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2017 Spring Technical Meeting

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[See table of contents](#)

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Geological Association of Canada Newfoundland and Labrador Section

ABSTRACTS

2017 Spring Technical Meeting

ST. JOHN'S, NEWFOUNDLAND AND LABRADOR

The annual Spring Technical Meeting was held on March 13 and 14, 2017, in the Johnson GEO CENTRE on scenic Signal Hill in St. John's, Newfoundland and Labrador.

This year Monday started with general sessions that included presentations from students and professionals on a wide range of topics. Tuesday featured a special session entitled "Golden Opportunities: Gold Mining and Exploration in Newfoundland and Labrador 2017" sponsored by Altius Minerals Corporation which also included a poster session and prospectors showcase sponsored by Research & Development Corporation of Newfoundland and Labrador.

As always, this meeting is brought to you by volunteer efforts and would not be possible without the time and energy of the executive and other members of the section. We are also indebted to our partners in this venture, particularly the Alexander Murray Geology Club, the Johnson GEO CENTRE and the Newfoundland and Labrador Department of Natural Resources. We are equally pleased to see the abstracts published in *Atlantic Geology*. Our thanks are extended to all of the speakers and the editorial staff of the journal.

JAMES CONLIFFE AND HAMISH SANDERMAN
TECHNICAL PROGRAM CHAIRS
GAC NEWFOUNDLAND AND LABRADOR SECTION

Strontium isotopes provide evidence for non-catastrophic reconnection of the Black Sea to World Ocean during the last deglaciation

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The Black Sea is the world's largest anoxic basin, and its recent bottom sediments are rich in organic matter because of little seafloor degradation. This restricted setting is a potential analogue for the semi-enclosed Kimmeridgian basin in the North Atlantic region. The onset of restricted conditions in the Jurassic might be similar to what occurred during the early Holocene in the Black Sea. The Holocene history of the Black Sea has been highly debated for the last 20 years. There is general agreement that the almost fresh Black Sea 'lake' and the Mediterranean Sea were reconnected in a short interval of time after the last glacial period, but the timing and mode of this reconnection as well as the level of the Black Sea at the time remain open questions. Since reconnection, the Black Sea has been a stratified water body with poor ventilation of its deep waters, promoting organic-matter accumulation.

Most published geochemical data used to underpin interpretations of the Holocene history come from short cores collected along the northwestern Black Sea shelf where the sedimentation rates in the Holocene were slow, so thicknesses of Holocene sediment are ~70 cm. In contrast, MUN core MAR02-45 has more than 10 times higher resolution thanks to a much greater thickness of Holocene sediments. This core is 9.5 m long with a continuous high-resolution sedimentary record in its lower 6.8 m, spanning 10.3–5.5 cal ka. Sr isotopic studies performed on molluscs from this core indicate that the $^{87}\text{Sr}/^{86}\text{Sr}$ values change from 0.708874 to 0.709147 during time interval between 9431 and 6948 calendar years before present. This supports an idea of non-catastrophic although rapid reconnection of the Black Sea to the world ocean. Oxygen and carbon isotopic ratios and trace elements in ostracods across the same interval can provide constraints on environmental conditions during the onset of the modern conditions of anoxia in the deep basins of the Black Sea, and will be evaluated during ongoing research.

A geophysical study of the Gullbridge tailings facility, central Newfoundland, Canada

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In recent years concerns have been raised over the physical stability of the Gullbridge tailings dam in central Newfoundland. The dam was designed to act as a barrier separating copper tailings produced by the former Gullbridge copper mine from a schedule 2 salmon river and intervening wetlands to the west. The mine was in operation from 1971–1974 and during this period over 1 million tonnes of acid-generating tailings were deposited within the wetland area.

The main focus of this study is the Gullbridge dam site. Research conducted on the dam site will involve examining its structure and in particular looking for leaks and associated erosion. The spontaneous potential survey is of great importance to dam monitoring studies as it is the only method that responds directly to fluid flow. Electrical methods such as the direct-current resistivity survey are effective at locating conductive seepage paths causing internal erosion, and are often combined with other surveys such as ground penetrating radar for locating voids in embankments. Magnetic surveys will be deployed to examine the magnetic signature along the embankment, and electromagnetic survey methods will be used to measure lateral and vertical changes in conductivity associated with conductive copper tailings.

A secondary focus of this study is the wetland site. Research conducted in the wetland will use ground penetrating radar to characterize its structure by examining the bathymetry of the bog material. Electromagnetic ground conductivity surveys will be used as a possible means of tracking metal contamination.

Little information is known about the construction history and design of the dam, and tailings dams as such the one in Gullbridge require continuous monitoring over time. In order to repair the physical instabilities of the dam, the structure of the dam must be extensively interpreted and analyzed.

Early Paleozoic volcanic rocks of the Kechika Group, Pelly Mountains, Yukon, Canada: a record of post-breakup magmatism within the ancestral North American margin

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Passive margins result from continental breakup and are thought to represent a change in tectonic regime from active rifting to quiescence and subsidence. In simplistic models of continental breakup, magmatism is not expected within the passive margin following the initiation of seafloor spreading. Such models of continental breakup cannot explain the presence of post-breakup volcanic rocks within passive margin sequences, including those within the Cordilleran miogeocline of northwestern Canada. To understand the tectonic significance of post-breakup magmatism and its relationship to lithospheric-scale lineaments in the northern Cordillera, a field-based project was designed to characterize the physical stratigraphy, geochronology, and geochemistry of Upper Cambrian to Ordovician volcanic rocks of the Kechika Group, central Pelly Mountains, south-central Yukon.

