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

Targeted Geoscience Initiative 3
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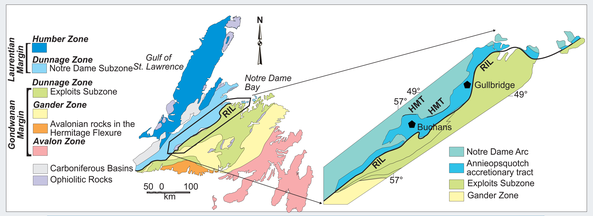



Figure 1: Distribution of the 4 main geological zones of Newfoundland and the location of the Annieopsquotch accretionary tract.

## Geological Setting

The Buchans Group (465 Ma) lies within the Annieopsquotch accretionary tract (AAT), a section of accreted peri-Laurentian continental arcs and backarcs formed during the Early to Middle Ordovician (Figure 1). The AAT is bound to the west by the Lloyds River fault, found adjacent to the Notre Dame and Dashwoods Arc, and to the west by the Red Indian Line, a major suture zone separating rocks of peri-Laurentian and peri-Gonwanan affinity. The formation of the AAT is characterized by the formation of two arcs: The Robert's Arm and Red Indian Lake/Buchans Arcs (Figure 2). Sub-greenschist to amphibolite facies metamorphism is syn- to post accretion, and associated with either burial (prehnite-pumpellyite) or contact metamorphism. Accretion of terranes to Laurentia was progressive. The Buchans Group was accreted and imbricated along west-dipping, oblique-reverse faults. Although major structures have been recognized, multiple generations of folding and faulting occurs with common reactivation of faults making structural interpretations extremely difficult.

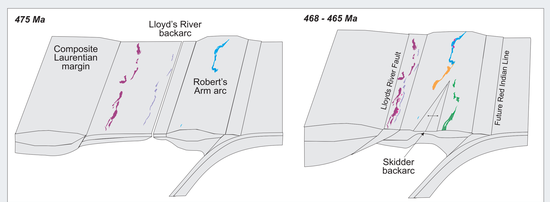
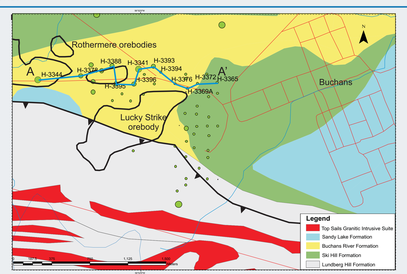



Figure 2: Tectonic setting and development of the AAT. First, formation of the Roberts Arm arc associated with west-dipping subduction outboard of the composite Laurentian margin. Next, accretion of the Roberts Arm arc, formation of the Buchans group within the Red Indian Lake arc, local extension forming the Skidder basalt and continued closing of the Iapetus Ocean and further deformation.

## Buchans Group

The Buchans mining camp is characterized by a number of unusually high grade low-tonnage volcanogenic massive sulphide deposits (VMS) hosted by a bimodal calc-alkaline continental arc sequence. The mining camp produced a total of 16.2 Mt of ore at an average grade of 14.5% zinc, 7.6% lead, 1.3% copper, 126g/t Ag, and 1.37g/t Au rivalling most other VMS districts. The Buchans Group has been separated into the Lundberg Hill, Ski Hill, Buchans River, and Sandy Lake Formations. The Lundberg Hill Formation is characterized by felsic pyroclastic rocks, rhyolite, tuffaceous wacke, siltstone, minor basalt, chert and iron formation. The Ski Hill Formation is characterized by basaltic to andesitic pyroclastic rocks with minor felsic tuff. The Buchans River Formation is characterized by rhyolite, felsic tuff, pyritic siltstone, polylithic conglomerate, and high grade in situ and transported sulphide ore bodies. The Sandy Lake Formation is characterized by basaltic pillow lava, epiclastic and polylithic pyroclastic volcanics, tuff, and tuffaceous sedimentary rocks.




