MERC-ME-2019-197

METAL EARTH

2019
Field Trip Guide

CANADA FIRST RESEARCH EXCELLENCE FUND | APOGÉE CANADA FONDS D'EXCELLENCE EN RECHERCHE

Canada

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Chibougamau, Québec

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Metal Earth excursion in Chibougamau – September 9th, 2019

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With the help of Patrick Houle (MERN)

The 2019 crew and their trusted vehicles in a typical day of Chibougamau. From left to right: Marcel Belalahy Brandy (FA), Nesrine Mokchah (FA), Mathieu Robin (FA), Adrien Boucher (MSc), Marie Kieffer (MSc), Yohannes Degnan (FA), Julien Huguet (MSc) and Pierre Bedeaux (RA).

Foreword

This fieldtrip is focusing on the part of the Chibougamau transect lying south of regional road 113, which broadly corresponds to the northern faulted contact of the Opemiska Group. The aim is to present geological and economical contexts with potential interest for mineral exploration. This fieldtrip also emphasizes results from several Metal Earth MSc projects, and establishes links between surface geology and the 2017 seismic survey. This activity is complementary to the 2018 fieldtrip that focused on the northern part of the transect and that presented results from other MSc projects. Most of the regional geology section is copied from the 2018 fieldtrip excursion booklet.

Stops location

Table 1: Stops and locations (UTM NAD83 U18)

Station	UTME	UTMN	Length	**Description**
AFB0217	523993	5482485	2h	Stop #1 – Guercheville Fault
UCD0137	513299	5497975	2h	Stop #2 – Moly Desgagné showing (Eau Jaune Complex)
UCB0005	515874	5510071	1h	Stop #3 – Volcanism stop (Obatogamau Fm.)
PCB0186*	520821	5512820	0.5h	Stop #4 – Fluvial environment (Haüy Fm.)
PCB0245	519602	5514570	1h	Stop #5 – Turbidites and graphitic shales (Blondeau Fm.)
PCB0288*	515913	5514921	1h	Stop #6 – Dacitic lobes (Blondeau Fm.)

*Optional stop

Geology of the Chibougamau area

The Chibougamau transect of the Metal Earth project is 162 km long and extends, from N to S, from the Opatica Subprovince (immediately north of the Barlow pluton) to south of the Caopatina Formation. The Chibougamau area has been mapped by generations of geologists, and the following description is based on several syntheses (Daigneault and Allard 1990, Leclerc et al. 2017, Polat et al. 2018).

Chibougamau is known for its historical mining camp; the Central Camp, a Cu-Au porphyry mineralization related to an intrusive phase of the Chibougamau pluton (Pilote et al. 1998b, Pilote 2006). The Chibougamau area displays distinctive features compared to the southern, gold-endowed, Abitibi Subprovince, such as an absence of komatiite, the presence of large-scale E-W-striking folds (10-20 km extension in the N-S direction), and an abundance of magmato-hydrothermal mineralized systems.

The Chibougamau area comprises some of the oldest volcanic rocks of the Abitibi Subprovince; i.e. the ~2791-2799 Ma Chrissie Formation (Leclerc et al. 2017). These rocks are overlain by the two volcanic cycles of the Roy Group. Each cycle comprises a thick accumulation of mafic to intermediate lava flows topped by felsic eruptive centers. The Roy Group is topped by the ~2700 Ma basin-restricted sedimentary rocks of the Opémisca Group (Leclerc et al. 2017, Polat et al. 2018).

The rocks of the first volcanic cycle (cycle 1) correspond to the Obatogamau and Waconichi Formations. The undated Obatogamau Formation has a tholeiitic affinity, contains characteristic plagioclase macrocryst-bearing mafic volcanic rocks, is mostly made of basaltic to andesite lava flows intercalated with more evolved volcanic centers, and may be genetically related to the LDC (Polat et al. 2018). It is topped by the intermediate to felsic volcanic rocks with tholeiitic to calc-alkaline affinities of the circa~2.730-2.726 Ga Waconichi Formation (Leclerc et al. 2017). The Waconichi Formation contains several exhalative units (chert and iron formations) and sulphide accumulations related to VMS systems (e.g. Lemoine mine) (Mercier-Langevin et al. 2014). Based on their extent in the field, these VMS likely formed around small eruptive centers (Allard 1976). In the southern part of the region, the turbiditic sedimentary rocks of the Caopatina Formation are coeval with the Obatogamau Formation.

The second volcanic cycle (cycle 2) comprises the ~2.724 Ga Bruneau Formation (Davis et al. 2014), a pile of mafic lava flows, and the Blondeau Formation, a thick pile of volcanoclastic deposits, felsic extrusions, as well as chemical and clastic sedimentary rocks with a maximum age of 2.721 Ga (Leclerc et al. 2012). In the area visited by this excursion (Figure 1), cycle 2 is topped by conglomerate-sandstone fluvial sequences of the Stella and Haüy formations (Opemiska Group).

The main intrusions of the Chibougamau area correspond to the Lac Doré Complex, a large ~2.728 Ga (Mortensen 1993) layered intrusion, and to the Chibougamau pluton, a ~2.718 Ga (Krogh 1982) a polyphase pluton. The Lac Doré Complex contains V- mineralization and hosts the Cu-Au Central Camp, which is related to an intrusive phase of the Chibougamau pluton (Arguin et al. 2018, Mathieu et Racicot 2019, Mathieu 2019). Other notable intrusions correspond to three ultramafic to

~2.717 Ga (Mortensen 1993) mafic sills of the Cummings Complex, to several syn-volcanic TTG and syn- tectonic granodiorite, and to sanukitoid intrusions (Barlow and Opémiska plutons).

Regional greenschist facies metamorphism is ubiquitous in the Abitibi Subprovince and in the Chibougamau area. Higher grade assemblages (amphibolite facies) are observed in contact aureoles and near the Proterozoic Grenville Front, (Rivers et al. 1989). Deformation formed several E-W- to NE-SW-oriented anticlines and synclines. The stratigraphy is also complicated by smaller-amplitude folds and by a large amount of reverse and strike-slip faults (Daigneault and Allard 1990).

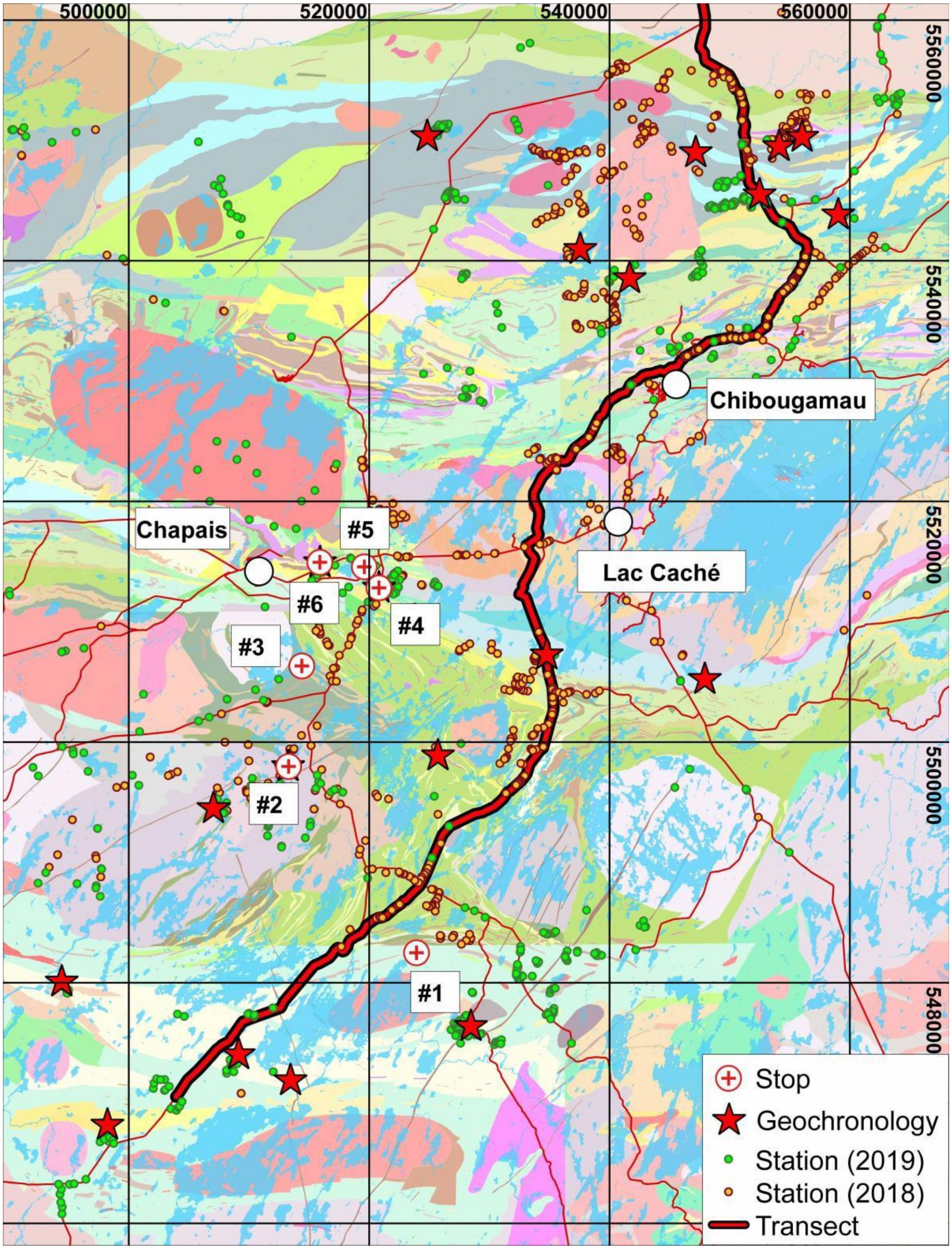

Figure 1: Simplified geological map of the Chibougamau area with 2019 fieldtrip stops (SIGEOM 2016, MERN).

Stop #1 – Guercheville Fault

The Guercheville Fault is an east-striking anastomosing deformation zone lying north of the Caopatina Group sedimentary basin and south of the Eau Jaune Complex. The Guercheville Fault is spatially associated with a seismic reflector of the Metal Earth survey. The structure was initially observed west of the Caopatina Group sedimentary basin and its extent is ill-defined near the transect.

The outcrops are a series of east-trending trenches. The main lithology is basaltic lava flows of the Obatogamau Formation. Glomeroporphyric plagioclase and pillow rims are locally observed (Figure 2a). Still, most of the primary features are obliterated by deformation, hydrothermal alteration and metamorphism.

The fault footprint is several hundred meters wide (around 1300 m) and is characterized by a shallow dip toward the north (30-60°) and high strain (Figure 2b). Stretching lineation is subhorizontal and delta-type shear sense indicators suggest dextral strike-slip (Figure 2c). Strong carbonatization is observed on all trenches and this alteration has a combined width of around 250 m. Rocks are overprinted by high grade metamorphism as suggested by millimetric to centimetric amphibole porphyroblasts. Amphiboles are randomly distributed within the foliation plan (Figure 2d).

The Guercheville Fault is interpreted as a regional-scale structure separating the Caopatina Formationa on the south from the Roy Group to the north. This could explain the difference of younging direction between the northern and southern blocks. Characteristics of the fault suggest a thrust deformation related to a N-S shortening event, which was subsequently re-activated as a strike-slip fault. Metamorphism is amphibolite facies, which is uncommon in the area. This high grade metamorphism can be explained by the Hazeur Pluton located south of the trenches.

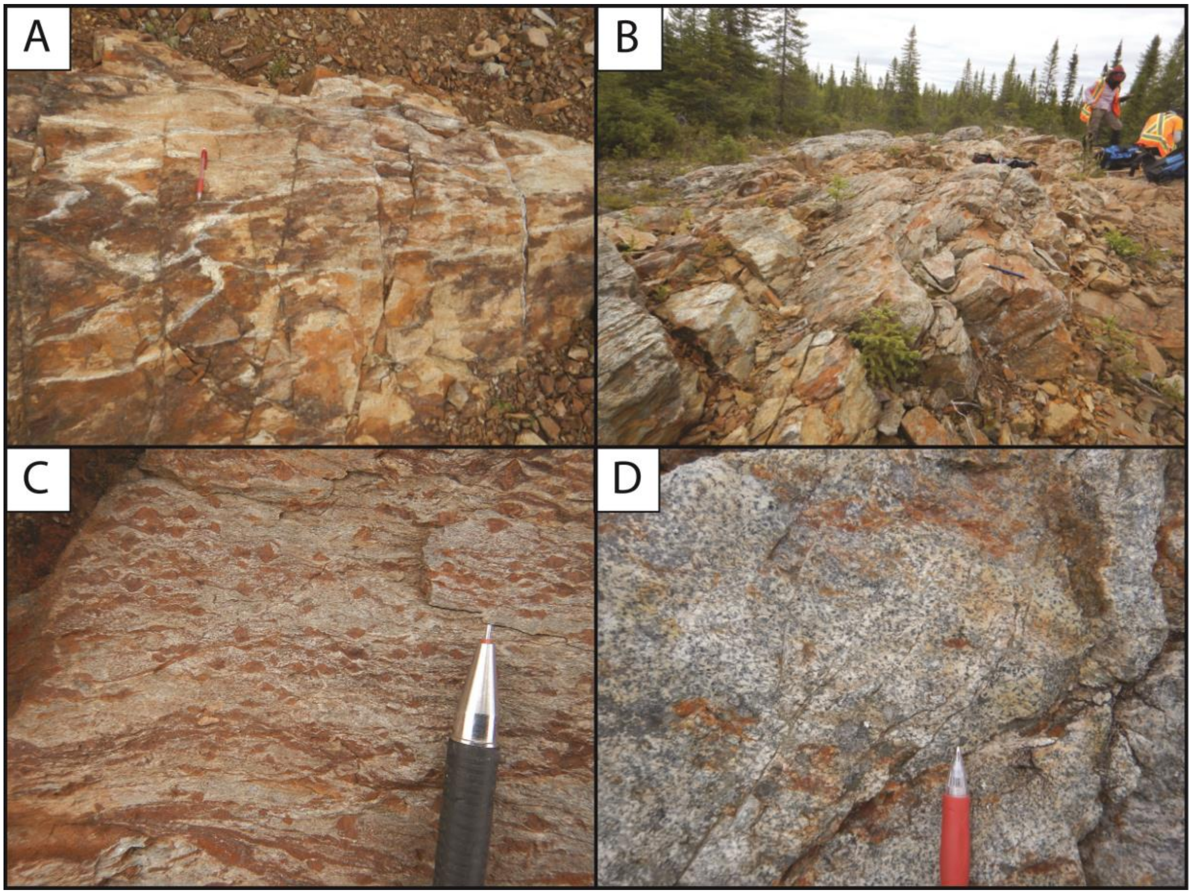

Figure 2: Geological features of the Guercheville Fault. A) Pillowed basalts. B) Side view of the shallow-dipping Guercheville Fault. C) Carbonate alteration associated with the fault. Delta-shaped carbonate porphyroblasts that indicate dextral movement. D) Amphiboles (probably hornblende) randomly distributed inside the main foliation (amphibolite facies metamorphism). Note: the pencil points toward the north.

Stop #2 – Moly-Desgagné Mo showing (Eau Jaune Complex)

The Eau Jaune Complex is one of the largest intrusions of the Chibougamau Metal Earth seismic transect, with an area of several hundreds of square kilometers. The multiphase intrusion is formed by at least 7 distinct phases. It contains enclaves of metamorphosed mafic rocks (amphibolite facies) and displays a complex structural history. The characterization of lithologies, metamorphism and deformation is the subject of a MSc project at the UQAC (M. Kieffer). Part of the intrusive phases and their relation to deformation and metamorphism can be observed on the outcrops of the Moly-Desgagné molybdenum showing.

The Moly-Desgagné main outcrop (Figure 3) is mainly composed of a coarse-grained dioritic phase (Figure 4a) observed as an enclave in a fine-grained diorite. These two phases are cut by a tonalitic phase (Figure 4b) and an aplitic dyke. The rocks recorded several deformation events: 1) an early and poorly developed N-S foliation, which is locally folded; and (2) the main NW-SE foliation (striking N110 to N130) is highlighted by amphiboles and feldspar alignment. This foliation developed throughout amphibolite facies metamorphic conditions. The deformation was coeval with the injection of brecciated pegmatite dykes (Figure 4c) and the development of NW-SE subvertical deformation corridors (mylonites). Some of these corridors are chlorite-rich and record both deformation events; the N-S foliation is faintly imprinted on the edges of the corridor. The abundance of chlorite in these corridors points to a retrograde hydrothermal fluid circulation (greenschist metamorphic facies).

Hydrothermal activity also formed 5 generations of late quartz, quartz-tourmaline and tourmaline veins (Figure 4d). East-west-striking quartz veins are associated with carbonate alteration (ankerite). Pyrite occurs in some quartz veins, as well as the weak deformation affecting these veins, indicate that the hydrothermal system developed toward or after the end of the last deformation event. Molybdenum mineralization is mainly found along the wall of the quartz veins located in the chlorite-rich NW-SE- striking shear zones (retrograde metamorphism). Molybdenite flakes are also disseminated inside the late quartz veins. It shows that the Mo mineralization emplaced during several pulses or that it was remobilized.

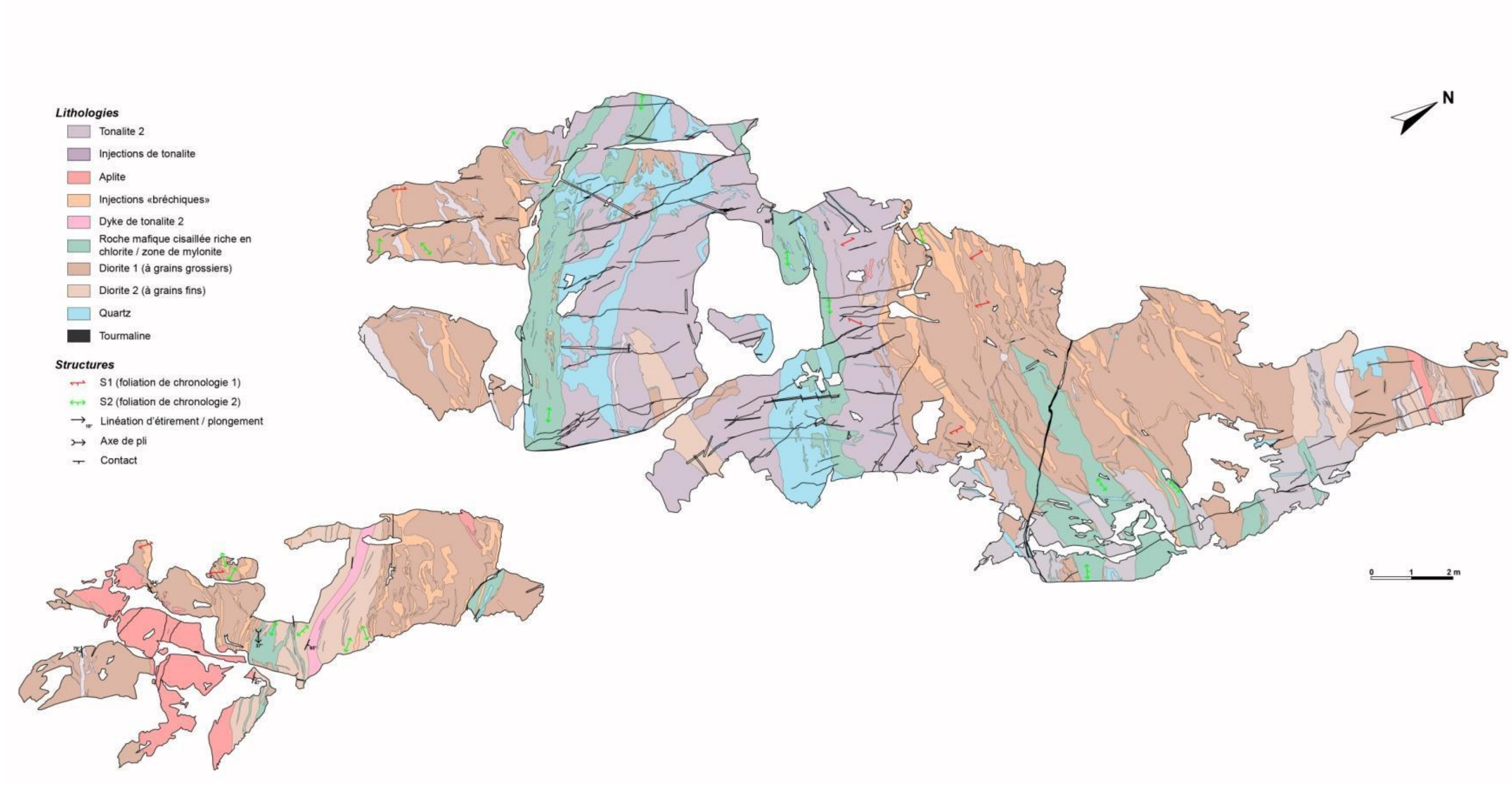

Figure 3: Detailed mapping of the Moly-Desgagné stripping

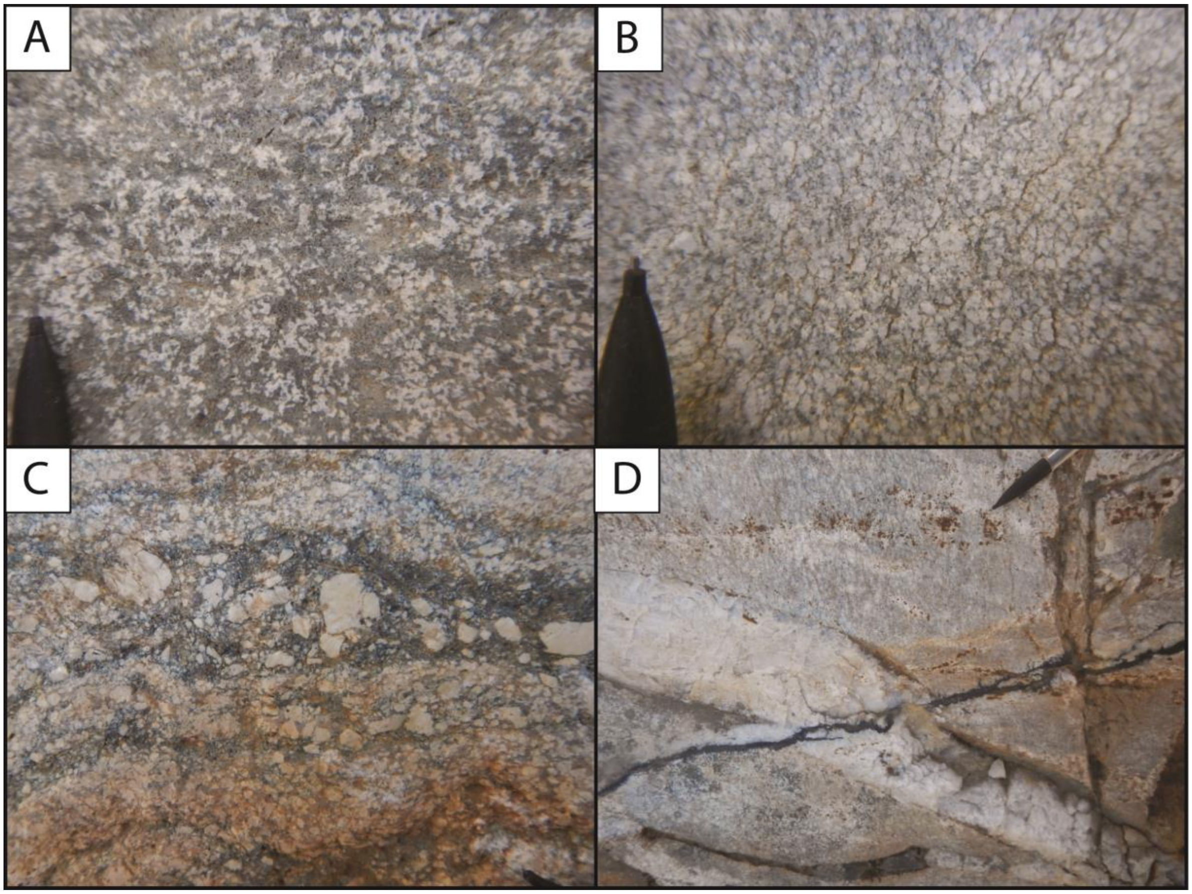

Figure 4: Typical facies of the Eau Jaune Complex; A) coarse-grained diorite; B) tonalite; C) brecciated pegmatite; and D) quartz vein cut by a tourmaline vein.

Stop #3 – Volcanic gap in the Obatogamau Formation

The stop #3 outcrop is part of the Obatogamau Formation. This formation is studied at UQAC as part of a M.Sc. (A. Boucher) of the *Metal Earth* project. The Obatogamau Formation is a large extent (100 km E-W) volcanic unit defined as a thick sequence of mafic tholeiitic lava. The flows may contain up to 15% of cm-long feldspar macrocrysts and glomerocrysts. The Obatogamau Formation corresponds to the lowermost unit of the first of the two volcanic cycles of the Roy Group and is topped by the Waconichi Formation. The chemical and petrological heterogeneity of the Obatogamau Formation remains poorly documented and its VMS potential hasn't been properly assessed.

The outcrop visited in the course of this fieldtrip displays several lava flows of basaltic-andesitic composition (Figure 5). The flows are separated by 1) a claystone horizon, interbedded with siltstone and a thin chert layer (Figure 6a), and 2) another chert level. These two horizons are of limited thickness (15 to 50 cm) and are weakly mineralized in pyrite and pyrrhotite. These sedimentary levels developed during gaps in the effusive volcanism. The convexity of the pillow basalts indicates a stratigraphic top towards the NE (Figure 6b), which is consistent with other observations made in the area. However, the strike in the claystone and siltstone level bedding horizon displays multiple variations which indicates the presence of the hinge zone of a local fold (Figure 6c). The pillowed lava flow located stratigraphically above the claystone and siltstone level contains less than 1% feldspar macrocrysts (Figure 6d), while the two lava flows located directly below are aphanitic. The macrocrysts have been recrystallized into clinozoisite and albite during regional greenschist metamorphism.

The lava flows on either side of the sedimentary horizons are of similar compositions according to whole rock chemical analyzes. This homogeneity in compositions is observed at the scale of the study area, with the noticeable exception of the top of the sequence in the vicinity of the Waconichi Formation, where compositions tend to be slightly more evolved and of transitional affinity. The chemical homogeneity of the lava flows implies limited magmatic differentiation leading to the eruptive events that formed the Obatogamau Formation. This also implies high effusion rates.

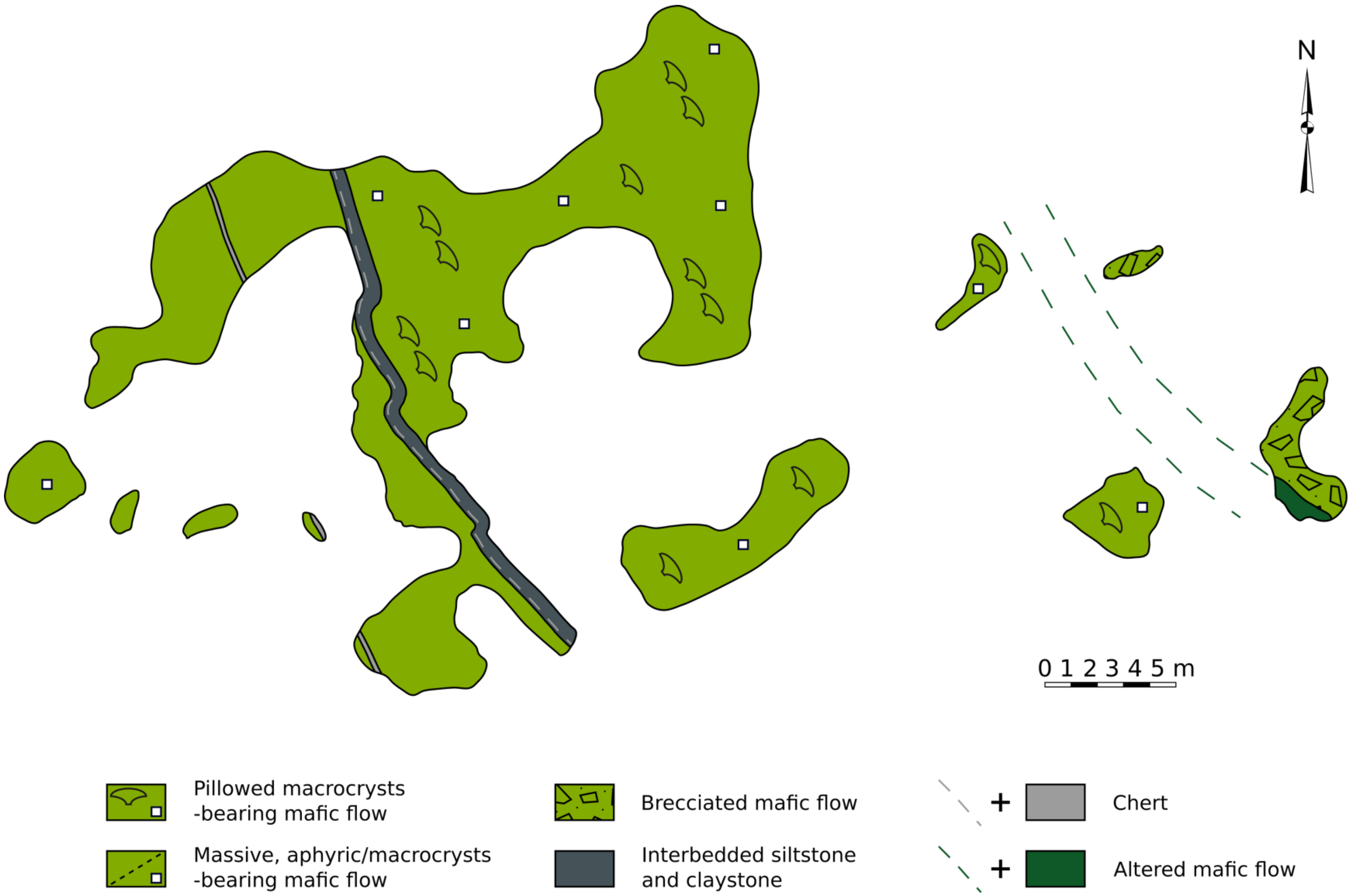

Figure 5: Detailled mapping of the mudstone-chert horizon interpreted as a volcanic gap inside the Obatogamau Formation.

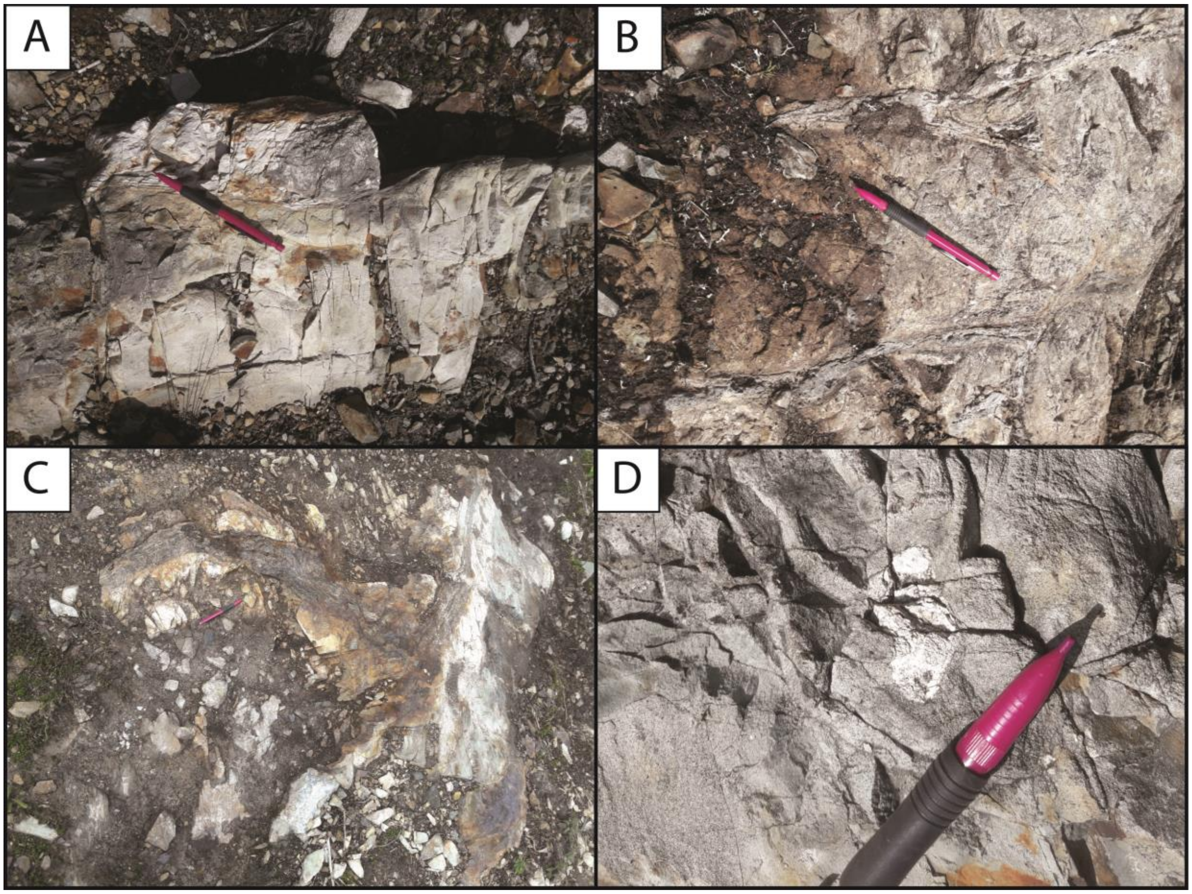

Figure 6: Volcanic and sedimentary facies of the Obatogamau Formation: A) chert, B) pillow basalt, with stratigraphic top-to-the-east, C) "Z"-shaped folded claystone horizon and D), feldspar macrocrysts in basaltic flows.