Latest Cambrian and Early Ordovician crystallisation ages are reported for Kechika Group pyroxene gabbro stocks using chemical abrasion (CA-TIMS) zircon U-Pb geochronology. Observed lithofacies of dated and undated Kechika Group rocks include pillow lava, sediment-matrix basalt breccia, and mafic sills, which are indicative of submarine volcanic centres and sediment-sill complexes. Chemically, all mafic rock samples have alkali basalt/foiidite and ocean island basalt geochemical signatures. Whole-rock trace element and Nd-Hf isotope geochemical data for some of the mafic intrusive bodies indicate contamination by evolved crustal rocks.

The age, depositional setting, and geochemical signature of Kechika Group strata are analogous to those of coeval mafic volcanic rocks in northwestern Canada, including the Menzie Creek Formation in the Selwyn basin and the Marmot Formation in the Misty Creek Embayment. Mafic volcanic rocks in the Menzie Creek and Marmot formations have been demonstrably linked to local extensional faulting. Field stratigraphic and analytical results suggest that magmatic rocks of the Kechika Group were generated as a result of low-degree partial melting of an enriched mantle source during Cambrian–Ordovician extension and rifting along the Cordilleran margin. Previously proposed

asymmetric rift models for continental margin evolution, including hyperextension, could explain the timing and geographic extent of post-breakup magmatism. Inferred transfer zones such as the Liard line that form at high angles to the rifted margin may have also controlled stratigraphic architecture and influenced regional tectonics, magmatism, and metal fertility. Potential analogues for Kechika Group volcanism include syn- to post-breakup rocks associated with the Orphan, Fogo, and Newfoundland Seamounts in the Grand Banks area, offshore Newfoundland.

A proposed method for determining a magnetic textural index using polynomial regression in a moving window

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The interpretation of airborne regional magnetic data is a common practice when developing regional scale geological maps. Standard interpretation involves visual inspection of the magnetic data and products generated from the data by filters, like vertical and horizontal derivatives, upward and downward continuation, reduction-to-the-pole and analytical signal. The interpreter uses these products to subdivide a survey area into regions of different magnetic character. These kinds of methods are time-consuming and inherently subjective but useful. With the advent of automated interpretation techniques and artificial intelligence, the need to quantify the properties of magnetic data that humans use to form a geological interpretation is necessary. Many methods have been suggested for automated lineament detection through automated edge detection or edge enhancement. Less work has been done in developing quantitative methods for analysing the texture of magnetic maps. In this study, an approach using polynomial regression in a moving window to calculate a general magnetic texture index is investigated. A series of polynomial surfaces of increasing order are found that best match the set of magnetic data. The lowest order polynomial that matches the magnetic data sufficiently well is said to represent the complexity of the texture of the magnetic data. The order of the polynomial is then assigned as the textural index for the point at the centre of the moving window for which the index was calculated. In this way, the textural index correlates to the complexity, such that increased complexity will lead to an increased magnetic texture complexity. These indices can then be used to provide further information to computational interpretation algorithms. Case studies using magnetic data from the Baie Verte Peninsula, Newfoundland, and Mine Centre, Ontario, illustrate the success of the method.

Investigation into the impact of a leaking oil exploration well on the scallop fishery in Port au Port Bay, Newfoundland, Canada

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In 2013 the scallop fishery in Port au Port Bay, Newfoundland began to drastically decline. The cause of this decline is still unknown; however, several abandoned oil exploration wells that were leaking an oily substance have been identified around the bay. This project investigated whether the decline of the scallop fishery could be related to contamination from a leaking oil well. Three types of sites were chosen, mapped, and sampled: a source site near an abandoned oil exploration well on Shoal Point, a fishing ground in Port au Port Bay where scallops were once abundant, and a background site in St. George's Bay where no change in the scallop fishery has been reported.

Sediments were collected from each site and extracted for their hydrocarbon and metal content. A sample of the oil that was leaking from the abandoned oil exploration well was also analyzed for its hydrocarbon and metal content for comparison with the sediments. Water samples were chemically characterized for signs of inorganic and organic contamination. Since there were no scallops present at the study sites, mussels were used as a proxy organism. Mussels were analyzed for metal contamination, $\delta^{14}\text{C}$, and their health indices. No evidence of hydrocarbon or metal contamination in the sediments, water, or mussels was detected. These results suggest the decline of the scallop fishery in Port au Port Bay cannot be explained by petroleum hydrocarbons from the leaking oil exploration wells.

The Argyle gold deposit, a recent discovery on Anaconda's Point Rouse project, Newfoundland, Canada

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Gold mineralization was first discovered at the Argyle prospect in mid-2014 through the collection of systematic B-horizon soil samples in and underexplored area ~5 kilometres west of the Anaconda Mining Inc.'s Pine Cove Mine on the Point Rouse project. Gold mineralization at Argyle is hosted within a 40 m-thick, gently north-dipping east-west striking gabbro sill that is interpreted to be coeval with the bounding mafic tuffs and flows of the Snooks Arm Group. The Argyle prospect is hosted in a magnetic gabbro that contains discrete zones of magnetite destruction associated with zones of hydrothermal alteration and gold mineralization. Gold mineralization is associated with 1–5% pyrite and the host structure to the mineralization is a weak to moderate IP chargeability anomaly.

Since 2014 systematic exploration including prospecting, mechanized trenching, geological mapping, ground induced polarization and magnetic geophysical surveys and preliminary diamond drill testing has outlined a zone of gold mineralization and associated hydrothermal alteration over a strike length of at least 600 m and down-dip for 225 m.

