon (TOC), Cu, Zn, As, Sb, Se, Be, and Co; elements added are Si, Ca, Al, and Sr.

Bent Hill and ODP are two long-lived (> 125,000 years), Zn-Cu massive sulphide deposits that are situated 9 km east of the rift axis along rift-parallel extensional faults. The Bent Hill deposit is 104 m thick and ?~200 m wide; the ODP deposit 350 m south of Bent Hill is of similar size. Combined tonnage for both deposits is ?~15–20 Mt. Metal grades are highly variable and range from high-grade Sp-rich sulphides (> 20% Zn) that are over 30 m thick in the ODP deposit to almost barren massive pyrite; average grades are 0.36% Cu and 4.66% Zn. The massive sulphide deposits was formed by the infilling and replacement of a clastic sulphide above a sulphide feeder zone. These sulphides are zone refined from a high-temperature core to the margins of the fluid upflow zone as follows: 1) Po + Is/Cp + Wz (Sp); 2) Sp + Po + Py; 3) Py + Ma. The sulphide feeder zone extends 100 m beneath the mounds and is comprised of veins and impregnations of Po (± Py) + Is + Cp that cut hydrothermally altered sediments.

Hydrothermal alteration consists of the following assemblages from the core to the margins of the feeder zone: 1) Qz + Fe-rich Ch + Ms + Po + Cp (> 300 °C); 2) Mg-rich Ch + Ab + Ms + Py; 3) Sm + An + Ba + Py; 4) Ca + Do + Il + Py (< 120 °C). The inner core has gained Si, Fe, Al, Mg, S, K, Mn, Cu, Ba, Zn, Se and Co, and lost Ca, Na, Sc, CO_2, TOC, and As. The enveloping zones have gained Mg and Fe at the expense of alkali elements bound in feldspar and micas. At the base of feeder zones is a laterally extensive (> 500 m) stratabound Deep Copper Zone (DCZ) up to 30 m thick composed of Cu-Fe-sulphides (average = 13% Cu) that infill and replace sandy turbidites that are pervasively altered to quartz and chlorite. The DCZ represents a stratal hydrothermal aquifer in sandy turbidites sealed by hemipelagic muds that has episodically fed hydrothermal vents along a north-south fault.

Mineral assemblages, fluid inclusions and isotopic data (Pb, Sr, S, C, and O) indicate that the Bent Hill-ODP deposits formed from > 350 °C fluids that reacted with basaltic crust. These deposits have been overprinted by 250–300 °C fluids generated in a hydrothermal reaction zone near the base of the sedimentary pile. The low permeability of sediments played an essential role in sulphide formation by reducing convective heat loss and by focusing fluid discharge at long-lived vent sites that have migrated off-axis. The focusing of thermal energy at discrete and long-lived vent sites may explain why the Bent Hill-ODP deposits are large compared to modern bare-ridge deposits (average = 0.2 Mt) and why ancient sediment-hosted VMS deposits are an order of magnitude larger, on average, than those hosted by volcanic rocks.

Preliminary experiments on mixing and unmixing of immiscible liquids

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Magmatic sulphide ore deposits originate from heavy, inviscid, immiscible liquid sulphide droplets that form within a stickier silicate magma which can also contain rock fragments and crystals. In the Voisey's Bay Deposit, Labrador, the ores now occur as pods and thick lenses in a network of conduits reaching up from a deeper source. The physics of the transport and accumulation of droplets is poorly understood. We have undertaken a series of small-scale experiments using analogue materials to investigate the mixing and unmixing of immiscible liquids with different physical properties (water and oil representing sulphide and silicate liquids) and the effect of adding solid particles (small beads representing crystals and rock fragments) to the system. We have found that density and viscosity contrasts and surface tension all affect rates of mixing and unmixing, and that the addition of particles can have interesting and unexpected consequences.

New outlooks on styles and classifications of VMS deposits in the Tulks Volcanic Belt: implications for exploration

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Since the discovery of the Tulks Hill VMS Deposit in 1962 by Asarco, the Tulks Volcanic Belt of the Victoria Lake supergroup in central Newfoundland has been periodically explored. Exploration has been successful in finding numerous other VMS deposits and prospects throughout the belt; the most recent being the Boomerang/Domino deposit that cluster at its southern end. This recent discovery refuted the notion, based on detailed borehole PEM surveys techniques conducted during the 1990s, that there was no VMS deposit potential in the top 300 metres of preserved stratigraphy.

Most of the VMS deposits discovered in the belt were found through a series of typical exploration techniques, including prospecting, stream, soil, and lake sediment surveys, and detailed ground and airborne electromagnetic geophysical surveys, however, not all deposits are amenable to such exploration techniques. The Boomerang and Tulks East deposits in the southern portion of the belt represent sub-seafloor replacement style ore bodies. The presence of relict quartz crystals from the original host rock to the ore reduces conductivity and these deposits are not necessarily responsive to traditional EM geophysical techniques. Although the deposits are associated with conductive graphitic sedimentary rocks, similar conduc-

tive horizons occur elsewhere in the belt where they have no association with mineralization. In addition, the deposits in the northern portion of the belt are classified as bimodal felsic VMS-epithermal style deposits, and contain acidic alteration minerals that are atypical of traditional VMS mineralization.

Recognition of the continuum of VMS deposit types in the Tulks Volcanic Belt, ranging from exhalative to replacement-style and potential debris flow style, coupled with the recognition of both felsic siliclastic and bimodal felsic VMS-epithermal type deposits highlights the complexities involved with exploration in the belt. Future exploration techniques should make use of alternative methods such as detailed gravity surveys, alteration mapping, lithogeochemistry, and volcanic and sedimentary facies mapping, in addition to the traditional geophysical tools.

VMS mineralization at the Ming Mine, Baie Verte, Newfoundland

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The Ming Mine is located approximately 13 km east of Baie Verte, Newfoundland and is one of the Consolidated Rambler Mines deposits. It operated from 1972 to 1982 and produced 2.1 Mt grading 3.5% Cu and 2.5 g/t Au. Production was halted due to declining metal prices and because mining operations reached the property boundary. The Ming Mine consists of volcanogenic massive sulphide ore with mafic-volcanic dominated hanging wall and felsic- dominated footwall. The Ming Massive Sulphide is composed of several moderately northeast-plunging, elongate lenses including the Ming South Zone, the Ming North Zone, the 1807 Zone and the Ming West Zone. Hanging wall mafic rocks consist of intercalated mafic flows, mafic intrusive rocks and minor turbidic sedimentary rocks. The felsic-dominated footwall consists of chlorite and sericite altered felsic volcanic rocks cut by abundant massive mafic intrusive rocks. A broad zone of copper mineralization occurs within the footwall known as the Ming Footwall Zone (MFZ). The MFZ consists of stringer chalcopyrite and pyrrhotite which is associated with strong chlorite and lesser sericite alteration. The temporal relationship between MFZ to the Ming massive sulphide zone is contentious. Deep directional diamond drilling exploration is ongoing to assess the downplunge extent of the various massive sulphide zones and to evaluate the extent of the Ming Footwall Zone. Mine rehabilitation including mine dewatering is underway and underground delineation drilling commenced in Fall 2007.