Stop #4 –Fluvial sequences (Haüy Formation)

This stop focuses on the Opemiska Group sedimentary basin and shows typical Stella and Haüy formation facies. This outcrop was sampled to evaluate sedimentation age using U/Pb analysis on detrital zircons. This analysis is part of a larger project aiming at comparing sedimentary environments and depositional ages in the sedimentary basins in the Chibougamau area.

The outcrop displays two main lithologies: sandstone and conglomerate (Figure 6a). Medium to coarse-grained sandstone commonly bears quartz grains. Sandstone is massive or thinly-bedded. It displays common oblique and curved cross-bedding (Figure 6b) and, locally, grading. These features point to channelling within sandstone beds (Figure 6c) and indicate a younging direction to the south and structural facing to the west.

The second unit is a typical Opemiska Group conglomerate, with mm- to cm-long rounded adjoining clasts of heterogeneous compositions (felsic to intermediate intrusion, sedimentary rocks, rhyolites, basalts). Matrix is made of coarse sandstone. Fragments are stretched and flattened along the main foliation.

The conglomerate unit includes some greenish clasts that correspond to porphyritic andesite (Figure 6d) of the Haüy Formation. These clasts are observed only in the Haüy Formation and distinguish it from the Stella Formation.

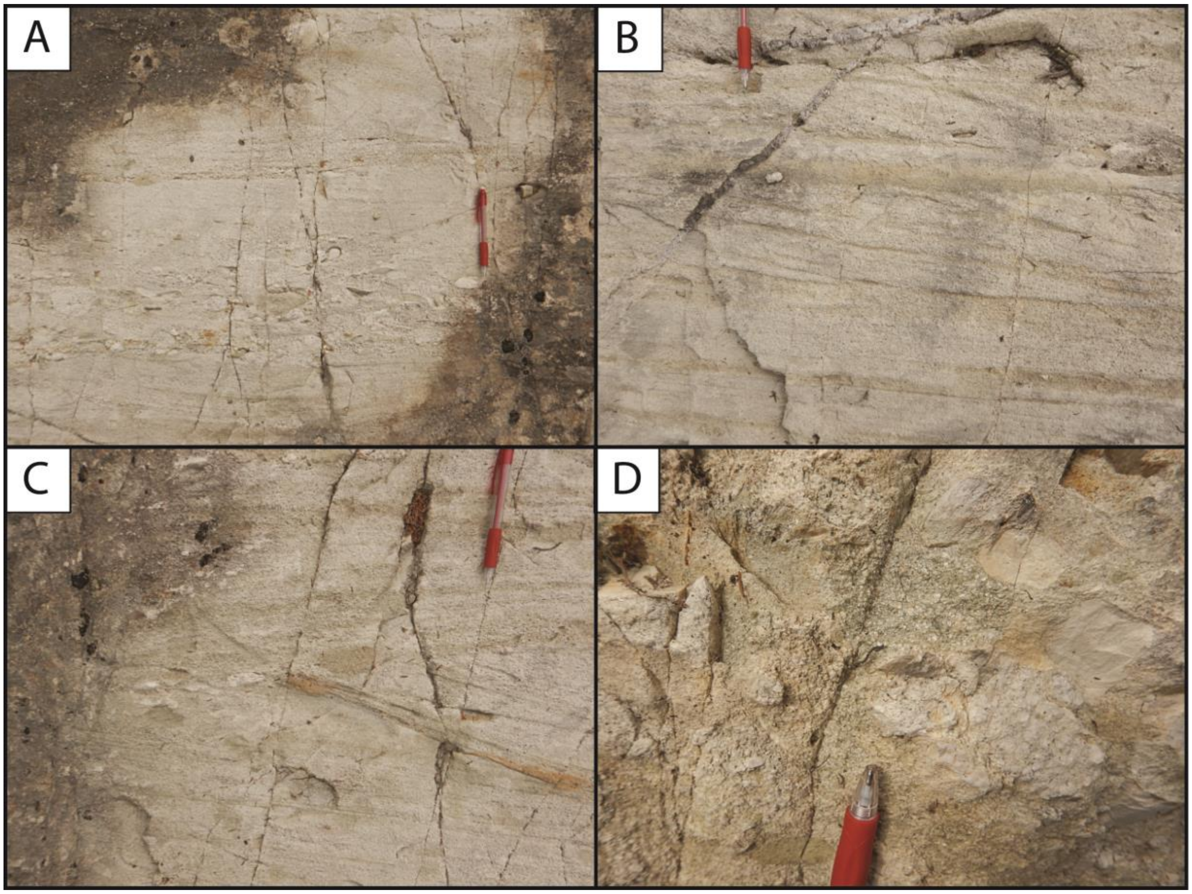

Figure 7: Sedimentary textures and facies of the Haüy Formation: A) Sequences of decimeter-thick medium- to coarse-grained sandstone and polygenic conglomerate bearing rounded and joined fragments. B) Oblique bedding inside a sandstone bed; C) Channel within sandstone beds indicating top-to-the-south; and D) porphyry andesite fragment from a volcanic unit of the Haüy Formation.

Stop #5 –Turbidites and graphitic shales (Blondeau Fm.)

This stop encompasses several outcrops of sedimentary and volcanic rocks of the Blondeau Formation. These outcrops are located next to the contact between the Blondeau Formation and the Opemiska Group.

The westernmost outcrops exhibit cm- to dm-thick beds of fine-grained sandstone and mudstone (Figure 8a). Beds strike N-S and are folded along the east-striking regional foliation. Loading structures and grading indicate top-to-the-west. Sedimentary rocks are cut by a felsic to intermediate dyke.

In the central part of the stripping, graphitic shales outcrop (Figure 8b). Bedding is obliterated by the east-trending foliation. Shales include many cm-long nodular pyrites (Figure 8c). Rocks are heavily rusted, and the most weathered parts form a *gossan* (iron cap), which is formed of Quaternary concretions resulting from pyrite oxidation.

Another outcrop lies next to the parking area and shows a clast-bearing volcanic rock (Figure 8d). Fragments are felsic extrusive rocks, as well as silicified shales. The matrix is altered and rusted.

These outcrops point to a deep marine environment dominated by turbiditic gravity flows (i.e. sequences of mudstones and sandstone) associated with local of volcanic activity (felsic lapilli tufs). Hydrothermal alteration and bacterial activity (nodular pyrite-bearing graphitic shales) are also syn-sedimentary features characteristic of the Blondeau Formation. Stop#5, as well as the felsic volcanic rocks of stop #6 and the occurrence of several Cu showings in the immediate vicinity of the visited area (less than 3 km) point to a VMS environment.

Stop #4 (fluvial sequence of the Haüy Formation) is located < 1 km to the east from stop #5. In both areas, younging directions are to the west, suggesting, at first glance, that the volcanic rocks of the Blondeau Formation overlie the fluvial sequences. However, rocks of the Opemiska Group are stratigraphically recognized as the youngest surface assemblage. This means that a local structural complexity moved the Blondeau Formation above the Opemiska Group in this area.

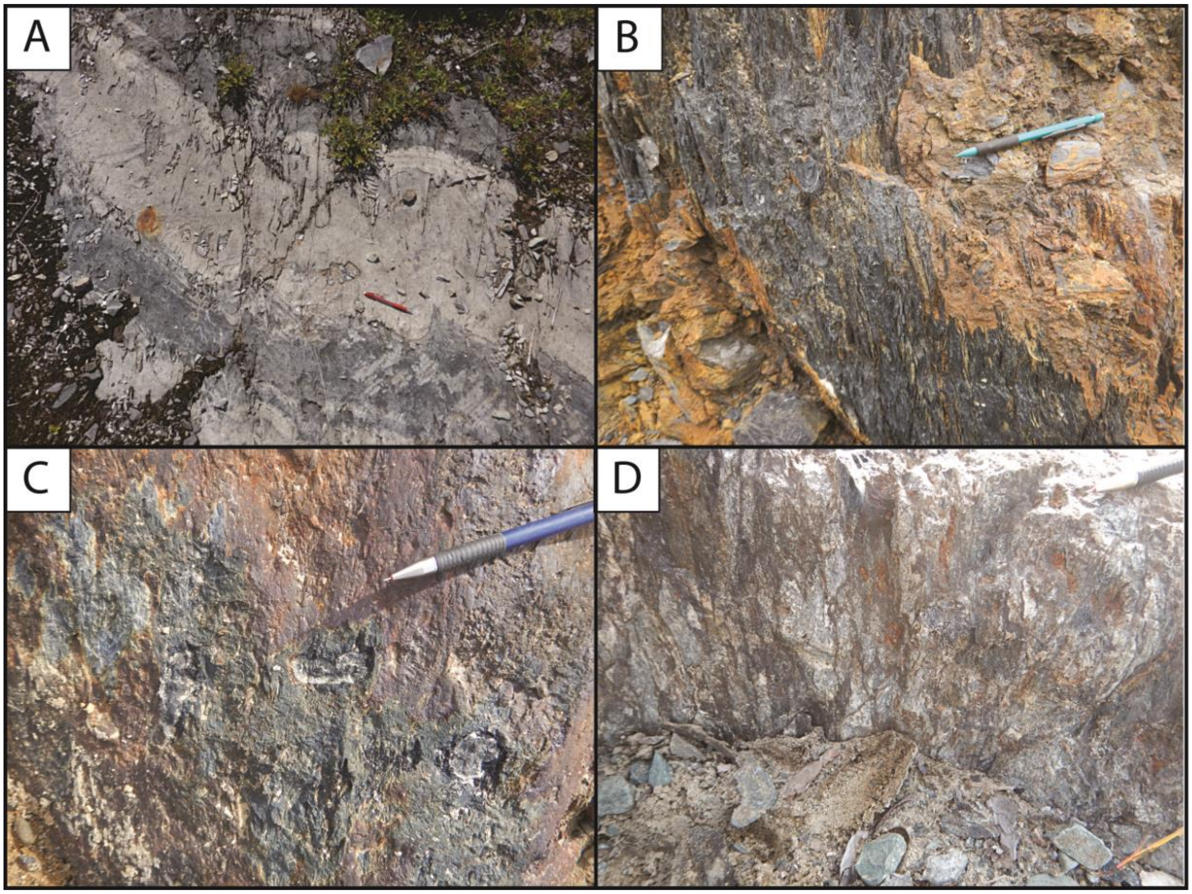

Figure 8: Typical lithologies of the Blondeau Formation. A) Turbidite sequence (sandstone and mudstone), with a stratigraphic top indicated by loading structures. B) Graphitic black shales. Regional foliation corresponds to the fissilility of the rock, as the bedding is obliterated by deformation. C) Cm-long nodular pyrites in black shale. D) Felsic lapilli tufs. Some fragments of silicified shales are locally observed. Matrix is rusted and altered.(weathering).

Stop #6 –Lobate dacite lava flows and fault zone (Blondeau Formation)

This trench is located at the contact between the Venture sill (Cummings Complex) to the north and the Blondeau Formation to the south. It is also located half-way between the Chibougamau and Chapais mining camps. The area is structurally complex, as indicated by the folding of the Cummings Complex and several faults.

In these outcrops, the Venture sill is a medium to coarse-grained pyroxene-bearing gabbro. To the north, the sill is mostly made of pyroxenite. The sill is poorly strained.

Contact between the sill and the Blondeau Formation is sheared and corresponds to a deformation zone that extends for several dozens of meters in volcanic rocks (Figure 9a). The fault zone is only a few meters wide in the competent rocks of the sill. The volcanic rocks are strongly sheared and strained, and their primary features are mostly obliterated. Volcanic rocks have a felsic composition, contain some quartz grains, as well as clasts stretched and flattened along the east-striking regional foliation (Figure 9b). Some transposed mafic dykes cut the volcanic rocks (Figure 9c).

A second outcrop lies to the south, outside the deformation zone. It displays feldspar- and quartz-bearing dacite lava flows with lobate structures whose rims are chloritized and locally epidotized (Figure 9d).

Rocks of the Blondeau Formation belong, in this area, to a small felsic volcanic center. Fragments observed in the sheared volcanic rocks are the deformed equivalent of the lobate dacite.

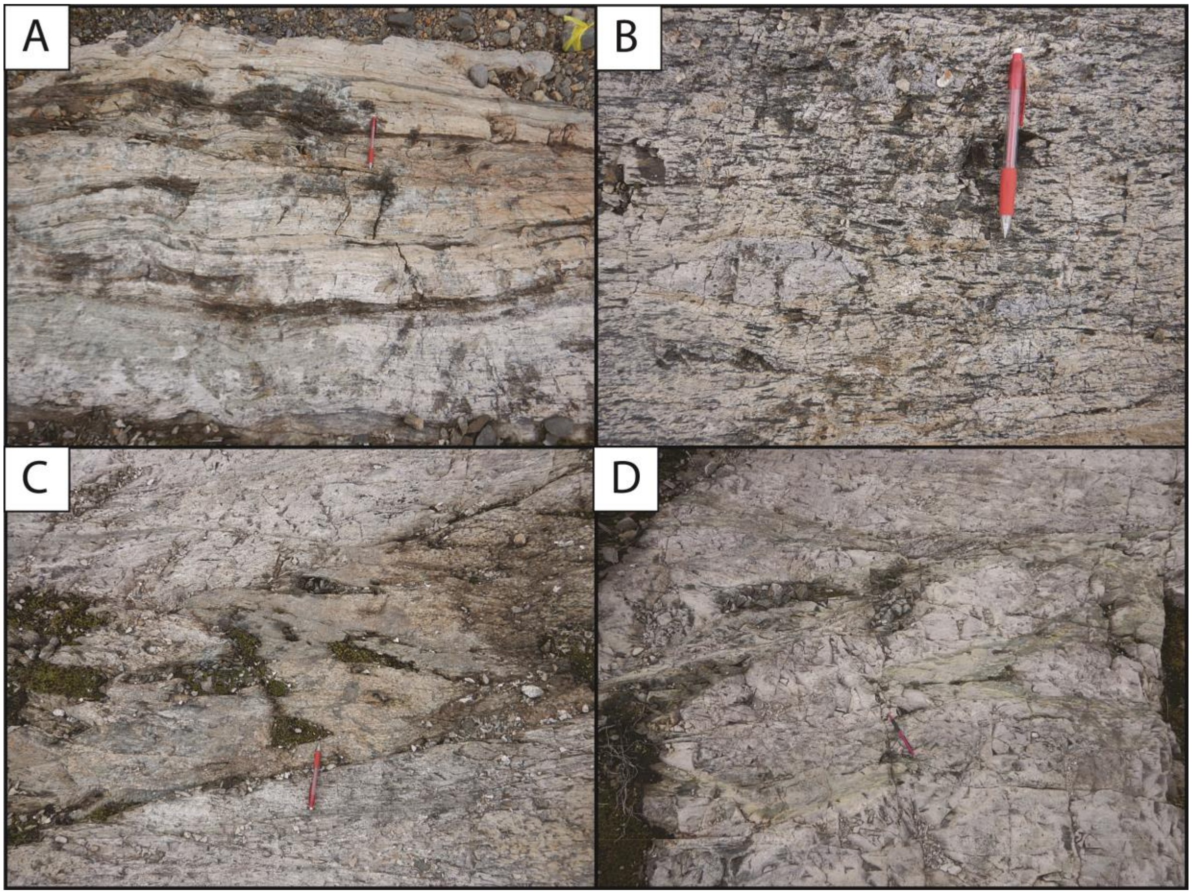

Figure 9: Features related to felsic volcanic flow of the Blondeau Formation: A) mylonitized felsic volcanic rock, B) fragments in the volcanic rocks, C) transposed mafic dyke and D) dacitic lobed lava flow.

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Annex – Stratigraphic log of the Chibougamau area (Leclerc et al. 2017)

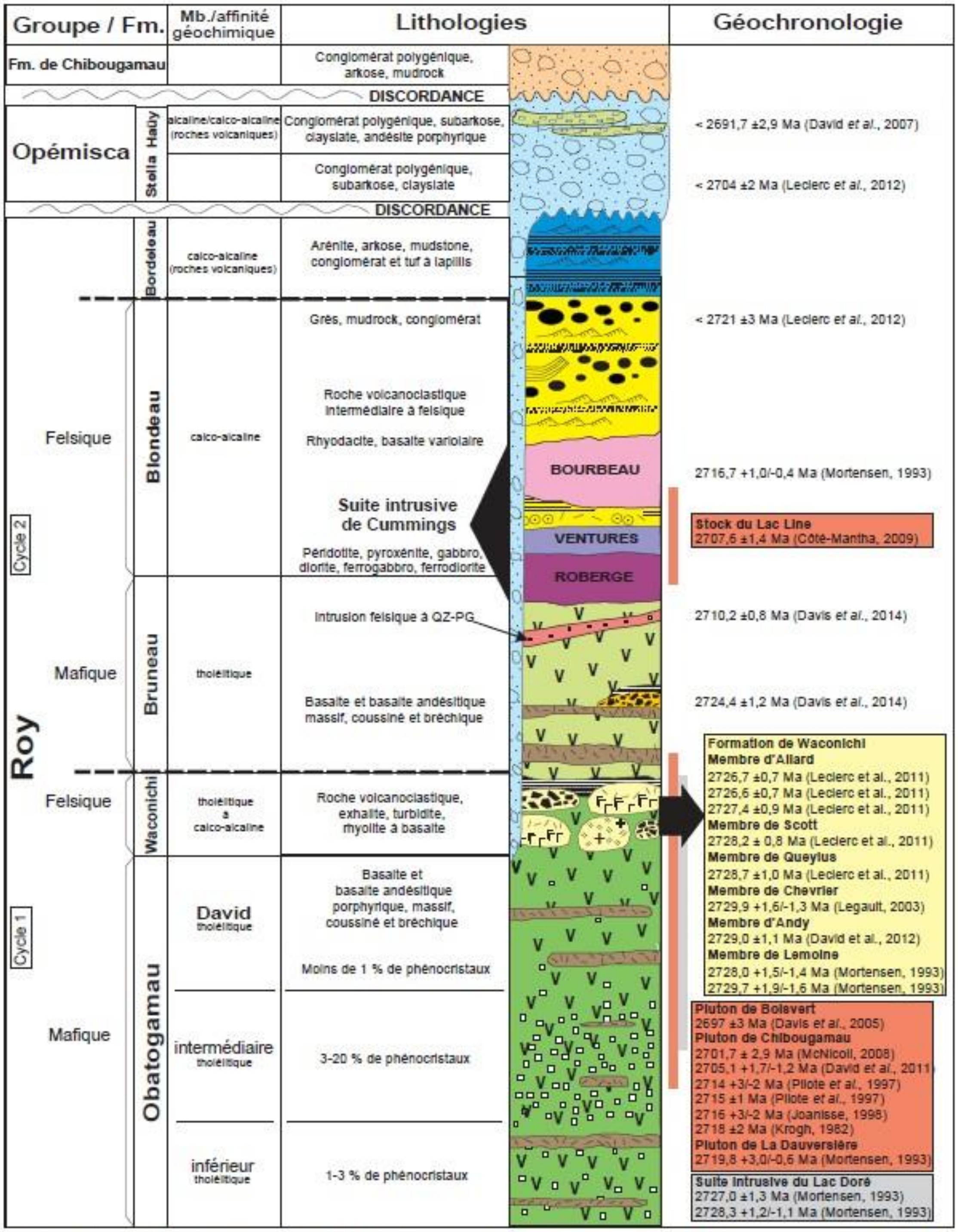

FIGURE 5 - Stratigraphie de la région de Chibougamau. L'affinité géochimique est donnée pour le faciès dominant. L'emplacement relatif des plutons granitoïdes est indiqué par un trait rose; un trait gris indique la position de la Suite intrusive du Lac Doré

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METAL EARTH

2019 Field Trip Guide

Cobalt, Ontario

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Geology, Mineralization, and Mining History of the Cobalt Region, Cobalt Ontario

Shawna E White & Louise Rush

INTRODUCTION

During the early 20th Century, Cobalt was one of the most prolific silver mining areas in the world. Almost 500 million ounces of silver and 24 million lbs of cobalt were produced from Ag-Co arsenide veins in the last century. The mineralized veins in Cobalt are hosted in Archean and Proterozoic units and have similar mineralogy, morphological characteristics, and proximity to Nipissing diabase sills and the regional unconformity (Figure 1). However, there is limited understanding of the structural and stratigraphic controls on their formation. The ore deposit type, part of the enigmatic five-element association (Ag-Ni-Co-As+/-(Bi, U)), is also poorly defined. Using a combination of new field mapping, geophysical interpretation, geochronology, and whole rock and stable isotope geochemistry, the Cobalt transect hopes to determine the controls on vein distribution and orientation, and understand the mineralization in the context of modern deposit models.

Currently, considerable uncertainty exists regarding the global cobalt supply as the Democratic Republic of Congo (DRC) produces more than half the world's cobalt. Other than these sedimentary-hosted Cu-Co ores from the DRC, much of the world's current cobalt supply is a by-product from the mining of Ni-Cu ores hosted in mafic and ultramafic intrusions. The recent emergence of Co as a critical metal (needed for high quality batteries) and interest in Canadian cobalt production has refocused exploration in the Cobalt region. Today, the camp is realizing a new life and attracting the attention of exploration companies. As a result there exists the opportunity to discover new and economically viable cobalt deposits. Increased exploration success will provide long term benefits to Ontario, in particular geologically similar districts such as Gowganda and Thunder Bay.

THE COBALT TRANSECT

The deep crustal 2D seismic reflection and MT data were collected during the summer of 2017 along a 40 km transect extending along highway 567 that runs parallel to Lake Timiskaming in Northern Ontario (Figure 1). Regions where detailed field work was carried out were chosen based on proximity to the geophysical surveys, historical economic significance (Cobalt Silver Area and South Lorrain Township), and exposure of Archean basement (Figure 1). Shawna White (Postdoc) was the sole researcher on the transect in 2018. In 2019, White was joined by MSc student, Louise Rush.

The work along the Cobalt Transect represents a portion of the larger Metal Earth project, a multiyear, multidisciplinary collaboration focused on determining the factors controlling mineralization within Archean greenstone belts. As part of this larger initiative, the Cobalt team will combine a regional geochemical assessment of the vein network in the Cobalt region with a much improved geologic model based on new geologic mapping, geophysical interpretation, and geochronology.

Shawna White (Postdoctoral Research Associate)

White has predominantly focused her mapping and sampling on Archean rocks in the Cobalt region, as new mapping demonstrates the importance of the Archean basement in controlling the distribution and orientation of mineralized veins. In well-stratified and cleaved basement rocks, mineralized veins follow foliations. Controls on vein orientation are less clear in regions where Archean basement units are massive. Although playing a critical role in vein placement, little is known of the nature of the Archean volcanic basement in the Cobalt region. The major challenge to understanding the nature of the Archean basement in the Cobalt embayment is the extensive sedimentary cover. By combining detailed mapping in all Archean inliers with geophysical data (which can penetrate deep into the subsurface) we can extend interpretations beyond and beneath the younger

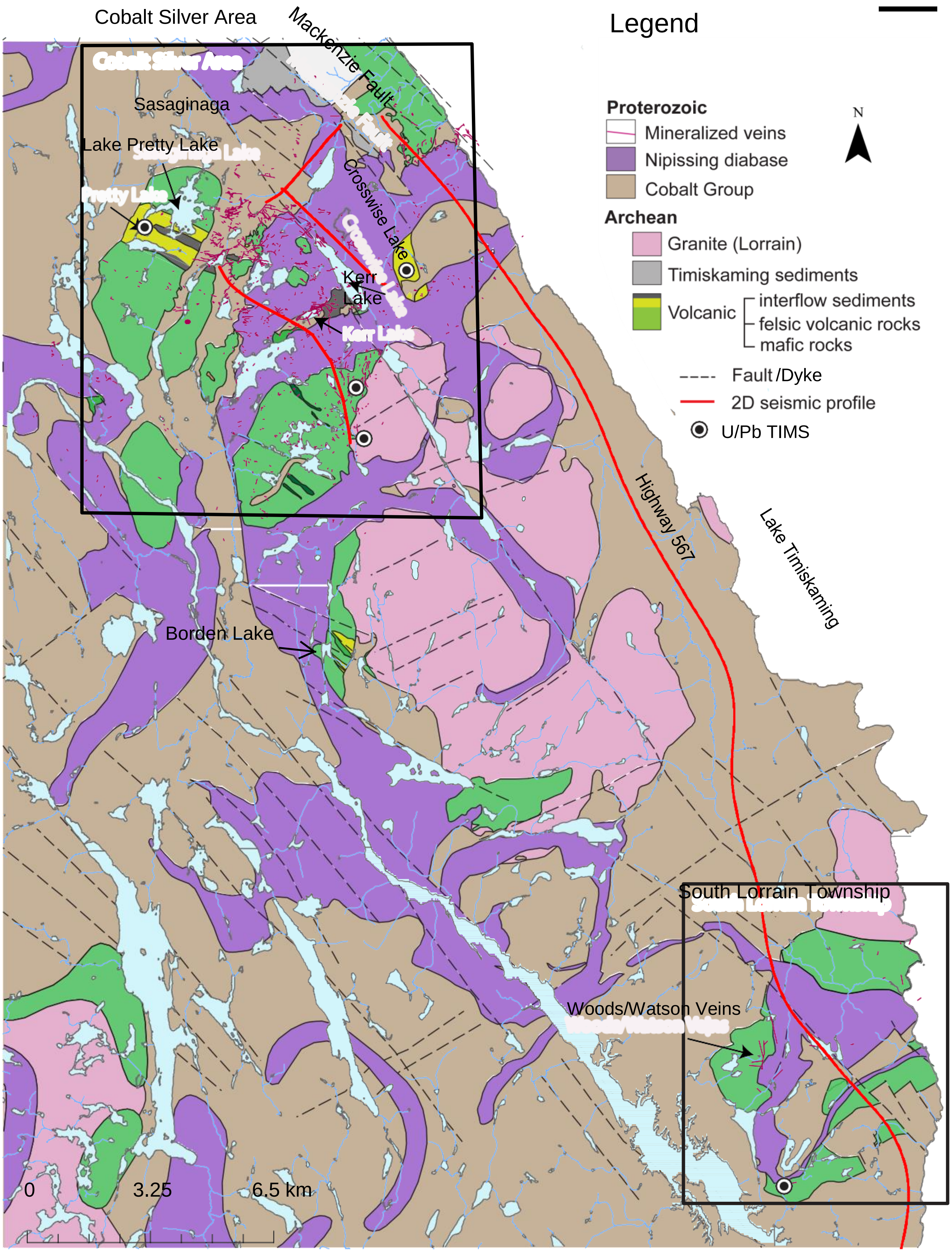


Figure 1: Geologic map of the Cobalt region with locations of mined mineralized veins and 2D seismic reflection profiles

units, building a geologic model for the poorly understood basement in the region.

New mapping, structural analysis, whole rock geochemistry and geochronology demonstrate an Archean volcanic stratigraphy with chemical affinities and ages correlative to volcanic units exposed within the adjacent Pontiac Subprovince (Guide Intro). These rocks, the youngest of any volcanic assemblage currently defined within the Abitibi Subprovince, could aid in our understanding of the connection between the Cobalt Embayment and the Pontiac Subprovince that is largely masked by sedimentary cover.

Louise Rush (Masters Student)

Historically, research and exploration in the Cobalt area was focused on specific veins rather than examining the series of veins extending throughout the entire Cobalt region. Louise Rush's research therefore, seeks to examine the metal zoning, physiochemical conditions of the hydrothermal fluids, hydrothermal alteration assemblages, and the origin of mineralization in a regional context in hopes of understanding the Cobalt deposit as a whole. Fieldwork in 2019 involved the collection of 338 samples from an area spanning over 1250 km^2 (Figure 4). A major difficulty will be the ability to identify systematic metal zoning or fluid characteristics within the Cobalt district. Previous compilation work indicates that there may be a regional zoning pattern of metals; however, that pattern may not hold up with detailed regional examination. Even if systematic metal or fluid characteristic zoning is not recognized, a shift in emphasis from metal zoning to structural controls will benefit new exploration models.

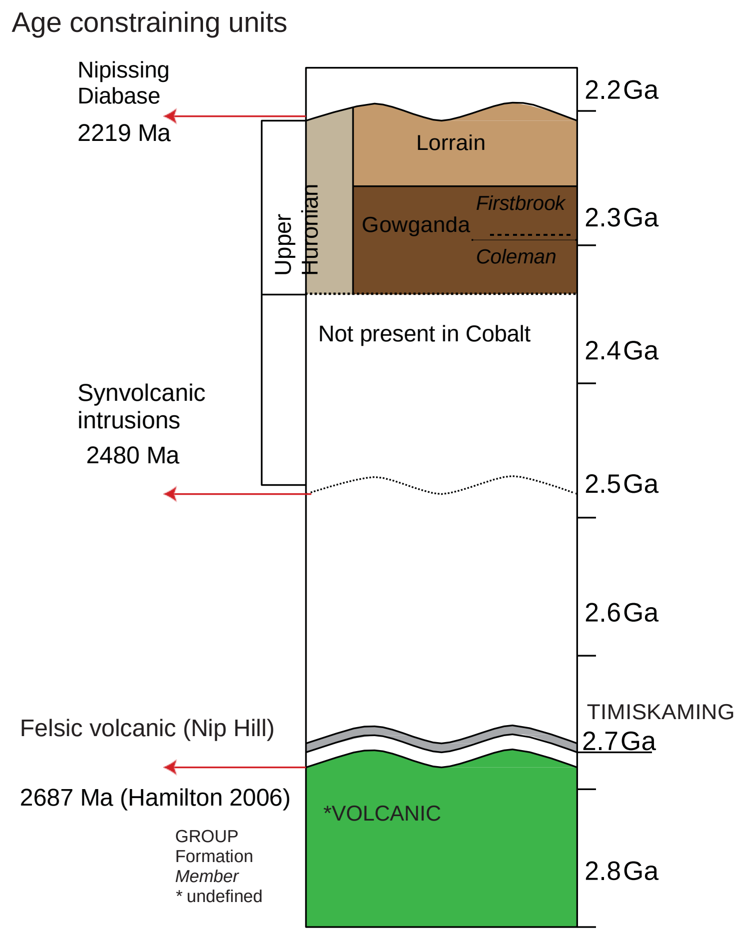


Figure 2: Stratigraphic column of sedimentary and volcanic units exposed in the Cobalt region. On the left are U-Pb ages from igneous units which constrain the age of stratified units

REGIONAL GEOLOGY

The current understanding of the regional geology in Cobalt (Figure 1) is largely based on the mapping by Thomson (1964a, 1964b, 1964c) and McIlwaine (1970). The region is largely underlain by Precambrian rocks, the oldest of which is Archean basement which consists of volcanic and interbedded sedimentary units (Figure 1) of the "Keewatin" type (e.g. Thurston, 2002), which make up the southernmost portion of the Western Abitibi sub-province within the Superior Province (Guide Intro). This succession was intruded by Archean mafic and ultramafic dykes and granitic batholiths. Conglomerate and sandstone of a Timiskaming type unit unconformably overlies older volcanic units (Figure 1, 2) in the most northern part of the Cobalt region (north of Haileybury). Sedimentary rocks of the Paleoproterozoic Huronian Supergroup (e.g. Sims et al., 1981) unconformably overlie the Archean basement, (Figure 1, 2) exposed only as inliers in the region (Figure 1). Only the Gowganda and Lorrain formations of the upper Huronian Supergroup (Figure 2) are exposed in the Cobalt area. The 2.2 Ga (Corfu and Andrews, 1986) Nipissing diabase, a suite of gabbroic dykes and sills (e.g. Lightfoot et al., 1993), intrudes both Archean basement and Paleoproterozoic cover (Figure 1) and constrains the upper age limit of the Huronian Supergroup in the region (Figure 2).