Initial drill testing (22 holes; 2 174 m) of the Argyle prospect in 2016 has returned encouraging preliminary results upon which to base future exploration and resource definition. Initial drill results include the following highlight grades: 2.09 grams per tonne ("g/t") over 14.0 m (18.0 to 32.0 m) in hole AE-16-20; 6.09 g/t over 8.9 m (35.0 to 43.9 m) in hole AE-16-11; 5.52 g/t gold over 15.0 m (34.0 to 49.0 m) in hole AE-16-40; 9.31 g/t gold over 6.0 m (86.8 to 92.8 m) in hole AE-16-39; 2.95 g/t gold over 15.0 m (94.0 to 109.0 m) in hole AE-16-43; and 2.91 g/t gold over 12.1 m (68.3 to 80.4 m) in hole AE-16-33.

The Argyle deposit is similar to and hosted within the same rocks as the nearby Stog'er Tight and Animal Pond gabbros and this deposit type forms a high priority target to find additional gold resources within the Point Rouse project.

Mesothermal lode gold in the Davidsville Group, eastern Dunnage Zone, central Newfoundland, Canada

PETER M. DIMMELL

Gold mineralization was first noted in quartz veins in "silky bluish slates" on the Gander River by Alexander Murray and James Howley in 1876. No attention was paid to this discovery until the late 1970s when Frank Blackwood, while mapping for the provincial government, discovered Au/As mineralization along the Gander River Ultrabasic Belt (GRUB) Line near Jonathan's Pond. Subsequent gold exploration, using widely spaced till sampling, pioneered by Noranda in the early 1980s, resulted in the discovery,

through prospecting follow up, of many gold showings between Gander Lake and Gander Bay on the coast, including the Knob, Bullet, Big Pond, Goldstash, Bowater, Duder Lake and many others.

The area lies in the Exploits subzone near the eastern edge of the Dunnage Zone in units of the Davidsville Group (DG), a NNE-trending belt of mainly slate, interbedded with thick, coarse-grained greywacke units and intruded by linear, mafic to ultramafic, dykes that trend NNE and NNW and are thought to dip subvertically. Alteration, associated with quartz veining and gold mineralization, includes sericite and iron carbonate, most intensely developed proximal (~20 m) to the main auriferous, quartz-veined zones, with the iron carbonate occurring locally as “spots” in the sedimentary units. Finely disseminated pyrite, coarse granular pyrite and arsenopyrite as fracture fillings and porphyroblasts (up to 3 cm), which cluster along bedding planes, are associated. Chlorite is noted in late fractures and veinlets.

Two, linear, NNE-trending, structurally related zones carrying extensive gold mineralization, including visible gold (VG), the Appleton Linear (AL) and Joe Batts Pond (JBP), which lie approximately 5 km apart, and can be traced for over 15 km each from Gander Lake to the north, are well defined in the Glenwood – Appleton area. Gold mineralized zones along the AL include: Dome, Road, Keats-Baseline, and Lotto on the east side and the Cokes, Hornet, Little, Powerline and Trench 26 on the west side, with extensive VG noted on the east side. Drilling has given values to 8.8 g/t Au over 4.3 m incl. 61.3 g/t Au over 0.6 m in LG-11 (Keats zone). On the JBP, two significant zones – H Pond and Pocket Ponds, approximately 2 km apart, have been defined by diamond drilling with values to 11.11 g/t Au / 11.9 m incl. 255 g/t Au / 0.5 m in HP-08-48 (Pocket Ponds).

The mineralized quartz veins both cross-cut the S_1 foliation and is folded by the F_1 fold system, interpreted to indicate that they are a late syntectonic structural feature. Textures in deformed veins are heavily modified; however, vugs with druzy quartz crystals and remnants of quartz crystals, formed perpendicular to the vein margin, suggest that the veins formed as extensional veins (Calon and Buchanan - 2004). Recent staking over the known gold showings and Au in till anomalies along the trend to the north and south of Gander Lake indicates that the systems have yet to be fully explored. It is anticipated that more discoveries will be made over the next few years.

Marathon's Valentine Lake property – an emerging gold camp in central Newfoundland, Canada

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Marathon Gold Corporation's 100% owed Valentine Lake property, consisting of 24 000 ha and located in south-central Newfoundland, is host to four orogenic-type structurally controlled gold deposits and numerous newly discovered gold occurrences. The updated NI 43-101 compliant property-wide resource, published February, 2017, reported the Measured and Indicated resource as 1 388 200 oz. Au at a grade of 1.91 and the Inferred resource as 766 500 oz. Au at a grade of 2.24 g/t Au. This represents a 31% increase in M & I resources, with 93% of this occurring in the Open Pit resource category, and a near tripling in the Inferred resources.

The gold, in quartz-tourmaline-pyrite (QTP) veining cutting the dominate host, the late Proterozoic (562 Ma) Valentine Lake Intrusive Suite as well as Cambrian–Ordovician sedimentary and volcanic rocks and Silurian conglomerate, occurs proximal to a 30+ km strike length of the Valentine Lake Thrust Fault. This major splay fault forms part of a deep structural crustal suture that extends NE-SW throughout the central Newfoundland, forming part of the root system of the Appalachian Mountain Belt, and providing the extensive conduit for the migration of the CO₂-rich gold-bearing fluids which gave rise to the Valentine Lake gold deposits. The QTP veins consist of two dominantly vein types; shear parallel QTP veins formed parallel to and along the penetrative steep NW dipping to sub-vertical regional foliation plane, and extensional QTP veins formed at high angle to the penetrative, moderate to steep NE-dipping regional stretching lineation. New geochronology on hydrothermal rutile collected from QTP veins within Marathon's Valentine Lake Property places mineralization occurring near the very end of the Salinic Orogeny (M. Barrington, pers. comm.), coinciding with the transition from regional compressive to oblique strike-slip tectonics.