On the Silurian rocks and the gold-bearing veins of White Bay, western Newfoundland

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The western side of White Bay is a scenic and geologically diverse area including rocks ranging in age from Mesoproterozoic to Carboniferous. It was the site of early geological explorations by Alexander Murray and James P. Howley, and also the location of some of the earliest gold mining on the island of Newfoundland. The gold-bearing veins that were exploited are hosted within Silurian sedimentary and volcanic rocks now known as the Sops Arm Group.

The traditional view of the Sops Arm Group is that it comprises five formations. The lowermost three formations (Lower Volcanic Formation, Jacksons Arm Formation and Frenchmans Cove Formation) are largely of terrestrial aspect, becoming finer-grained upwards in the sequence. The upper (and thicker) formations (Simms Ridge Formation and Natlins Cove Formation) are dominated by marine sedimentary rocks, but the latter also includes a thick sequence of subaerial felsic volcanic rocks. Three of the formations in the group are discontinuous along strike, and this pattern has generally been ascribed to primary facies changes within an integral and essentially continuous sedimentary sequence.

A different interpretation is here suggested for these Silurian rocks, in which the disparate terrestrial and marine sequences are unrelated, and were juxtaposed along an important structure termed the Long Steady fault zone. This disappearance of formations along strike suggests that they are excised by this regional fault zone. Although much of it is unexposed, the suspected fault zone is marked by localized strong deformation, and folding is best developed in less competent rocks in its hangingwall. Its history is unclear, but there are indications that it may have at one time been a west-directed thrust or reverse structure. Interestingly, many of the gold-bearing veins in the Sops Arm Group are located close to this regional fault zone, and some may be directly linked to minor associated structures. Hence, the fault zone may be an important regional control on gold mineralization, but it is probably not the only such factor. Auriferous veins (and indeed quartz veins in general) are more abundant in the south of the area, where later granites abound, implying that there could also be a thermal or genetic link to such magmatism, as originally (and eloquently) proposed by James P. Howley exactly 100 years ago.

Flatwater Pond Group: tectonostratigraphy and age constraints of an Ordovician ophiolite cover sequence, Baie Verte Peninsula, Newfoundland

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The Flat water Pond Group is situated on Baie Verte Peninsula and lies in the western part of the Dunnage Zone, along the Baie Verte Line. It unconformably overlies and is in fault contact with the Advocate Complex, a partially eroded ophiolitic complex consisting of peridotite, gabbro cumulates, sheeted dykes and very thin to non-existent boninitic lavas. Continental sedimentary and volcanic rocks of the Silurian (?) Micmac Lake Group unconformably overlies the Flatwater Pond Group. This study builds on previous bedrock mapping (work of W. Kidd in particular) and is augmented by a recent aeromagnetic survey and lithogeochemical and U/Pb geochronological data collected on key marker units.

The lower Flatwater Pond Group consists of several conglomerate to megaconglomerate units likely derived from the underlying Advocate Complex and adjacent Laurentian continental margin (Fleur de Lys Supergroup). These are overlain by mafic pyroclastic rocks, tholeiitic pillow basalts, clinopyroxene megacrystic mafic tuff (lapilli tuff), and associated pyroclastic rocks. The upper Flatwater Pond Group comprises tholeiitic pillow basalts and dacite, the former dated at ca. 476 Ma and containing Grenvillian- and Archean-age inherited zircons.

The Flatwater Pond Group is interpreted to have been deposited on ophiolitic crust obducted onto the Laurentian continental margin during the Taconian Orogeny. It is correlative with tholeiitic volcanic cover sequences of similar age found across the Baie Verte Peninsula including the upper Pacquet Harbour and Snooks Arm groups. The Flatwater Pond Group sustained penetrative deformation during the Salinic Orogen and later brittle ductile deformation associated with the Baie Verte Road fault, which has resulted in a complex and polyphase tectonic history.

A conceptual magmatic model for the genesis of Brunswick-type VMS deposits, Bathurst Mining Camp

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The metals in Brunswick-type, volcanic-hosted, massive sulphide deposits were largely derived from felsic magma that 1) formed by partial melting of lower continental crust; 2) ponded at mid-crustal depths (15–25 km) as reduced, "cold-granite" magma (750–800 °C and < 6 wt% H_2O); 3) evolved a compositionally zoned, large-volume chamber (by convective fractionation) with a crystal-poor, supersaturated upper part and a crystal-rich (20–30%), relatively dry, dominant-volume lower part, including an immiscible liquid-sulphide phase; 4) erupted explosively from mid-crustal depths producing first-phase felsic volcanism, without forming a caldera complex; and 5) generated sub-volcanic sills (the so-called "Bathurst porphyries") and small-volume, upper-crustal (< 5 km depth) chambers of dominant-volume magma during the waning stages of the magmatic system. The metal-rich magma in these upper-crustal chambers, predominantly within the Miramichi Group, underwent decompression melting of phenocryst phases and experienced renewed convective fractionation, resulting in the separation of metal-rich volatile phases that fed the ore-forming hydrothermal system. Most critically, this magma had to cool *in situ* without pyroclastic eruption. Today, this *in situ* magma is represented by intrusions like the Popple Depot Granite and Little River Lake Granite. Relative to the Bathurst porphyries, these granites are depleted in Cu, Pb, and Zn by approximately 10, 20, and 60 ppm, respectively. At 10% extraction efficiency, these differences are enough to produce 0.1, 0.2, and 0.6 million tonnes of Cu, Pb, and Zn metals (not sulphides), respectively, per cubic kilometre of magma in these upper-crustal chambers.

Overview of some key characteristics and genesis of the LaRonde Penna world-class Au-rich VMS deposit, Abitibi greenstone belt, Québec: implications for exploration

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The LaRonde Penna Au-rich VMS deposit is the second largest known deposit of its class (58.8 Mt at 4.31 g/t, containing 8.1 Moz of Au). It is located in the Blake River Group of the Abitibi greenstone belt and it is part of the Bousquet district. The ore consists of massive to semi massive sulfide lenses (Au-Zn-Ag-Cu-Pb), stacked in the upper part of a steeply dipping, southward facing homoclinal submarine volcanic sequence composed of extensive tholeiitic basaltic flows (Hébécourt Formation) overlain by tholeiitic to transitional, mafic to intermediate effusive and volcaniclastic units (lower member of the Bousquet Formation) at the base and transitional to calc-alkaline (FII ± FI-type) intermediate to felsic effusive (domes and flow breccia) and intrusive rocks (cryptodomes and dikes) on top (upper member of the Bousquet Formation). This volcanic architecture is thought to be responsible for internal variations in ore and alteration styles: in the upper part of the mine, the

20 North lens comprises a transposed pyrite-chalcopyrite (Au-Cu) stockwork (20N Au zone) associated with a large footwall discordant to semiconformable quartz - biotite ± garnet assemblage (distal) which transitions laterally into a proximal quartz-garnet-biotite-muscovite zone (gains in MnO, $Fe_2O_3^T$, and MgO and losses of Na_2O and K_2O). The 20N Au zone is overlain by a pyrite-sphalerite-galena-chalcopyrite-pyrrhotite (Zn-Ag-Pb) massive sulphide lens (20N Zn zone). The 20N Zn zone tapers with depth in the mine (1900 m) and gives way to the 20N Au zone where it consists of transposed stringers and local semimassive sulphides (Au-rich pyrite and chalcopyrite) enclosed within a large aluminous alteration halo composed of a quartz-pyrite-kyanite-andalusite assemblage that is interpreted to be the metamorphic equivalent of an advanced argillic alteration that has many similarities to that of metamorphosed high-sulphidation systems where all oxides except SiO_2 and Al_2O_3 have been leached.