.Figure 3: Compilation map of geology by Davenport (1996), structure and deposit data by Thurlow (1987), and drill hole distribution by Royal Roads Corp. just west of the town of Buchans.

## Architecture of the Lundberg Zone

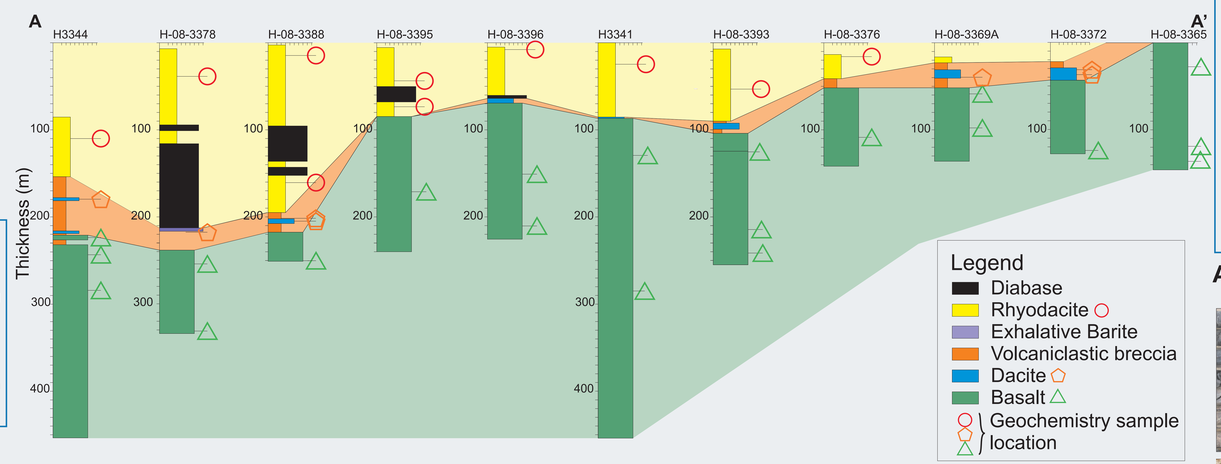



Figure 4: Stratigraphy and geochemistry of the Lundberg Zone. The basaltic unit is commonly silicified and sericitized at upper contacts within the mineralized polymetallic stockwork often mimicking dacititic textures. The volcanicalstic breccia is much thicker to the far west of the study area, and typically grades down-hole into normally graded sandstone, and siltstone with dispersed felsic clasts . The dacite unit is exclusively associated with the volcaniclastic breccia which hosts massive sphalerite-galena-pyrite clasts, however, the other felsic unit (rhyolite) observed at the top of the section is barren.

## Stratigraphy

Facies 1, a Basalt, is up to 360m thick constrained by drill hole depth. Facies 2, a dacite, ranges 5-40m thick, averaging 20m thick. Facies 3, a volcaniclastic breccia, ranges from 2-60m thick, averaging 5m thick. Facies 4, a rhyolite, ranges from 5-130m thick, locally thickening to 195m. All units except the dacite are intruded by diabase ranging from <1 to 130m thick. All 4 facies are correlative across much of the study area with some units pinching and swelling along across strike (i.e volcano-sedimentary and dacite). All facies gently dip to the northwest exposing more of the rhyolite in westward drill holes. Facies 1 is part of the Ski Hill formation, and the rest of the facies are grouped into the Buchans River Formation which hosts the ore.

## Geochemistry

80 samples were analysed at ActLabs, Ontario. Major oxides were determined by Fusion ICP, whereas trace elements were determined by Fusion-MS. Preliminary geochemical analysis of the first 40 samples has distinguished two separate felsic volcanic units, and a basalt/andesite (Figure 5). All units have distinct Nb anomalies, and a negative REE slope indicating a calc-alkaline arc affinity. The two different varieties of felsic volcanic rocks are differentiated based on REE's: The dacite is HREE-enriched, whereas the rhyolite is HREE-depleted. The HREE-enriched dacite is uniquely associated with mineralization as it is observed to lie stratigraphically in-between the volcaniclastic breccia and stockwork mineralized basalt.