Gold in quartz-tourmaline-pyrite veining was first discovered in 1985 by BP Canada Limited in the Valentine Lake Property and intermittent exploration on the property until 2009 led to the discovery of the Leprechaun and Valentine East (Victory) gold deposits. Marathon Gold Corporation commenced exploration work at the Valentine Lake Property in early 2010 and since that time, advances in our understanding of the structural controls, magnetic interpretation, and intense prospecting and trenching have resulted in the discovery of additional new zones of

extensive gold-QTP veining associated with 1st order splay off the main Valentine Lake thrust fault. The current gold deposits, all of which are open along strike and to depth, cover less than 10% of the total length of the highly perspective Valentine Lake Thrust Fault and associated splay faults. Exploration continues along the 10s of kilometres of as yet unexplored splay faults adjacent to the Valentine Lake Thrust Fault with drilling focused on developing additional near-surface open-pit as well as underground resources in advance of a planned late 2017 – early 2018 PEA.

The Wilding Lake Gold project: early success on a regional-scale structure

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The Wilding Lake project lies approximately 40 km south of the community of Buchans, Newfoundland. The project covers 215 km² (859 mineral claims) and is underlain by Cambrian to Ordovician volcanic and sedimentary rocks of the Tally Pond and Red Cross Lake groups, and the Silurian Rogerson Lake Conglomerate. The project is located immediately northeast of Marathon Gold Corporation's Valentine Lake project, which, as of April, 2015, had a reported mineral resource of greater than 1 million ounces of gold. The Wilding Lake project encompasses more than 50 km of the northeast-southwest trending Rogerson structural corridor, a district-scale structure thought to be a primary control on gold mineralization including Valentine Lake.

In late 2015, road construction north of Wilding Lake exposed several large quartz boulders; grab samples from which assayed up to 74.8g/t Au. In mid-2016, Altius Minerals Corp. acquired the property and carried out reconnaissance prospecting and soil sampling. A cluster of mineralized quartz-tourmaline boulders was located and trenching led to the discovery of the Alder occurrence. In November 2016, Antler Gold Inc. optioned the property and a trenching, soil sampling and line cutting program was initiated in the late fall of 2016. Numerous quartz boulders were located and trenching lead to the discovery of the Taz, Elm, Cedar and Dogberry gold occurrences.

The gold occurrences are associated with northeast-trending, shallowly southeast-dipping shear zones cutting the Rogerson Lake Conglomerate. Visible gold occurs within milky-white quartz-tourmaline shear and smaller

cross-cutting extension veins and are similar to the nearby Marathon Valentine Lake gold deposits. At Wilding Lake the veins also contain clots of coarse-grained chalcopyrite, hematite, and malachite.

The Alder vein system has been exposed over a strike length of 100 m. Channel results include: 6.0 g/t Au over 8.5 m, 8.7 g/t Au over 6.7 m and 49.3 g/t Au over 4.6 m. The Taz vein system lies 125 m southwest of Alder. Channel results include: 28.8 g/t Au over 1.0 m, 12.2 g/t Au over 0.9 m and 14.6 g/t Au over 0.65 m. The Elm vein system has been exposed for approximately 60 m and is open along strike in both directions. Results include 101.5 g/t Au over 0.5 m, 93.1 g/t Au over 1.3 m, 37.5 g/t Au over 0.9 m and 18.0 g/t Au over 1.2 m. The Dogberry vein system lies about 450 m southeast of Elm. Channel samples returned up to 46.5 g/t Au over 0.6 m and grab samples up to 78.8 g/t Au.

A ground magnetometer and IP survey has been completed over the Alder-Taz, Cedar-Elm and Dogberry zones. A regional airborne magnetic survey is being completed over both the Wilding and Noel Paul blocks. An aggressive exploration program is planned for 2017 and includes an extensive trenching and soil and till sampling program leading to an expected drill campaign in the fall/winter.

Nonlinear interactions of shear waves in an elastic medium

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With many of the world's conventional oil and gas deposits already in development or within stages of exploration, it is important to look for new approaches to interpret and develop non-ideal resources. Here, on the laboratory scale, we look at the nonlinear coupling of two shear waves whose interactions provide valuable information on the microstructure (particularly cracks and their orientations) and porosity of our rock samples. By understanding these parameters, we are developing methods to characterize the permeability caused by these fractures, which is key when exploiting unconventional oil and gas plays.

We present a laboratory experiment in which a strong-signal, lower frequency shear wave pump slightly perturbs the elastic properties of our sandstone sample. These changes are sensed by a lower amplitude, high frequency shear wave probe. The two waves propagate perpendicular to one another, but with their particle motions aligned. Specifically, we are measuring the delay in the high frequency shear

wave probe caused by the low frequency shear wave pump. The pump and probe signals are generated by a function generator, which is then transmitted through transducers and the results are recorded on a digital oscilloscope. The pump signal is amplified to achieve maximum perturbation; no amplification is used on the probe signal. A bandpass filter is used to reduce the amplitude of the pump, which allows a clear signal of the probe to be recorded. We observe the difference in the recorded wave interactions as a function of the orientation of cracks in the sample. This information can be used to characterize the fractures in the sample, which gives us further information on potential permeability within the sample.

Preliminary data collection has shown that this experimental design offers unique and interesting results. The probe signal shows a new oscillatory pattern in which the amplitude of the signal increases with increased voltage. Further data interpretation and collection are intended for honours studies.