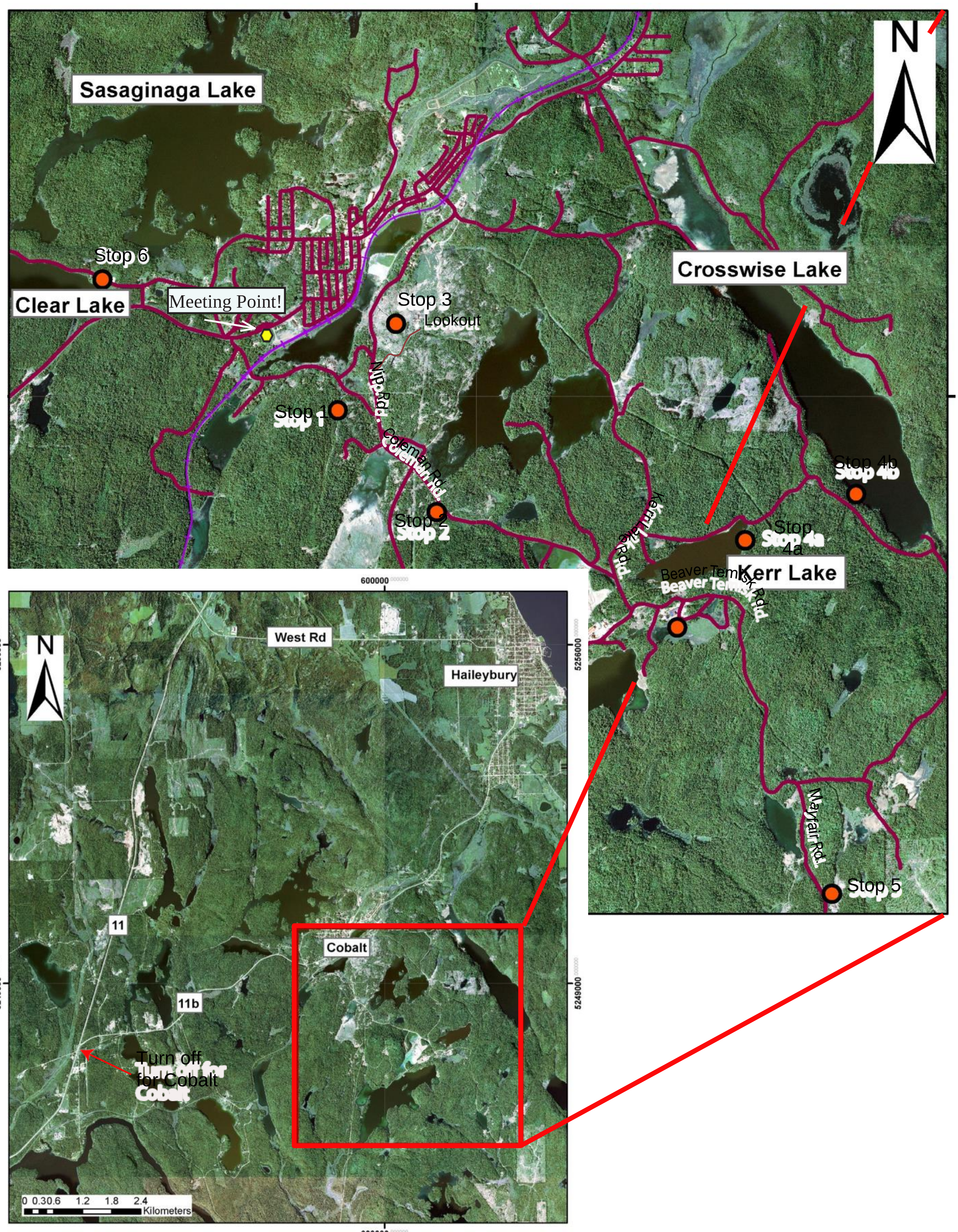


Figure 3: Locations of major roads, geographic locations and fieldtrip stops

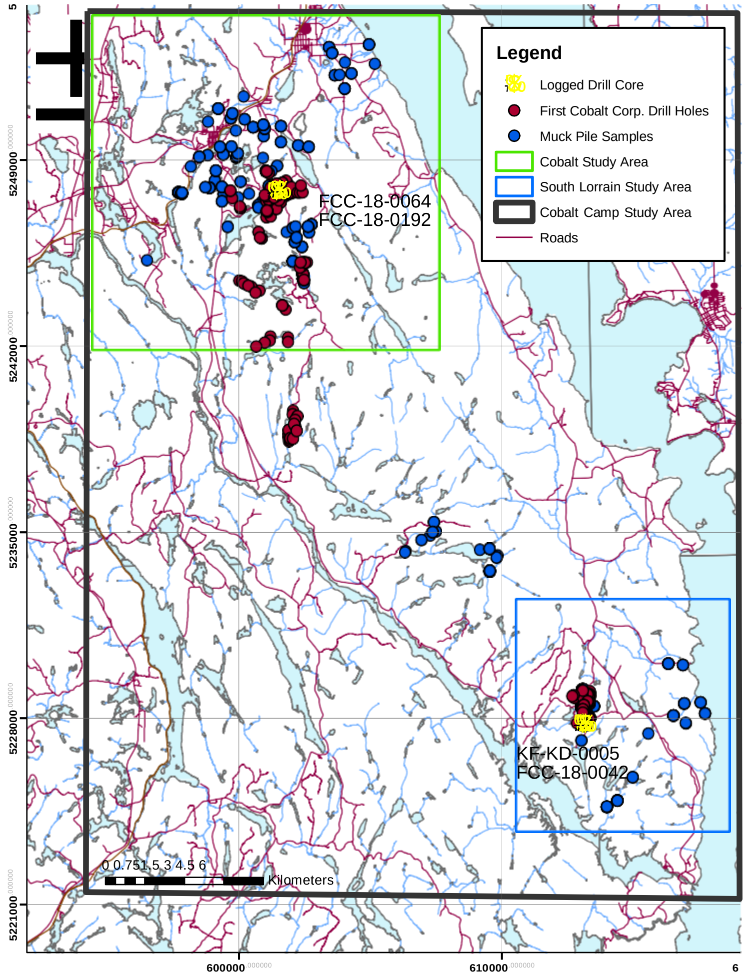


Figure 4: Map showing sample locations in the Cobalt Silver and South Lorrain study areas for Rush's project

FIELDTRIP STOPS

**Figure 3 is a map with all major roads, landmarks and fieldtrip stops.

Stop 1: Coleman Member of Gowganda Formation

Location: (599088, 5248909); *Traveling south down highway 11b from Cobalt, turn left off highway 11b onto Coleman Road (Figure 3). Turn right to go to "Site 4" for the Little Silver Vein (part of the Cobalt Historical mine tour).*

At this stop (Figure 3) we observe a small cliff face of planar laminated siltstone and very fine-grained sandstone of the Coleman Member of the Gowganda Formation (Photo A). Symmetrical ripples are also observed in both cross-section and on the top of bedding surfaces beautifully exposed here (Photo B). Although these varve-like sandstone and siltstone couplets are characteristically found in both the Coleman and Firstbrook members of the Gowganda Formation (Figure 2), the Firstbrook Member is defined to be stratigraphically above the last dropstone observed in the succession. Although clasts and dropstones (Photo C) are not observed near the base of this outcrop, towards the top of this small cliff you can see the more typical conglomerate facies of the Coleman Member indicating we are not in the Firstbrook Member (i.e., still stratigraphically below the Firstbrook Member).

Mining History: The Little Silver Vein site is interesting as it also shows the extensive, narrow, cut left behind after mining of a very high grade, discrete Ag-Co vein. It was discovered in the early 1900s and produced over 700 000 ounces of silver. The old "bracing" logs against the side of the cut and its narrow width demonstrate just how discrete the veins were and how uncomfortable these working conditions must have been. Today all these near surface "easy pickings" are gone. One goal of the Cobalt Transect is to determine the structural/stratigraphic controls on the vein emplacement to aid in targeting potential mineralized veins at depth beneath the extensive Proterozoic cover in the region.

Photo A: Planar laminated siltstone and very fine-grained sandstone of the Coleman Member of the Gowganda Formation

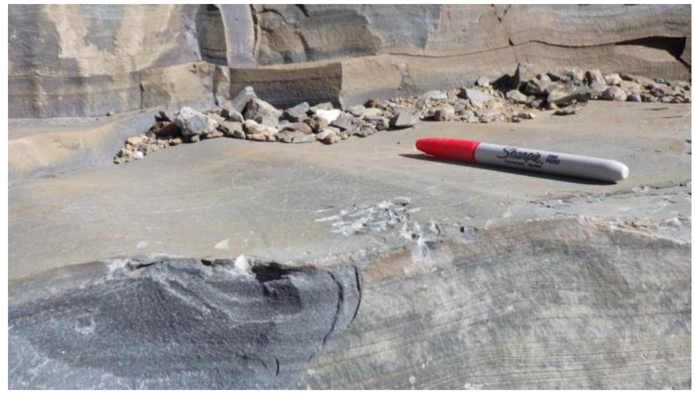


Photo B: Symmetrical ripples with sharpie parallel to ripple axis (Coleman Member, Gowganda Formation)

Stop 2: Coleman Member Polymictic Conglomerate

Location: (0599740, 5248233); *Leave stop one, taking a right at the exit to continue driving southeast on Coleman Road (turns into Glenn Lake Road) (Figure 3).* You'll see a (spectacular) flat, glacially smoothed and striated outcrop/pavement on your right.

Here we have moved up stratigraphy from stop 1 into the more "typical" facies of the Coleman Member - a polymictic, cobble to boulder conglomerate. The large variety of clasts (sedimentary and igneous) are glacially derived from multiple source regions. The image below shows a large granitic boulder (Photo D), a typical lithology found within both Coleman conglomerate and diamictite. In some outcrops of the Coleman Member, granitic clasts make up over 80 % of the clasts. We interpret that these clasts are likely derived from the Lorrain granite which outcrops extensively south of Cobalt (Figure 1).

This outcrop is particularly interesting as it actually displays evidence for multiple glacial episodes. One can observe the effects of the most recent glaciation in the form of glacial striations atop the smoothed surface of the outcrop.

Stop 3: Nipissing Hill

Location: (599472, 5249481); *Make a U-turn at Stop 2 and go back northwest along Coleman Road. Take a right on Nipissing Road and then your first right to go up to the Nipissing Hill Lookout. There is a parking lot at the top of the Hill (Figure 3). From here you will walk south (left) of the old foundation (where the lookout is located) towards the first waypoint listed for this stop.* This stop has multiple interesting short stops. We will first look at (a) and (b). Stops (c) and (d) will be discussed if time permits.

(a) Archean Interflow Sediments

Here you'll see a relatively thick sequence of subvertically oriented siliceous mudstone, siltstone and sandstone. These sediments are interbedded with predominantly mafic volcanic (with lesser felsic) units which underlie the majority of the region (we will visit typical mafic volcanic units at stop 6). These interflow sedimentary rocks are crucial to our understanding of the structure in the area, in that folds and faults are difficult to observe in massive volcanic units but are readily observed in layered sedimentary rocks. In this outcrop you will see many faults and minor folds. On a regional scale, single horizons of these sedimentary rocks cannot be mapped from a given Archean inlier to another inlier; however, an understanding of regional folding events and fold generations can be untangled by studying exposures like this one on Nip Hill. Structural way up/facing is also crucial to our understanding of regional deformation styles. Photo E shows beautiful load features (ball and flame structures) which indicate these units face top to the north. This is consistent with pillow tops, also younging north, along the southern extent of Nipissing Hill.

Photo C: Glacial dropstone in laminated mud and siltstone of the Coleman Member of the Gowganda Formation

Photo D: Boulder of Granite in glacially derived polymictic boulder conglomerate of the Coleman Member, Gowganda Formation.

Photo E: Load features (ball and flame structures) formed in Archean Interflow sedimentary units. These structures are important for determining younging direction of the succession

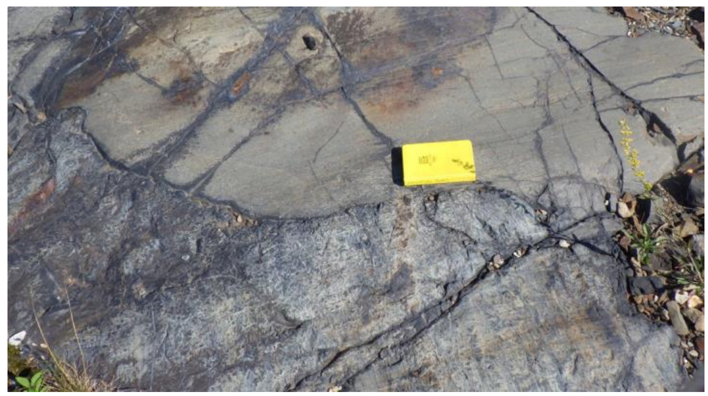


Photo F: An outlier of Coleman sediments overlies and is surrounded by older Archean interflow sedimentary units

Photo G: The Archean-Proterozoic unconformity between vertical Archean sediments and overlying, shallow-dipping Proterozoic sedimentary units

As a point of interest, veins in many of the historic mine sites across Cobalt follow the strike of local bedding of the interflow sedimentary units, suggesting that these units played an important role in localizing fluids (e.g. north Nipissing Hill: Thomson's map shows two important veins mined along interflow beds).

(b) Unconformity

The base Huronian (Archean-Proterozoic unconformity) is also beautifully displayed across Nipissing Hill. An irregular topography (from erosion and faulting) generates a complex pattern of inliers (of older Archean) and outliers (of younger Coleman) across the hill. Photo F shows an approximate outlier of green, sandy siltstone (Coleman) overlying vertical beds of Archean interflow sedimentary rocks. The unconformity (Photo G) dips gently west here.

The importance/role of the unconformity to the mineralization system has been a topic of much debate. More recent work by Potter and Taylor (2010) suggests that fluid mixing across the unconformity generated re-dox reactions which ultimately led to the precipitation of sulphides and arsenides.

Photo H: Photo of Archean felsic volcanic unconformably overlain by Paleoproterozoic Coleman conglomerate. Ryan Wells, field assistant.

(c) Archean Felsic Volcanic

Location: (599751, 5249719); Walk about 400 m NE towards stops (c) and (d). At this portion of the outcropping we observe a fine-grained, massive felsic volcanic flow (Photo H), interbedded with a thick succession of pillowed mafic flows. This unit was dated at 2687 Ma as part of the Abitibi compilation in 2005 – 2006 (Hamilton 2006). This unit is of interest to us as it is was the only volcanic unit dated in the region before the Metal Earth program. Although it was recognized as having an age equivalency with the Krist Fm, a felsic and fragmental volcanic unit associated with the basal part of the Porcupine assemblage (Hamilton 2006). The abundance of mafic flows in the Cobalt region, and lack of thick turbitite successions, indicates it is unlikely part of the Porcupine assemblage.

(d) Base Coleman and Unconformity

Here, the base of the Coleman Member contains angular felsic volcanic fragments, much like the felsic volcanic unit in the immediate basement (Photo I). Incorporation of local basement into the basal conglomerate of the Coleman Member is a common feature observed in the Cobalt region which suggests proximal derivation from immediate basement sources.

Photo I: A graben of Coleman sediments, containing angular felsic volcanic fragments, surrounded by the Archean felsic volcanic basement units

Stop 4: Kerr and Crosswise Lake

Location 4a: (601783, 5248047); *Leave stop 3 the same way you came in (leave the lookout, take a left at Nipissing Road and another left at Coleman Road). Continue southeast down Coleman/Glenn Lake Road until you get to Kerr Lake Road. Take a left here. Take your first right into the lake. The road will continue to the northeast, along the north shore of the lake. Drive to the most northeast part of the lake which is the above listed waypoint.*
***Note: From here we will divide into two groups depending on your personal interests. Group A will start at this stop (4a) and Group B will continue onto Stop 4b with Shawna. If time permits we will switch groups so that both groups will get to see both stops.*

Logging and sampling select core (provided by First Cobalt) was a key component to Louise's field work. The aim was to choose representative holes from the South Lorrain and Cobalt Silver areas (Figure 1) to compare host lithologies and extent and style of alteration and mineralization. Core sampling will allow for identification of alteration associated with base-metal sulphide enrichment and Co-Ni-arsenide veining, as well as mineralization paragenesis. By doing detailed analysis of fracturing patterns we might also discern fracture vs. porous fluid flow.

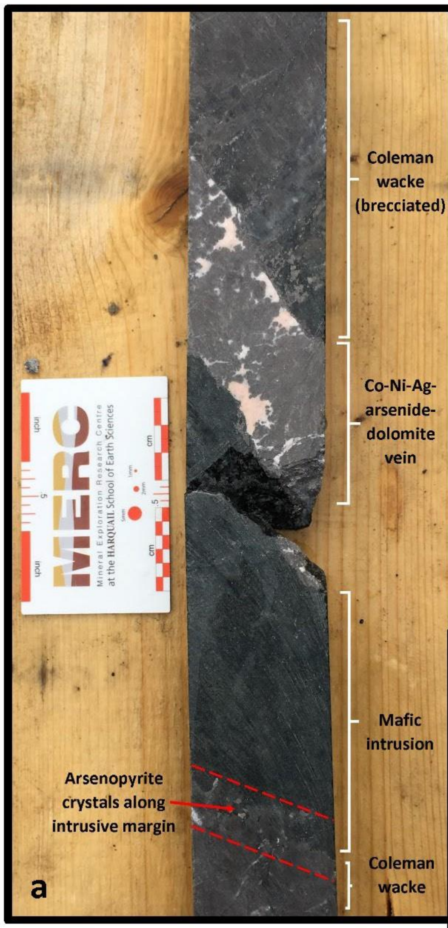
An important deliverable of Louise's thesis is to determine any potential relationships of the high base-metal content of the Archean basement to the Ag-Co-Ni veins. Initial compilation work indicates a difference in the distribution of cobalt relative to silver (and other metals), suggesting that the metals may have been deposited during different events or were decoupled during transport and deposition.
Stop 4a will showcase both the core drilled here at Kerr Lake and outcrops along the northern shore of the Lake (Coleman Member) which are particularly rich in sulphides.

(Stop 4a) Kerr Lake: Drill Holes FCC-18-0064 and FCC-18-0192 and Coleman Member Outcrops

The Kerr Lake drill holes are located in the Cobalt Silver Area (Figure 1,4). These holes were chosen based on their anomalously high metal content. The shallow core intersects monomictic and polymictic conglomerate, sandstone, siltstone, and lesser diamictite of the Coleman Member which we will also look at here along the north shore of the lake. The Coleman Member around Kerr Lake contains disseminated sulphides within the matrix surrounding conglomeritic clasts under Kerr Lake. Within Archean siliceous black shale there is spectacular base-met-al-sulphide enrichment. Euhedral sphalerite and galena occur pervasively throughout the shale in patches, some-times accompanied with euhedral, rhombic calcite (Figure 5c). Pyrrhotite nodules also spot the shales (Figure 5d). Drill hole FCC-18-0192 provides excellent examples of Co-arsenide-carbonate veining at the contact of a mafic intrusion cross-cutting Coleman Member sediments (Figure 6a).

Figure 5: **(a)** A typical example of sulphide mineralization within pillow basalt selvages; **(b)** Chalcopyrite within and along the margins of quartz-carbonate veins. The vein has a chlorite rim and a pale green alteration halo of epidote-chlorite-silica, with the greatest sulphide enrichment within the epidote zones; **(c)** Galena, chalcopyrite, sphalerite, pyrrhotite within interflow mudstone of the Archean basement seen in the Kerr Lake stratigraphy; **(d)** Sulphide nodules, occasionally rimmed with quartz, within black shale; **(e)** Sulphides associated with carbonate and quartz infilling space between mudstone clasts; **(f)** Mudstone/shale breccia with pyrrhotite infill.

The sulphides, particularly pyrite-pyrrhotite-sphalerite, seem to have a higher affinity for the black mudstone over other lithologies. Galena, chalcopyrite, and sphalerite commonly occur along and within carbonate-quartz veining. One interpretation for the unusual geochemistry observed at Kerr Lake is that a halo of high metal content is sourced from the Archean basement and mobilized through fluid circulation and concentration into fractures. The method of ore precipitation may be from a redox change across the unconformity. Lithological boundaries, such as intrusive margins, may represent planes of weakness where faults and/or fractures formed, allowing for later vein infill. Mineralized veins at intrusive boundaries have been observed in outcrop along a lamprophyre-basalt contact (Figure 7).



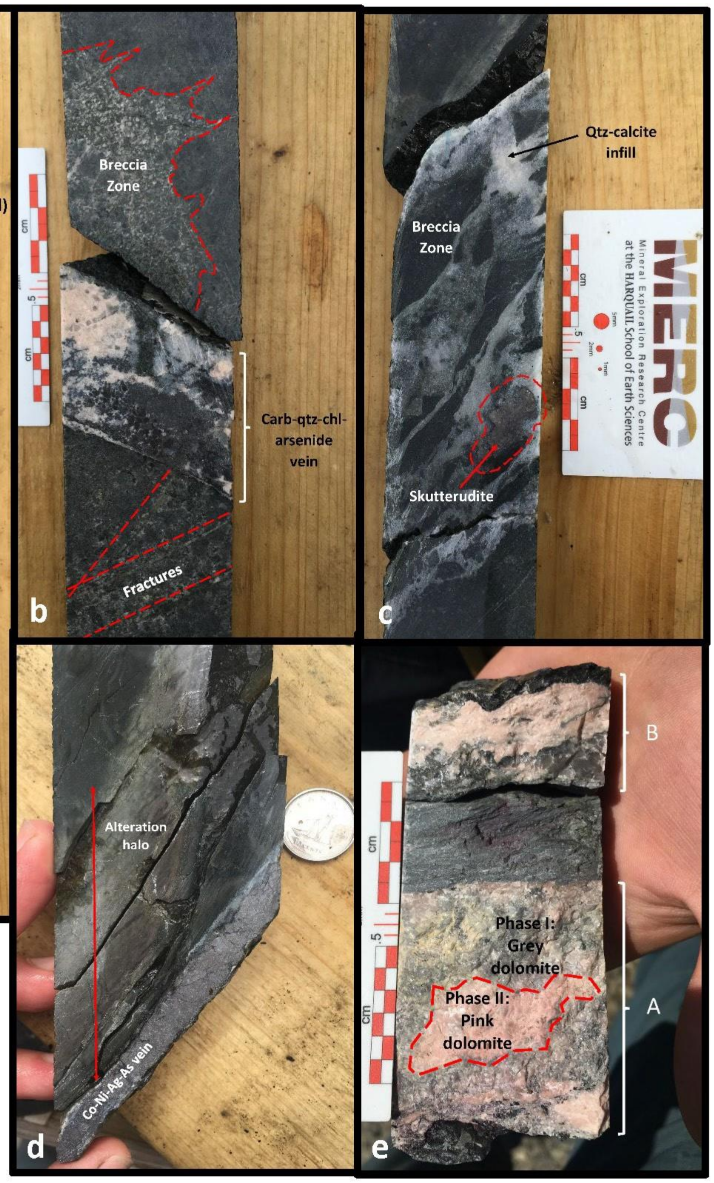


Figure 6: (a) The image shows a brecciated wacke against a mafic intrusion (not diabase) that is dotted with euhedral arsenopyrite crystals. The vein is massive rosette arsenides with pink dolomite. The upper contact returns to brecciated wacke. This sample may provide insight on the structural control on vein emplacement; **(b)** A good example of a carbonate-quartz-arsenide vein with chlorite inclusions. The adjacent host rock is altered and brecciated at the upper margin and heavily fractured at the lower margin; **(c)** An example of wall rock brecciation with quartz-carbonate infill containing arsenides; **(d)** A typical example of a pure-arsenide vein that cuts all lithologies of the Cobalt stratigraphy, with an alteration halo. This particular sample is hosted within pillow basalt of the Archean basement in the Keeley Frontier Property; **(e)** Zone A shows an early grey dolomite with later pink dolomite which formed due to dissolution of the former. A wall rock inclusion separates Zone B of the vein, in which quartz bounds recrystallized dolomite that has experienced ductile shearing. Other drill core veins and muck pile samples also exhibit this ductile shear-like fabric with brecciated arsenides within, suggesting a secondary fluid event that transported Co-Ag-Ni-arsenide ore.

At this stop, clasts within the Coleman Member are again lithologically similar to the immediate underlying Archean basement (Photo J). An unusually thick succession of Archean interflow sediments is intersected in drill core beneath the lake and is exposed in patchy but continuous outcrop from Kerr Lake to the west shore of Crosswise Lake (Figure 1). These Archean sediments are predominantly siliceous mud, sandstone, shale and chert.

Mining History: Kerr Lake was home to the Crown Reserve Mine, which was active from 1908-1921. In 1907, a trench was dug to drain Kerr Lake which allowed access to the rich ore. Lowering the water level allowed the excavation of the Crown Reserve shaft, which extended to a final depth of 800 ft. The lake was pumped dry multiple times, first in 1913 and then another three times, during the life of the mine (Cobalt mining tour). An entire network of quarried out passages reside under Kerr Lake, which total more than 13 km over an area of 23 acres. Dr. Drummond, another important historical figure for the Cobalt Mining Camp, claimed 80 acres adja-cent to Kerr Lake. This gave rise to the Drummond Mine, with its remains visible across the water.

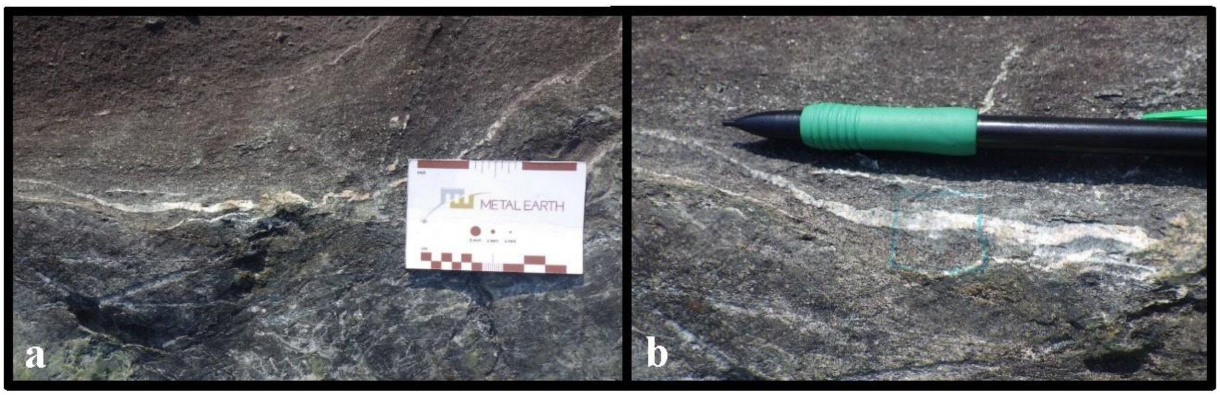


Figure 7. (a) Calcitic-dolomitic vein running along lamprophyre-basalt intrusional contact; **(b)** Very fine, very reflective, silvery wisps believed to be mineralization along the basalt-lamprophyre contact.

Keeley-Frontier Property: Drill Holes KF-KD-0005 and FCC-18-0042

At the Keeley Frontier-Silver City property, two major veins – the Woods Vein and the Watson Vein (Figure 1) – branched in a N-S fashion. Drill hole KF-KD-0005 (2017) was drilled to intersect the main Woods Vein (mined out) to determine if there were any remaining cobalt-rich offshoots. Due to a successful drilling season (having intersected cobalt-rich veins), FCC-18-0042 was drilled the following year to determine if the N-S running vein veered to the west as a function of interpreted regional folding.

These holes intersect cobalt mineralization and spatially-associated alteration in the Archean mafic volcanic and intrusive units. Pillow basalts contain high grade base-metal sulphides within selvages and fractures (Figure 5a). With increasing depth, there is an increase in pyrrhotite, chalcopyrite, and galena abundance. This coincides with an increase in chlorite-silica-epidote alteration severity, giving the basalts a banded appearance (Figure 5b). Sul-phides were also disseminated within the pillow basalt and incorporated within, and along, the edges of carbon-ate-quartz veins. Intrusions also contain trace disseminated sulphides inferred to be magmatic in origin. Several increments of Co-Ni-arsenide veins with alteration haloes also cross-cut the basalt (Figure 6d)

(Stop 4b) BIF Breccia: Crosswise Lake

Location: (602519, 5248353); *Continue on the road (from stop 4a) to the north, past the pole line. Continue on this main road which curves south near Crosswise Lake (Figure 3). Continue driving south until you see a pull off to the left. Stop here. You should be able to access the waypoint (602519, 5248353) by a short bushwack through the woods from this road.*

At this stop, along the west shore of Crosswise Lake, a previously unrecognized outcrop of a BIF breccia is observed. The breccia contains both BIF (banded iron formation) and sand/silt clasts (Photo K). Lithologically,

Photo J: Coleman conglomerate with clasts of siliceous mudstone and siltstone likely derived from immediate Archean basement

Photo L: clast of strongly magnetic banded iron formation showing jasper laminations. These clasts are elongated, subangular pieces of beds which are likely derived from a proximal source

Photo K: BIF breccia – part of the Archean interflow succession. This unit contains both angular to subangular clasts of banded iron formation and angular to rounded clasts of sandstone/siltstone

sand/silt clasts are similar to the Archean interflow succession mapped locally. Combined with the subangular to angular nature of the BIF clasts (Photo L) we suggest a proximal source. Although no known local occurrences of BIF are exposed in the region (the closest is in Temagami) it is quite probable that BIF units are present beneath the extensive Proterozoic sedimentary cover in the Embayment. In 2018, First Cobalt intersected a thin (~40 cm) interval of BIF below Kerr Lake, giving evidence for the presence of BIF's within the Archean succession in the Cobalt region.

Stop 5 (Time Permitting): Beaver-Temiskaming Property

Archean Basement Lithologies: Pillow Basalt

Location: (602358, 5245704); *Leave Kerr Lake the way you came in. Take a left on Kerr Lake Road and drive to the end, turning left on Beaver Temisk Road. Take Beaver Temisk Road all the way south and continue onto Mayfair Road south. Your waypoint is on your left.*

This outcrop is a good example of prominent geologic units (basalt) and typical volcanic textures observed throughout the Cobalt region. Pillowed basalt flows dominate the region. Photo M shows an example of pillow lava, facing northeast. Internally, pillows display a typical jig-saw fragmentation we observe in the region (Photo N). Hyaloclastite (Photo O) is commonly observed within rinds/selvages of the pillows). A cross-cutting, fine-grained, biotitic lamprophyre dyke with crustal xenoliths and incorporated wall rock (basalt) is also observed here.

Although the volcanostratigraphy in the Cobalt region is litologically not unlike other volcanostratigraphic successions throughout the Abitibi Subprovince, little is known about the age and structure of the basement in Cobalt. The age of the felsic volcanic unit dated at Nipissing Hill and new ages from our work with Metal Earth (Stop 7) indicate that these volcanic units are younger than any other volcanostratigraphic unit currently defined within the Abitibi. Both north (Larder Lake) and south (Temagami) the volcanic units are older.

Photo M: Pillows showing top to the NE

Photo N: Autobrecciated fragmentation of pillows with fragments displaying jig-saw textures

Photo O: Hyaloclastite within pillow selvages- a commonly observed feature

Muck Pile and Carbonate-Quartz Veins

One main objective of Rush's summer fieldwork was to obtain uniformly dispersed mineralized (Co, Ni, Ag, As) samples across the embayment. Samples come from both First Cobalt Corporations' 2017 and 2018 drill core and muck piles located at historical past-producing mines (Figure 8). On the Beaver-Temiskaming Property we see a collection of typical muck piles that may still contain significant mineralization – skutterudite-nickeline-silver-sulphide-carbonate-quartz veins have all been observed here and samples show textural evidence of syn-precipitation of ore and gangue mineralization. From the collected suite, select samples will be analyzed using detailed petrographic work, SEM-EDS imaging and analyses, and in-situ LA ICP-MS analyses of gangue and ore phases. These techniques will allow us to constrain all relevant aspects of ore formation (i.e., alteration and mineral paragenesis).

Figure 8: Examples of muck piles visited for sampling. **(a)** Overgrown muck pile with low potential for representative samples; **(b)** Large muck pile at sites of greater past production with more potential for representative samples in the Kerr Lake area. Photographed: Field assistants Ryan Wells (left) and Bradley Piche (right), for scale.

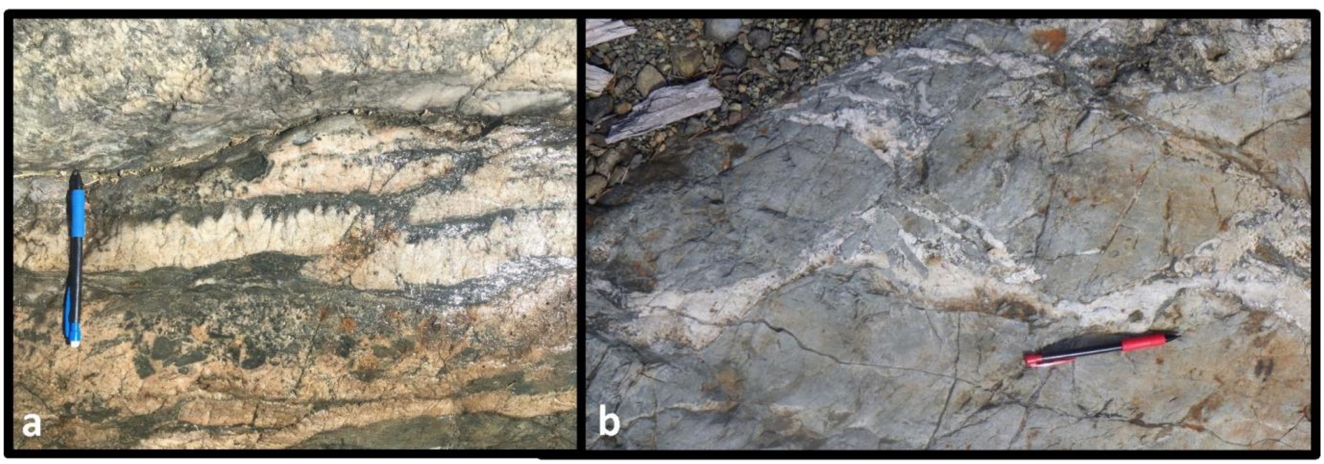


Figure 9: **(a)** Comb Quartz exposure within in-situ veins in outcrop at the Beaver-Temiskaming property; **(b)** Wall rock fragmentation and quartz-carbonate vein exposure in outcrop at the Beaver-Temiskaming property.

The northern part of the outcrop exposure here at the Beaver-Temiskaming site also displays one of the only in-situ quartz carbonate veins known for the calibre of its preservation and proximity to a major silver-bearing vein (mined out) (Figure 9). Although barren, these veins exhibit beautiful comb quartz textures, cross-cutting relationships, fragmentation and brecciation of vein material and host rock, as well as alteration of wall rock pillow basalt. Observations suggest multiple episodes of fracturing, vein formation, deformation, and alteration due to hydrothermal fluids. The euhedral quartz may be used for fluid inclusion petrography to determine P-T-X conditions of the veining event.

Stop 6: Rhyolite Breccia

Location: (597530, 5249769); *From this site we will return to highway 11b (drive back up (north) on Mayfair Road, then north on Beaver Temisk, continue onto Glenn Lake/Coleman Road and return to highway 11b. Turn left to head west on highway 11b. Take a right on Sharp Lake Road, followed by a quick left onto west Cobalt Road. The outcrop is on your right.*

This outcrop is a good representation of the felsic volcanic units which underlie much of the region surrounding Sasaginaga Lake to the north (Figure 1). This monolithic rhyolite breccia is comprised completely of porphyritic rhyolite fragments, with curviplanar outlines, which often display jigsaw-fit textures (Photo P). This auto-brecciated texture implies non-explosive fragmentation processes, likely generated at the exterior of a more massive, coherent flow. Farther north, both massive and brecciated flows are observed. We sampled this unit just to the north along Pretty Lake (Figure 1). It yielded a fraction of tiny euhedral zircons which gave concordant ages of 2689 Ma that agree with ages previously reported by Hamilton (2006).