## Lundberg Facies

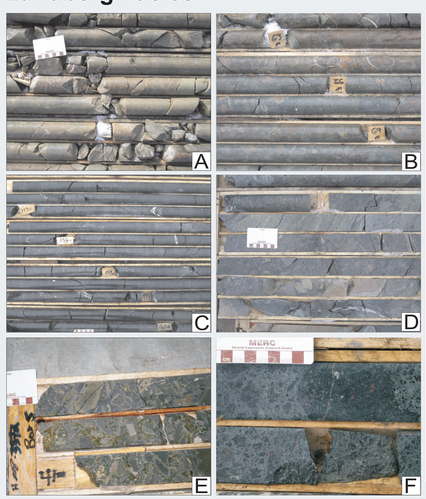


Figure 5: A. Rhyolite, H3386-Sample G077. Characterized by rhyolitic red groundmass with 15-30% white, euhedral, feldspar pheno- to glomerophenocrysts.
B. Chloritized Brecciated rhyolite, H3378. Characterized by 4cm angular to subrounded rhyolitic clasts with 15-30% feldspar phenocrysts.
C. Diabase, H3406. Characterized by black to dark grey, phaneritic to porphyritic texture with 0-15% chloritized pyroxene phenocrysts and amygdule-rich upper and lower contacts.
D. Volcaniclastic breccia, H3388. Characterized by sandy to silty, pyritic matrix and dacitic, sandstone, siltstone, chert, basalt, and sulphide clasts ranging from <1 to 60cm.
E. Monomictic brecciated dacite with quartz-sericite altered clast margins and up to 15% sericitized feldspar phenocrysts, H3341.
F: Quartz-chlorite-carbonate scoreacous, hyaloclastic, basaltic breccia, H3386.

## Lithogeochemistry

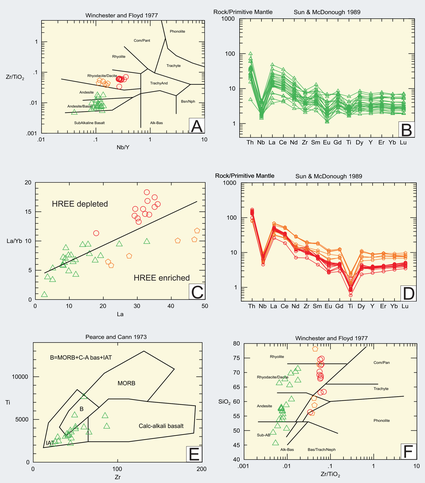



Figure 6: A. 3 distinct volcanic units are recognized: Basalt/Andesite (green triangle), dacite (orange octagon), and rhyolite (red circle). B. Spider Plot of Basalt/Andesite unit distinguishes a calc-alkaline,mature arc affinity for the basaltic unit.
C. La/Y over La separates the rhyodacite and dacite units on the basis of HREE enrichment/depletion. Basalts have similar La/Yb ratios as the dacite, but lower La.
D. Spider plot further distinguishes the two felsic calc-alkaline arc units.
E. Basalt discrimination diagram of immobile elements Ti and Zr indicates a volcanic arc origin for Lundberg basalts.
F. Winchester and Floyd (1977) diagram displaying silica mobility in the three volcanic units.