The variations in ore and alteration styles along the 20 North lens show that the hydrothermal system evolved in time and space from near-neutral seawater-dominated hydrothermal fluids, responsible for Au-Cu-Zn-Ag-Pb mineralization, to highly acidic fluids with possible direct magmatic contributions, responsible for Au ± Cu-rich ore and aluminous alteration in response to the evolving local volcanic setting that controlled the nature of the ore-forming fluids. The host sequence is interpreted to have been generated in an intermediate setting between back-arc basin and volcanic arc environments. This setting could be responsible, at least in part, for the Au enrichment of the VMS deposits of the Bousquet district and represent an exploration target in other volcanic belts.

Tectonostratigraphy and geological history of the Cape St. John Group, Baie Verte Peninsula, Newfoundland

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The Cape Saint John Group is a polydeformed Silurian volcanic sequence located on the Baie Verte Peninsula in the Newfoundland Appalachians. The Cape St. John Group rests with angular unconformity on Ordovician volcanic rocks of the Snooks Arm Group (Dunnage zone) and is intruded by the ca. 430 Ma Cape Brule porphyry. The Cape St. John Group comprises red weathering conglomerate, sandstone and siltstone near its base and these are overlain by massive amygdaloidal basalt flows. These are in turn overlain by intermediate lapilli tuffs and a thick sequence of dacitic to rhyolitic pyroclastic rocks including minor lava flows and tuff breccia, and abundant tuff, welded tuff and lapilli tuff. The deposition of the Cape St. John Group occurred in a subaerial continental setting and followed the obduction of ophiolite on the Laurentian margin and eruption of an ophiolite cover sequence (e.g. Snooks Arm Group). The presence of welded ash flow tuffs, locally coarse pyroclastic breccias and ring dyke complexes in the nearby Burlington granodiorite, suggest that felsic pyroclastic volcanism may be related to caldera collapse of a central volcanic edifice(s). Basaltic rocks have high TiO_2 contents (~2 wt. %) consistent with a continental tholeiitic volcanic signature. Felsic rocks appear to be overrepresented with respect to the original basaltic magma in terms of a fractional crystallization model and there is a gap in distribution of the rocks with respect to SiO_2 content at intermediate compositions. These could be the result of either a crustal density filtering process or partial melting of the underlying continental margin crust.

The Cape St. John Group sustained complex deformation during the Salinic and younger orogenic events. In the south, the volcanic rocks were metamorphosed to greenschist facies and contain a predominant east-striking foliation related to open, upright folds. To the north the sequence is at amphibolite metamorphic grade and overturned into large recumbent folds. Later north-trending, upright cross folds affect the Cape St. John Group and diminish in wavelength and amplitude westward toward the interior of the Baie Verte Peninsula. The study of the structural history of the Silurian Cape St. John Group provides important timing constraints on regional deformation on Baie Verte Peninsula. Similar recumbent folding can be observed in the polydeformed Ordovician rocks of the Pacquet Harbour Group and Cambrian to Ordovician rocks of the Ming's Bight Group to the west.

Robert's Arm volcanic belt, central Newfoundland: Late Ordovician–Early Silurian underthrusting and regional metamorphism of a peri-Gondwanan Darriwilian–Caradocian arc complex beneath Laurentia

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The oldest and youngest Iapetan arc complexes in the Newfoundland Appalachians occur in the Exploits Subzone on the peri-Gondwanan side of the oceanic Dunnage Zone. The highly metamorphosed peri-Gondwanan strata presently included in the Robert's Arm volcanic belt comprise mafic-dominant Darriwilian and felsic-dominant Caradocian sequences of island arc and back arc rocks. Situated within the structurally lower and most tectonized part of the Robert's Arm thrust stack, such metavolcanic and metasedimentary rocks contain considerably more felsic volcanic strata, and are younger than, similar arc-rift and extensional arc deposits in the western Wild Bight Group. They are host to an even younger suite of pretectonic calc-alkaline gabbros than those observed crosscutting the Wild Bight Arc and the negligibly strained, chlorite grade, oceanic tholeiites and alkali basalts of the Exploits back-arc basin.

Amphibolite facies belts of schist and gneiss were regionally metamorphosed and intruded by foliated granites in the Early Silurian and, in part, in the Middle-Late Ordovician. Structurally, they lie directly below greenschist facies Early Ordovician volcanic rocks in the easternmost part of the peri-Laurentian Notre Dame Subzone. Syntectonic sheets of pyroxenite, gabbro and diorite were preferentially emplaced into highly anisotropic quartz-veined tracts of mafic schist and turbidite lying closest to the Red Indian Line. They were a heat source for the regional high T – low P metamorphism that accompanied the late phases of underthrusting of the composite Laurentian margin by one of the westernmost arc complexes in the peri-Gondwanan Dunnage Zone.

Northwest-trending domes and basins refold earlier nappes and control the regional disposition of thrust sheets within most parts of the Robert's Arm belt. These structures formed prior to the opening of the Botwood Basin and the Springdale Caldera. However, certain northeast-trending cross folds and associated northwest-dipping reverse faults in the basement rocks of the Roberts Arm belt may have been reactivated during closure of these Silurian depocentres. Very rapid uplift of metamorphic tectonites, particularly those in the olistostrome-bearing peri-Gondwanan segment, occurred in the late Llandovery before the posttectonic emplacement of the epizonal Hodges Hill and Topsails batholiths.

It is herein proposed that a tectonic complex of late Middle Ordovician mineralized bimodal volcanic strata and arc-related metasedimentary migmatites, together with early Late Ordovician quartz-phyric felsic schist, andalusite-garnet semipelite, cordierite-lineated pelitic schist and amphibolitized metatuff - alkali basalt, is locally preserved on the peri-Gondwanan side of the Red Indian Line suture in the central Dunnage Zone.

Exhalites: their genesis and use in volcanogenic massive sulphide deposit exploration

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It has long been recognized that there are spatial relationships between certain types of chemical sedimentary rocks and volcanogenic massive sulphide (VMS) deposits. These rocks are most commonly iron-rich (termed iron formations), but they may also contain significant Mn, Ba, P, and other elements. These rocks were first referred to in the Canadian literature as tuffites or exhalites. They can occur in the immediate vicinity of VMS mineralization and typically at the same horizon, or lower or higher in the stratigraphic sequence. These thinly banded, or bedded to laminated rocks are mostly thought to have formed from hydrothermal precipitates of submarine hydrothermal vent fluids that settled on the ocean floor.