The felsic volcanic units exposed in the Sasaginaga area are atypical for Archean units in the Cobalt region, which are predominantly mafic volcanic flows. Although farther south (near Borden Lake, Figure 1), felsic volcanic units have been mapped by previous workers (e.g. Born et al. 1988), we question this interpretation. During recent mapping this past summer, we observe that these felsic units are conspicuously thin, massive, and do not con-tain features indicative of either an intrusive or extrusive nature. In a couple of locations the boundaries also have unusually shallow dips, which are uncharacteristic of the stratified Archean units which display predom-inantly subvertical orientations. They can also cut obliquely (low angle) to regional structural trends of mafic flows. We interpret they may represent intrusive bodies.

Photo P: Rhyolite breccia comprised completely of porphyritic rhyolite fragments which often display jigsaw-fit textures. This texture is commonly observed in felsic volcanic units exposed in the region

Stop 7 (Time Permitting): Timiskaming Sedimentary Units

Location (600005, 5260029): *Head back to highway 11b and travel northeast towards Haileybury. Go through the town of Haileybury and head north on Lakeshore Drive. It is on your left (west side of road) when heading north (Figure 3).*

Photo Q: Clast supported polymictic conglomerate, Timiskaming succession

Photo R: Moderately sorted, coarse grained, trough cross-bedded sandstone, Timiskaming succession

Photo S: BIF clast within polymictic conglomerate, Timiskaming succession

At this stop we look at typical conglomerate and sandstone of the Timiskaming succession. Here we have thick beds of massive, clast supported polymictic conglomerate (Photo Q) interbedded with medium to thick beds of trough cross-bedded (Photo R), heterolithic sandstone. There are also jasper and BIF clasts within this conglomerate (Photo S). This fluvial facies is easily distinguished from the Coleman polymict conglomerate by its moderate to well-sorted sandy matrix and presence of trough cross-beds. The Coleman conglomerate generally has a matrix with silty, planar laminations or it is a very poorly sorted sandy siltstone.

In the Cobalt region, Timiskaming units are only exposed along steep, northwest-striking faults which dissect the region (Figure 1). New mapping demonstrates that Timiskaming sedimentary rocks extend farther south, along the Mackenzie fault. Understanding the role these faults played in terms of either controlling deposition or preservation of Timiskaming units is an outstanding question.

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History of the Cobalt Mining Camp:

The Temiskaming First Nations tribes first noted the presence of mineralization in the area back thousands of years (Cobalt Mining Museum). The first written historical reference of silver in Canada was in Jacques Cartier's writings during his 1535-1536 voyage (History of the Cobalt and Gowganda area, 1924). The next historical record of silver is when local first nations showed Sieur de Troyes a siting in 1686 during his military voyage northward from the Ottawa River, and then later on a map published in France in 1744. These two sources refer to the "Anse a la mine", which is a silver-galena-bearing vein deposit located 13 km southeast of the town of Cobalt along Lake Temiskaming's east coast, which is claimed to be the first noteable mineral discovery in Northern Canada (Cobalt Mining Museum). This Pb-ore deposit was later re-discovered by Ottawa lumberman E.V. Wright in 1850 and is now the site of the Wright Mine (Barlow 1899; Miller 1913; Knight 1924; History of the Cobalt and Gowganda area, 1924; Cobalt Mining Museum).

Because the majority of the Cobalt Embayment is covered by the Huronian sedimentary succession and subsequent glacial till cover in certain areas, little bedrock, and consequently little silver veining, was exposed at surface. Fortunately, this glacial action founded the first silver discovery. In 1903, a silver-bearing float was spotted along the northeast margins of the Cobalt Embayment. Since then, a vast number of discoveries led to the production of over 100 shafts operating over 85 years to produce 600 million ounces of silver, 45 million pounds of cobalt, 16 million ounces of nickel, and 5 million pounds of copper, with production peaking in 1911 (Andrew et al., 1986; Kissin, 1992; History of the Cobalt and Gowganda area, 1924). The Cobalt Camp produced an estimated $8 billion dollars present day equivalent from its polymetallic exploits.

The most successful mines were the O'Brien, Tretheway, Drummond, Cobalt Lake, Nipissing 81, Right-of-Way, Coniagas, Colonial, Nova Scotia, and the Hudson's Bay Mines, among others. Most silver discoveries were of exposed oxidized veins in outcrop or from methodical trenching down to bedrock radiating out from previous vein discoveries where there was extensive forest cover. Veins in outcrop were typically very thin, approximately 20 cm wide, but intersected and branched with other veins in extensive vein networks that could pinch and swell linearly up to a few kilometers. One vein network could lead to the production of 40 million ounces of silver. (History of the Cobalt and Gowganda area, 1924). Discoveries slowed over time after the easy surface showings were claimed. Discoveries then geared towards cobalt-arsenide-carbonate veins in hopes of crossing into native silver once reaching greater depths (History of the Cobalt and Gowganda area, 1924).

With Cobalt gaining more attention and receiving a larger flux of newcomers in hopes of making their fortune, exploration expanded to the Casey and Harris townships in 1906, and the South Lorrain, Miller Lake, Gowganda, Elk Lake, and Maple Mountain regions afterwards. Even further expansion eventually lead to the Larder Lake, Porcupine, Kirkland Lake, and Matachewan discoveries from 1906-1916 (History of the Cobalt and Gowganda area, 1924).

Ontario’s first provincial geologist, Dr. Willet Green Miller conducted a study on the Cobalt geology starting in 1904. He produced his classic geological report in 1913, one of the first mapping endeavours of the area. C.W Knight published successive geological report of the Cobalt and South Lorrain regions in 1924. Many maps and further geological reports have been produced over the following decades.

In its prime, the Cobalt Mining Camp was one of the last wild west culture towns in Canada. Saloons and false-front architecture rimmed the main streets that flourished with the “silver rush” energy. 1903-1913 was deemed the “Cobalt Silver Boom” – 600 prospecting licenses were allotted by the end of 1905, and a total of 6747 new issued and 2908 renewed over the next two years (Cobalt Mining Museum). Trenching, blasting, and construction restructured Cobalt’s terrain. Lakes were drained to expose the full extent of silver veins, including Kerr Lake and Cobalt Lake. This sudden growth meant poor town management, especially with respect to waste and water treatment (Cobalt Mining Museum). A period of alcohol prohibition across the camp led to liquor smuggling, public drunkenness, and eventually resulted in twenty-two police raids infiltrating illegal drinking establishments (Cobalt Mining Museum). To control the problem, the North Ontario Police Force was created in 1909.

In 1919, recent events such as WWI meant global conflict and a struggling economy. Soldiers returning from battlegrounds had a newfound rebellion against poor working conditions. Workers all across Canada were going on strike, led by veterans of gold rush wars in the United States. This led to the birth of the Cobalt Miners Union, which won the eight-hour workday (from 10-12 hour days, 7 days a week) and better wages for the working class. Cobalt workers went on strike in 1907, 1914, and 1919 (the same year as the Winnipeg General Strike, the most famous strike in Canadian history). The Union also contributed significantly towards the Workers Compensation Act and set the first workplace safety standards (Cobalt Mining Museum).

The majority of the mines had closed by the early 1920s, however small operations continued into the 1940s. The Silver Miller Mines gave way to Cobalt’s second silver boom when new veins were discovered adjacent to Brady Lake. The 1950s saw an increase in exploration because of the new interest in elemental cobalt, as little was known about the element and its applications in the early mining days. Certain mines reopened, such as the LaRose and Miller Mines.

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METAL EARTH

2019 Field Trip Guide

Dryden, Ontario

CANADA FIRST RESEARCH EXCELLENCE FUND | APOGÉE CANADA FONDS D'EXCELLENCE EN RECHERCHE

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Structure, stratigraphy, and context of gold occurrences in the Dryden area of Ontario

Ben M. Frieman, Gaetan Launay, Rebecca Montsion,
Kendra Zammit, and David Downie

(Trip leaders: Ben M. Frieman and Gaetan Launay)

Introduction

Archean greenstone belts in the Superior Province are variably endowed with base and precious metal resources despite similarities in rock types, ages and tectonic settings. For example, both the Abitibi and Western Wabigoon Subprovinces formed during a similar time frame in the Neoarchean (~2750-2700 Ma) and are comprised primarily of juvenile mafic volcanic successions that were emplaced in a subaqueous environment. However, while the Abitibi subprovince contains numerous base and precious metal deposits (e.g., >150 Moz Au), the western Wabigoon subprovince (WWS) contains only a few (e.g., < 10 Moz Au). Identifying the factors contributing to variable metal endowment in greenstone belts represents one of the primary goals of the CFREF Metal Earth Research Program, led by Laurentian University. To constrain these factors, the geology of the lesser endowed western Wabigoon subprovince (WWS) is being resynthesized in order to develop a new geodynamic model for its formation and to compare to better mineralized belts in the Superior Province.

This field trip aims to provide an introduction to field observations that constrain our understanding of the relative timing and style of gold occurrences and deposits in the Dryden area of Ontario (Fig. 1). The WWS in the Dryden area is composed of 2750-2715 Ma mafic volcanic successions and 2715-2710 Ma Porcupine-like turbiditic successions (Beakhouse, 1995; Davis, 2005). These supracrustal packages underwent greenschist to amphibolite facies metamorphism (protolith names are being used for simplicity) and were variably intruded by 2750-2680 Ma granitic, granodioritic, and/or tonalitic plutonic rocks. They are juxtaposed between Meso- to Neoarchean gneissic-plutonic rocks of the Winnipeg River and Marmion terranes. Outcrops that provide a representative view of the stratigraphy and structure of the Dryden area will be visited. In particular, this field trip will focus on domains adjacent to the Wabigoon and Manitou-Dinorwic deformation zones. These deformation zones represent major regional structures that accommodated progressive strain during regional amalgamations, may have acted as fluid conduits and, thus, are potential hosts to orogenic gold occurrences.

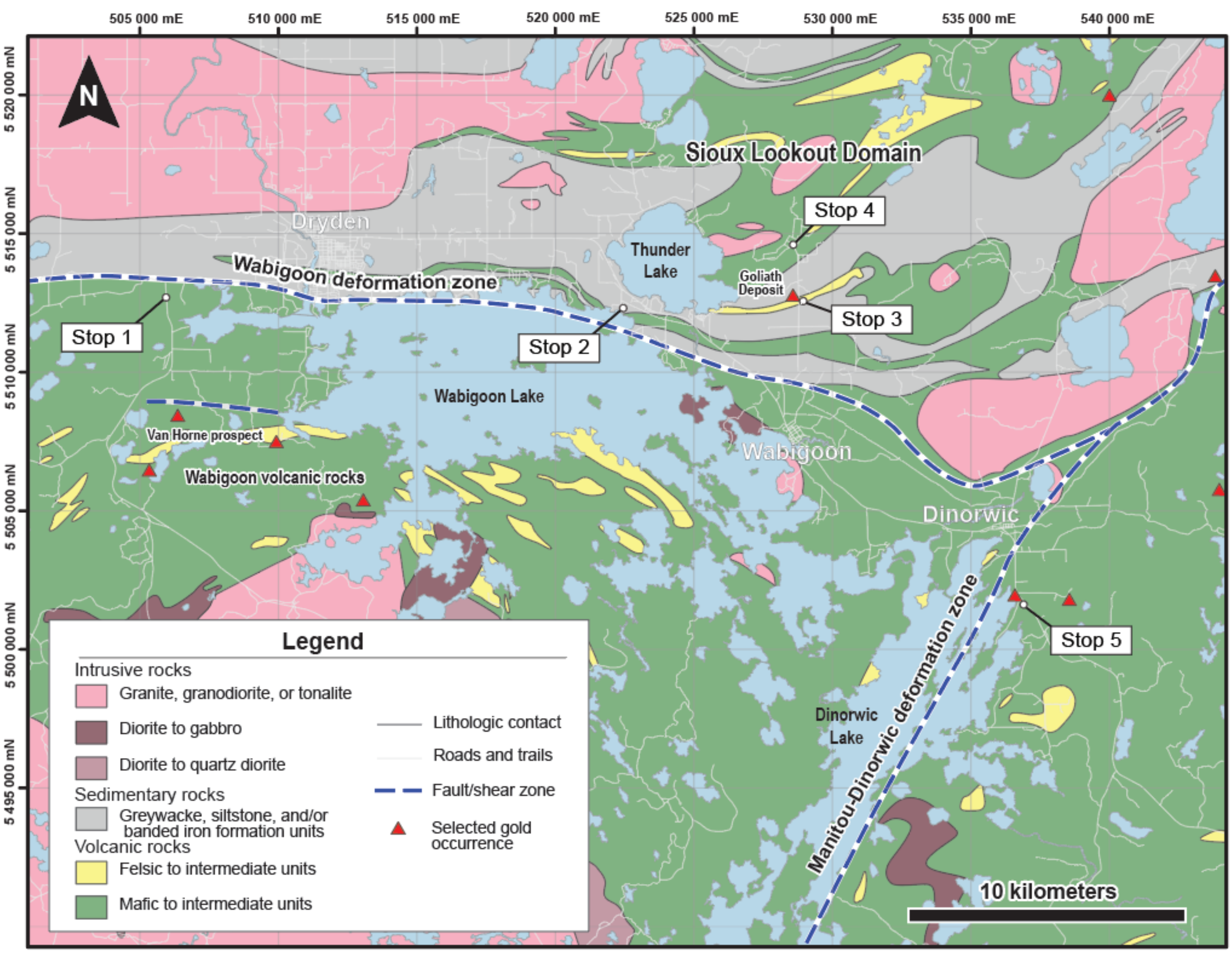

Fig. 1 – Simplified geologic map of the Dryden area highlighting the regional deformation zones, selected gold occurrences, and locations visited on this field trip (modified from Blackburn, 1979).

This field trip begins at the Walmart parking lot on Highway 17 on the eastern side of Dryden, ON. From the Walmart take a left onto Highway 17 and proceed west ~3.2 km to Marguerite Street and take a left at the stoplight. Follow Marguerite through Gordon Road for ~3 km to ON-594 and take a right at the stop sign. Continue on ON-594 for ~4.3 km and take a left onto Highway 502 towards Fort Francis. Proceed for ~200 m and park on the right shoulder. At this stop, please be aware of the highway traffic as the shoulder is narrow and, if available, wear high visibility safety gear.

Stop 1: Structure and alteration observed within the Wabigoon deformation zone on Highway 502 (UTM: 15U 505950 mE, 5512710 mN)

This stop provides observational constraints on the deformation history and relative timing of alteration that are associated with ductile shear localization along the Wabigoon deformation zone (Wdz). The Wdz is a major E-trending deformation zone that separates Wabigoon volcanic rocks in the south from sedimentary and volcanic successions of the Sioux Lookout Domain to the north (Fig. 1). Along its length, the Wdz is associated with a wide (>2 km) corridor of intensely deformed and penetratively foliated rocks. At this location, deformation is localized in mafic volcanic rocks that occur as chlorite, iron carbonate-chlorite, and, locally, talc-chlorite schists. The schistose units display a strong, subvertical to N-dipping, and E-trending foliation (260/88) (Fig. 2A). Within the central portion of the outcrop, abundant quartz and calcite filled amygdules occur (Fig. 2B). These are elongate and stretched parallel to a lineation that plunges steeply to the west (80→267). In many cases, the amygdules are pervasively altered, containing iron carbonate-rich material (Fig. 2B). These also form well-developed shear sense indicators such as σ-clasts that indicate north-over-south kinematics. These observations in conjunction with the fabric orientations are interpreted to reflect an early period of reverse thrusting along the Wdz (i.e., D_1).

Quartz-carbonate-tourmaline veins are abundant at this outcrop (Fig. 2A). These range in size from narrow (<1 cm) to relatively large (~20-30 cm) veins that are coincident with m-scale zones of disseminated wall rock alteration. Typically, the veins cross-cut the foliation but are themselves sheared into parallelism with the dominant fabric and/or are boudinaged forming asymmetric pods. These observations indicate that vein emplacement was broadly synchronous with thrust motions along the Wdz and that the upflow of potentially gold-bearing fluids was occurring at this time. While no gold is documented at this locality, a higher-order parallel splay of the Wdz occurs several kilometers to the south where exploration activity is ongoing at the Van Horne gold prospect.

After you are done observing this outcrop area, return to your vehicles and carefully turn them around to return towards Dryden. Return to Highway 17 via Gordon Road and take a right. Continue on Highway 17 towards the east for ~12.2 km and take a right onto Elm Bay Road. Stay left at the fork and proceed south on Elm Bay Road ~350 m to a large shed. Take a left at the shed, continue on the drive for ~20 m, and park at the top of the entrance to the gravel pit. The outcrop occurs ~50 m to the east of the parking area.

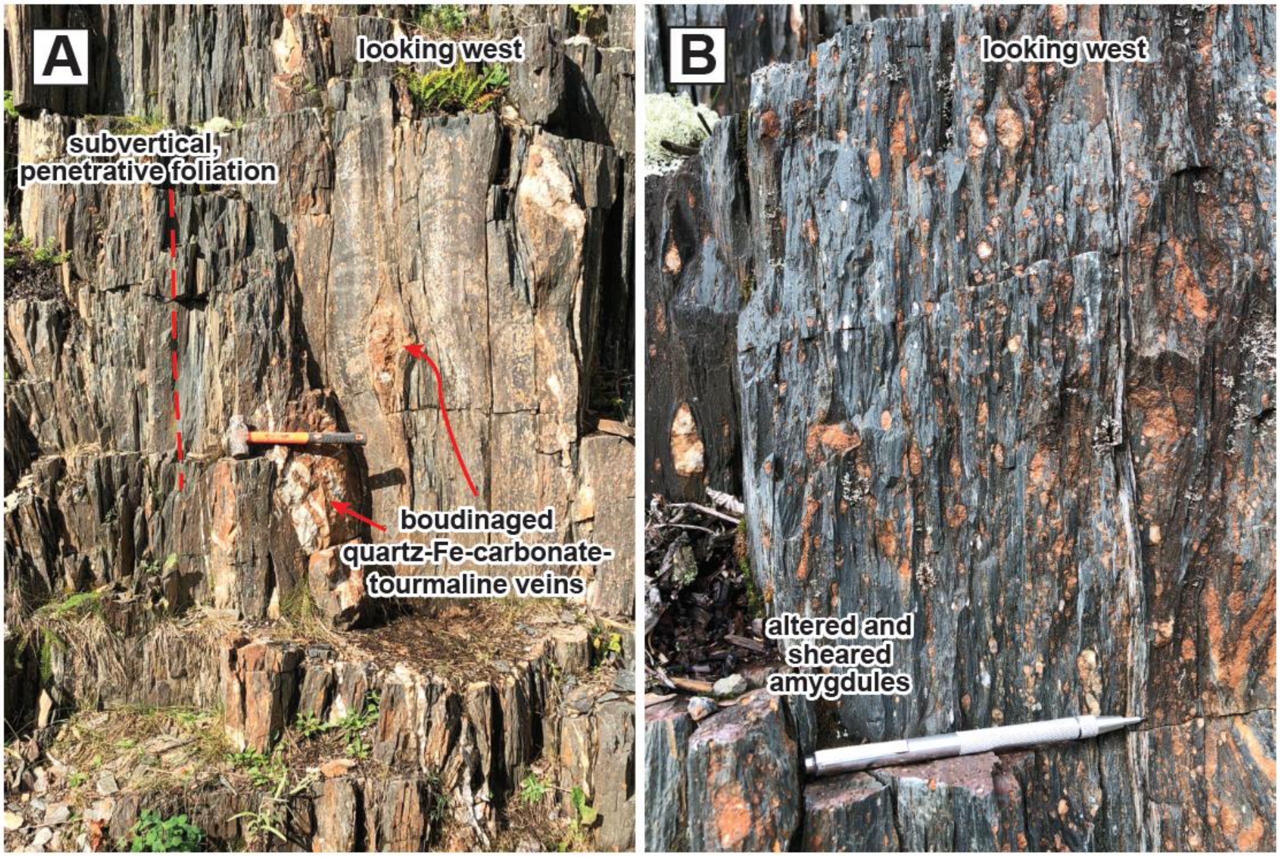

Fig. 2 – (A) Penetratively foliated and altered chlorite schists observed within the Wabigoon deformation zone at stop 1. Note the boudinaged quartz-carbonate-tourmaline vein that form asymmetric pods. (B) Locally abundant amygdules within metvolcanic rocks that are deformed, forming asymmetric σ-clasts, which contain Fe-carbonate-rich alteration assemblages.

Stop 2: Structure observed in the Thunder Lake sedimentary rocks north of the Wabigoon deformation zone (UTM: 15U 522840 mE, 5512550 mN)

This stop illustrates structures common to domains north of the Wdz, which Beakhouse et al. (1995) referred to as the Sioux Lookout Domain (Fig. 1). The Sioux Lookout Domain is distinct from domains to the south of the Wdz by higher metamorphic grades (upper greenschist to amphibolite facies), suggesting that it represents a deeper crustal level. Porcupine-like turbiditic rocks form several discrete panels that are termed the Brownridge, Thunder Lake, and Zealand sedimentary units. These greywacke-dominated successions are restricted to domains to the north of the Wdz and their southern extent generally marks the location of the Wdz (Fig. 1). The sedimentary rocks have been interpreted to be in conformable contact with mafic volcanic rocks of the 2735-2725 Ma Brownridge and Thunder Lake volcanic rocks based on similar facing directions (Beakhouse, 2000). However, the age of the youngest detrital zircon grains within these rocks are ~2715-2710 Ma, suggesting that their contact relationship may be unconformable or structural (Davis and Trowell, 1982).

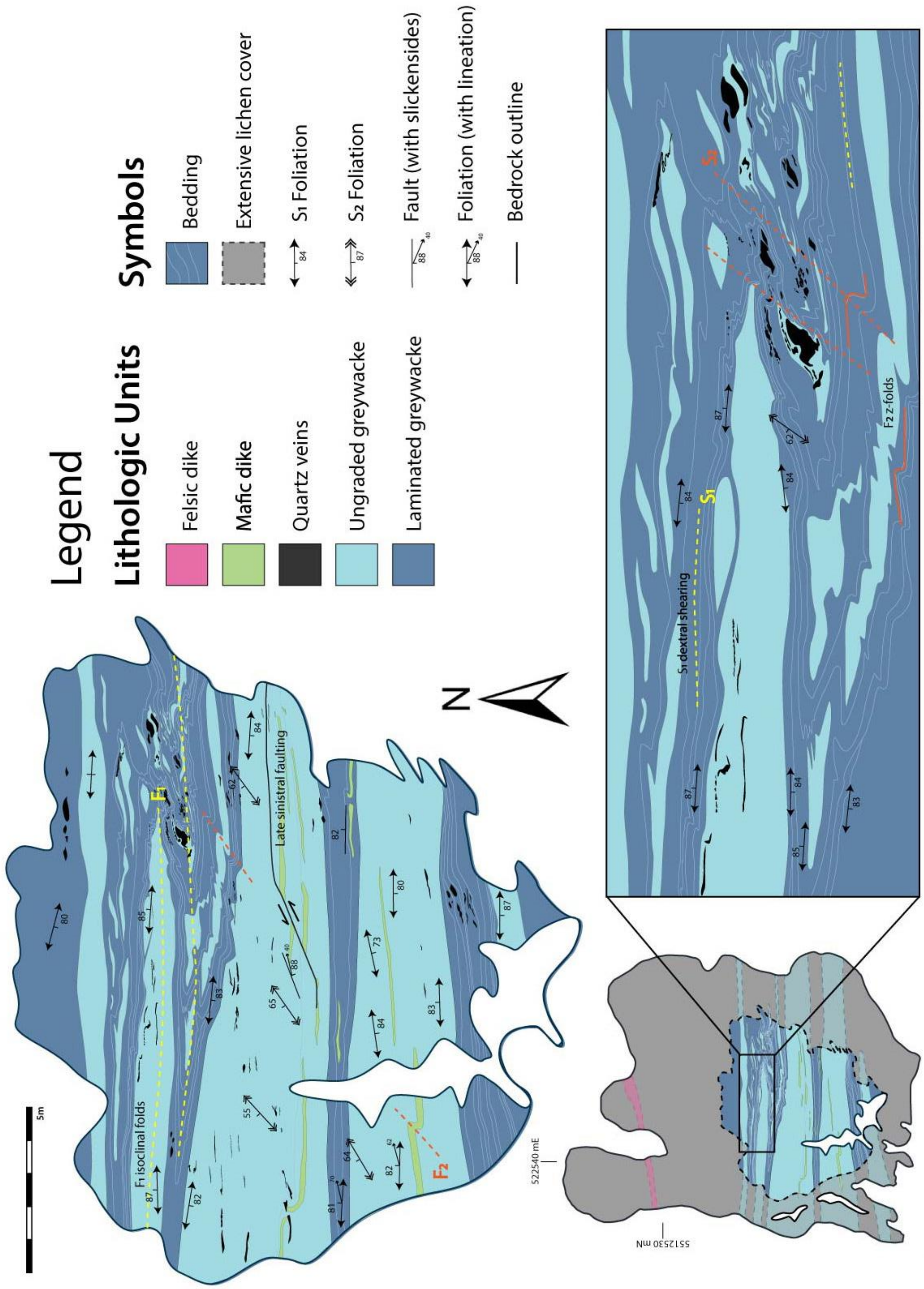

Fig. 3 – An outcrop map of the features observed in the Porcupine-like Thunder Lake sedimentary rocks that occur north of the Wabigoon deformation zone at stop 2.

Both the sedimentary and volcanic rocks are complexly folded and faulted forming a broad (>2 km) zone of ductily deformed rocks. The outcrop at this stop is comprised mainly of greywacke of the Thunder Lake sedimentary rocks with minor mafic dikes, felsic dikes, and quartz veins. Two main deformation events can be recognized including an early phase of shortening (D_1) and a later phase of dextral strike-slip or transpression (D_2). Early shortening resulted in isoclinal F_1 folds with steeply-plunging fold axes that are easily observed in the northern portion of the outcrop (Fig. 2). The dominant foliation (S_1) observed here and within the Wdz is E-trending, subvertical and defined by aligned grains of chlorite or biotite. Progressive deformation (D_2) was characterized by a transition to dextral shear. D_2 shear resulted in re-folding of F_1 folds forming asymmetric F_2 Z-folds and boudinage of quartz veins forming σ-clasts (Fig. 2). Asymmetric F_2 Z-folds display an axial planar S_2 crenulation cleavage that is NE-trending and moderately-dipping towards the NW (Fig. 2). Lastly, a late-stage of deformation is documented at this locality. In the central portion of the outcrop, a small-scale sinistral fault crosscuts the S_1/S_2 fabrics.

After we are done at stop 2 return to your vehicles and proceed back to Highway 17 and take a right to continue east. Proceed for ~5.6 km to Anderson Road and take a left. Continue on Anderson Road for ~1.6 km to Nursery Road and Take a left. Drive for ~2.4 km and park along the right side of the road just prior to the hydro line. The outcrops of stop 3 occur on the east side of the road.

Stop 3: Felsic volcaniclastic facies of the Thunder Lake sedimentary succession (UTM: 15U 528820 mE, 55012420 mN)

This stop provides an opportunity to observe felsic volcanic and/or volcaniclastic rocks that are the primary host for mineralization within the ~1,229,800 Oz Au equivalent (measured and indicated) Goliath Deposit (Trinder et al., 2017). The felsic volcanic and volcaniclastic units form a map-scale package that is conformable with greywacke successions of the Thunder Lake sedimentary rocks, which extend for ~5 km along strike to the west (Fig. 1). Due to the intensity of deformation, alteration, and metamorphism, the felsic volcanic and volcaniclastic rocks occur primarily as sericite schists. This outcrop area exposes one of these units. The outcrop is dominated by a felsic volcaniclastic unit that contains abundant quartz phyric clasts. While this unit is widely occurring in the outcrop area, interbedded biotite schists are more common in the southern portion. Structure at this outcrop is consistent with features observed at the previous stop, indicating a shared structural history. F_1 isoclinal folds of the primary compositional layering are common (Fig. 4A) and an E-trending S_1 foliation is well-preserved (Fig. 4B). Early structure is overprinted by a NE-trending foliation that is axial planar to asymmetric Z-folds (Fig. 4C). S_2 fabrics contain a well-formed moderate to steeply, W-plunging lineation (L_2) that is defined by aligned grains of biotite, sericite, and/or aggregates of quartz (Fig. 4C). Several generations of quartz (± tourmaline) veins occur at this location. These include an early formed set that is parallel to S_1 and are typically boudinaged as well as a younger set that crosscut earlier veins, is oblique to S_1, and commonly NE-trending (Fig. 4B). Anomalous gold values are documented at this location however no high-grade gold values were reported. To better observe the characteristics of the economic mineralization in the Goliath Deposit, we will view a representative section of drill core at the local exploration office of Treasury Metals.

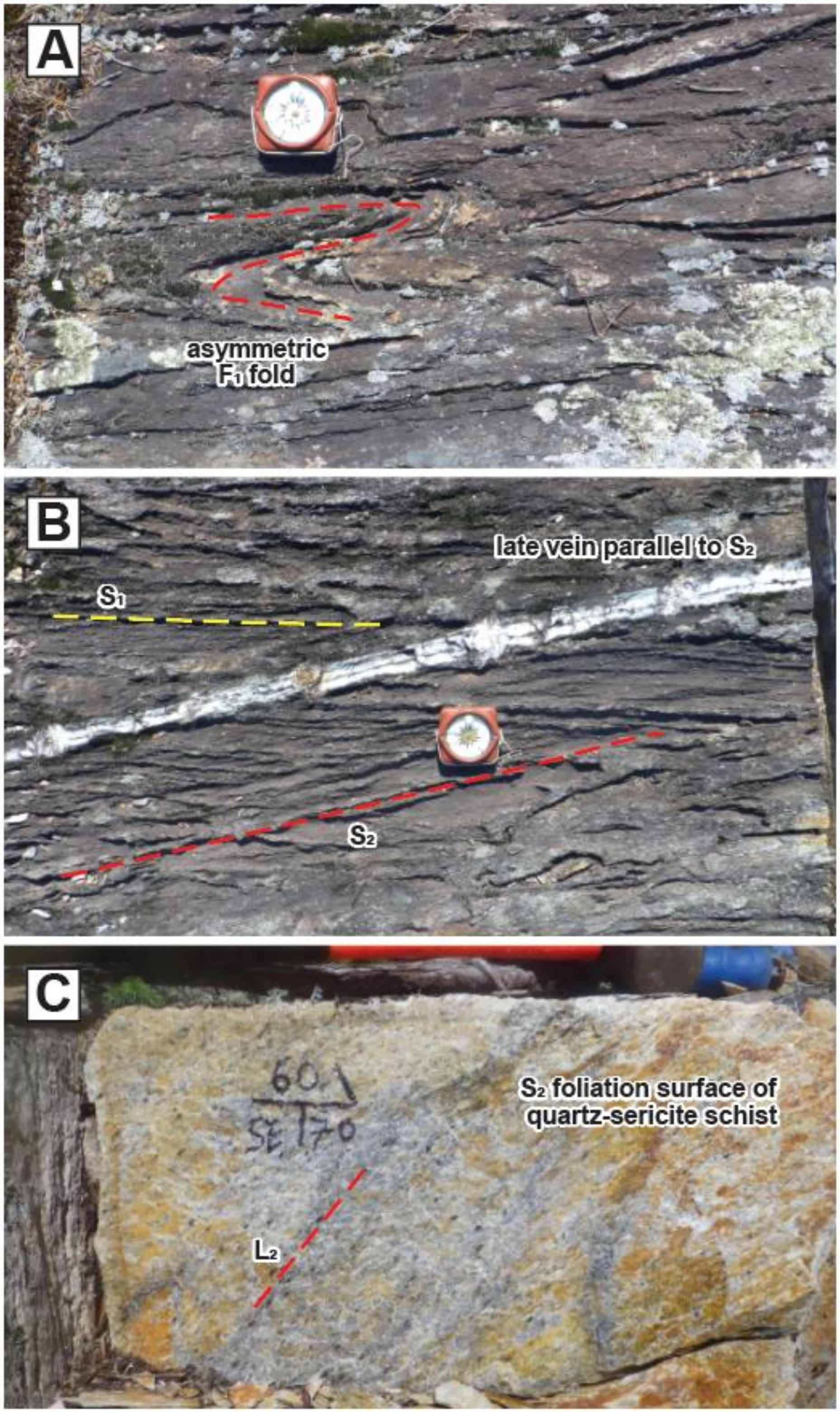

Fig. 4 – Representative features observed within felsic volcaniclastic rocks observed at stop 3. (A) Asymmetric folds of compositional layering. (B) E-trending S_1 fabrics overprinted by S_2 fabrics and a milky

quartz vein. (C) Representative example of an S_2 foliation surface with a well-developed L_2 mineral lineation.

When finished at stop 3 return to your vehicles and continue north on Nursery Road for ~2.1 kilometers to the Treasury Metals exploration office and park in the dirt lot outside the main building. We will go inside the facility to view representative drill core.

Stop 4: Mineralized drill core of the Goliath Deposit (UTM: 15U 528635 mE, 5514530 mN)

The Goliath Deposit, owned and operated by Treasury Metals, represents the most advanced exploration project in the Dryden area. It has a long history of development including extensive exploration executed by Teck in the 1990s. Recent exploration efforts by Treasury Metals included infill drilling, soil sampling, and IP surveys, which has resulted in delineation of an economic resource (Figs. 5 and 6; Puritch et al., 2015). The deposit is currently in the late stages of environmental assessment with extraction proposed to be accomplished through construction of an open pit (Fig. 6). The deposit footprint extends for >2.5 km along strike with the highest grades of mineralizing occurring in several stratobound, ~W-plunging ore shoots that define two primary high grade zones, the Main Zone and C Zone (Figs. 5 and 6; Puritch et al., 2015). These shoots occur parallel to the regional L_2 lineation, suggesting that mineralization, in part, reflects remobilization of base and precious metals during D_2. However, the highest grades of mineralization are spatially associated with felsic metavolcanic rocks of the Thunder Lake assemblage. This association along with observed gold-rich base metal assemblages within the felsic metavolcanic units are consistent with formation in a VMS-like setting. Thus, the Goliath Deposit appears to represent a rather unique hybrid volcanogenic-orogenic deposit type, which is being investigated by Metal Earth researchers.