## Alteration and mineralization

Alteration throughout the Lundberg zone varies from weak to intense, varying within, and between stratigraphic units. Alteration of the groundmass of the rhyolite to chlorite (green- to black), sericite (white to beige), hematite or specularite is common. Alteration of the volcaniclastic breccia is limited to rare strong sericite and weak chlorite, whereas mineralization is common with 1-2% massive sphalerite, galena, chalcopyrite, and pyrite clasts averaging 1 cm, but up to 20 cm in length. Not only does mineralization occur as clasts, but also as brecciated exhalitive barite deposits along similar horizons. The brecciated exhalative deposits are metal-rich, consisting of up to 4.52 % combined Zn-Pb-Cu, 102.77 g/t Ag, and nearly 1g/t Au over 3.92m. The dacite unit typically has a quartz-sericite-pyrite altered groundmass with feldspar phenocrysts reflecting the same alteration. The dacite is typically unmineralized, but rare massive chalcopyrite veins are observed having average grades up to 5.3g/t over 1 m. The basalt unit is typically altered to chlorite and quartz-sericite assemblages, and hosts the majority of the Lundberg zone, a polymetallic, sphalerite-galena-chalcopyrite stockwork. Along these mineralized quartz-carbonate-rich veins, alteration haloes of chlorite and sericite-fuchsite are rare, but observed. Bladed calcite and quartz pseudomorphs of bladed calcite are common within mineralized veins, with individual blades ranging from <1 to 3 cm in length.

## Alteration and Mineralization of Major Volcanic Units

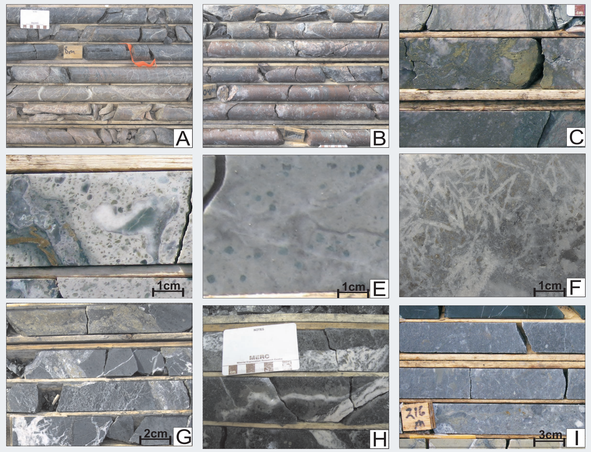


Figure 7: A. Chloritized rhyolite, H3396-Sample G013. B. Hematized rhyolite, H3408. C. Silicified Dacite with chalcopyrite veining, H3386. D. Silicified basalt, H3406-Sample G199. E. Quartz-sericite-fuchsite alteration within the basalt, H3393. F. Bladed calcite with disseminated pyrite and sphalerite, H3398. G. Disseminated sphalerite-galena-pyrite veins, as well as in-situ brecciation of basalt, H3369A, H. Bladed calcite, as well as an alteration halo of sericite-fuchsite around a quartz-carbonate vein, H3365. I. Exhalative barite, H3378.

## Implications for Buchans VMS genesis

Mineralization within the Lundberg zone is associated with only one felsic volcanic unit (dacite) based on stratigraphic and geochemical constraints. This implies that stockwork mineralization, as well as formation of massive sulphide mounds, was restricted to one stratigraphic horizon. Intense bladed calcite observed within the polymetallic veins of the Lundberg Zone indicates that precipitation of the sulphides was induced by phase separation of hydrothermal fluids by sub-seafloor boiling. Boiling of hydrothermal fluids occurs over a wide range of pressure and temperature conditions, but, as pressure decreases (i.e. shallowing water column) boiling is inevitable. Boiling of the hydrothermal fluid can account for the low grade (1.83% Zn, 0.67% Pb, 0.38% Cu, 5.5g/t Ag) of the Lundberg zone. The rising hydrothermal fluid is depleted in metals upon reaching the seafloor due to precipitation over a large boiling area, and deposition of massive sulphide mounds is limited. The Lundberg Zone exhibits some characteristics of epithermal deposits, suggesting deposition in a low hydrostatic pressure environment; however, it is also associated with typical Kuroko-style VMS mineralization (e.g. Lucky Strike). These contrasting characteristics suggest that the Buchans area represents the transition between typical VMS and epithermal paleoenvironments.

## Acknowledgements

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