Zn (\pm Pb) mineralization on the Great Northern Peninsula, Newfoundland, Canada

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The Hare Bay and Pistolet Bay areas of the Great Northern Peninsula are host to numerous carbonate-hosted Zn deposits and occurrences, including the Round Pond Deposit, Salmon River Prospect, and Twin Ponds Prospect. These mineral occurrences are hosted in the Ordovician St. George Group and the Cambrian Port au Port Group, and two types of Zn-mineralization have been recorded from the studied occurrences. Crack breccia, a type of collapse breccia, has been recorded in trenches and outcrops at the Round Pond Deposit (grab samples up to 24.46 wt.% Zn) and Twin Pond Prospect (grab samples up to 11.96 wt.% Zn). Mineralization consists of sphalerite (and saddle dolomite) cementing angular fragments of host rock lithologies, with minor galena and pyrite also locally recorded. Pseudobreccias, formed by the selective replacement of fabrics in the host rocks, have been recorded at the Salmon River Prospect, as well as stratigraphically below the crack breccias at the Round Pond Deposit and the Twin Ponds prospects. This mineralization style is characterized by disseminated sphalerite occurring in secondary dolomite

and quartz-orthoclase-dolomite cements. Assay data from pseudobreccia grab samples from the Salmon River prospect have returned up to 20.04 wt.% Zn. Non-mineralized pseudobreccias are also common throughout the study area, occurring in a linear belt stretching for more than 60 km from Cape St. Norman in the north to the Salmon River area in the south.

Several analytical techniques including: Electron Probe Micro Analysis, Secondary Ion Mass Spectrometry, Scanning Electron Microscopy - Mineral Liberation Analysis, transmitted and reflected light microscopy and bulk rock geochemistry were used to determine the chemistry of the mineralizing fluid, origin of the fluid and metals and timing of mineralization of these smaller deposits and occurrences. This data is being compared to other data from the region, including the former Newfoundland Zinc Mine in Daniels Harbour, in an attempt to define whether these occurrences represent manifestations of the same mineralizing event, which could impact regional mineral exploration.

Time-lapse full-waveform inversion: how wrong are we and how do we find out?

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Multiple seismic data sets are often recorded to monitor changes in Earth properties. The first survey acquired over a field is called a baseline survey and all the following surveys are called monitor surveys. Thus far, Full Waveform Inversion (FWI) has been efficiently used to image changes in Earth properties between surveys. The goal of FWI is to deliver a velocity model of Earth properties by using measured and predicted seismic data. As in any other measurement, uncertainty is very important particularly as we are often looking for small changes inside a reservoir.

To determine how errors in the model translate into errors in the final image, we are using a method called Alternating Full Waveform Inversion (AFWI). In AFWI we use the differences in how baseline and monitor models converge to determine a set of weights. These weights are then used to constrain the final joint inversion for changes in material properties, highlighting areas that have been identified as having the highest probability of changes.

In this study we use a simple 2D numerical model of two horizontal reflectors where the distance between them changes from the baseline to monitor model. We create one hundred noise realizations and add them to the velocity models. We then apply AFWI to determine the final time-

lapse change image. For each of these images the distance between the two recovered reflectors Δz is calculated and then plotted on a histogram.

Our results follow a normal distribution with most concentrated around the mean value, which is the true change in this simple model. This outcome opens the possibility of calculating the absolute errors. Current and future work is focused on addressing this.

Genesis of barite associated with the Lemarchant Zn-Pb-Cu-Ag-Au-rich volcanogenic massive sulphide deposit, Newfoundland, Canada

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The Zn-Pb-Cu-Ag-Au-Ba Lemarchant volcanogenic massive sulphide (VMS) deposit contains massive sulfide intimately associated with barite, and hosted within the Cambrian Tally Pond belt. Barite is massive to locally bladed, and is remarkably homogeneous chemically regardless of texture. Sulphur isotope ($\delta^{34}\text{S}$) results on bladed and massive barite are similar (24.7–28.1‰), and have a mean value of 27‰, which is similar to Cambrian seawater sulphate (~26–30‰). Whole-rock strontium isotope ratios ($^{87}\text{Sr}/^{86}\text{Sr}$) of barite range from 0.706993 to 0.707510. Fluid inclusion petrography in bladed barite shows three types of fluid inclusions with low-salinity, carbonic-rich inclusions being the most abundant. Homogenization temperatures (T_h) determined on carbonic-rich inclusions range from 211°C and 276°C, with most of the temperatures measured between 245°C and 250°C with an average calculated salinity of 1.6 wt.% NaCl equivalent. The estimated minimum trapping pressures of carbonic-rich fluid inclusions range from ~1.7 kbars to ~2.0 kbars (~6–7 km depth).

The results of this study indicate a complex origin for the barites. Sulfur isotopic data are consistent with barite forming via the mixing of VMS-hydrothermal fluids with Cambrian seawater sulphate. In contrast, the Sr isotope values are lower than mid-Cambrian marine $^{87}\text{Sr}/^{86}\text{Sr}$ and suggest that some of the Sr was derived from older continental basement (e.g., underlying Neoproterozoic Crippleback Intrusive Suite and Sandy Brook Group). Calculated fluid inclusion isochores

(on a P-T plot) from homogenization temperatures and pressures in the bladed barite are consistent with regional greenschist facies metamorphic conditions and represent metamorphic re-equilibration. Moreover, it illustrates that while barite may preserve original textures akin to modern barites, the fluid inclusion results are reset and do not reflect primary conditions of formation.