Bulk geochemical data indicate that in addition to direct hydrothermal input of certain elements, exhalites contain variable contributions from clastic/volcaniclastic detritus and seawater. The hydrothermal component is generally greater than 40 wt.%, and commonly greater than 70 wt.%. Element associations indicate that Fe, Mn, Pb, and Zn are generally of hydrothermal origin, whereas Al and Ti originate from detrital clastic/volcaniclastic material. Varying physicochemical conditions of the venting fluids and the depositional site (e.g., temperature, fO_2, pH, Eh or pE, fS_2, fCO_2, and ionic strength) can control the proximity of exhalites to sulphide mineralization, their layering, and their mineralogy. Other extrinsic controls affecting the distribution and mineralogy of iron formation include the degree of detrital input and the degree of basin isolation from this input, rate and longevity of hydrothermal venting, fluid/rock ratio, bottom currents, and the basin topography, and any subsequent metamorphism.

There have been several attempts to use exhalites in the exploration for concealed VMS deposits. Primarily these attempts have used spatial and temporal relationships to mineralization, and bulk geochemical, mineralogical, and mineral chemical vectors. These approaches have met with varying degrees of success. Some studies have determined that there are characteristic minerals or a suite of minerals that are useful indicators of proximity to mineralization; however, others have failed to identify such relationships. Elevated concentrations of elements originating from the hydrothermal source and ratios of hydrothermal elements to clastic elements have proven to be useful indicators for mineralization in several area or camps, including the Bathurst Mining Camp, New Brunswick. Positive europium anomalies may serve as effective guides to mineralization because they seemingly reflect high-temperature (> 250 °C) venting. However, this is not a universal axiom since not all exhalites possess such anomalies. Variations in the composition of certain minerals in exhalites are not a universal panacea in the guide to mineralization because different districts exhibit different trends. Thus, the application of exhalites in exploration to a specific area must be evaluated and tailored on a deposit or district/camp basis.

An overview of volcanogenic massive sulfide (VMS) deposits of the Newfoundland Appalachians: lassification, mineralization styles, and grade-tonnage data

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The Newfoundland Appalachians host more than 40 volcanogenic massive sulphide (VMS) deposits that contain >

100,000 tonnes of sulphide-rich material. Collectively, they represent an aggregate geological resource of ~112 million tonnes (geological resource) with production and reserves of ~ 46 million tonnes. At current metal prices past production would be worth ~ CAN $43 billion, whereas the geological resources of these deposits (i.e., past production, reserves, potential resources) would be worth CAN $60 billion.

Cambrian to Ordovician volcanic-arc, arc-rift, and back-arc basin assemblages within the Dunnage zone host the bulk of the VMS deposits of the Newfoundland Appalachians. The deposits can be classified into five main groups: 1) mafic-type deposits (Cu-rich, mostly hosted by ophiolitic rocks – e.g., Bay of Islands, Little Deer); 2) bimodal mafic-type deposits (Cu-Zn rich, hosted by bimodal sequences dominated by mafic rocks – e.g., Rambler, Ming, Point Leamington); 3) bimodal felsic-type deposits (Zn-Pb-Cu-rich, hosted by bimodal sequences dominated by felsic volcanic rocks – e.g., Buchans, Duck Pond); 4) felsic siliciclastic deposits (Zn-Pb-Cu-rich, hosted by sediment-rich bimodal sequences – e.g., Boomerang, Tulks East); and 5) hybrid bimodal felsic deposits (VMS-epithermal hybrids – e.g., Bobby's Pond, Daniels Pond).

There has been considerable past research on VMS deposits in central Newfoundland leading to an outstanding regional geological and tectonostratigraphic framework for mineralization. In recent years, however, there have been major advances in our knowledge of VMS deposit emplacement history (i.e., exhalative versus sub-seafloor replacement); alteration systems; and the volcanic, sedimentary, and intrusion facies associated with mineralization. These new advances will be critical for future exploration and genetic models for VMS deposits in Newfoundland. These new advances, coupled with recent exploration successes in central Newfoundland (e.g., Boomerang, Lemarchant), production at the Duck Pond deposit, and advanced projects (e.g., Ming), suggest a very bright future for VMS exploration and development in central Newfoundland.

TGI 3 Appalachians: an overview

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The third phase of the Targeted Geoscience Initiative (TGI 3) was instigated in 2005 by the Government of Canada who committed $25M over five years to support geological mapping of base metal reserves in established mining communities. By improving the geoscience knowledgebase in targeted mining districts, some of the inherent risk in exploration and development associated with the extension of known reserves at existing mining operations and the search for new, deeply buried deposits will be mitigated. This will be achieved through focussed mapping and geophysical surveys, developing new exploration methodologies for buried deposits and helping train highly qualified personnel for base metal exploration. It was determined that research was to be focused in four regional projects (Appalachians, Abitibi, Flynn Flon and Southeastern BC) and one thematic one aimed at finding hidden deposits (Deep Search).

For the TGI 3 Appalachians Project research is being focused on upgrading the geoscience knowledge base in central Newfoundland (primarily the Buchans - Robert's Arm belt, Victoria Lake Supergroup and Baie Verte Peninsula) and the Bathurst Mining Camp, New Brunswick. The Bathurst Mining Camp (BMC) and Central Mobile Belt, Newfoundland, represent two of Canada's most important base metal regions. However the potential of discovering new major deposits is hampered by the geological complexity and lack of surface expression. Basic geological studies, combined with the application of new techniques and technologies, are key to increasing exploration and discovery rates. The bedrock geology of the BMC is well constrained at surface, but poorly understood at depth. Improved understanding of the 3D geological structure will enhance the ability to vector in on mineralised horizons, even in hitherto unprospective areas, e.g., beneath Carboniferous cover. New strategic geophysical surveys, combined with extensive existing data will allow us to model the regional 3D structure of the BMC and better project the surface geology to depth. In the Central Mobile Belt of Newfoundland, detailed geological knowledge of the local and regional structure, stratigraphy and tectonic setting is vital for base metal exploration. The Buchans - Robert's Arm belt is host to a number base metal past producers and a major area of current exploration, and yet remains largely geologically undefined beyond the immediate vicinity of the mines. Strategic geochemistry, geochronology and geophysics, in combination with detailed bedrock mapping will enable extrapolation from the well constrained mine sequences and thus provide a focus for future exploration. Similar methods are also being applied in the Baie Verte Peninsula that hosts the past-producing Rambler Mine. In the highly prospective Victoria Lake Supergroup bedrock geology was recently mapped by the Red Indian Line TGI project. However, extensive till cover hampers base metal exploration and requires the addition of surficial mapping/geochemistry.