The mineralized zones occur as tabular composite units composed of intensely hydrothermally altered felsic metavolcanic rocks interlayered with minor argillaceous metasedimentary rocks. In drill core, seven lithologies are commonly observed. These are a biotite-muscovite (BMS), muscovite-sericite (MSS), biotite (BS), and chlorite-biotite (Chl-BS) schists as well as thin (10-15 cm wide) iron formation (IF) units, arkosic metasedimentary (MSED) units with ‘quartz eye’ porphyroblasts, and quartz-feldspar porphyry (QFP) units. Treasury Metals maintains a representative section of mineralized drill core allowing for an opportunity to observe the lithological and mineralogical characteristics related to mineralization. Assay sheets will be provided in order to allow you to correlate where mineralized zones occur relative to the alteration assemblages and the MSS, BMS, and MS units.

In drill core, the MSS forms a distinctive white, sericite-rich unit that displays gradational contacts with interbedded BMS and BS units. The BMS and BS units appear dark grey to black and commonly contain fine-grained (mm-scale) garnet porphyroblasts. The intensity of alteration and deformation makes recognition of primary volcanic and sedimentary textures difficult. Mineralization is most closely associated with the MSS units where pervasive sericite alteration, silicification, and gold- or silver-bearing disseminated sulphides occur. Native gold and silver (electrum) are rarely observed macroscopically but are texturally associated with translucent quartz veins and stringers that are deformed into parallelism with the dominant foliation and finely disseminated zones of galena and sphalerite (Puritch et al., 2015). These form overgrowths on earlier pyrite, pyrrhotite, and, rarely, chalcopyrite grains. Sulphide veinlets are commonly folded and transposed into parallelism with the S_2 foliation.

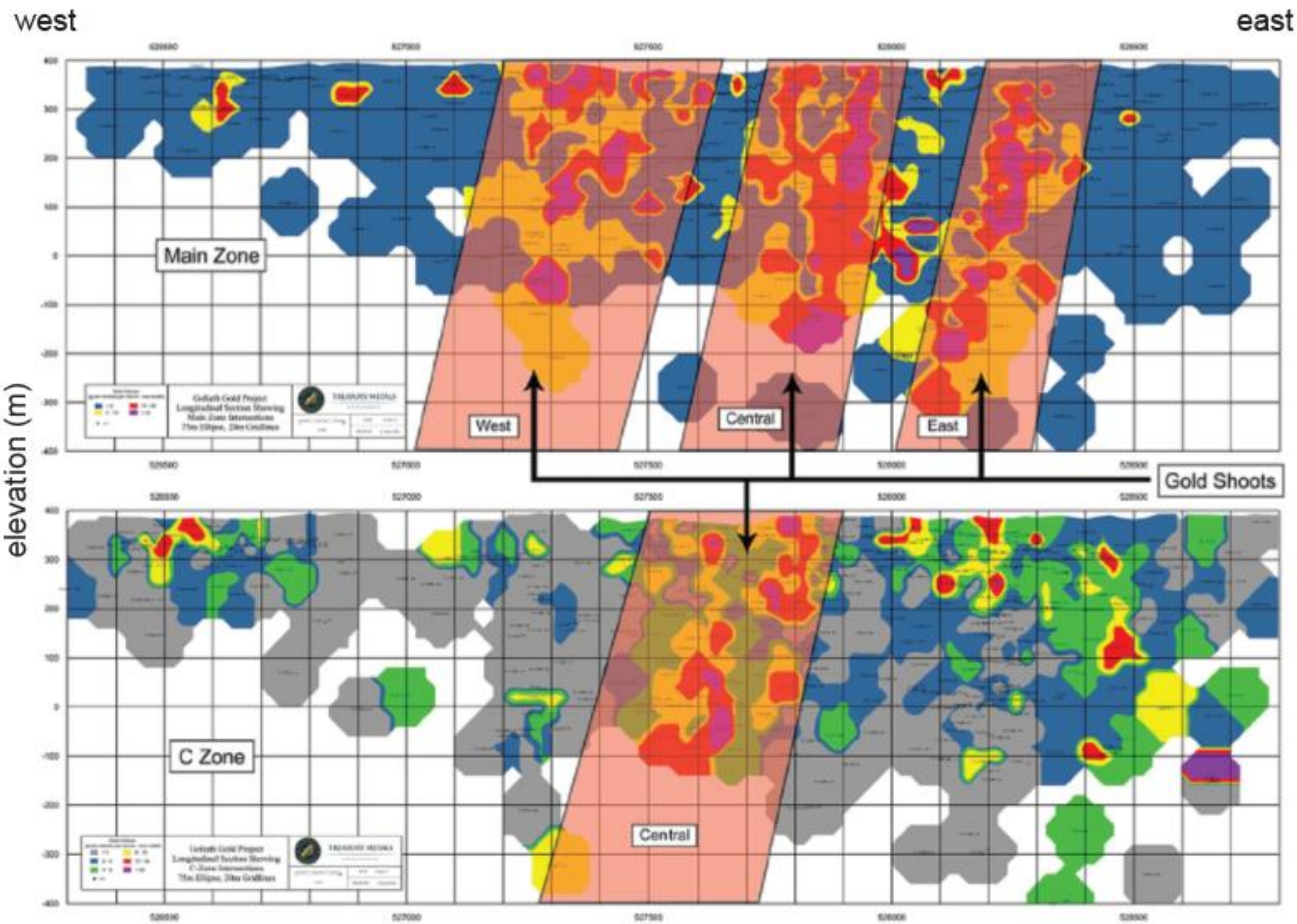

Fig. 5 – Longitudinal section through the Main and C Zones of the Goliath Deposit showing the westerly plunge of the high-grade ore shoots (from Puritch et al., 2015).

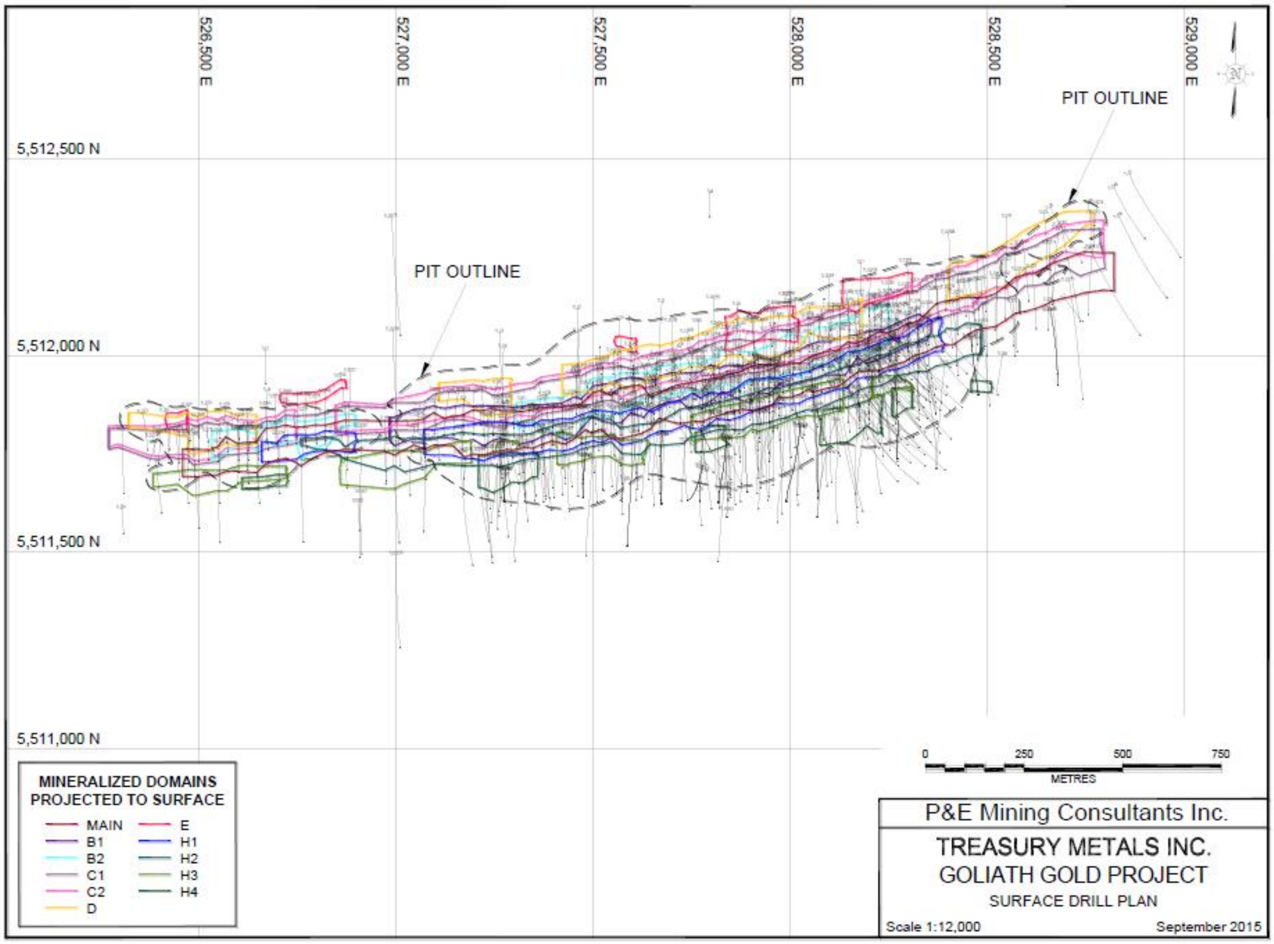

Fig. 6 – Plan view of the major mineralized domains delineated within the Goliath Deposit with the outline of the proposed open pit indicated (from Puritch et al., 2015).

Return to highway 17 via Nursery and Anderson Roads and take a left to proceed east. Continue for ~14.2 km to Robertson Road, which is ~3 km after the junction of Highway 17 with Highway 72 towards Sioux Lookout. Take a right onto Robertson Road and park alongside the road before the first curve. Outcrops occur along the side of Highway 17 directly south of Robertson Road. At this stop, please be aware of the highway traffic and, if available, wear high visibility safety gear.

Stop 5: Structure and characteristics of the Manitou-Dinorwic deformation zone along Highway 17 at Robertson Road (UTM: 15U 556780 mE, 5501875 mN)

This stop displays structures common to the Manitou-Dinorwic deformation zone (MDdz). The MDdz is a major, regional, northeast-trending high-strain corridor that extends for >60 km along strike from Upper Manitou Lake in the southwest through Dinorwic Lake in the northeast where it is exposed along highway 17 (Fig. 1). The MDdz hosts a number of orogenic gold occurrences, mainly in the southwest near Upper Manitou Lake where a series of early 20th century mines collectively produced ~20,000 Oz of gold (Parker, 1989). Along its length, the MDdz is marked by intense fabric development, heterogeneous alteration, silicification, and structurally controlled quartz-carbonate veins. At this stop, deformed basaltic rocks display a subvertical foliation that strikes towards the northeast (~045/88). Aligned grains of chlorite on these foliation surfaces plunge steeply to the south (82→180). These fabric relationships are interpreted to reflect a transpressional strain regime. In several locations at this outcrop area, the dominant northeast-trending foliation can be observed to overprint an earlier ~east-trending fabric that is interpreted to relate to deformation associated with the Wdz. This suggests that peak deformation along the MDdz post-dates D_1 shortening and, potentially, D_2 shear along the Wdz.

Several generations of veins can be observed at this locality. Early-formed composite quartz-carbonate veins are irregularly folded and are roughly foliation parallel (Fig. 7). Banded vein structures suggest cyclic emplacement during progressive deformation. These veins are texturally associated with a younger generation of shallowly- to moderately-dipping vein sets. Both of these vein generations are locally associated with narrow zones of disseminated sulfide minerals and Fe-carbonate alteration halos (Fig. 7B). In contrast, a late generation of veins are represented by discontinuous, moderately- to shallowly-dipping arrays of tension gashes (Fig. 7A). These are mainly filled with calcite and no observable wall rock alteration. The calcite-filled tension gashes crosscut the foliation and all earlier generations of veins and form prominent erosional surfaces, particularly in the southern portion of the outcrop.

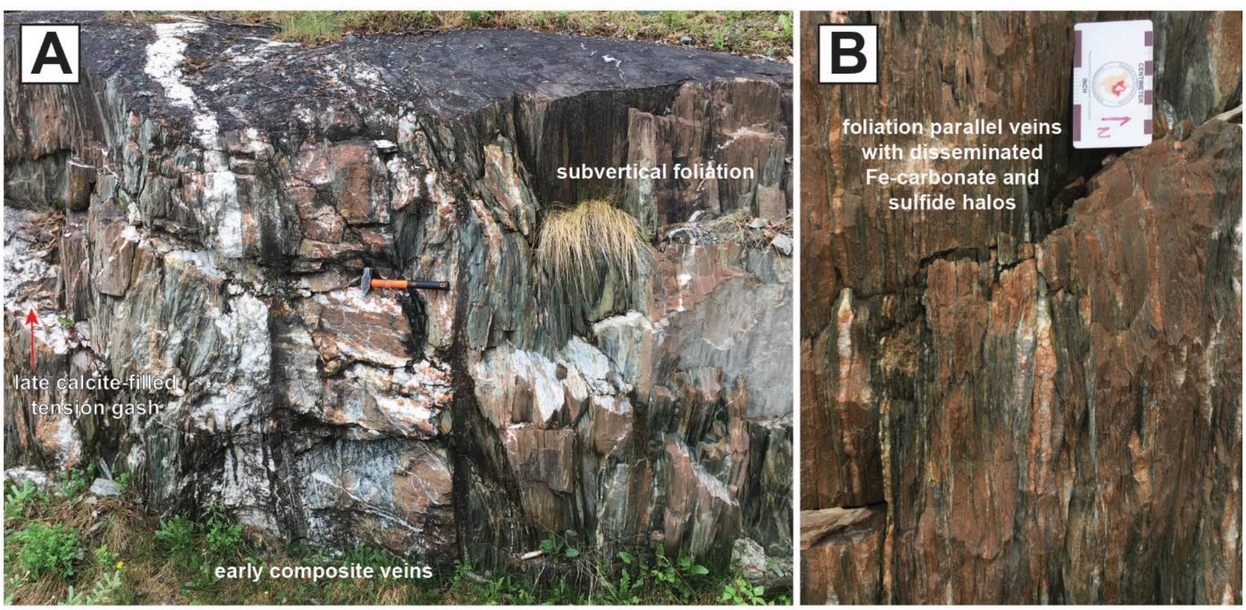

Fig. 7 – Features associated with the Manitou-Dinorwic deformation zone at stop 2. (A) Strongly foliated basalt with composite, early-formed quartz-carbonate veins. (B) Steeply-dipping veins with associated sulfide and Fe-carbonate alteration of the host rock.

Ongoing work along the MDdz seeks to constrain the kinematic history, timing of deformation to other regional deformation zones (e.g., the Wabigoon deformation zone), and potential relationships to orogenic gold mineralization. To establish these relationships, detailed structural mapping, geochemical, and paragenetic studies are being conducted by Metal Earth researchers, which includes this locality

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METAL EARTH

2019
Field Trip Guide

Geraldton, Ontario

CANADA FIRST RESEARCH EXCELLENCE FUND | APOGÉE CANADA FONDS D'EXCELLENCE EN RECHERCHE

Canada

The Geraldton-Onaman transect – Volcanology, metamorphism, deformation and mineralization

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Excursion leader: **Zsuzsanna Tóth**

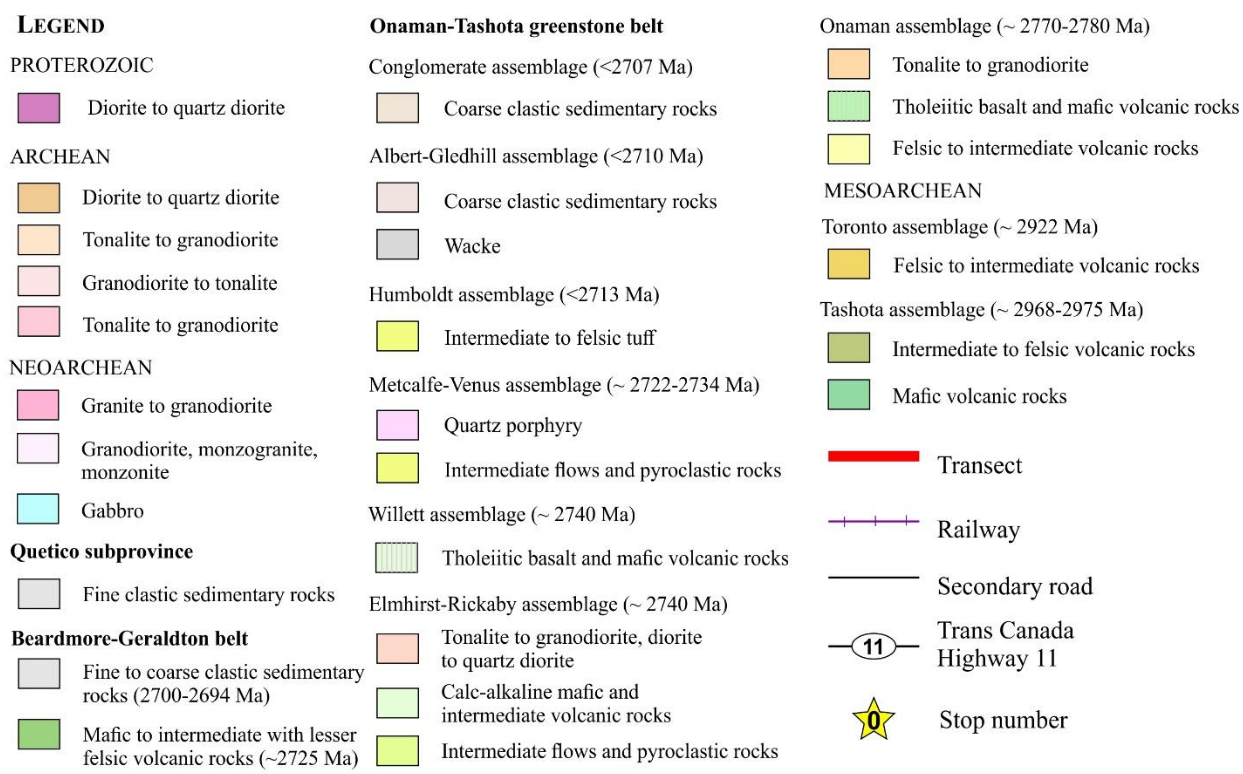
Meeting Location: intersection of Highway 11 and Kinghorn Road, 8:15 am, Friday, September 13. (Stop 0 on Fig. 1; UTM NAD 83 Zone 16 468575E, 5505341N; 38 km west of Geraldton, 43 km east of Beardmore, 7 km east of Jellicoe)

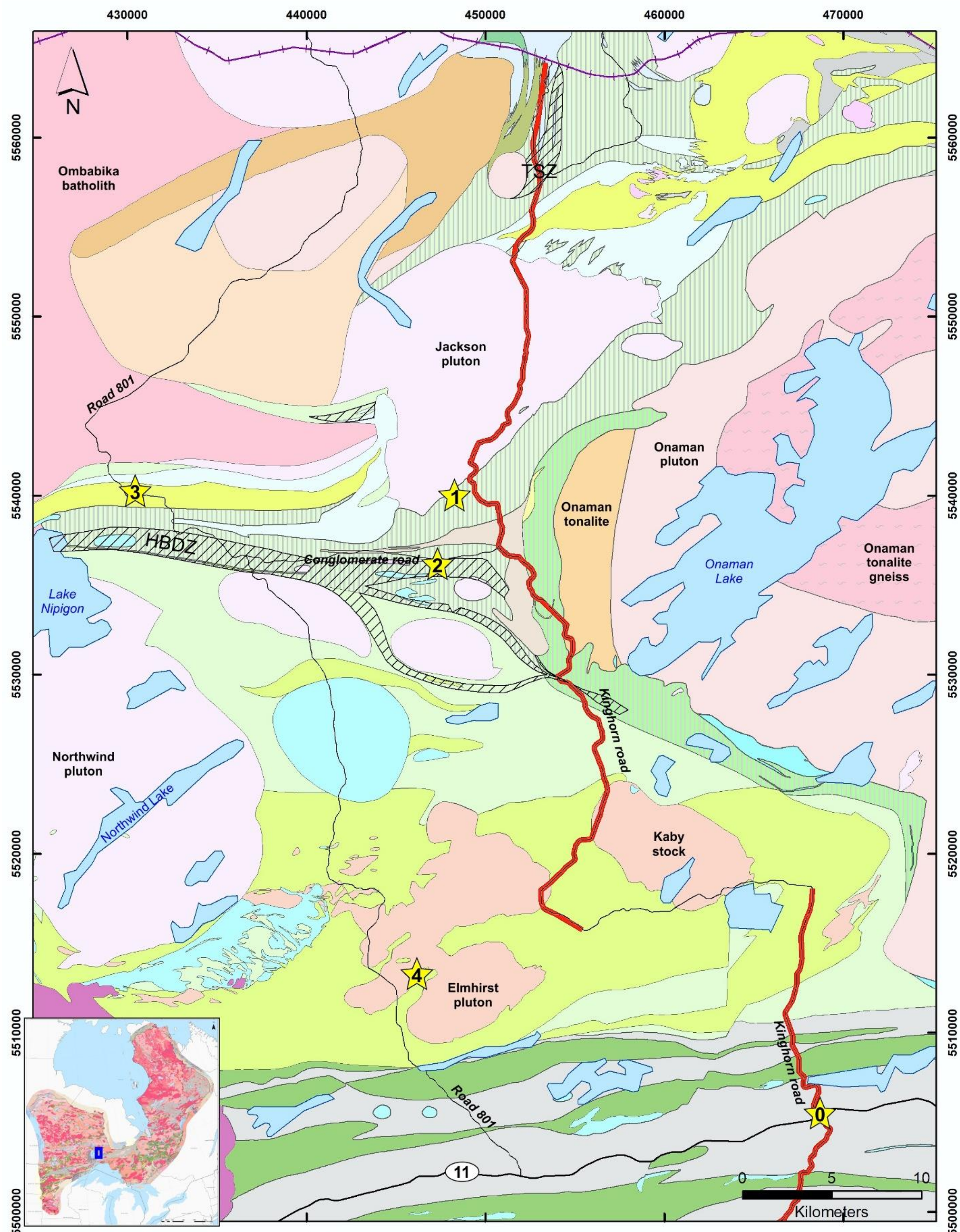
Metal Earth is a large, $104 million research initiative that seeks explanation for the differential metal endowment experienced between the extremely well-endowed Abitibi greenstone belt and other, less-endowed greenstone belts across the Archean Superior Province. The bulk of the research focuses on better understanding the geological evolution of 12 transects across Quebec and Ontario. The methods applied include: field mapping, geochemistry, detrital, igneous and metamorphic geochronology, isotope geochemistry and geophysical methods such as reflection seismic, magnetotelluric, gravity and aeromagnetic surveys.

The Geraldton-Onaman transect is one of the lesser base and precious metal-endowed transects (ca. 100 km long) extending from the Mesoarchean to Neoarchean Onaman-Tashota greenstone belt (OTGB) to the Neoarchean metasedimentary Quetico subprovince in the western Superior Province (Figure 1). Keaton Strongman, PhD candidate, is characterising the volcanic stratigraphy and the syn-volcanic mineralization styles across the OTGB. Anna Haataja, MSc student, aims to establish the Archean metamorphic events of the OTGB with primary focus on the contact metamorphism related to the late intrusions. Ben Mark's MSc research focuses on the structural evolution of the north-striking Tashota shear zone that was previously suggested to mark the boundary between the Mesoarchean and Neoarchean assemblages of the OTGB. This project also characterises the gold mineralization and its structural control in and around the Tashota area. Zsuzsanna Tóth, research associate, is responsible for describing the structural evolution of the OTGB and the compilation of existing data. She is also interested in the petrogenesis, age and geodynamic setting of the metasedimentary and intrusive rocks in and around the OTGB.

In summary, the Geraldton-Onaman transect aims to fill the knowledge gap in the geological evolution of the OTGB in order to achieve comparability between the modestly and well metal-endowed greenstone belts, the Onaman-Tashota and Abitibi greenstone belts, respectively.

Figure 1. *Geological map of the Onaman-Tashota and Beardmore-Geraldton greenstone belts compiled by Tóth after Stott et al., 2002 and Johns et al., 2003 that shows the Geraldton-Onaman transect of Metal Earth and the planned field trip stops. The striped areas mark the two most important deformation zones in the OTGB. The inset map is modified after Montsion et al., 2018. All coordinates are given in NAD 1983 Zone 16.*

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Stop 1 – Garnets in the Willet assemblage – Mapping the extent of the contact aureole around the Jackson Pluton, and possible pressure-temperature-time estimation

Drive north on Kinghorn road to the kilometer 60 marker and then turn left (west) at UTM 449156E, 5540805N. Follow this road for approximately 950 m until a clearing opens up on your left. Following the pink flagging tape, hike about 170 m along an old logging trail until you reach the ridge at UTM 16 448261E, 5540193N.

The ca. 2740 Ma Willet assemblage, which is mainly composed of massive to pillowed tholeiitic basalt, represents the dominant unit of the Onaman-Tashota greenstone belt (OTGB) (Stott et al. 2002). According to Stott and colleagues (2002), this assemblage was formed either in a back-arc basin setting, or represents a mixture of ocean floor and primitive island arc material. Previous studies in the area reported garnet-hornblende-plagioclase mineral assemblages and hornfelsic texture in the Willet assemblage near the southern margin of the 2684±8 Ma Jackson pluton (Thurston, 1980; Bjorkman, 2017) suggesting the presence of a contact aureole around the Jackson pluton, although one has never been mapped in detail before. This outcrop exposes a clast-supported breccia from the Willet assemblage that contains metamorphic garnet and black amphibole (likely hornblende) within its alteration. The breccia consists of light-coloured monolithic clasts (Fig. 2A-B) containing black amphibole and feldspar that exhibit a strong subvertical lineation (Fig. 2E-F). The clasts have a dark, amphibole-rich alteration rim where they come into contact with the matrix (Fig. 2B-D), which is predominantly made up of epidote, and in some places, garnet and randomly oriented amphiboles. This indicates two generations of metamorphic amphiboles, with the lineated ones (Fig. 2E-F) being pre- or syn-tectonic, and the unaligned ones being post-tectonic in origin. The presence of alteration rims, epidote in the matrix, and the association of garnet with the strongest alteration suggest that this texture is the result of metamorphosed hydrothermal alteration. The protolith is unknown, but is thought to represent one of three possibilities: 1) a hydrothermally brecciated and altered metabasalt, 2) a volcaniclastic breccia that has been hydrothermally altered, or 3) a tortoise shell jointed metabasalt that was later subject to hydrothermal alteration. The hydrothermal fluid and the heat for metamorphism are likely derived from the Jackson pluton that is found just 200 m northwest of this outcrop.

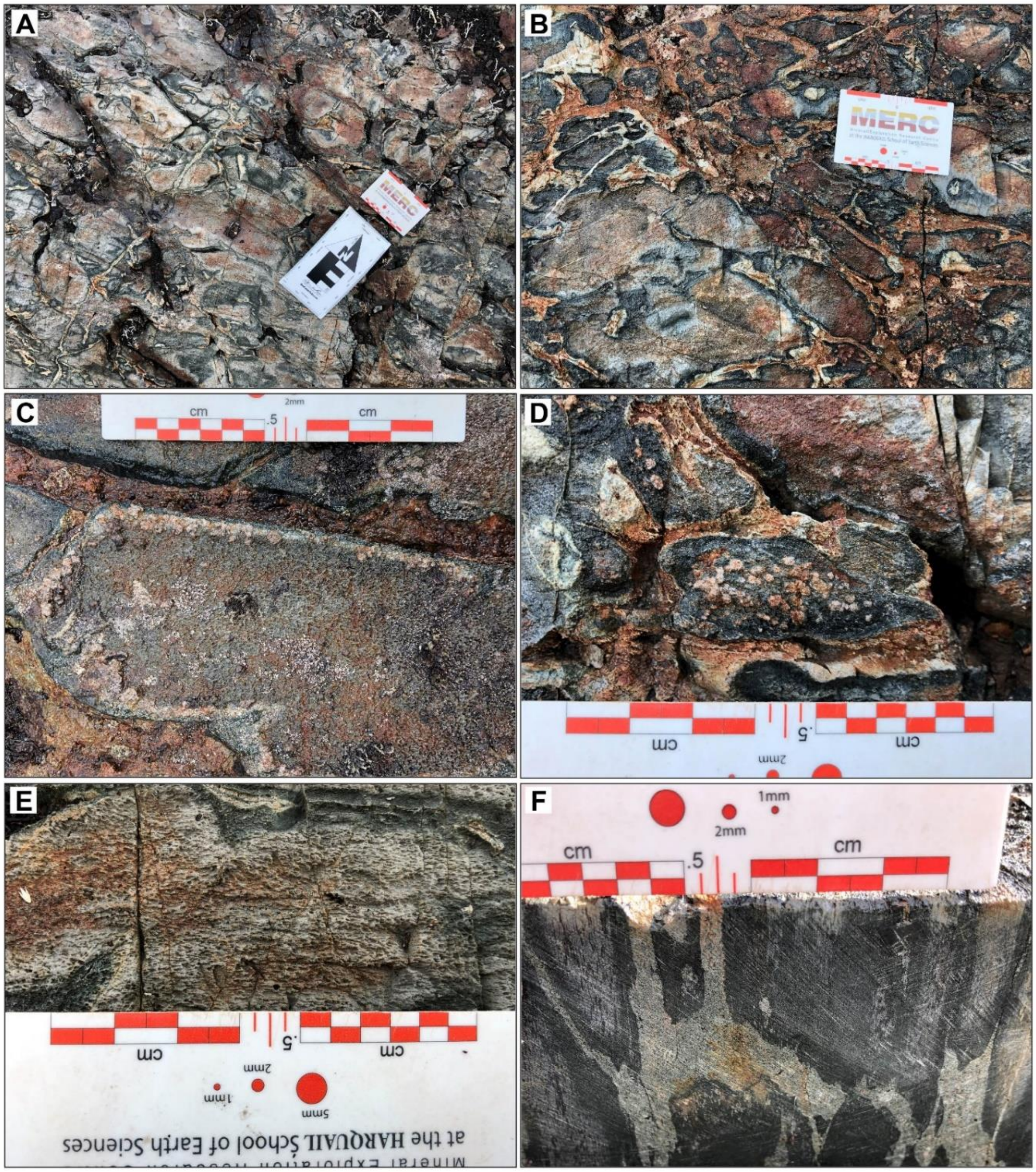

Figure 2A) *Brecciated, clast-supported, hydrothermally altered Willet assemblage metabasalts. Clastic texture defined by light green-gray blocky clasts with thin, dark green alteration rims, and a light green epidote-rich matrix.* ***B)*** *Overview of garnet distribution. Note that more altered and rusted clasts (top right) contain more garnets at their edges and extending into their cores. Less altered clasts (bottom left) contain no garnets.* ***C)*** *Garnets occurring in a moderately altered clast only in its alteration rim.* ***D)*** *Garnets occurring in the center of a smaller, highly altered clast. Note the darker colour of the clast suggesting a thicker alteration rim extending into the clast core.* ***E)*** *Weathered-out amphiboles within a clast showing the strong lineation on the outcrop surface.* ***F)*** *Channel cut wall showing the strong subvertical amphibole lineation within the clasts.*

STOP 2 – THE CONGLOMERATE ROAD STRIPPING

Drive back south on Kinghorn Road and turn west onto Conglomerate road (road name posted at ca. kilometer 55 or UTM 450717E, 5537208N). Drive 3 km west along Conglomerate road, then turn south onto a narrow grassy access road at UTM 447686E, 5536423N. Drive south for about 150 m.

This large exposure is a historical Au-Mo showing known since 1924 (Amukun, 1980) that has been mechanically cleared and expanded in 2009-2010 (Roach, 2011). Massive and pillowed mafic flows of the ca. 2740 Ma tholeiitic Willett assemblage are exposed on the bulk of the stripping (Fig. 1). A laminated, chlorite-rich unit is exposed in the central and the northern part of the exposure that may represent mafic tuff or siltstone with dominantly mafic volcanic source rock. The mafic volcanic rocks contain layers of light grey, quartz-rich clastic sedimentary interflow units interpreted as mudstone to siltstone beds. Subsequently, the mafic volcanic rocks and interflow units were intruded by syn-volcanic mafic to intermediate dikes and much younger, presumably syn-tectonic lamprophyre and 2703.5 Ma quartz-feldspar porphyry dikes (Hamilton, 2019, unpublished data). Two styles of mineralization are exposed: 1) The mudstone beds are strongly sericite-carbonate altered and contain barren, stratabound sulfide replacement possibly representing syn-volcanic seafloor hydrothermal activity. 2) Abundant quartz-carbonate±sulfide (pyrite-molybdenite) veins are surrounded by up to 20 cm thick biotite-carbonate-sulfide alteration haloes that yielded gold values up to at least 22 g/t (Roach, 2011). With the increase of quartz-carbonate veining, several meters thick zones of biotite-carbonate-quartz stockwork form in presumably pillowed and massive mafic flows as well as in lamprophyre dikes.