Electric and magnetic signatures of reducing springs at the Tablelands Ophiolite, Newfoundland, Canada

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Winter House Canyon is incised into the ultramafic Tablelands Ophiolite massif in western Newfoundland. The canyon contains springs characterized by high pH, large negative Eh values and the active precipitation of carbonate. The unusual electro-chemical and magnetic properties of these springs indicates that geophysical techniques may be able to determine the extent, geometry and location of the underground streams which feed the springs. The reducing waters emerging from the springs have Eh values of ~ -700 mV. As the self-potential (SP) geophysical method involves measuring electrical potential differences, the Eh contrast between the springs and the surrounding area produced SP anomalies related to the reducing fluids percolating through the subsurface. The high alkalinity of the reducing springs is thought to be the result of active serpentinization of ultramafic rock. Since low temperature serpentinization results in the production of magnetite, there exist magnetic anomalies which correspond to areas of past and present serpentinization. Based on these considerations, a 100 m x 30 m area next to a known spring was surveyed by SP using new, low-noise electrodes built for this project, and a magnetic survey, using a fast, GPS enabled Overhauser magnetometer was carried out over an area of 1500 m x 200 m along Winter House Canyon, in an effort to locate and map the reducing groundwater. The geophysical data revealed that the known spring sites produce strong, coherent magnetic and SP responses. In the survey down the canyon, a new spring was discovered at the site of a magnetic high, and future exploration targets corresponding to possible new spring sites were found. Furthermore, structural elements of the massif, not visible on the exposed outcrop, were identified. Correlation of the surveys revealed sets of parallel, linear magnetic and SP anomalies. The strike of these anomalies indicates that reducing fluid appear to follow long faults roughly perpendicular to the axis of the canyon and so at right angles to previously assumed faulting.

Whole-rock geochemistry, Sm-Nd isotopes, and U-Pb geochronology of mafic granulites from the Canyon domain, central Grenville province, Canada

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The late Paleoproterozoic to Mesoproterozoic (~1.7–1.2 Ga) evolution of the active southeastern margin of Laurentia terminated with the Grenvillian continental collision and the development of a large, hot, long-duration orogen (LHO) at ~1.09–0.98 Ga, part of which is preserved in the orogenic hinterland as imbricated stacks of high-grade gneisses, that contain a large repository of the geological evolution of both the pre-Grenvillian active margin and the subsequent Grenvillian continental collision.

The geological evolution of MP granulite-facies mafic gneisses from the Canyon domain (Manicouagan area, central Grenville Province) is investigated through whole-rock major and trace element chemistry, Sm-Nd isotopes, and CA-TIMS geochronological analyses, which suggest that their protoliths were derived from depleted to slightly enriched asthenospheric mantle, and evolved through variable degrees of fractional crystallization and contamination by crust, or were modified at source, and that they range from pre-Grenvillian to Grenvillian in age. The pre-Grenvillian gneisses from the southern Canyon domain comprise two suites, one consisting of a suite of mafic sills that intruded into a ca. 1500 Ma supracrustal metasedimentary sequence (Complexe de la Plus Value) at $1438 \pm 73/-64$ Ma in an extensional arc/back-arc setting, and the other previously dated coeval to slightly younger suite of mafic rocks that was emplaced at 1410 ± 16 Ma in a compressional arc/back-arc setting. The Grenvillian mafic gneisses from the central and northern part of the domain were emplaced as dykes and sills at 1006 ± 4 Ma (in the Vein Complex) and 997 ± 2.6 Ma (in the Layered Bimodal Sequence) in a late-orogenic extensional setting.

Considered together with other information, the data for the pre-Grenvillian mafic rocks support a model of a long-lived continental-margin arc and back-arc on southeast Laurentia during the Mesoproterozoic (ca. 1.5–1.4 Ga), whereas the record of late-orogenic (~1.0 Ga) mafic magmatism followed by granulite-facies metamorphism is compatible with deep-seated processes (e.g., slab break-off, delamination or crustal foundering, convective thinning etc.) leading to thinning of over-thickened crust in a collapsed LHO, associated with decompression melting of rising asthenosphere and conductive heating of the thinned crust.

New geochronological constraints on the timing of magmatism for the Bull Arm Formation, Musgravetown Group, Avalon terrane, northeastern Newfoundland, and implications for the tectonic evolution of the Bonavista Peninsula, Canada

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New age constraints are presented for the volcanic-dominated Bull Arm Formation of the Avalon terrane in Newfoundland. Historically, the age has been interpreted from the single previous geochronological constraint, $570 \pm 5/-3$ Ma, obtained from a rhyolite flow on Wolf Island where no contact relations are exposed. This rhyolite was later reinterpreted as part of the overlying Rocky Harbour Formation but its initial interpretation as Bull Arm Formation had already become entrenched in the literature. New U-Pb zircon (CA-TIMS) geochronology results for rock samples from the west and east margins of the Bull Arm Formation (Musgravetown Group) on the Bonavista Peninsula (Plate Cove volcanic belt: PCvb) of northeastern Newfoundland yielded ages of 592 ± 2.2 Ma and 591.3 ± 1.6 Ma, respectively. Quartz- and potassium feldspar-phyric, banded rhyolite from the Isthmus of Avalon, nearly 100 km south of the Bonavista sites, yielded an age of 605 ± 1.2 Ma.

The Isthmus rhyolite is overlain by diamictite, possibly correlative to the 579 Ma glaciogenic Trinity facies/Gaskiers Formation, indicating a depositional hiatus, and/or faulting. It is also a possible source of age-equivalent volcanic detritus in upper parts of the 620–605 Ma, arc-adjacent, turbidite-dominated, Connecting Point Group (CPG) at Bonavista Bay. There, north-verging, thrust-stacked CPG rocks are unconformably overlain by ca. 600 Ma glomerocrystic, calc-alkaline basalt of the lower Bull Arm Formation. Aphyric basalts of the PCvb comprise two petrologically distinct, but similar, series of transitional (weakly calc-alkaline) basalts derived from lithosphere-contaminated, enriched shallow mantle source. The earliest is approximately coeval with ca. 592 Ma, east-side-down extension along the PCvb margin that culminated in deposition of a coarse clastic wedge. The younger PCvb series is petrologically similar to dykes that cut Musgravetown Group rocks younger than the 579 Ma Trinity diamictite. These grey siltstones and overlying distal turbidites were deposited during tectonically quiescent times. North-directed thrusting, likely part of Avalonian orogenesis, occurred again post-565 Ma. This terminal

Neoproterozoic event preceded deposition of the early Cambrian Random Formation and possibly parts of the Neoproterozoic Crown Hill Formation.