Enhancing the understanding of the 3D architecture of the Bathurst Mining Camp, New Brunswick

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The Bathurst Mining Camp (BMC), northern New Brunswick, is host to numerous base metal deposits, including the world class Brunswick #12 Mine. However, as with other long established areas of high mineral potential, the next generation of deposits likely to be cryptic, whether buried beneath a few metres of till or hundreds of metres cover rocks. In order to find these deposits basic geological studies, combined with the application of new techniques and technologies, will be key. In the BMC the bedrock geology is reasonably well constrained at surface, but remains poorly understood at depth. Improved understanding of the 3D geological structure will enhance the ability to vector in on mineralised horizons, even in hitherto unprospective areas, e.g., beneath the Carboniferous cover. The main activities in the BMC fall into five general categories.

The first of these is a new ground-based, gravity survey based on a nominal 1 km grid (modified in relation to access constraints). Gravity measurements were made at 3539 locations. Observations were made using Lacoste and Romberg gravity meters, and were tied to the National Gravity Network. Gravity data were reduced to a sea level datum assuming a mean crustal density of 2.67 g/cm3 to produce Bouguer anomalies. Terrain corrections were determined and applied to the Bouguer anomalies. The gravity maps are based therefore on terrain corrected Bouguer anomalies, the accuracy of which is estimated to be ± 0.17 mGal. The positions of gravity stations were determined by a differential GPS with horizontal and vertical accuracies estimated at ± 1.0 m and ± 0.5 m, respectively. The shaded Bouguer gravity anomaly map (linear interval) is interpolated to a 250 m grid. The linear colour intervals are 1.5 mGal. The Bouguer gravity field was upward continued 375 m prior to computation of the vertical derivative.

Although the Bouguer gravity map illustrates many of the major geological features of the BMC such as the Nine Mile Synform, "blueschist nappe" and Pabineau Granite, it does not obviously delineate the internal structure of the main felsic pile within which the majority of the VMS mineralisation occurs. However the first vertical derivative map does illustrate a remarkable correlation between VMS prospective areas and high values. Massive sulphide horizons are too small to have been consistently registered at this resolution of survey, thus it is believed that the effect is linked to the metasomatic alteration associated with the VMS producing fluid systems.

The gravity data will be combined with existing geophysical and rock properties data to form a 3D geophysical model. In turn this will aide in the production of a series of transects across major structural and/or economically significant parts of the BMC. A 3D GIS will be developed to incorporate the geology from the transects along with inversions from the geophysical modelling to give a 3D structural model of the whole of the Bathurst Mining Camp. A preliminary phase is already underway with the development of a 3D GIS for the Heath Steele area, including the incorporation of existing geophysical data, drill-hole projections and pre-existing geological structural models.

MMI, enzyme leach and mercury geochemical techniques to analyse soil/till have proven useful for finding deeply buried deposits in various places, but have yet to be adequately tested in the BMC. Their applicability for deep exploration in the BMC is being explored by detailed sampling over mineralized control sites that are buried by till and/or by Carboniferous sedimentary rocks. In addition a trial till tracer mineral study is being conducted to see if the distribution of heavy minerals within the till can be used to vector back towards base metal deposits.

The rostroconch mollusc *Euchasma* Billings, 1865 from the Lower Ordovician Catoche Formation (St. George Group), western Newfoundland, Canada

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The distinctive rostroconch *Euchasma blumenbachi* (Billings, 1859) is the type species of the genus *Euchasma* Billings, 1865. Originally described from the Romaine Formation of the Mingan Islands, Québec, Canada, the species is also known from elsewhere in Québec (Luke Hill Formation), as well as North-East Greenland (Cape Weber Formation), Virginia, U.S.A. (Beekmantown Group) and Texas, U.S.A. (Scenic Drive Formation). However, *Euchasma blumenbachi* (Billings, 1859) is most common in the subtidal Catoche Formation limestones of western Newfoundland. Well preserved, silicified specimens are documented from Garden Hill, western Port au Port au Peninsula; the species also occurs in the Stratotype and Reference sections of the Catoche Formation in the Eddies Cove West—Port au Choix area and at Cape Norman; it ranges from the Early Ordovician, Late Canadian (latest Jeffersonian) *Strigigenalis brevicaudata* Zone to the Late Canadian (Cassinian) *Benthamaspis gibberula* Zone.

Tectonostratigraphy of ophiolite and volcanic cover, Baie Verte Peninsula, Newfoundland

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The Baie Verte Peninsula is underlain by Cambrian to Ordovician rocks of the Laurentian continental margin and lower Ordovician ophiolites, locally hosting VMS mineralization, that were thrust onto the margin during the Taconian orogeny. The ophiolites are covered by a lower Ordovician mafic-felsic volcanic sequence. Uplift and erosion of the accretionary continental margin and its cover was followed by lower Silurian continental volcanism prior to the onset of the Salinic orogen and younger strike-slip deformation.

The Betts Cove ophiolite complex and overlying Snooks Arm Group comprise a well preserved stratigraphic record of ophiolite and volcanic cover formation on the Baie Verte Peninsula. The ophiolite comprises ca. 489 Ma mafic and ultramafic cumulates, sheeted dykes and pillowed, boninite lavas. Overlying intermediate TiO_2 boninites and plagioclase-phyric island arc tholeiitic basalts host Cyprus-style VMS mineralization, and are locally capped by ophiolite-derived conglomerate. Local tilting and erosion was followed by deposition of the Snooks Arm Group comprising jasper-bearing cherts and conglomerate (Nugget Pond Horizon), intermediate volcaniclastic rocks and tholeiitic basalts, cpx-megaphyric andesite and dacite tuff. Volcanic-derived turbidities are overlain by tholeiitic, high TiO_2 basalt, graptolitic black shale, ca. 467 Ma rhyolite and tholeiitic OIB basalt and talus breccia. The lower Pacquet Harbour Group to the west has ophiolitic affinities and comprises boninite pillow lavas overlain by island arc tholeiitic basalt and felsic volcanic rocks dated at ca. 487 Ma (with 1 and 2.6 Ga inheritance) that host the Rambler and Ming mine VMS deposits. These are locally capped by red cherts and overlain by a cover sequence of volcaniclastic rocks and high-TiO_2, plagioclase phyric tholeiitic basalts, felsic tuffs and volcanic-derived turbidites. The Pointe Rousse Complex comprises dismembered ophiolite including serpentinized harzburgite, ultramafic and mafic cumulates, sheeted dykes and pillowed boninites and low TiO_2 tholeiitic basalts. It is covered by a red jasper iron formation (Goldenville Horizon), intermediate volcaniclastic rocks, a cpx-megaphyric andesite tuff breccia, and high TiO_2 tholeiitic basalts and ca. 482 Ma gabbro. To the west, the Advocate Complex comprises mantle harzburgite, ultramafic and mafic cumulates and sheeted dykes. The upper ophiolite section is largely missing and is overlain by ophiolite-derived conglomerate and megaconglomerate of the lower Flatwater Pond Group. These are overlain by plagioclase-phyric pillow basalts, cpx-megaphyric mafic tuff, and felsic volcanic rocks locally dated at ca. 476 Ma with 1 Ga and 2.6 Ga inherited components. We propose that 489–487 Ma ophiolite crust was obducted onto the eastward-tapered margin (present) resulting in erosion later followed by continental margin volcanism between ca. 482 and ca. 467 Ma.