The Conglomerate road stripping is located in the Humboldt Bay deformation zone (HBDZ), a major east-striking structure that can be traced for at least 24 km eastward from the shore of Lake Nipigon (Fig. 1). The HBDZ deflects to the southwest around two small, late-tectonic, sanukitoid suite granodiorite-monzonite intrusions (Stott et al., 2002). The lithologies on this exposure reflect complex deformation (Fig. 1). An early, very strong foliation (S_{1L}) contains a steeply west-plunging mineral lineation (L_{1L}, Fig. 3A-B). Quartz-feldspar porphyry dikes were boudinaged during D_{1L} deformation (Fig. 3C) and locally display a strongly folded S_{1L} foliation, thus D_{1L} deformation took place after 2703.5 Ma. All lithologies, S_{1L} foliation and the biotite-carbonate-quartz stockwork were folded by outcrop-scale, Z-shaped F_{2L} fold with locally strong axial planar S_{2L} cleavage (Fig. 3A). A dextral transcurrent component during the progressive D_{2L} deformation is indicated by the: 1) Z-shaped asymmetry of the outcrop-scale F_{2L} fold, 2) Z-shaped folding of the axial planar S_{2L} cleavage along the short limb of the outcrop scale fold where the parasitic F_{2L} folds are expected to have S-shaped asymmetry, and 3) quartz-carbonate veins that were emplaced parallel to the axial plane of F_{2L} folds and were boudinaged prior to getting Z-folded (Fig. 3D). The S_{2L} foliation is locally crenulated by small, symmetrical, moderately to steeply NW-plunging F_{3L} folds with an axial planar crenulation cleavage.

This exposure is an excellent source of information regarding the importance of the Humboldt Bay deformation zone that marks the boundary between two, approximately synchronous, ca. 2740 Ma mafic volcanic packages, the tholeiitic Willett and the calc-alkaline Elmhirst-Rickaby assemblages (Stott et al., 2002). The known tectonic activity along the HBDZ postdates the formation of its host rocks by more than 35 m.y. Finally, syn-tectonic, atypical orogenic Au-Mo mineralization was introduced early during the deformation history but post-dating the emplacement of the quartz-feldspar porphyry dikes. The HBDZ is a regional-scale, major structure whose evolution carries important clues on the evolution and the assembly of the eastern Wabigoon subprovince. The HBDZ was proposed to be a long-lived, reactivated structure that marks a possible terrane boundary between the Winnipeg River terrane, in which Neoarchean granitoids recycled 3.4 Ga basement, and other undefined, younger terranes in the eastern Wabigoon subprovince (Tomlinson et al., 2004).

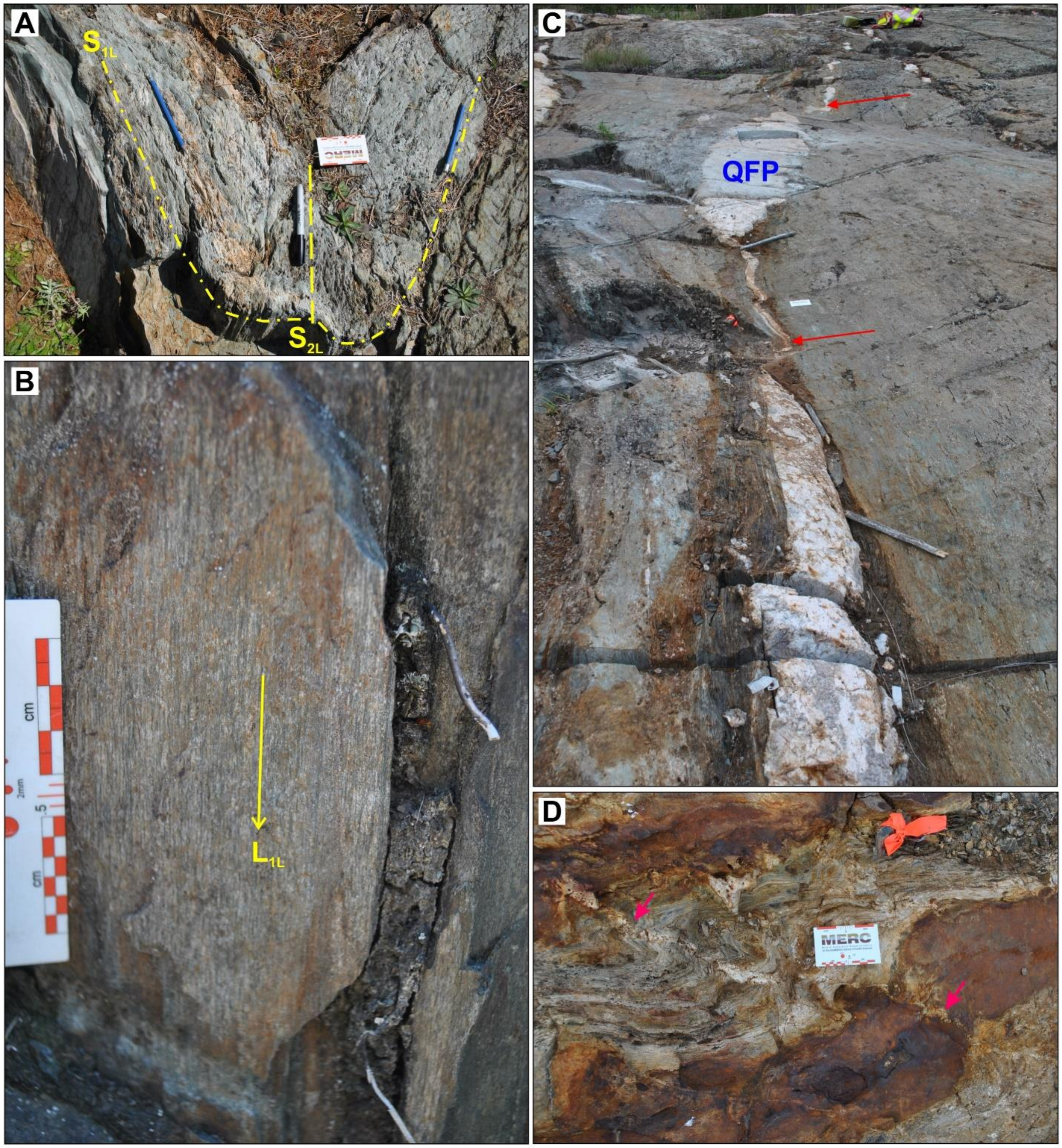

Figure 3A) *Strong, chloritic S_{1L} foliation is folded by F_{2L} fold with axial planar S_{2L}.* ***B)*** *Steeply plunging L_{1L} mineral lineation along folded S_{1L} foliation.* ***C)*** *Quartz-feldspar porphyry (QFP) dike boudinaged and later folded by outcrop-scale F_{2L} folds.* ***D)*** *Stratabound carbonate-sericite-sulfide alteration in mudstone to siltstone. Quartz-carbonate veins are emplaced parallel t the axial plane of F_{2L} folds and are boudinaged and subsequently Z-folded.*

STOP 3 – THE HUMBOLDT ASSEMBLAGE CRYSTAL TUFF AND TUFFACEOUS CONGLOMERATE

Continue along the Conglomerate road until the intersection with the 801 road (UTM 436597E, 5536644N). Turn right onto the 801 to head north, and drive for 8.4 km. At kilometer 52 (~UTM 430732E, 5540001N) turn right (north) onto a dirt logging road and drive for another 172 m to a series of large well exposed outcrops on the left (west side; UTM 430736E, 5540179N).

The Humboldt assemblage is a 1.3 km thick package of volcaniclastic and sedimentary rocks located east of Humboldt Bay, Lake Nipigon (Fig. 1). The Humboldt assemblage is <2713 Ma and bridges the gap in time between the extrusive volcanic activity of the Metcalfe–Venus assemblage (*circa* 2734–2722 Ma) and the unconformably overlying "Timiskaming-like" sedimentary Albert–Gledhill and Conglomerate assemblages (<2710 and <2707 Ma, respectively; Stott et al. 2002). The Humboldt assemblage consists of two main lithofacies. The lower unit is a polylithic, matrix-supported conglomerate containing ~35% medium-grained, rounded tonalitic clasts, along with various other fragment types, including fine-grained, subangular fragments (2 to 40 cm in size) of volcanic rock and banded iron formation (Fig. 4A-B). This conglomerate contains a fine-grained, well-sorted, quartz-crystal tuff matrix that lacks abundant ash-sized material. The conglomerate grades normally upwards over several metres into the second lithofacies, a package of quartz±feldspar crystal tuffs, lapilli tuffs, and lapillistones that are similarly fines-depleted. The latter tuffs form roughly 30-50 cm thick beds with abundant flaser beds indicating tidal to subtidal depositional environment (Fig. 4C), and contain up to 25% broken and angular quartz crystals. Finely bedded to laminated siltstone and crystal tuff layers (Fig. 4D) within the sequence display normal grading and scours that indicate stratigraphic facing is to the south.

The crystal tuff lithofacies contains a few green, chlorite-rich lenses with the correct bulk composition to develop garnet during metamorphism. The garnets occur as red-brown anhedral aggregates that are stretched into the foliation, suggesting pre-tectonic metamorphism. It is unknown whether they are regional or contact metamorphic in origin, but future work will determine their pressure-temperature conditions of formation. It is important to note that within the assemblages in the Humboldt Bay Deformation Zone (HBDZ), the metamorphic grade increases from greenschist to amphibolite along strike towards the west. Further study is required to explain this observation.

The Humboldt assemblage reflects the first large scale occurrence of intrusive fragments within clastic material in the belt, and thus records the initial stages of orogenesis, uplift, and exposure of the belt to subaerial conditions. The presence of essential volcanic material and volcaniclastic rocks records the final stages of extrusive volcanic activity within the belt, and suggests that volcanism largely halted during later orogenesis. The occurrence of this assemblage adjacent to the extensive HBDZ (Fig. 1) suggests that this structure may have originated as a basin forming normal fault, allowing for the local preservation of the sedimentary material, that was later reactivated as a reverse fault, as indicated by the strong vertical lineation along the HBDZ.

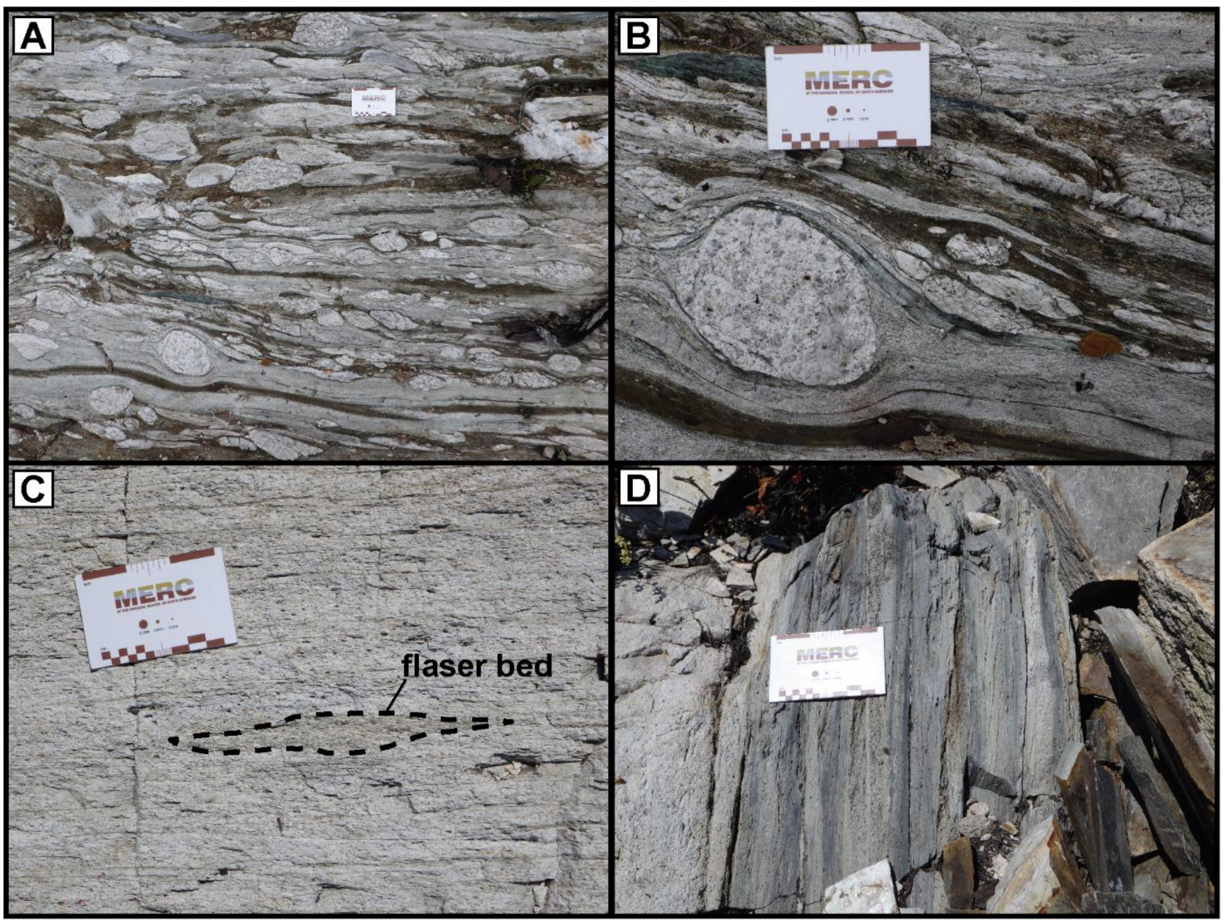

Figure 4. *Photos of key lithofacies within the Humboldt assemblage.* ***A)*** *Conglomerate with a quartz-crystal tuff matrix and fine silty interbeds hosting large tonalite clasts.* ***B)*** *A rounded tonalite clast in a quartz-crystal tuff bed of the conglomerate.* ***C)*** *Finely bedded, fines-depleted, quartz-crystal tuff with possible lensoidal flaser bedding.* ***D)*** *Interbedded siltstone and crystal tuff beds within a crystal tuff package;*

scoured crystal tuff beds indicate facing to the south (left). A felsic, monolithic lapilli tuff overlies the siltstone (far left).

STOP 4 – THE ISHKODAY CRK ZONE

Continue south along the 801 Road until kilometer 14, ca. 130 m past the Namewaminikan River bridge to the River Road, turn left (east) onto this road (UTM 444865E, 5512635N) and drive for 1 km then turn right (south) onto the dirt logging road at UTM 445717E, 5513169N. Follow this road to the end (ca. 800 m), then walk along the flagged ATV trail 300 m into a series of large stripped outcrops (UTM 445819E, 5512339N).

The Ishkoday Au-Ag-Zn-Pb-Cu-W property is hosted within the uppermost member of the 2740 Ma Elmhirst-Rickaby assemblage (Fig. 1; Stott et al., 2002), a calc-alkaline volcanic assemblage composed of a lower formation of pillowed mafic flows overlain by an upper formation of monolithic and locally heterolithic intermediate volcaniclastic rocks and minor felsic flows. The local stratigraphy of the Ishkoday showing consists of a lower unit of heterolithic, vitric fragment-bearing lapilli stones, tuff breccias and minor lapilli tuffs that are interpreted as dome collapse-related block and ash flow deposits related to partial collapse of the underlying flow-banded rhyolite dome. This sequence is intruded by a series of syn-volcanic intermediate, felsic, and minor mafic dikes. The largest mafic dike is an approximately 1 km wide aphanitic, aphyric, intermediate dike informally called the "Ishkoday Stock" which hosts the majority of the mineralisation. This unit is in-turn intruded by coarser syn-volcanic intrusions to the NW and SE.

Mineralisation at the Ishkoday property occurs in two separate and diachronous styles: 1) an early, likely syn-volcanic hydrothermal system (informally called the "Ishkoday" style) manifested as discordant, zoned, stockwork-style pipes consisting of a magnetite-actinolite core and an peripheral zone of comb-textured quartz veins, patchy to pervasive epidote alteration, and minor pods of chlorite alteration and pseudo-breccia (Fig. 5A, C, D, E); and 2) syn- to early-tectonic, fault-fill style, crack-seal textured, Au-Ag-bearing quartz veins (informally called the "Sturgeon River" style) with a distinct chlorite alteration halo that locally includes minor iron carbonate and pyrite (Fig. 5B). Cross-cutting relationships between the veins and the various porphyritic dikes indicate that the Sturgeon River veins postdate the Ishkoday style mineralisation; however, the two mineralised systems have similar orientations and spacing, suggesting similar, structurally controlled fluid conduits. Some of the intermediate dikes comprising the porphyritic dike swarm crosscut the Ishkoday style alteration (Fig. 5F), while others are altered by it, therefore the hydrothermal activity was concomitant with extension and rifting, a possible underlying geodynamic driving force to deposit Ishkoday style mineralisation.

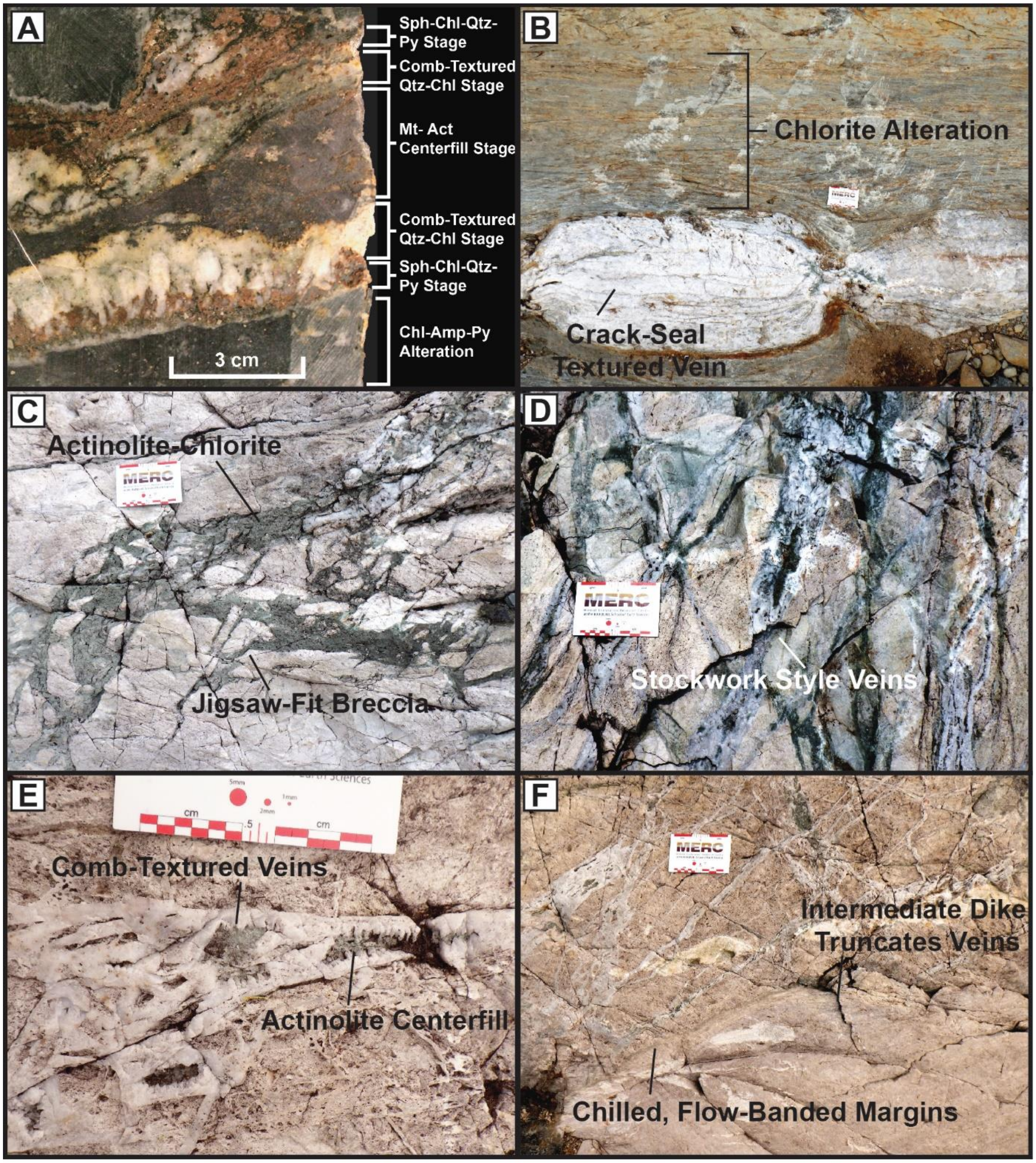

Figure 5. *Breccia and vein textures from the CRK zone at the Ishkoday Property.* ***A)*** *Comb-textured quartz-sphalerite-chlorite-pyrite veins with center-fill stages of magnetite-actinolite-monazite.* ***B)*** *Chlorite alteration envelope around a crack-seal textured, boundinaged quartz vein from the Sturgeon River style mineralisation.* ***C)*** *In-situ actinolite-chlorite-silica-filled breccia, note the jigsaw fit textures and highly angular clasts.* ***D)*** *Stockwork-style, comb-textured quartz veins with actinolite-chlorite center-fills from the Ishkoday style mineralisation.* ***E)*** *Comb-textured veins with actinolite center-fill stages.* ***F****) Stockwork style veins truncated by a flow banded, aphanitic, intermediate dike, demonstrating the syn-rift timing of this hydrothermal system.*

Acknowledgements

The Geraldton-Onaman transect crew thanks Argonaut Gold and Laurion Mineral Exploration Inc. for giving access to their properties, Myron Nelson, for providing accommodation to our crew at his Metcalfe Lake area cabin as well as Bella Li, Kav Lokuliyana, Jacob Pinter, Amir Sandarusi and Matt Lin for assisting our work during the field season. This is MERC–Metal Earth publication number MERC-ME-2019-197.

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MERC-ME-2019-197e

METAL EARTH

2019 Field Trip Guide

Larder Lake, Ontario

CANADA FIRST RESEARCH EXCELLENCE FUND | APOGÉE CANADA FONDS D'EXCELLENCE EN RECHERCHE

Canada

Metal Earth – 2019 Ben Nevis – Larder Lake Field Trip Guide

The field trip will start at 08.30 am on September 10th. Please make your own way to the Visitor centre car park in Larder Lake, located at the 'big fish'.

K.E. Rubingh[1], and S.A. Kisluk[1]

[1,] Metal Earth, Mineral Exploration Research Centre, Laurentian University, Sudbury, Ontario, P3E 2C6

The Ben-Nevis Larder Lake transect (Figure 1), within the Abitibi Subprovince of the Superior Province, is approximately 45km in length. The Metal Earth research areas are focused on the northern, central and southern domains of the transect, that were chosen respectively to investigate: - i) the metal endowment associated with the Ben Nevis volcanic complex (2696.6 +/- 1.3 Ma) of the Blake River Group (2701+/-3 – 2698.5+/-2 Ma) (Péloquin et al., 2008); ii) understand the nature of the early deformational history of the Larder Lake Cadillac Deformation Zone (LLCDZ), which is host to several significant gold occurrences; including the Kerr-Addison past producing mine, and iii) a series of alkaline composite intrusive rocks along the Lincoln-Nipissing shear zone (LNSZ), that host low grade gold mineralization; iv) a comparison of the alteration and structure of the LNSZ with the LLCDZ.

This field trip guide will focus on the northern portion of the transect in the Ben Nevis Volcanic Complex and research by Metal Earth MSc student, Stefanie Kisluk and will be led by Kate Rubingh (Research Associate). This research project will focus on understanding the lithostratigraphic and geochemical controls on VMS mineralization in the Ben Nevis Volcanic complex, to assist in developing a model for regional metal endowment of the Blake River Group.

Ben Nevis Volcanic Complex

The Ben Nevis Volcanic Complex (2696.6 ± 1.3 Ma) is hosted by the Archean Blake River Group (2701 ± 3 –2698.5 ± 2Ma) (Péloquin et al., 2008). The Blake River Group in Quebec is well documented and is host to 33 volcanogenic massive sulphide (VMS) deposits totalling 125Mt. However, the Ben Nevis Volcanic Complex, despite its similarities in age, lithology, geochemical characteristics and styles of synvolcanic mineralization, VMS deposits of comparable size have not yet been identified (Ayer, 2005).

The Blake River Group in Quebec has excellent exposure and metal endowment, with significant Cu – Zn VMS mineralization within the Noranda mining camp, and Au-rich VMS mineralization is associated with the Doyon- Bousquet-LaRonde mining camp (Gibson and Watkinson, 1990; McNicoll et al., 2014; Dubé et al., 2007; Mercier-Langevin et al., 2007a, b, 2011). The Blake River Group has been subdivided into the Misema and Noranda formations (Goodwin, 1977; Péloquin, 2000) and is intruded by felsic to mafic synvolcanic and syntectonic dikes, sills, and plutons (Piercey et al., 2008; Pearson and Daigneault, 2009). Recent studies have interpreted the Blake River Group as a mega-caldera complex which formed at 2704 to 2696 Ma over an area of at least 2500km^2 (Mueller et al., 2009; Mueller et al 2012; Pearson and Daigneault, 2009; Rogers et al. 2014).

The Ben Nevis Volcanic Complex consists of basaltic-andesite to rhyolite lavas and volcaniclastic rocks (Péloquin, 2000; 2008) and is associated with the earliest phase of the mega-caldera complex – the Misema Caldera, which formed between 2704 and 2702 Ma, as a result of the amalgamation of shield volcanoes fed by volcanic activity along the Misema Caldera ring faults (Pearson and Daigneault, 2009). The Ben Nevis Volcanic Complex is poorly understood with respect to its metal endowment, however mapping by Jensen (1975) provided a regional stratigraphic framework (Jensen and Langford, 1985), which was further refined by Péloquin (2008). Geochemical studies to define the regional alteration and mineralization (Piercey et al., 2008) illustrate that semiconformable alteration in a VMS environment is present in the Ben Nevis volcanic centre (Ioannou et al., 2004; Weiershäuser and Spooner, 2005) and a zone of intense carbonatization related to VMS alteration has been documented (Grunsky, 1986, 1988; Grunsky and Agterberg, 1988; Hannington, 2003) within the outer and inner ring faults of the Misema caldera. Major magmatic episodes and changing mineralization styles are related to an evolving geodynamic setting (Mercier-Langevin et al 2011). This project aims to further refine the geological setting for the Ben Nevis Volcanic Complex within the Blake River Group, in terms of alteration and associated VMS mineralization to define the geodynamic setting favourable for mineralization and thereby understand metal endowment in the Ben Nevis Volcanic Complex.

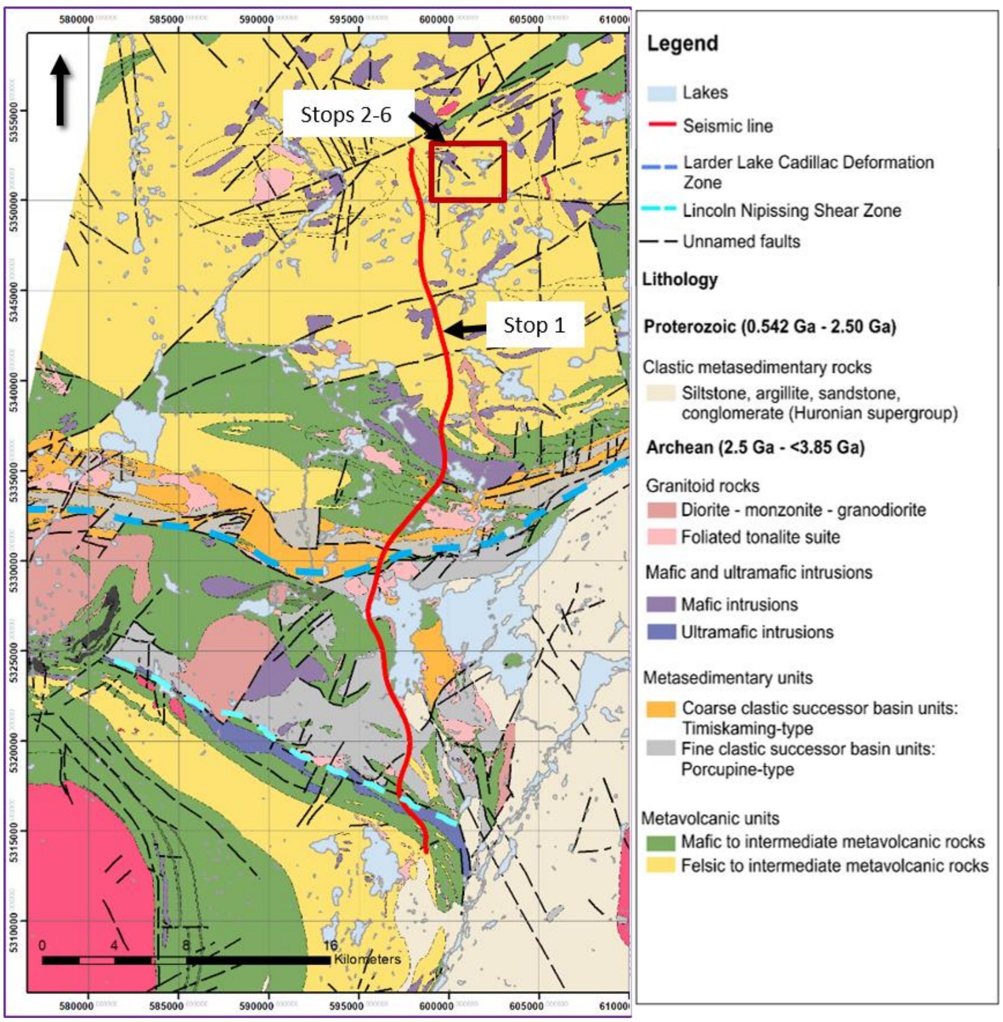

Figure 1: *Regional Geological map to illustrate the Ben Nevis - Larder Lake transect with the location of the seismic line in red which follows the main highway. Field trip stop 1 location is illustrated and the field trip stops 2 to 6 are shown by the area in the red rectangle (in house compilation map by Montsion, 2017).*

Stop 1: Mafic pillowed volcanic rocks (599634, 5342371; UTM Zone 17N, NAD83) Ashley Gold Mines Limited property.

From Larder Lake town, head east on 5th avenue (highway 66) towards Virginiatown for approximately 750 m. Then turn left onto Larder Lake Station Road (Fig. 2) and travel north for another 15 km to reach Stop 1. The outcrop is located on the right hand side of the road.

The mafic pillowed volcanic rocks of the Blake River Group observed here at stop 1 (Fig. 1) show well developed pillow selvedges with abundant vesicles which are concentrated at the top of the pillow. Pillow facing directions are consistently North younging on the regional compilation map (Péloquin, 2005) which is not well defined at this outcrop based on pillowed shapes. Features observed here are abundant vesicles towards the top of the pillow and pillow selvedges show carbonate alteration. The pillows are weakly flattened and aligned parallel to the main regional E-W foliation, which is defined by the flattening of pillows.

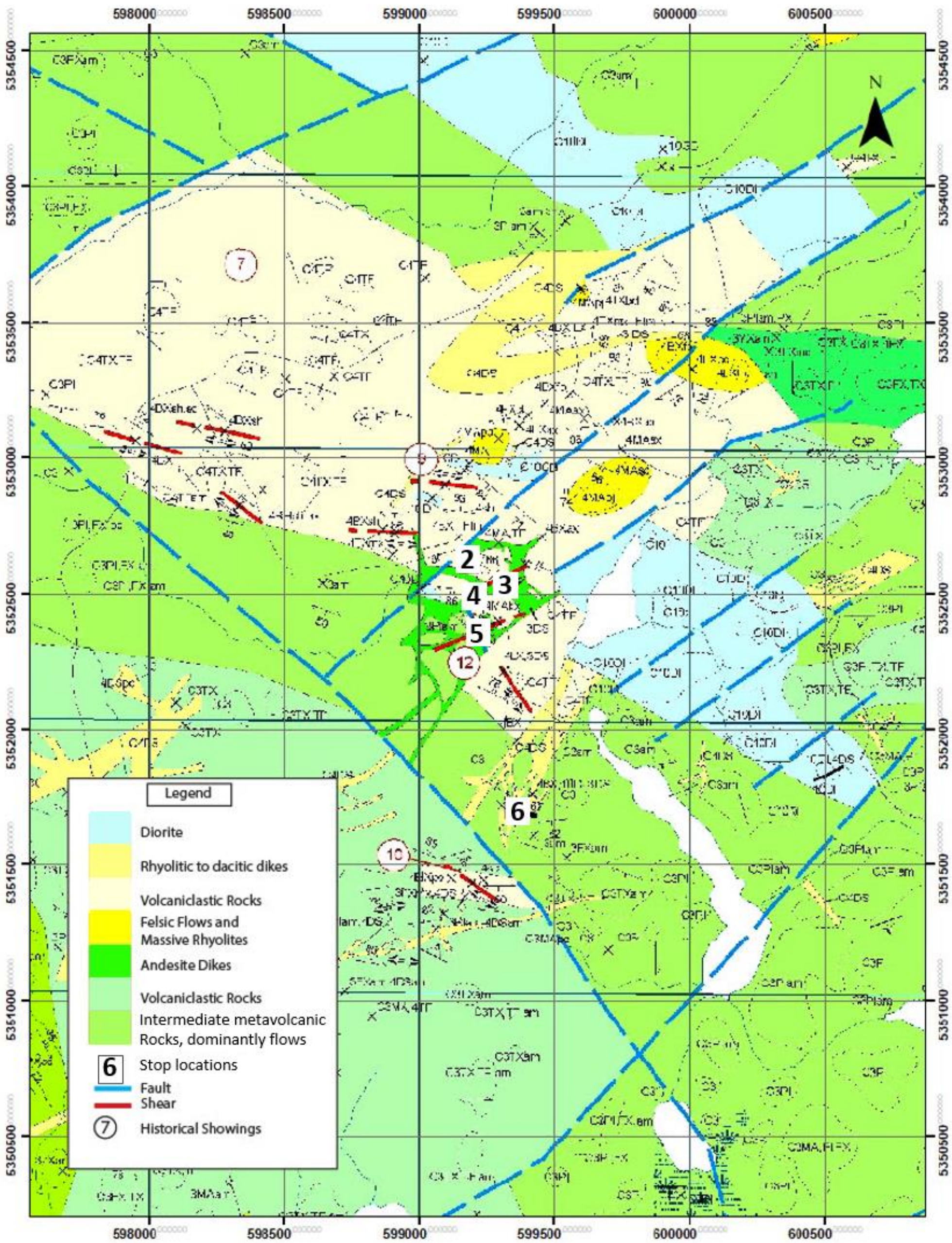

Figure 2: *Regional Geological compilation map modified after (Péloquin, 2005) showing the outcrop locations for stops 2 – 6. The map grid uses Universal Transverse Mercator (UTM) co-ordinates, which are using North American Datum 1983 (NAD83), in zone 17. Historical showings 7,9,10 and 12 represent the Roche-North (Zn, Pb, Ag, Au), Roche-South (Zn), Interprovincial South (Zn, Pb, Cu) and Interprovincial North (Zn, Pb, Au, Cu, Ag), respectively.*

Stops 2 – 6 Canagau and Erhart properties (Ben Nevis Resources Inc.)