Onshore deformation associated with the opening of the Labrador Sea from the Aillik Domain of the Makkovik Province, Labrador, Canada

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Continental rifting between Greenland and Canada began in the Early Cretaceous or possibly earlier and culminated in the production of oceanic crust in the Paleocene, and ultimately the formation of the Labrador Sea. The onshore exposures adjacent to modern, offshore passive continental margins, including Labrador, often preserve evidence of deformation from the pre-, syn- and post-rift phases of continental breakup. Here, brittle deformation from onshore Labrador is characterized in the Paleoproterozoic Aillik Domain of the Makkovik Province alongside measurements of the pre-rift basement metamorphic mineral fabric. Stress inversion was performed twice on the field data obtained from brittle deformation, firstly on all data with kinematic indicators (A), and secondly only on deformation associated with abundant epidote mineralization that also displayed kinematic indicators (B). Both inversions show well-constrained, extensional deformation (near vertical σ_1) with σ_3 orientated 276° and 254° for A and B, respectively. Field observations indicate that the epidote mineralization is likely to be a localized effect, possibly due to fluid leaching from mafic dykes, and thus all the deformation may be related to the same event. The fault-containing dykes have been dated as ca. 590–555 Ma, and the most significant extensional event post this age is the rifting prior to the opening of the Labrador Sea. Furthermore, the results show similar extension directions to the first of two extensional phases related to the opening of the Labrador Sea identified by previous studies in West Greenland. It is therefore concluded that an onshore record of brittle deformation related to the opening of the Labrador Sea is exposed in the Aillik Domain. Furthermore, analysis of the orientation of the basement fabric with respect to calculated rifting direction indicated that basement structures may have been orientated such that they were particularly susceptible to rift propagation.

Host-rock reactivity in the generation of gabbro-hosted orogenic Au in the Baie Verte Peninsula, Newfoundland, Canada

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Gabbro-hosted orogenic Au is present in three significant localities on Baie Verte's Point Rouse Peninsula, including the Stog'er Tight deposit, the Animal Pond prospect, and the recently discovered Argyle deposit. In all three deposits mineralization is hosted with vari-textured to pegmatoidal gabbro that intrude, but are likely coeval with, parts of the Snooks Arm Group. The gabbros are oxide-apatite-rich with variable amounts of plagioclase, pyroxene, ilmenomagnetite and apatite, and have enriched mid-ocean ridge basalt (E-MORB) to ocean island basalt (OIB) immobile element signatures. The alteration in the gabbros varies in intensity with distal/weak alteration consisting of weak leucoxene, partial albite alteration of feldspars and minor epidote. Proximal to mineralization there is a distinct metre to 10s of metre-scale zonation with an envelope of epidote-albite-(leucoxene-calcite) and proximal to mineralization (i.e., within metres) intense albite-chlorite-ankerite--pyrite-(hematite). With increasing alteration intensity there are enrichments in CO_2 -CaO-Na₂O-Fe₂O₃-Mo-W-As-Bi-S with Au.

At the micro- to nano-scale gold is associated with pyrite that shows multiple generations of growth, often with cores that contain relict ilmenite and rutile, and rims that are inclusion poor, but containing gold; gold is also found as free grains in cracks and along grain edges and interpreted to have been remobilized. Additionally, Au is also spatially associated with hydrothermal zircon (overprinting primary baddeleyite), monazite ((CeLa)PO₄) and xenotime (YPO₄). Gold deposition resulted from the reaction of Au- (as Au(HS)₂⁻) and CO₂-Na-REE-Y-bearing fluids with Fe-Ti-rich host rocks, resulting in wall rock sulfidation and pyrite formation, Au deposition, and the coincident formation of hydrothermal albite, ankerite, zircon (from baddeleyite), and monazite and xenotime (from apatite).

Intrusion-related precious-metal mineralization in the northern Mount Peyton intrusive suite: implications for the origin of the Mount Peyton trend, central Newfoundland, Canada

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Exploration, west of Glenwood in the Mount Peyton intrusive suite, has outlined a 13.5-km, north-northwest-trending corridor, termed the Mount Peyton trend, which is anomalous in gold, silver, arsenic, and antimony. In the south-southeast part of the trend, mineralization occurs at the Corsair, Hurricane, and Peyton prospects and the Sabre and Commanche showings; in the north-northwest, mineralization occurs at the Slip and associated showings. Mineralization at Corsair and Hurricane consists of narrow (typically <2 cm), sulphide-poor quartz veins that have broad (cm- to 13 m-scale) pyrite–arsenopyrite–sericite–siderite–silica alteration envelopes in fine-grained quartz diorite, locally intruded by monzogranite. The alteration zones and mineralized veins are northeast trending and moderately southeast dipping, and veins at surface correlate with one set of conjugate regional joint surfaces. Mineralization at Hurricane–Corsair has elevated concentrations of As, Au, Sb, Ag and locally Cd. At the Slip showing, gabbro–diorite is cut by straight margined, miarolitic monzogranitic dykes containing pyrite–muscovite–calcite–chalcopyrite ± galena ± arsenopyrite-filled miarolitic cavities that have anomalous Au, As, Sb, and Ag, and enrichment in Cu, Pb, Zn, Mo, and Bi. The data show that the mineralized monzogranite at the Slip showing is a late-stage, deuteric fluid-enriched and metal-bearing residual magma that intruded a slightly older gabbro–diorite. A CA-TIMS U–Pb zircon crystallization age of 418 ± 1.6 Ma constrains the age of the miarolitic monzogranite and ‘intrusion-related’ gold mineralization and places a minimum age on the gabbro–diorite and granophyric monzogranite. Similar metal enrichments along the length of the Mount Peyton trend suggest that the metal endowment of this mineralized corridor may be, at least, in part, a result of contributions from such, ‘intrusion-related’ fluids. The Hurricane–Corsair mineralization and that along the length of the trend may represent more distal, vein-related, disseminated mineralization structurally above miarolitic granite dykes and cupolas.