Remote predictive mapping of the Baie Verte Peninsula, Newfoundland: integration of geophysical and remote sensing imagery

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The Baie Verte Peninsula is a geologically complex area of the northwest coast of Newfoundland. This region is composed of multiple geological domains that have undergone multiphase tectonic activity resulting in unconformities and thrust boundaries. Contemporaneous with the deformation, intrusions and volcanic cover sequences added to the complexity of the geology. Like many other exploration areas the degree of rock exposure is highly variable: around the coast exposure is often very high, whereas inland the exposure is very poor. Producing a geological map in this type of situation requires the continuation of contacts from regions of well defined and constrained boundaries into areas with poor outcrop control and hence speculative boundary locations. Where adjacent rock units have different physical properties an estimate of the location of the contact can be derived from regional surveys. In addition the spatial relationship between the observed geological contact and local topographic surface provides a constraint on the local geometry of the contact. Extending this geometry information into the subsurface allows for the possible construction of 3D geological models. Interrogating these 3D models can provide insights into the temporal and spatial evolution of magmatic and tectonic processes.

Multiple data sets are available for the Baie Verte Peninsula. Four sources of topographic data, each with different spatial resolution are available. While each of the DEM data sets map the same major structures, the lack of internal consistency prevents their use for defining more detailed features. Integration of the regional scale airborne radiometric survey with the high resolution aerial photographic record provides a clear delineation of some geological boundaries. A new high resolution aeromagnetic survey of the peninsula like earlier surveys documents the strong magnetic signals associated with the ophiolite sequences, but also shows that onshore portion of the Betts Cove complex is part of a much larger regional fold structure. This new survey also reveals new structures within the Pacquet Harbour Group that were not apparent in

previous lower resolution surveys. In situ physical and optical property measurements have been acquired to provide ground truth constraints to assist in the interpretation of the remotely sensed imagery.

3D geophysical and geologic modeling of the Betts Cove Ophiolite, Newfoundland

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The Betts Cove Ophiolite Complex and overlying Snooks Arm Group of the Baie Verte Peninsula, Newfoundland, are associated with a high amplitude magnetic anomalies and accompanying extensive topographic relief. This study aims to develop a comprehensive three dimensional geologic model for the Betts Cove Ophiolite complex. Physical properties including magnetics, gravity and surface structural trends are integrated in order to interpret unresolved parameters regarding the arrangement of ophiolitic units in relation to the surrounding cover sequences.

The Betts Cove Ophiolite is an assemblage of ocean floor volcanic rocks forming a part of the Notre Dame Subzone of the Dunnage Zone of the Newfoundland Appalachians. Emplacement of the ophiolite sequences are believed to have occurred in the early Paleozoic during closure of a marginal basin associated with the Iapetus Ocean. Bonitic affiliations revealed in petrological and chemical analyses suggest the ophiolite formed in a fore-arc spreading environment. Although extensively mapped, much of this complex is hidden by vegetative cover and remains to be fully defined. Integration of detailed topographic information with GPS controlled field mapping will be used to better define the geometry of the complex.

A large dataset of surface structural information for the Betts Cove Complex will provide the geologic constraint missing from previous inversion models of the ophiolite. High resolution magnetic data incorporating horizontal gradient measurements combined with unit specific susceptibility values are used in order to better discriminate between magnetic sources. The inclusion of remnant magnetization information acquired from field samples accounts for the trends resulting from the effect of previous magnetic fields. Differential GPS measurements together with radar altimeter data recorded simultaneously with the aeromagnetic survey provide a new high resolution DEM of the Betts Cove area. Calibration of this DEM is provided by 20 cm resolution ground based GPS data which was collected as part of a regional gravity survey. A model of best statistical fit is then generated as an end result. An accurate 3D model of the Betts Cove area highlighting new faults and geometry will be a valuable asset for further mineral exploration in the Baie Verte Peninsula.

The Boomerang and Duck Pond VMS deposits, Newfoundland: birth by "raining" or "stewing"?

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Studies of modern subsea and "fossil" volcanic hosted massive sulphide (VHMS) systems have led to an appreciation of a range of environments of formation within this deposit type. Individual massive sulphide lenses can grow from the accumulation of gentle, black smoker-generated, "sulphide rains" onto the floors of oxygen-starved basins, or can form as sediment capped, sub-seafloor replacement deposits. This presentation illustrates primary sulphide depositional textures preserved at the Boomerang and Duck Pond deposits, which demonstrate the individual environments of sulphide deposition in these two important Newfoundland examples

Morphology and sedimentology of raised-beach sequences as a proxy indicator of past sea-ice intensity, Canadian Arctic Archipelago

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Growing concern about the state of Arctic sea-ice has been highlighted in the recently published ACIA report (2005). The alarming trends of decreasing sea-ice extent and thickness in the Arctic Ocean stress the need for comprehensive studies of past sea-ice variability. The primary goal of this study is to investigate whether raised beach sequences, preserved on the emergent coastline of the central Canadian Arctic, contain a proxy record of past sea-ice intensity. The research approach is to compare variations in beach morphology and sedimentology with a proxy record of sea ice intensity derived from driftwood and whalebone occurrences on emerged beaches. It is hypothesized that periods of reduced sea ice intensity and increased open water would expose shorelines to higher and more prolonged wave energy, leading to better developed beach berms. More specifically then, the study will: a) document variability in beach morphology and sedimentology as a function of age and b) assess the extent to which variations in wave energy between the periods of more or less open water have a recognizable expression in the preserved beaches.

Three study sites on Lowther Island, Nunavut, were selected based on a combination of the following characteristics: (1) a well-constrained postglacial emergence history, which allows beach age to be derived from beach elevation; (2) a coastal system that is relatively simple in terms of sediment supply, configuration, and energy regime; (3) coincidence with ongoing modern beach monitoring by the Geological Survey of Canada; and (4) representation of modern sea ice intensity regimes. Methodology includes: remote sensing using airphotos and high-resolution satellite imagery; ground surveys using RTK GPS to map modern and relict beaches; analysis of sediments on beach ridges of varying age; and GIS.

Lowther Island has experienced isostatic uplift for more than 9000 yr (9 ka) leading to the development of extensive raised-beach sequences. Preliminary results from three study sites on Lowther Island suggest a regional pattern in raised-beach morphology. Series of massive and well-developed single-crested beaches are intercalated with numerous and closely spaced beaches of smaller amplitude and often multi-crested. Well-developed beaches are located between 0 and 2, 5 and 7, and 9 and 11 metres of elevation. These elevations correspond to the modern period, 1.25 to 1.75 ka BP and 2.25 to 2.5 ka BP, respectively. These ages do not necessarily correspond to periods of light sea-ice as interpreted from the distribution of driftwood and whalebone.