Stop 2: Trailhead location (599240, 5352600; UTM Zone 17N, NAD83

From Stop 1 continue north on Larder Lake Station Road for approximately 12 km to reach access location (598148E, 5353207N), which is an unnamed side road on your right hand side. This is the main access road into the Canagau and Erhart properties. Continue along this unnamed road for approximately 2 km. Park on the road at the trailhead location, marked by flagging tape on your right hand side, to access the trench location for stop 2. Continue on foot for 3 m to reach the main trench.

At the subsequent 3 trench locations (*stops 2,4,5*) (Figure 2) the heterolithic felsic and mafic volcaniclastic rocks, mafic andesitic volcanic rocks, rhyolite dykes and mafic dykes of the Canagau property are observed. A rhyolite from the Canagau area was dated at 2696.6 ± 1.3 Ma (Péloquin and Piercey, 2005; Péloquin et al., 2008). The Canagau occurrences are characterized by NE and SE trending sulphide rich veins (pyrite, galena, sphalerite, quartz), pyrite stringers and disseminated sulphides.

Lithological description for aphyric felsic lapilli tuff unit

The northern eastern portion of this trench (Figure 3) shows a series of finely laminated beds within an aphyric, aphanitic felsic lapilli tuff. Low angle beds (0 – 15º) and steeper beds (50 – 60º) are defined by white and dark green layers defining parallel laminae in 2– 20 cm fine ash beds. Coarser material is observed within these fine ash beds which also contains fine laminations that are at a high angle to the fine ash beds (Figure 4A). Rounded light coloured altered feldspar clasts, with a uniform colour and a diameter ranging from 0.6 – 1.3 cm are observed in these beds. These rounded clasts are not observed in the very finely laminated ash beds.

Structure

Beds are finely laminated and defined by lighter and darker coloured layers. The foliation defined by chlorite is at a high angle to bedding.

Alteration and Mineralization

Chlorite and lesser carbonate alteration define the main foliation. Darker coloured finely laminated beds show chlorite alteration. Sulphide mineralisation is weakly disseminated throughout the coarser beds, as illustrated by euhedral pyrite weathered out pits.

Interpretation

Possible interpretations for the observed bedforms are: - 1) a sequence of possible channel structures, in an environment of rapid deposition of fine ash material, from suspension fallout through the water column. Successive channels truncate one another in quick succession; 2) a pyroclastic surge deposit where re-working of such deposits by water can also produce both planar and cross bedded deposits. However, the abundance of fine ash components lessens this latter probability unless they are subaerial deposits. The pale coloured rounded clasts maybe accretionary lapilli, which may have been erupted from a subaerial vent and deposited as suspension particles in a subaqueous environment.

The overall environment for the Ben Nevis Complex is currently interpreted as shallow subaqueous but below storm wave base indicated by a lack of wave induced bedforms and considerable volume of andesitic basaltic pillowed lavas.

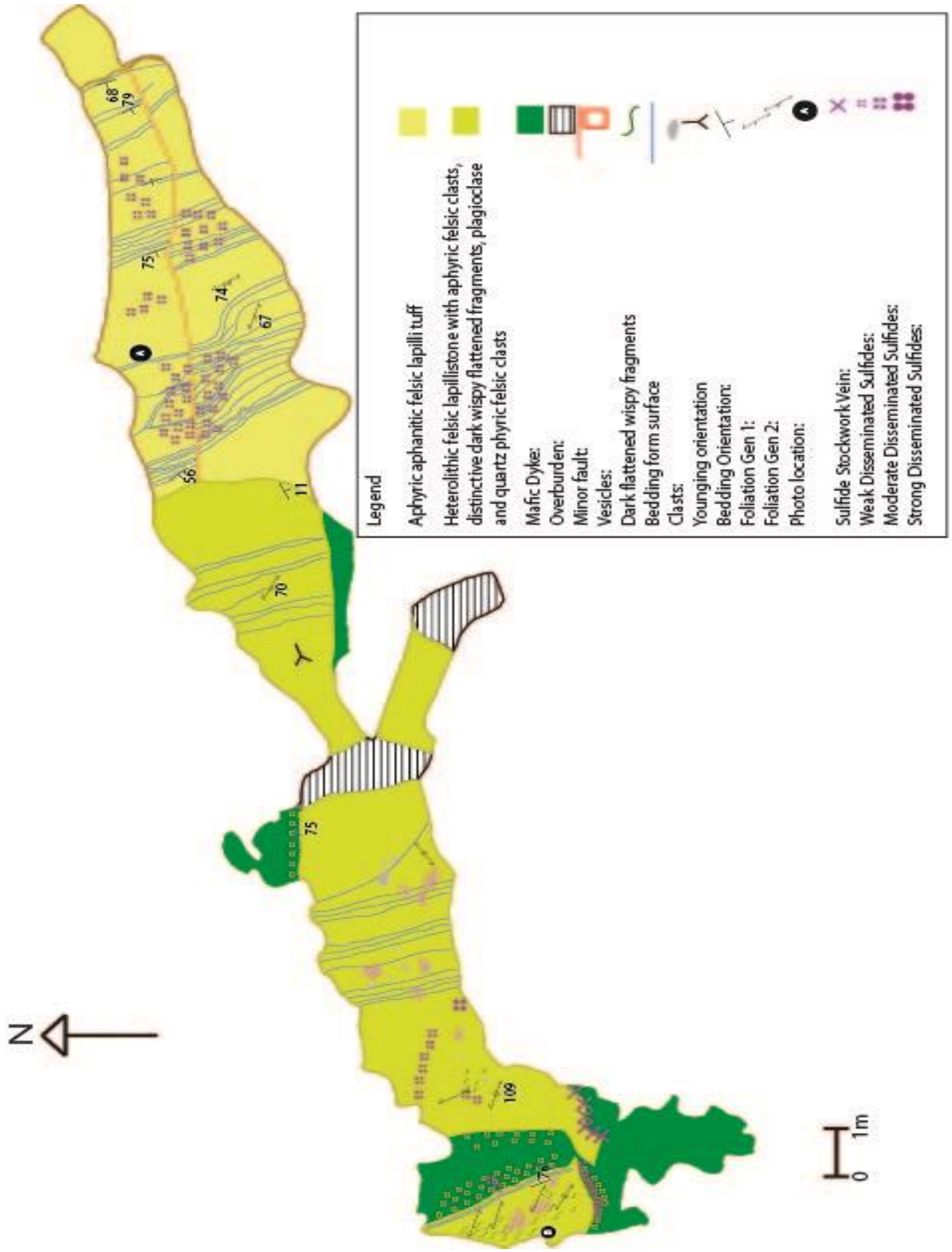

Figure 3: *Stop 2 – outcrop map showing lithology, structure and alteration.*

Lithological description for the felsic heterolithic lapillistone unit

The western part of this trench (Figure 3) comprises a heterolithic felsic lapillistone to tuff breccia unit, where clast sizes show a weak normal grading with tops to the east, based on clast size distribution. Clast types and relative range of sizes observed are: - 1) white rounded to subrounded aphyric aphanitic felsic clasts, 5 – 40 cm; 2) white angular to subangular to subrounded finely laminated aphyric aphanitic felsic clasts, 30 – 100 cm; 3) pale green-brown to dark green wispy flattened fragments with 5- 8% feldspar and <1% quartz crystals, 4 – 27 cm long (Figure 4B); 4) dark green ragged irregular margins of fragments which are subangular and display fine internal laminations 8 – 20 cm long; 5) white to cream 2% plagioclase phyric, <1% quartz subrounded felsic clasts with rounded and intact crystals. The most abundant clast types are clast type 1. Overall, this unit is densely packed with less than 15% ash sized material. Mafic dykes cross cut these units and show abundant vesicles throughout.

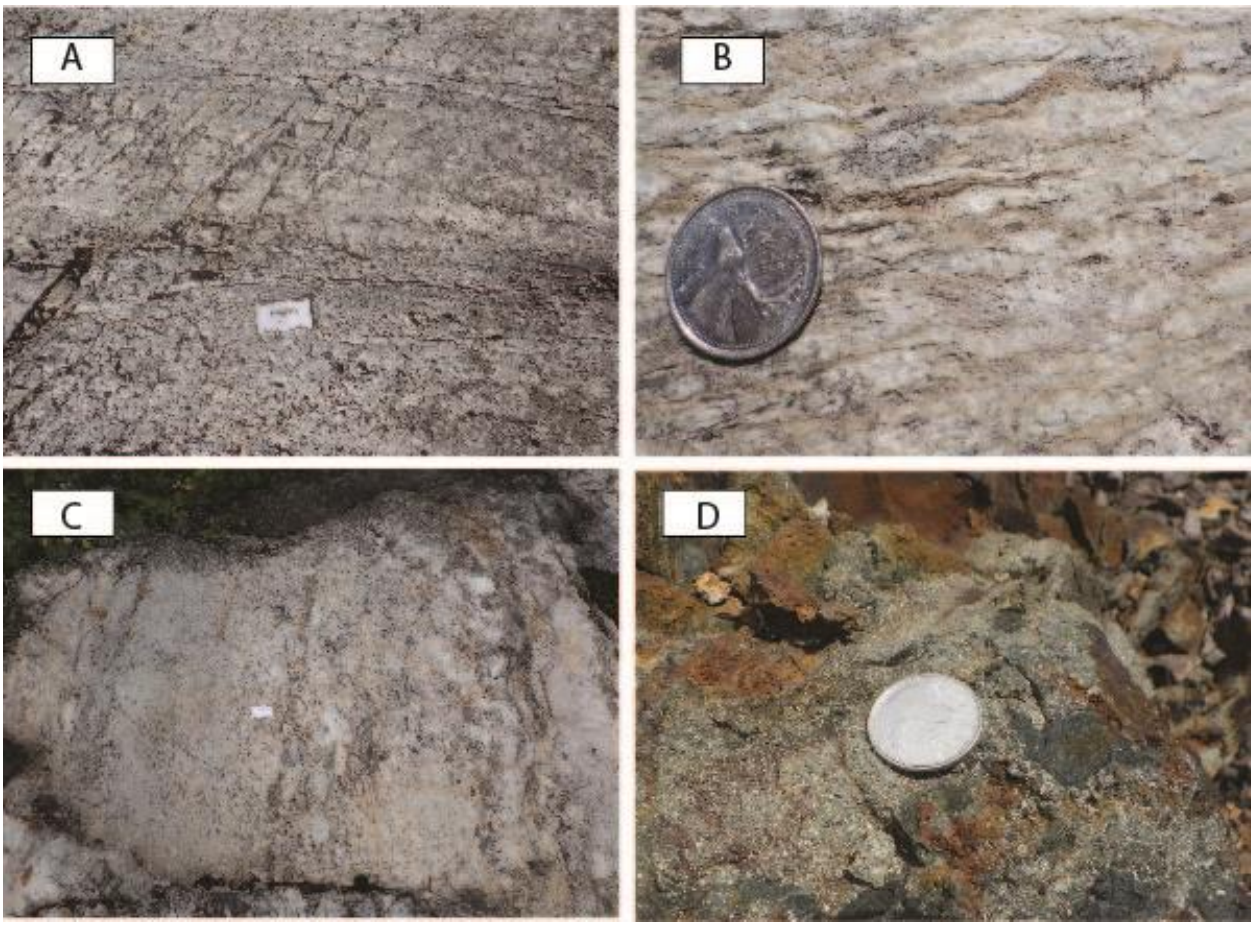

Figure 4: *Photo locations A to D. A) finely laminated tuff beds, stop 2, grain size card 8.5cm for scale; B) Wispy flattened fragments defined by chlorite and carbonate alteration, stop 2, coin 23.81mm for scale; C) Bedding within the heterolithic felsic lapillistone unit, stop 3, grain size card 8.5cm for scale; D) brecciated clasts of the mafic dyke, within the main sulphide vein, stop 3, coin 23.81mm for scale.*

Structure

The main foliation is ESE – WNW striking and dips moderately to steeply to the southwest. This foliation is defined by the strong flattening foliation of the dark wispy flattened clasts, a moderately well developed flattening foliation of the felsic clasts and the alignment of chlorite and sericite which wraps around the felsic clasts.

Mineralization and alteration

The mafic dyke (Figure 3) is strongly carbonatized. Sulphide alteration is pervasive throughout, both in the clasts and in the matrix. The sulphides are identified by weathered out euhedral pits and sulphide staining. The most abundant sulphide mineralization is located at the contact with the felsic volcaniclastic unit and the mafic dyke.

Interpretation

This depositional unit contains several clast types, the most abundant clasts are aphyric aphanitic felsic clasts, however the dark wispy flattened fragments are interpreted as possible pumice fragments which were originally vitric and were subsequently altered and flattened. These pumice fragments are indicative of an explosive pyroclastic eruption, however the rounded to subrounded shape of the other clast types and weak normal grading, of large clasts and blocks to fine ash beds, within this unit is indicative of a reworked and re-sedimented mass flow deposit. At the top of the succession, the mass flow deposits progress into suspension fall deposits, as defined by successive channel fill deposits.

Stop 3: Trailhead location (599288, 5352550; UTM Zone 17N, NAD83)

Continue along the unnamed road for 50m to reach stop 3. Park on the road which accesses the trench location for stop 3 which is located by a flagged trail on your left hand side. Continue on foot for 8 m to reach the main trench.

Lithological description

The heterolithic felsic lapilli tuff to lapillistone unit as described at Stop 1 is observed at this stop (Figures 5, 4C), which also contains the characteristic distinctive wispy flattened clasts and locally preserved in fine tuff beds are 1cm rounded clasts which are possibly accretionary lapilli. Additional clast types locally observed here, which are not observed at stop 1, are rounded to sub-rounded sulphide clasts (3% abundance). In sharp contact with this unit are plagioclase phyric mafic flows/sills, which are parallel to bedding, and contain an abundance of vesicles on one margin. Internally they exhibit polygonal cooling cracks. Plagioclase phyric mafic dykes with fine grained mafic minerals (possibly biotite) also cross cut this unit and are folded. These units are truncated by aphyric to quartz phyric rhyolite flows/sills, which have distinct flow banded margins with the heterolithic felsic lapilli tuff to lapillistone unit. Late aphyric aphanitic felsic dykes cross cut all units. However, the contact relationships observed with these felsic dykes and the mafic dykes are not sharp. The contact is typically brecciated and /or fluidal (Figure 6E). A heterolithic mafic and felsic volcaniclastic rock is observed which has been intruded by multiple injections of mafic dykes which all exhibit fluidal to brecciated margins and cooling cracks are observed in the centre of the dykes.

Structure

The relationship between bedding and cleavage is consistently at a high angle (Figure 5). The main foliation is SE-NW striking and steeply dipping to the SW defined by flattened of felsic clasts and the distinct wispy flattened fragments. The mafic flow/ sill is located within units of similar composition, it is parallel to bedding and the abundance of vesicles to the upper margin is most likely indicative of a mafic sill. A series of late sinistral offsets along minor brittle faults is observed at several locations.

Mineralization and alteration

Chlorite alteration is observed within the wispy flattened fragments and defines the foliation. Sulphide mineralization is disseminated throughout. The main sulphide mineralization is concentrated within the brecciated sulphide vein which contains wall rock fragments within the massive sulphide (Figure 4D). Proximal to the vein margins is strong chlorite and carbonate alteration.

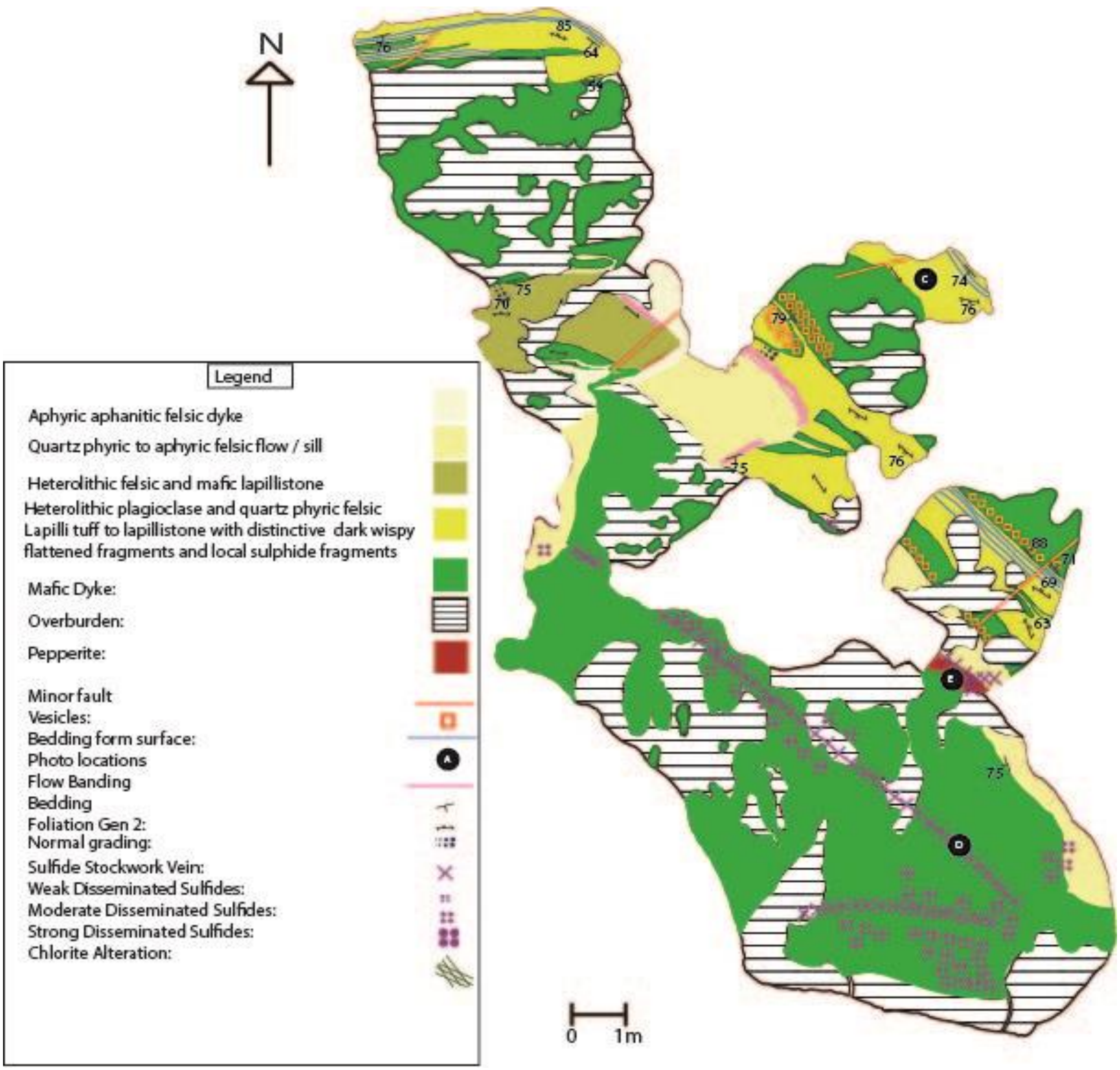

Figure 5: *Stop 3 – outcrop map showing lithology, structure and alteration and photo locations C, D, E.*

Interpretation

The fluidal and brecciated margins observed with the aphyric felsic dyke in contact with the heterolithic mafic and felsic volcaniclastic rock and similar contacts observed with the mafic dykes represent a peperite texture. This texture is interpreted as intrusion of the mafic dykes and the aphyric felsic dykes into unconsolidated sediment. Therefore, these multiple injections of dykes into partially consolidated material indicate the dykes are synvolcanic. This has implications for the mineralization which is associated with a sulphide brecciated vein that is truncated by the rhyolite flow / sill.

Stop 4: Canagau shaft Trailhead location (599296, 5352384; UTM Zone 17N, NAD83

Continue along the unnamed road for 166m to reach the trailhead for stop 4. Park on the road which accesses the trench location for stop 4 which is located by a flagged trail on your right hand side. Continue on foot for approximately 10 m to reach the Canagau shaft.

The Canagau shaft observed here and the respective tailings exhibit sphalerite, galena, chalcopyrite, bornite and pyrite. Mineralization is associated with east striking shear zones in the rhyodacite. These observations are confirmed in the report by Jensen (1975) which describes a 60 lb underground bulk sample that was collected at the Canagau mine in 1927, and produced 3.4 oz /ton silver, 3.76 % lead, 6.46 % zinc. A grab sample from 1969 taken from near the shaft was analysed at Swastika Laboratories as: - 0.75 oz /ton gold, 0.96 oz /ton silver, 0.04 % copper, 1.86 % lead, 3.94 % zinc (Jensen, 1975).

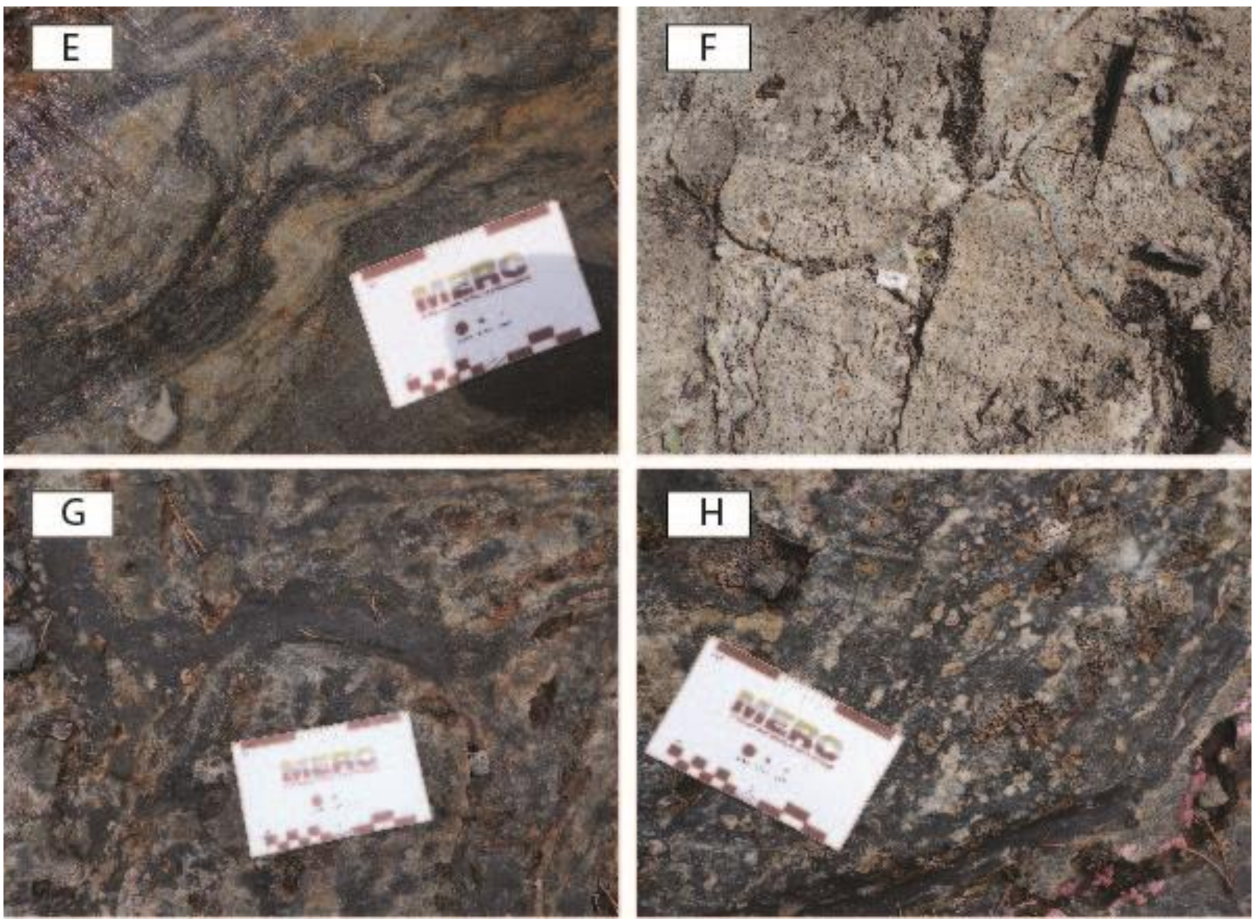

Figure 6: *Photo locations E to H. E) fluidal texture at the margin of the felsic dyke with the mafic dyke on stop 2, Figure 5; F) large well developed mafic pillowed lavas, showing distribution of vesicles within the pillows, stop 5, Figure 7; G) chloritized pillow selvedge at stop 6, Figure 8; H) carbonate altered amygdules within the chloritized pillows. (All photos show an 8.5cm grain size card for scale)*

Stop 5: Trailhead location (599282, 5352314; UTM Zone 17N, NAD83)

Continue along the unnamed road for 70m to reach the flagged trail for access to stop 5 located on the right hand side. Park on the road. Continue on foot for approximately 20 m to reach the trench located at stop 5.

Lithological description of the Felsic lapillistone and mafic pillowed lavas

At this stop (Figure 7) we review the contact between the aphyric aphanitic felsic lapillistone to tuff breccias and the mafic pillowed lavas. The aphyric aphanitic felsic lapillistone contains densely packed clasts that are subrounded and locally flow banded. The matrix is aphyric and the clasts are monomictic aphyric felsic clasts. (Note at the northern end of the outcrop an area 1.5 m – 30cm composed of scoriaceous fragments is identified within the otherwise monomictic felsic volcaniclastic rocks). The contact with mafic pillowed lavas is sharp and at the contact is a finely laminated sediment (5 – 8 cm wide). On top of this sediment lie mafic pillowed lavas (Figure 6F). These pillow shapes are moderately well defined 0.5m to 5.5 m and contain abundant vesicles throughout. The greater abundance of vesicles appears to lie on the side of the pillows not adjacent to the contact with the felsic volcaniclastic rocks. The pillow selvedges are 1 – 2cm wide and finely laminated beds are observed around the pillows (Figures 6F and 7).

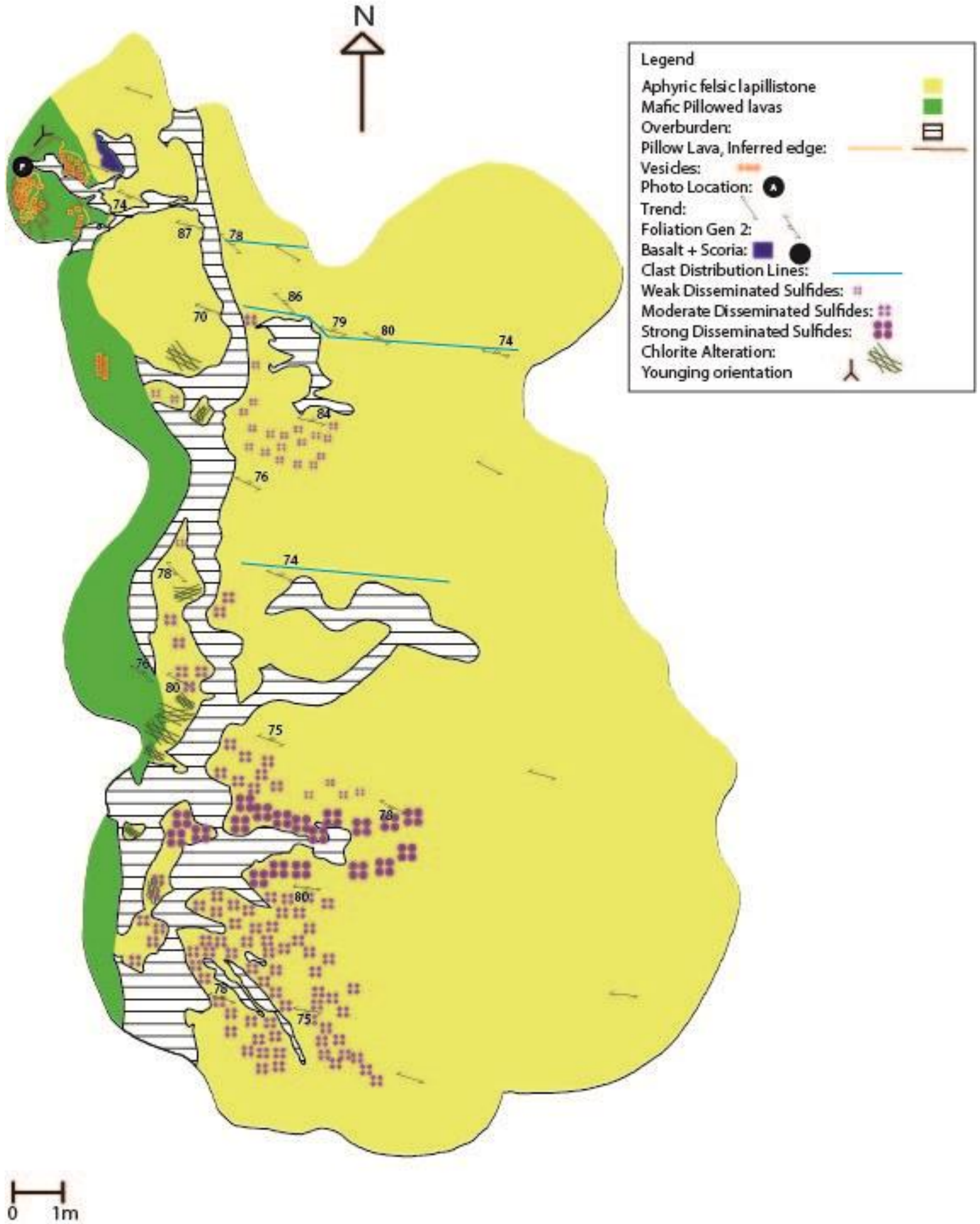

Figure 7: *Stop 5 – outcrop map showing lithology, structure and alteration.*

Structure

The main foliation is defined by chlorite alteration wrapping around felsic clasts and defining weakly aligned clasts. This foliation is SE-NW striking and steeply dipping to sub vertical to the NE or SW. Facing directions in the pillows are interpreted to the SW which is consistent with previous mapping by Gagnon, 1996 and is consistent with the regional interpretation. The shape of the pillow structures is not unequivocal, but they display a distinctive pillow-shaped bulbous upper surface with a downward pointing tapered cusp on the lower surface, but due to their weak flattening and large size, there is insufficient outcrop exposure, to use these criteria alone to determine pillow facing directions. Therefore, pillow facing directions are based on the abundance of vesicles towards the top of the pillows and the bedded inter-pillow infiltration sediment.

Mineralization and Alteration

Carbonate alteration is weakly developed in the pillows and at the contact between the pillows and felsic volcaniclastic deposits at the north. There is a strong increase in carbonate alteration across the outcrop from north to south. Chlorite alteration is weakly developed here, however these felsic volcaniclastic rocks were likely originally chlorite altered to enable extensive carbonate alteration. The strongest carbonate and sulphide mineralization is concentrated in the felsic volcaniclastic rocks, and is focused along a structure trending ESE-WNW which is discordant to the contact with the mafic pillowed lavas.

Interpretation

The felsic volcaniclastic unit described here is interpreted as a mass flow deposit, in situ rhyolite breccia, from mass wasting of the rhyolite dome.

Stop 6: Trailhead location for Erhart property (599440, 5351800; UTM Zone 17N, NAD83)

Continue along the unnamed road for 514m to reach the large open clearing at 599332E, 5352137N, which is the turnaround location on the road and access to Stop 6. Park in the clearing which accesses the trench location for stop 6, which is located by road and trail access. Continue on foot for approximately 400 m to reach the trailhead for access into the trench location for stop 6. (Note that the road to the trailhead location is driveable for those that need driving access. However, the turnaround location and space for vehicles at the trailhead is limited). Continue on foot for a further 35m from the trailhead to access the trench.

Lithological description for mafic pillowed lavas and aphyric intermediate dykes

The mafic pillowed lavas contain a high abundance (70%) of vesicles. The pillow selvedge ranges in thickness from 1cm to 3cm. The pillow shapes are poorly defined and the range of pillow sizes is variable >2m to 30 cm or less. The contact between the pillowed lavas and the intermediate dykes is sharp (Figure 8). The intermediate dykes are aphyric and strike NE. An intermediate sill is identified, based on the conformable relationship to stratigraphy from regional mapping and evidence of columnar joints which are perpendicular to the margin and are curved. This has been previously interpreted by Gagnon, (1996) to indicate magma drainage back into the pipe, and the thick (25cm) chilled margins were considered shallow level emplacement at less than 400m sub seafloor.

Structure

Pillow facing directions were indeterminate at this location. The regional foliation is consistently SE-NW striking and steeply dipping to sub vertical. A series of intermediate dyke's trend NE.

Mineralization and alteration

Strong chlorite alteration is observed in the pillow selvedges (Figures 6G, 8). Strong carbonate alteration is observed in the vesicles in the mafic pillowed volcanic rocks and massive flows (Figure 8), which are filled with carbonate alteration (Figure 6H). Sulphide mineralization is observed as disseminated locally throughout the intermediate dykes, mafic pillowed lavas and massive mafic flows. Moderately strong stringer and disseminated sulphide mineralization and weak carbonate alteration is associated with fractures associated with late NE striking intermediate dykes and NE trending sulphide brecciated veins.