Neoproterozoic epithermal environments of the southern Burin Peninsula region, Newfoundland, Canada

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The southern Burin Peninsula region of the western Avalon Zone in Newfoundland is dominated by volcanic rocks of the ca. 590–570 Ma Marystown Group and is host to numerous examples of epithermal-related hydrothermal alteration. This epithermal alteration is hosted in both mafic and felsic volcanic rocks and is locally accompanied by appreciable gold mineralization. Visible/Infrared Reflectance Spectroscopy (VIRS) has identified characteristic minerals associated with both high- and low-sulphidation style epithermal systems. High-sulphidation related occurrences are characterized by zones of intense silicification accompanied by the development of alunite, pyrophyllite, and dickite alteration and locally developed zones of vuggy silica. Low-sulphidation related occurrences are characterized by the development of chalcedonic silica veins displaying crustiform-colloform banding along with discrete zones of hydrothermal brecciation. This style of mineralization is accompanied by white mica alteration that is indicative of a low temperature environment.

Despite the extensive Quaternary cover developed throughout the southern Burin region, till and lake sediment geochemical anomalies have aided in the discovery of several of the identified epithermal occurrences, while other anomalies in the region have yet to be explained. In spite of the challenges created by the poor exposure and the often cryptic nature of the associated alteration minerals, recent discoveries in the area demonstrate the potential of these rocks to host epithermal-related mineralization within a relatively underexplored portion of the province.

The Heritage (Point May) prospect: Neoproterozoic low-sulfidation epithermal Au-Ag mineralization in the Avalon zone of Newfoundland, Canada

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The Heritage project is located on the southern shore of the Burin Peninsula, within a part of the Avalonian terrane increasingly recognized for its potential for epithermal precious metal deposits. Other significant prospects within this district include Big Easy (low-sulfidation Au-Ag), Hickey's Pond (high-sulfidation Au), and Stewart (high sulphidation Au/porphyry-Cu). First discovered in 2011, the 4.5 km by 2 km Point May epithermal system (PMES) contains both multi-episode vein breccias and discrete veins. Drilling on the PMES has intersected two parallel mineralized zones, with the best intercept to date yielding 44 g/t Au and 10 516/t Ag.

The High Beach Andesite (HBA) is the host of the PMES; it consists of a thick succession of tuff, tuff breccia, and coarse pyroclastic rocks. These lithologies, as well as the presence of flow-banded rhyolite – are interpreted as broadly indicative of an arc-type volcanic environment during a protracted period of active magmatism. Interestingly, the abundance of jasperoidal fragments and fracture fillings in parts of the HBA implies a shallow sub-aqueous paleo-environment during emplacement of some of the volcanic rocks.

The PMES appears to be structurally controlled, with mineralization in close proximity to parallel shear zones. It has been suggested that these structures could be attributed to extensional forces during (incipient) back-arc rifting, which is further implied by the presence of a large scale horst-like structure identified on the property.

The PMES is a low-sulphidation epithermal system, as evidenced by banded and crustiform veins and bladed silica-adularia, accompanied by clay-chlorite-adularia alteration. Surface alteration is characterized by an outer silica – phengite zone, which surrounds an inner chalcedony – adularia – illite – chlorite zone. Surface sampling of the PMES has identified two discrete NNE-trending mineralized vein-breccia zones located on the eastern and western boundaries of the inner alteration zone (the Eagle and Pinnacle zones, respectively). Mineralized quartz veins are identified in core by the presence of ginguero style mineralization, comprising black 'sooty' irregularly serrate stringers, or coatings on fragments, which contain a characteristic

mineral assemblage: native silver and acanthite, with lesser naumannite, electrum, galena, clausthalite, chalcopryrite, and/or sphalerite.

Alteration halo and lithogeochemistry of the Pine Cove orogenic gold deposit, Baie Verte Peninsula, Newfoundland, Canada

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The Pine Cove orogenic Au deposit is hosted in a volcano-sedimentary sequence and gabbro sills of the Snooks Arm Group, Baie Verte Peninsula. The deposit is primarily hosted in gabbro sills and footwall strata consisting of high-Ti tholeiitic basalts, tuffs, greywacke, and hematitic mudstone. Hanging wall rocks consist predominantly of transitional to calc-alkaline tuffs and volcanoclastic turbidites. Lithogeochemistry suggests that footwall rocks correlate with the Venam's Bight Formation and hanging wall rocks correlate with the older Bobby Cove Formation, both of the Snooks Arm Group, indicating an overturned stratigraphic sequence.

Gold mineralization occurs with disseminated pyrite contemporaneous with quartz-calcite ± albite breccia-veins that occur along contacts between gabbro sills and footwall strata. Two distinct alteration assemblages are identified at Pine Cove: proximal sericite-rutile and distal epidote-titanite. A less consistently-developed spatially intermediate alteration zone consists of carbonate as pervasive groundmass alteration, porphyroblasts, and within veins. The alteration halo may extend as much as 100s of metres from ore, but is asymmetric due to proximity to the brittle-ductile Scrape Thrust fault, which truncates the lower part of the deposit.

Alteration and mass balance calculations for the alteration associated with the Pine Cove deposit shows enrichments in CO₂, K₂O, S, Rb, W, In, Pb, Bi, Te, Se, Cs, and Ba, and depletions in As, Sb, and locally Na₂O, similar to orogenic Au deposits globally.