"Beds rather than regular veins or lodes": VMS deposits, plate tectonics and the emergence of metallogeny in central Newfoundland

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Alexander Murray's recognition of the sedimentary nature of VMS deposits in Newfoundland may have been the first important metallogenic insight from the study of these deposits. But it was certainly not the last.

The Appalachian Orogen in Newfoundland provides exceptional exposure and preservation of the tectonic elements of a Paleozoic orogenic belt. The Cambrian and Ordovician volcanic sequences of central Newfoundland are abundantly endowed with VMS deposits that exhibit a wide variety of geological characteristics and settings. They provide a world-class laboratory for the study of VMS deposits in their tectonic context. Given the prominence of Newfoundland in early plate tectonic interpretations of orogenic belts, it is not surprising that Newfoundland VMS deposits have played a prominent role in global metallogenic analysis since the early 1970's. VMS metallogeny has both benefited from, and made significant contributions to, our evolving understanding of the tectonic history of the orogen.

Metallogenic analysis of Newfoundland's VMS deposits originally focused on data that was readily available; the geological character of the host rock sequences, the stratigraphic setting of the deposits, and their relative metal contents. Deposit level studies and detailed mapping of the volcanic sequences, particularly by MUN graduate studies in the early 1970's, were critical in documenting the nature and volcanic affiliation of the various deposits. Early metallogenic analyses used these data to postulate tectonic settings for the various deposits, using modern island arcs, back arc basins and oceanic ridges as models.

Lead isotope studies of the ores and early lithogeochemical studies of the host rocks provided some of the first indications that simplistic, single-stage models of the development of Iapetus and its associated metallogeny were untenable. For example, the recognition of a first order break in lead isotope compositions in VMS deposits between the eastern and western parts of the central mobile belt played a key role in the recognition of the Notre Dame and Exploits Subzones. This led to the realization that some volcanic sequences had apparently formed in widely disparate parts of Iapetus. However, it was precise U-Pb dating and detailed trace element and isotope petrochemical studies beginning in the 1980's that clearly demonstrated the temporal, geological and tectonic complexity of the volcanism and its associated VMS deposits and provided precision and improved resolution to the tectonic and metallogenic interpretations.

A detailed gravity survey on the Baie Verte Peninsula, Newfoundland: preliminary results and geological integration

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The Baie Verte Peninsula, located on the northern coast of Newfoundland, defines the North American terminus of the Appalachian Orogen. It is composed of multiple terranes that have undergone extensive tectonic activity, uplift, and deformation, with intrusions, volcanic cover sequences and unconformities adding to the intricacy of the geological model. New geophysical data has been acquired in the area as part of the Target Geoscience Initiative 3 (TGI3). This involves a high resolution airborne magnetic survey (Coyle and Oneschuk, 2008), and the ground gravity survey detailed here.

The new dataset comprises 364 stations on 12 profiles across the Peninsula, with spacing varying from 200 m to 2 km between stations. The data was acquired with two gravity meters (a Lacoste & Romberg G-meter with 0.01 mGal of sensitivity, and a Scintrex CG-3 digital meter with a resolution of 0.005 mGal). Positioning was accomplished with a Magellan Promark 3 differential GPS system. In order to obtain < 0.2 m vertical accuracy, stations were occupied with the rover DGPS for at least 10 minutes. GPS bases were set at different locations throughout the survey, so that the base-rover distance would be < 15 km. All the bases were occupied for at least 8 hrs, and the raw data was sent to Canadian Spatial Reference System (CSRS) for postprocessing. Thus, the bases were all positioned to < 0.05 m in the vertical and < 0.02 m in the horizontal. The gravity data was reduced with the standard procedures (drift, free air, Bouguer corrections). Terrain correction was computed using the 90 m SRTM digital elevation model of the area.

The location of the profiles was selected based on the geological problems that needed to be addressed. Among them, a) geometry of the Rambler rhyolite, which is spatially associated with VMS mineralization; b) geometry of the Betts Cove Complex and volcanic cover of the Snooks Arm Group; c) nature of the crust beneath the Cape Brule porphyry; d) the Cape St. John Group, which may partially overlie ophiolitic rocks; e) geometry of the faulted contact at the Ming's Bight Group; f) geometry of the Burlington granodiorite – Flatwater Pond Group faulted contact; g) geometry of the Baie Verte Line, which separates the dismembered ophiolites of the Advocate Complex from the Fleur de Lys Supergroup.

Preliminary modelling of some anomalies shows good correlation with the available geological information. The data will be modelled and integrated with the high resolution airborne magnetic data, geology, and petrophysical information collected in the area at the same time of the survey.

Historical and recent mine data rescue through 3D data integration and analysis

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Vast amounts of data are collected over the course of exploration programs. These projects are often undertaken near mature mining camps, and in many cases further away from known mine areas in the riskier regions undertaken as green/brown field exploration. To reduce this risk, a better understanding of mineralization, stratigraphic and structural relationships at the mine scale is required. By investigating the deposit and its relationship with host rocks at the mine scale, diagnostic characteristics may emerge which allow us to extend exploration strategies where data is more sparse. Mature, or out of operation, mining camps can provide a wealth of information. Often companies have acquired properties not currently being mined and do not realise the full potential of what they have. A host of impediments to pulling this rich data together conspires to prevent explorationists from engaging in this critical support exercise leading up to exploration planning. If the property was acquired well after the mine closed then there may not be any staff or experts remaining at the site, thus loosing valuable contacts to assist in rescuing the historical data. Recovering historical data may be a challenging and daunting task without this corporate memory of meta-data information. Data is rescued through recovering these essential elements that indicate data quality, spatial characteristics such as accuracy and projection, storage media and formats, data structures and lithology codes, and to be practical, where data is physically located. All of these elements form part of the data rescue workflow that is crystallizing from real world practice of data rescue on existing historical mining camps.

A case study of recovering and analysing historical data was conducted on the Heath Steele property in northern New Brunswick. The goal of the project was to recover data by bringing as much useful information together as possible in a reasonable time frame into a common 3D environment. Specific challenges included; a) missing or inconsistent rock code nomenclature, b) up-scalable classifications and stratigraphic interpretations absent, c) poor or absent geometric control. Of these three challenges listed, if the third one is not defined then a possible target cannot be properly referenced. Typically, with historical data, the resource is developed in a mine grid and/or an engineering gird. These can mean drillhole collars, geological observation, maps, cross sections and other such data can be located on any number of local grids. In order to integrate all these data types into one environment a set of transformation methods is needed to put all information into one target coordinate system, such as a 3D environment, which more accurately and realistically represents the collective data. The fact that these transformations were lost in the case study suggests a lack of value placed on an up-scaling approach to exploration, as well as the likely lack of a common practice and need to move from mine information to region scale studies. Unfortunately this is most likely the norm in mature camps.

Often with the recovery of historical data this is the first time the data is visualized in the same 3D coordinate space. Depending on the resolution and abundance of the data, first order patterns and trends of the deposit may be discernable with visual inspection alone, and new targets can be identified. By integrating structural data and geological contacts from surface maps, interpreted geologic features can also be extended into the third dimension through 3D interpretation and down plunge projection methods which contribute to construction of a final 3D geologic map. This exercise of pulling the data into a single context is the first step in mature camps towards development of an up-scalable exploration strategy that can reach to the greenfields regions. The local 3D context contains the geological relationships, alteration and mineralization characteristics, a more realistic spatial context for the ore, and a better way to represent all scales in which key relationships may be expressed. This local knowledge of the deposit at the mine and camp scale can then help to extend or characterize similar spatial relationships further out into the greenfields regions. This is exactly what is needed to reduce the risk and costs of doing exploration beyond the head frames and for intelligent targeting of deeper ore.

The tectonic architecture of the vestiges of Iapetus Ocean in the Newfoundland Appalachians

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Laurentia's Humber margin expanded eastwards (present coordinates) during the Early to Middle Palaeozoic (ca. 500–390Ma) due to a protracted history of accretion of suprasubduction zone oceanic terranes and ribbon microcontinents. Normal oceanic lithosphere was rarely, if ever accreted and generally lost during subduction of the main tract of the Iapetus Ocean. The accretion of the Dashwoods, Ganderia and Avalonia microcontinents induced the Taconic (ca. 500–450 Ma), Salinic (ca. 445–425 Ma) and Acadian (ca. 421–400 Ma) orogenies respectively, with the locus of collision progressively shifting eastwards. Both the peri-Laurentian Dashwoods and peri-Gondwanan Ganderia microcontinents independently interacted with supra-subduction zone oceanic crust during the Late Cambrian to Early Ordovician on opposite sides of the Iapetus Ocean, prior to their accretion to Laurentia. The accretion of the Dashwoods microcontinent with its arc suprastructure and associated oceanic arc terranes during the Early to Middle Ordovician caused the Taconic orogeny, leading to significant tectonic thickening of the colliding arc terranes. The Taconic orogeny terminated with accretion of all outboard peri-Laurentian suprasubduction zone rocks during the late Ordovician, mainly due to arrival of the leading edge of Ganderia (Popelogan-Victoria arc). Closure of the wide oceanicTetagouche-Exploits back-arc basin that separated this ensialic arc from Ganderia's trailing edge, culminated in accretion of the latter with Laurentia during the mid Silurian (ca. 433–425 Ma), causing the main phase of the Salinic orogeny. Coincident with Ganderia's accretion to Laurentia, Avalonia started to converge with Ganderia by closing the narrow oceanic seaway that separated them. This convergence produced the Silurian coastal volcanic arc, which is only preserved in the Hermitage flexure of southern Newfoundland, but much better in maritime Canada. Inversion of its accompanying backarc or intraarc basins (Mascarene-La Poile) at ca. 421 Ma signals the start of the Acadian collision between composite Laurentia and Avalonia. Laurentia-Avalonia_convergence was accommodated by a shallowly-dipping (flat slab), which produced retro-arc, west-vergent structures.

The Tambogrande VMS deposit, Perú: size matters !

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The 'giant' Tambogrande volcanogenic massive sulphide (VMS) deposits within the Cretaceous Lancones basin of northwestern Perú are some of the largest Cu-Zn-Au-Ag-bearing massive sulphide deposits known. The Lancones basin is known to contain three deposits: TG1 with 109 Mt tons of 1.6% Cu, 1.0% Zn, 0.5 g/t Au and 22 g/t Ag, TG3 with 82 Mt 1.0% Cu, 1.4% Zn, 0.8 g/t Au and 25 g/t Ag, and B5, with comparable massive sulphide intersections to TG1 and TG3. The TG1 deposit also hosts an oxide zone with 16.7 Mt of 3.5 g/t Au and 64 g/t Ag (indicated, inferred and probable mineral resources). This presentation will review the geodynamic setting and timing of mineralization, the paleomorphology of the VMS environment and local volcanic and structural controls on sulphide deposition, and discuss models of ore formation related to the petrogenesis of the associated bimodal volcanic suite. Lessons learned from Tambogrande may have applications to VMS districts globally.

Trench parallel translation of accreted terranes along the Laurentian margin, Newfoundland: implications for timing and distribution of mineral deposits

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The easternmost unit of the peri-Laurentian Notre Dame Subzone, the Buchans-Robert's Arm belt, is host to numerous volcanic-hosted massive sulphide deposits deposited and deformed during the Middle Ordovician closure of the Iapetus Ocean and intervening marginal basins. Distinction between the peri-Laurentian and the accreted peri-Gondwanan arc complexes has been well constrained in previous studies on the basis of stratigraphic, isotopic and structural contrasts. However, the evaluation of the along-strike variability within the Buchans- Robert's Arm belt has not been well documented, as the resolution of the data was insufficient. Very detailed stratigraphy, Sm/Nd isotopes and zircon inheritance have allowed us to recognize two distinct, but coeval and kinematically-related, peri-Laurentian arc sequences in central

Newfoundland, namely the Buchans Group (ca. 467–462 Ma) and Red Indian Lake Group (ca. 466 to 460 Ma). Thus, we are now able to resolve for the first time how the peri-Laurentian margin responded laterally both during development and subsequent accretion of the peri-Gondwanan terranes.

The Buchans Group is characterized by calc-alkaline arc basalt, rhyolite and granodiorite at its lowest stratigraphic levels. These are overlain by a sequence of calc-alkaline basalt and rhyolite which contain a key stratigraphic horizon characterized by a volcanogenic and granitoid boulder conglomerate and significant VMS mineralization. In contrast, the coeval Red Indian Lake Group is characterized by a tholeiitic, back-arc basin-like basalt sequence at its base overlain by a volcanogenic breccia-conglomerate and calc-alkaline bimodal arc sequence. The differences in Sm/Nd isotopic characteristics, zircon inheritance, and stratigraphic relationships suggest that the Buchans and Red Indian Lake groups formed upon distinctly different peri-Laurentian basement sequences; however the tectonic history of the groups inferred from these and geochemical data suggest kinematically complimentary development. We propose that the Red Indian Lake and Buchans groups were originally along strike equivalents. The reconstruction of original relationships between the arc systems has important implications for the development of the Laurentian margin and for the prospectivity of terranes and distribution of mineral deposits.

Analog experiments on transport and mixing of immiscible liquids

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Although there has been extensive work on magmatic sulphide deposits the dynamics of immiscible sulphide deposits remain poorly understood. At Voisey's Bay for example, the deposits range from massive to disseminate from one location to another. It is likely that the changing geometry of the conduits and velocities of fluids affected the way in which the immiscible sulphides were transported and eventually deposited. Of particular interest is to determine what type of flow regime gives rise to different types of segregation and deposition of the immiscible sulphide from the silicate liquid.

A series of preliminary fluid experiments have been carried out to investigate transport and deposition of immiscible liquids when they are injected through a series of small conduits that vary in diameter. A mixture of oil and water (representing the silicate and sulphide liquids) are pressed through a permeable disc(s) in a piston and cylinder experimental set up.