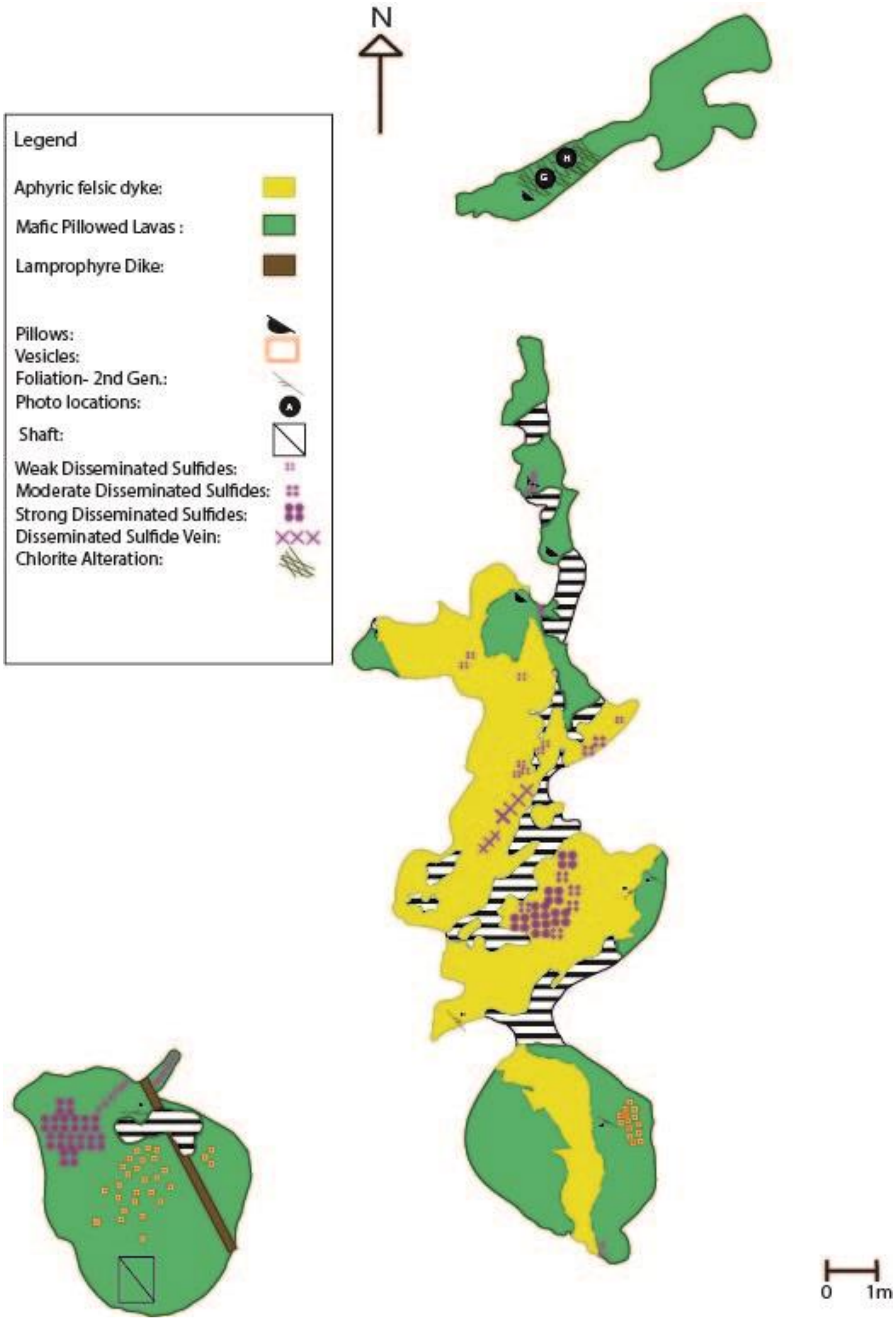

Figure 8: *Stop 6 – outcrop map showing lithology, structure and alteration.*

Interpretation

Previous interpretations by Gagnon, (1996) considered that these dykes were feeders to the Canagau rhyolite flows. Proximal VMS alteration is indicative from the strong chlorite alteration, and weak to moderate carbonate alteration, which is displayed at the Erhart trench. Mineralization is predominantly spatially associated with the dyke margins and local stringers zones at Erhart.

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METAL EARTH

2019 Field Trip Guide

Rainy River, Ontario

CANADA FIRST RESEARCH EXCELLENCE FUND | APOGÉE CANADA FONDS D'EXCELLENCE EN RECHERCHE

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Stratigraphic and structural characteristics of the Rainy River area (Western Wabigoon - Quetico subprovinces)

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Meeting Location: Green's BBQ and bar, Nestor Falls. 8:30 am, Monday, September 9.

Introduction

The Rainy River transect is part of the larger Metal Earth project led by the Mineral Exploration Research Centre (Laurentian University, Sudbury) and whose the main objective is to constrain factors controlling the metal endowment within Archean greenstone belts. The Rainy River transect area lies within the western Wabigoon and the Quetico subprovinces that form part of the Archean Superior Province. Although greenstone belts composing the western Wabigoon subprovince are generally poorly endowed in base and precious metals (< 10 Moz Au), the Rainy River greenstone belt (RRGB) is marked by the occurrence of the Rainy River gold deposit (3.7 Moz Au; New Gold report, 2014) and constitutes a very prospective terrain for Au, Ag, Cu, Ni, Co and PGE mineralization. These occurrences comprise variable deposit styles (e.g. volcanogenic Au-rich sulfide deposit related to felsic volcanism, magmatic Ni-Cu-Co-PGE sulfide deposit) and were formed as result of several mineralizing events. The Rainy River crustal block also includes numerous major regional structures that could act as conduits for mineralized fluids and potentially host gold mineralization. Despite numerous studies focused on the mineralization of the Rainy River gold deposit (Wartman, 2011; Pelletier et *al*., 2014; Pelletier et *al*., 2015), the regional geological and metallogenic setting of this district remains poorly constrained.

The purposes of this study are to constrain (i) the stratigraphic and the structural frameworks of the RRGB and the Quetico subprovince, (ii) the geodynamic evolution of the Rainy River - Quetico crustal blocks, and (iii) to place the formation of mineral deposits in complete crustal-scale context. To address these topics a multi-disciplinary approach combining geological mapping, geochemistry and geochronology will be applied. The interpretation of seismic, magnetotelluric and gravity data sets from geological mapping will be also performed in order to determine the geology of the Rainy River transect at depth. Ultimately, the compilation of these results will permit determination of the metallogenic evolution of the RRGB and identify the factors controlling the metal endowment in the western Wabigoon subprovince.

The research on the Rainy River transect is carried out by a MSc student (Mattea McRae) and the transect RA (Gaëtan Launay). This field trip aims to introduce the preliminary results obtained during the 2019 field season, which was mainly focused on the stratigraphic and structural setting of the Rainy River greenstone belt (RRGB) and the Quetico subprovince. The first part of this field trip constitutes an introduction of the geological characteristics of the mafic and felsic volcanism of Off-Burditt-Clearwater Lake that exhibits a well preserved volcanic plumbing system and represents a good analog of the mineralized volcanic center of the Rainy River gold deposit. The second part focuses on (i) the boundary between the mafic-felsic volcanic rocks of the RRGB and the metasedimentary sequence of the Quetico subprovince, and (ii) the structural characteristics and metamorphic grade through the Quetico subprovince.

Regional geological setting

The RRGB belongs to the western Wabigoon subprovince (WWS). This subprovince is mainly composed of metavolcanic sequences organised as anastomosing belts surrounding large younger granitoid batholiths (Fig. 1) (Percival, 2007). Based on lithostratigraphic and structural criteria, these volcanic rocks can be regrouped into four main sequences (Blackburn et *al*., 1991): (i) the lower mafic sequences mainly composed of tholeiites, (ii) the intermediate to felsic volcanic sequences composed of calc-alkaline lava flows, coeval intrusions and pyroclastic rocks, (iii) the upper ultramafic to mafic sequences composed of tholeiites, and (iv) the sedimentary sequences composed of turbidites and alluvial sediments. These different units were mainly affected by a regional greenschist metamorphism and locally exhibit an amphibolite metamorphism related to the emplacement of batholith intrusions. The rise of these granitoid batholiths also caused the formation of synformal structures in volcanic sequences and their margin are often marked by the occurrences of regional shear zones. Most of tectonic structures and fabrics of the WWS are related to the progressive N-S accretionary regime that occurred during the central Superior Orogeny (2720 to 2660 Ma) (Melnyk et *al*., 2006; Percival et *al*., 2006b). This north-south shortening triggered folding, shearing and faulting accompanied by metamorphism and plutonism.

The metavolcanic units composing the RRGB are bounded on the north by the Sabaskong batholith, on the southeast by the Flemming-Kingsford batholith, on the east by the Jackfish Lake pluton and by the Quetico fault to the south. All of these batholiths are variably deformed and interpreted as syntectonic intrusions (Blackburn, 1976). Three late tectonic plutons of monzogranite to quartz monzogranite (the Burditt Lake, Finland and Black Hawk stocks) intruded the RRGB. The calc-alkaline intermediate to felsic metavolcanic rocks of the RRGB occur as isolated volcanic centers but can be spatially correlated to each others and to other felsic volcanic units through the WWS. These intermediate metavolcanic rocks host most of the Rainy River gold mineralization (Richardson Township) and also the mineral occurrences occurring in the Off-Burditt-Clearwater Lake area.

To the south, the RRGB is bounded by the Quetico subprovince (QS), interpreted as a forearc sedimentary basin with depositional ages (2698 to 2690 Ma) overlapping the arc magmatism occurring in the WWS (Percival, 2007). The QS consists mainly of metasedimentary rocks of turbiditic origin and rare conglomerates that derived probably from the WWS. Metamorphic grade varies from greenschist at the margins to upper amphibolite and local migmatite in the central intrusive granite zone. The boundary between the RRGB and the QS corresponds to the Quetico fault, a 200 km east-west striking subvertical shear zone characterized by a dextral movement related to a transpressive regime (Davis *et al*., 1989; Blackburn *et al*., 1991; Fernàndez *et al*., 2013).

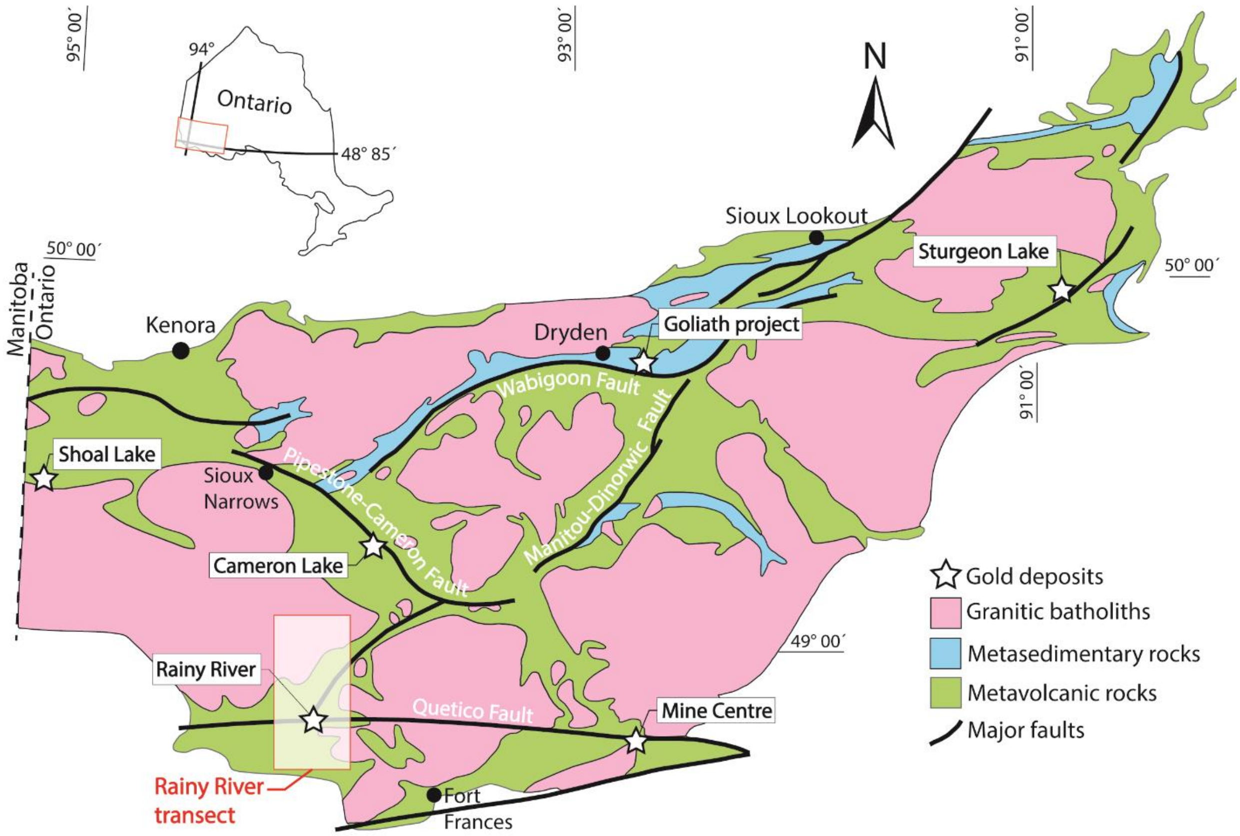


Figure 1 Simplified geological map of the western Wabigoon subprovince displaying the location of the main Au deposits and prospects (modified from Blackburn et *al*., 1991).

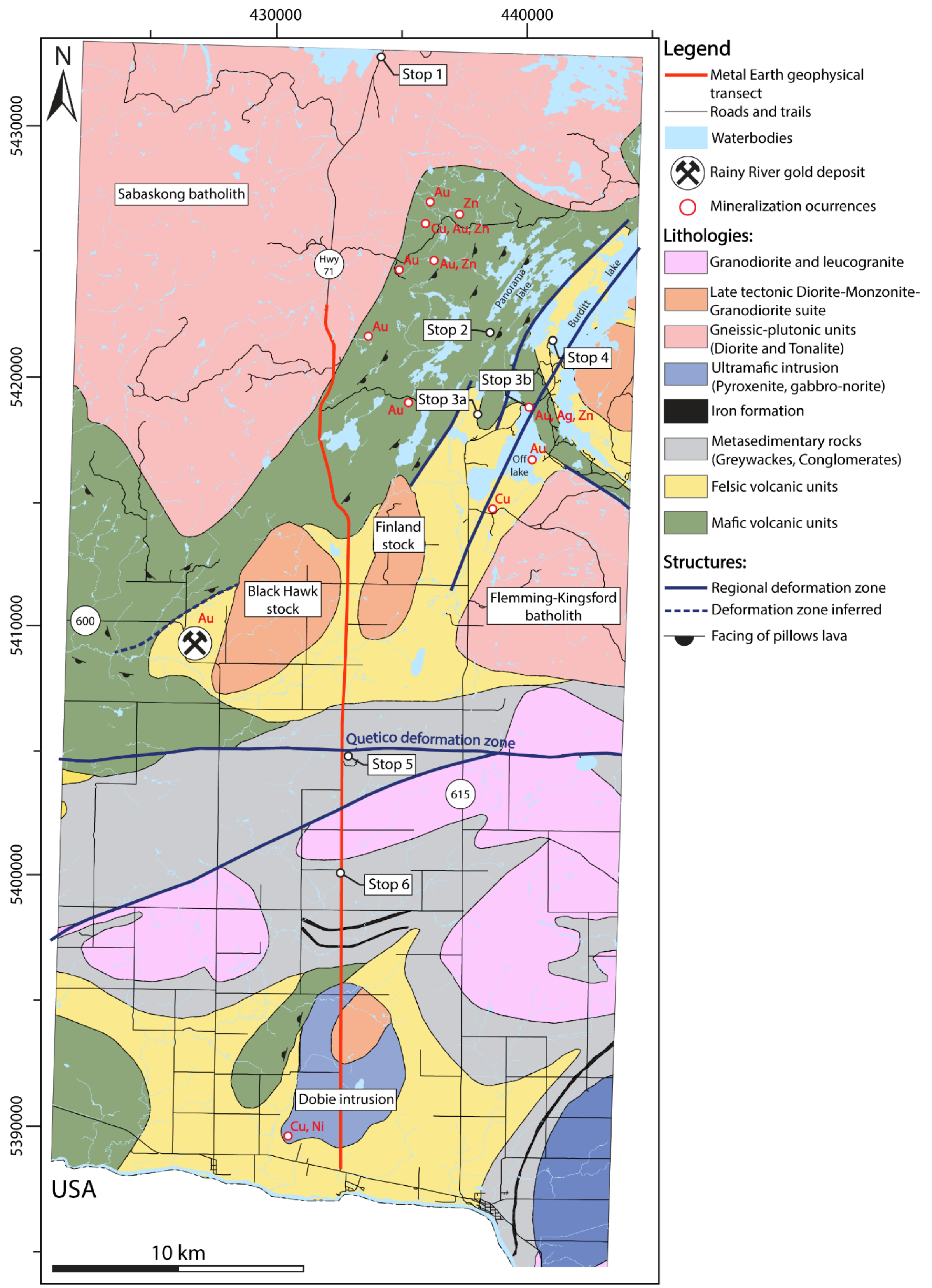


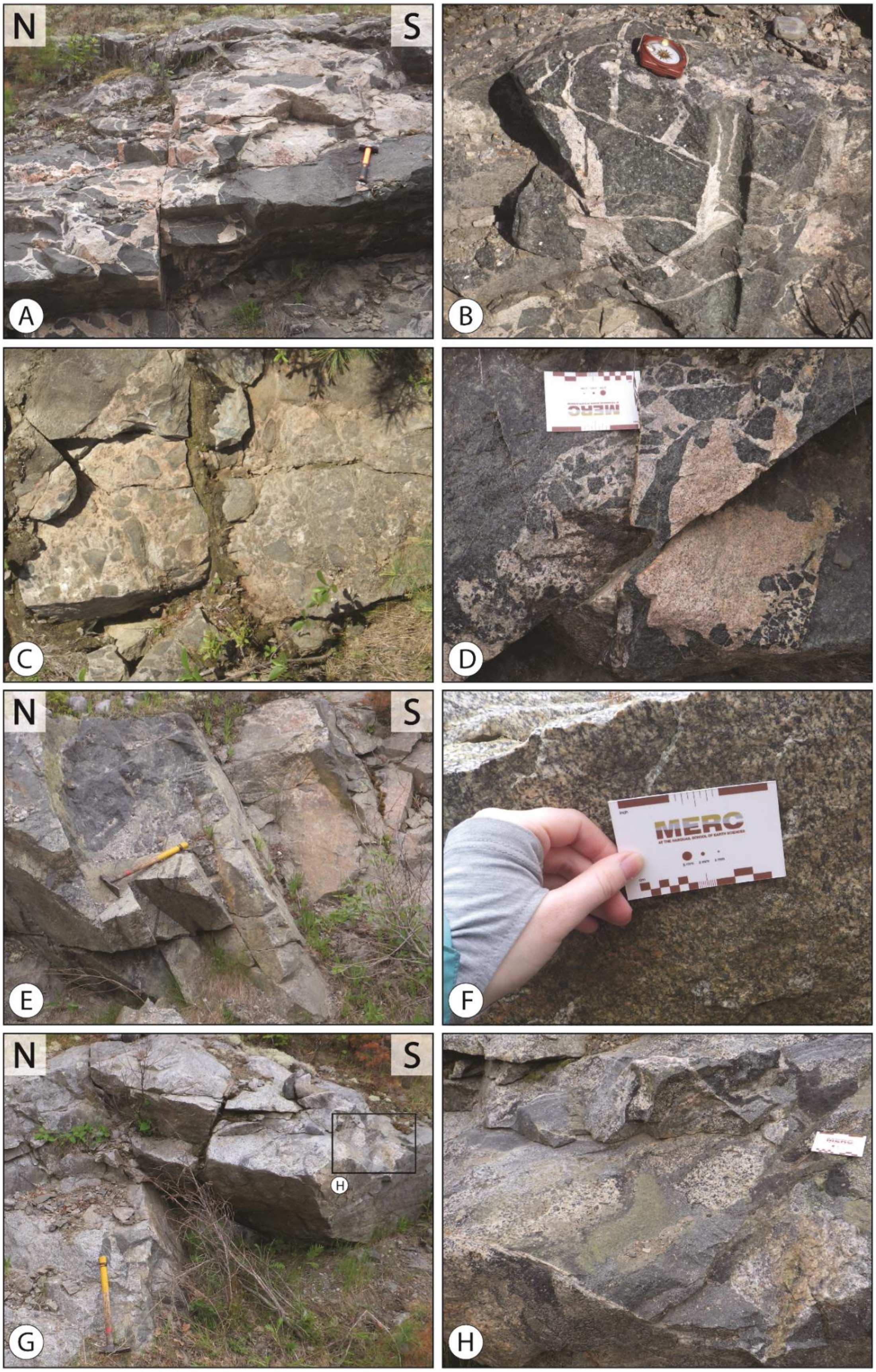
Figure 2 Geological map of the Rainy River transect displaying the field trip stops (NAD83 Zone 15).

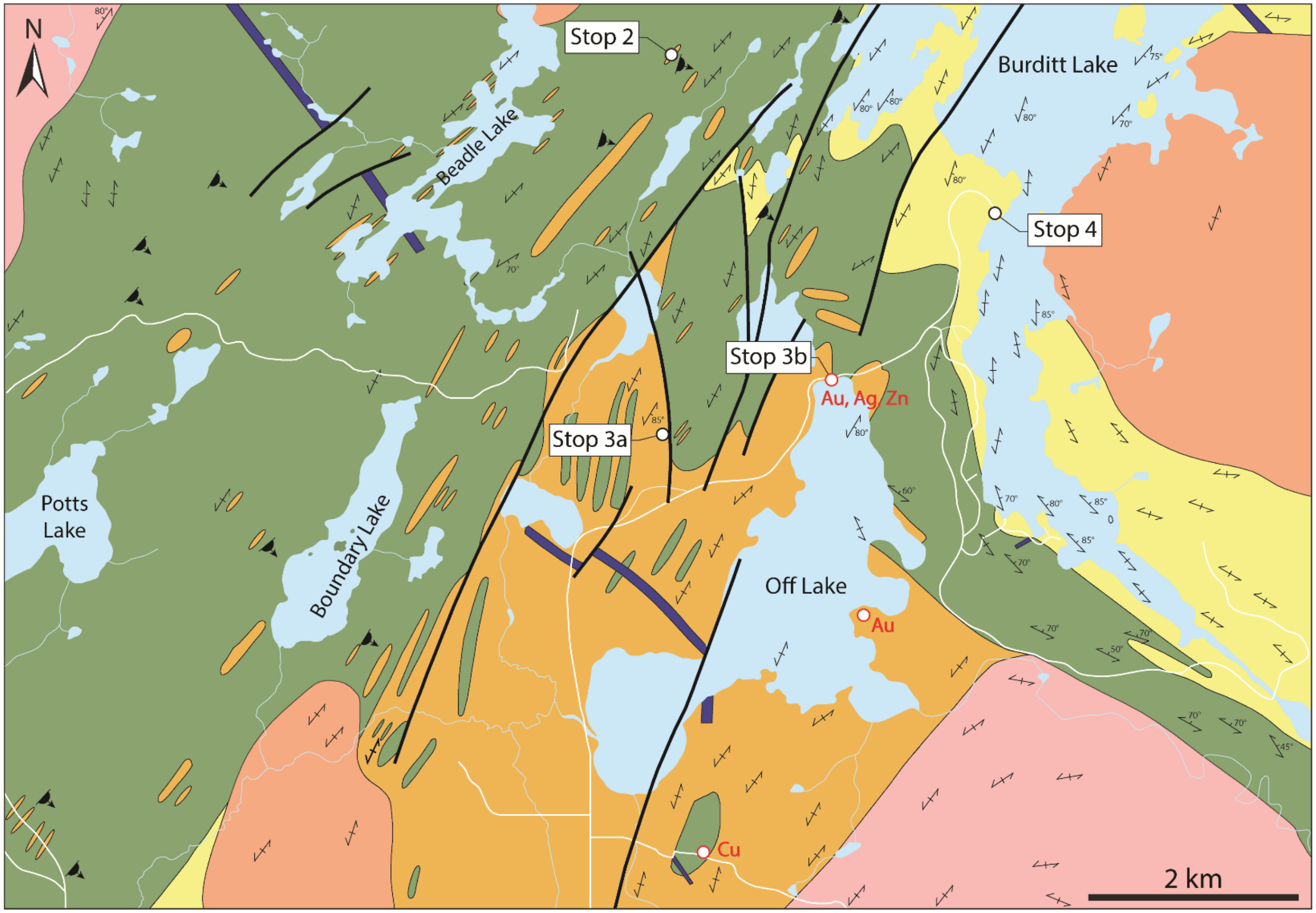
Stop 1: Mafic to ultramafic enclave in the Kishkutena tonalite of Caliper Lake, Sabaskong batholith

Take highway 71 in the south direction until Larsen's *camp. Vehicles can be parked on the parking of the camp. The rock exposure is located in the east side of the Trans Canada highway 71 close to the Larsen*'s *camp (UTM: 15U 434209 mE, 5432886 mN)*

The Sabaskong batholith is a complex and polyphased intrusive body composed of a series of diapiric plutons mainly composed of tonalitic to granodioritic gneiss forming gneissic domes. Late granitoid plutons of various compositions (diorite to monzogranite) occur between these gneissic domes. The Kishkutena hornblende-biotite tonalite (2724±1.9 Ma) constitutes the most common facies and is exposed over 110 km^2 (Davis and Edwards, 1982). At Caliper Lake, metamorphosed mafic to ultramafic enclaves are present in the Kishkutena tonalite. This stop exposes one of these enclaves (Fig. 3). This coarse grained amphibolitized enclave can display a chlorite-epidote alteration and is marked by a brecciated texture related to the emplacement of the Kishkutena tonalite (Fig. 3a to 3d). The contact between this enclave and the tonalite is sharp (Fig. 3e) and can be followed to the mafic volcanic unit of the RRGB to the southeast using aeromagnetic interpretation. Accordingly, these enclaves could be mafic intrusions that fed the mafic volcanism that occurred in the RRGB and at Kakagi Lake (Davis and Edwards, 1982). Several samples for petrographic and geochemical analysis have been collected to compare with mafic volcanic unit of the RRGB and test the hypothesis of a potential genetic link between these two mafic magmatic systems. A weak, NW-SE striking foliation steeply dipping to the NE can be observed in the tonalite (Fig. 3f). Occurrences of rounded enclaves of the Kishkutena tonalite in gabbro dykes (Fig. 3) suggest an overlap in timing of mafic and felsic magmatism. Geochronological samples of mafic rocks and tonalite have been collected in order to constrain the timing of these different magmatic activities.

Figure 3 Field photographs displaying mafic-ultramafic enclave occurring in the Kishkutena tonalite of the Sabaskong batholith. (a) to (d) Mafic-ultramafic enclave brecciated and crosscut by the Kishkutena tonalite. (e) Contact between the mafic-ultramafic enclave and the Kishkutena tonalite. (f) Well foliated tonalite. (g) and (h) Enclaves of tonalite surrounded by mafic rocks.





Lithologies:

- Diabase
- Late tectonic Diorite-Monzonite-Granodiorite suite
- Gneissic-plutonic units (Diorite and Tonalite)
- Felsic volcanoclastic rocks (Tuff, tuff breccia, lapilli-tuff, lapillistone)
- Felsic lavas and intrusions (Rhyolitic and dacitic lavas, quartz-feldspars porphyry, quartz porphyry)
- Mafic volcanic units (gabbro, massive basalt, pillows, porphyritic lavas)

Structures:

- Fault/shear zone
- Facing of pillows lava
- Vertical foliation
- Inclined foliation

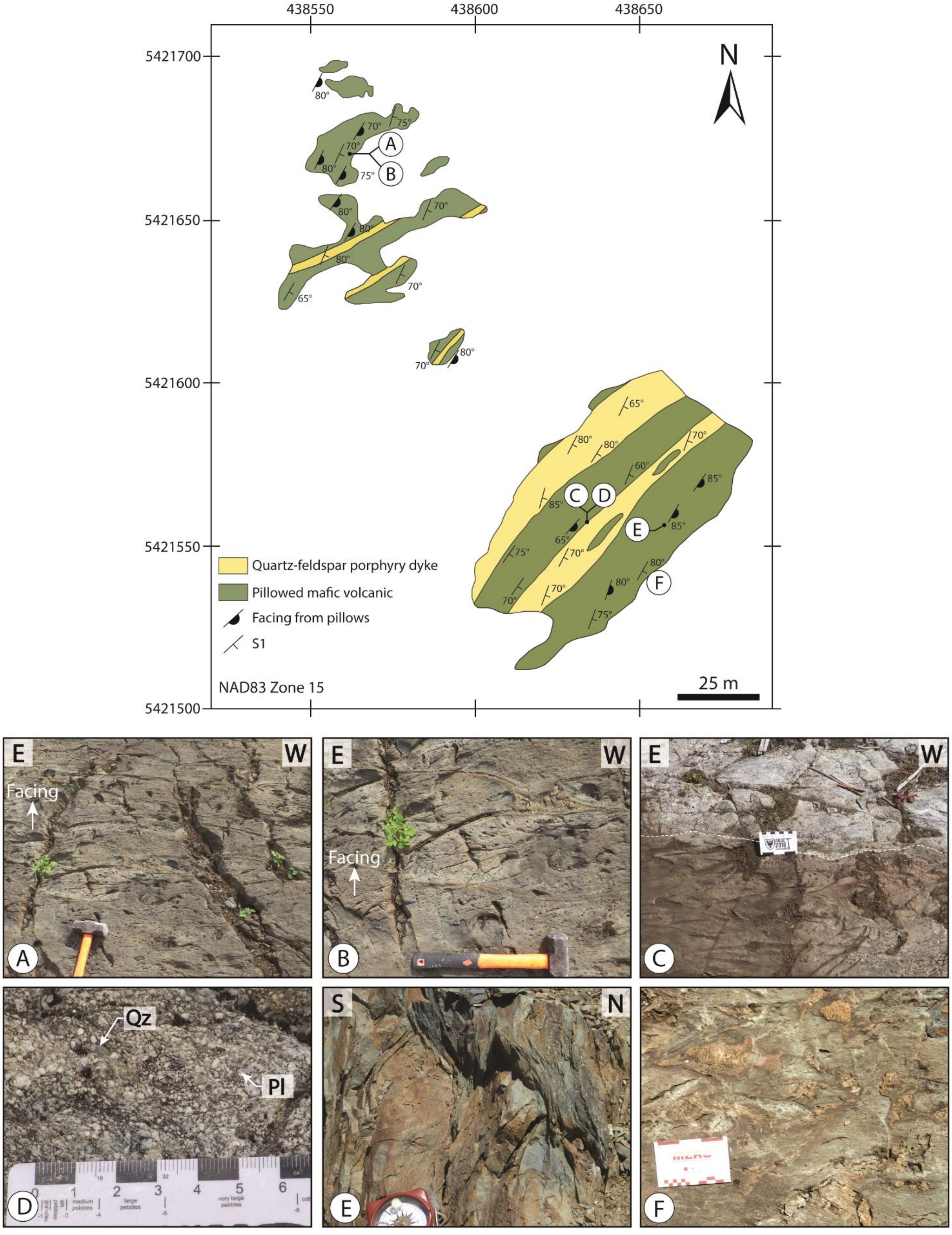
Figure 4 Geological map of the Off-Clearwater-Burditt Lake area

Stop 2: Pillowed mafic flows and quartz-feldspar porphyry sills of the lower mafic sequence of the RRGB

Return to your vehicle and continue south on the highway 71, turn on the left at the Finland corner taking the Lampi road. Follow this road to the end and turn left onto highway 615. Continue on this road until Burditt Lake, turn left onto the road leading to the Pipestone air base, and continue on this road for ~ 50 m, turn left at the crossroads and continue until the power station. Park the vehicles on the parking close to the power station. Rock exposure is located under the power lines close to the power station (UTM: 15U 438557 mE, 5421697 mN)

The lower mafic metavolcanic unit of the RRGB consists mainly of a succession of gabbroic intrusions, massive basaltic lava flows, porphyritic lava flows and pillow lavas. Based on the facing determined from pillowed flows, it appear that the metavolcanic stratigraphy of the Off-Burditt Lake is characterized by a southeasterly facing homoclinal sequence occurring between the Sabaskong and the Fleming-Kingsford batholiths (Fig. 2). This outcrop illustrates the stratigraphic variation of the RRGB. This includes massive to pillowed flows (Fig. 5a and 5b) and flow breccia (Fig. 5f). The pillows display well-developed selvages and contain abundant large vesicles (Fig. 5b). These pillows are steeply dipping and exhibit clear southeast facing consistent with the regional stratigraphy of the mafic metavolcanic unit. A weak foliation parallel to the pillows that strikes NE and dips steeply to the SE suggests that pillows were weakly flattened during the regional deformation. Chlorite alteration and disseminated sulphide mineralization marked by boxwork textures can be locally observed along the pillow selvages (Fig. 5e) and foliation planes. These sulphides define a mineral lineation plunging steeply to the NE (52/75). Dikes and sills of quartz-feldspar porphyry (QFP) can be observed between pillowed and massive basaltic flows (Fig. 5). These QFP exhibit porphyritic texture composed of quartz eye and plagioclase phenocrysts (Fig. 5d). Like pillows, the QFP dikes were weakly foliated. A more intense deformation of pillows along contact with QFP dikes can be observed (Fig. 5c) and suggest competence contrast between these two lithologies and a preferential deformation of pillows during the regional deformation.

Figure 5 Geological map of the *"power station"* outcrop exposing a succession of pillow basalt and quartz-feldspar porphyry sills (locations on the map correspond to placement of photographs). (a) and (b) Pillow lavas displaying a southeast facing. (c) Sharp contact between pillow basalt and quartz-feldspar porphyry (QFP). (d) QFP displaying porphyritic texture marked by quartz eyes and plagioclase phenocrysts. (e) Selvages of pillows chloritized and mineralized in sulphides. (f) Pillow breccia epidotized.



Stop 3a and 3b: The Off Lake quartz-feldspar porphyry sub-volcanic intrusion

Return to your vehicle and come back to the highway 615. At the stop sign, turn right, continue on this road until Pony Lake and turn right onto the road leading to a quarry. Continue on this road for ~1 km and turn on the left at the crossroads down the hill. At this spot vehicle can be parked on this side road, the outcrop is located at ~50 m (UTM: 15U 438246 mE, 5418472 mN).

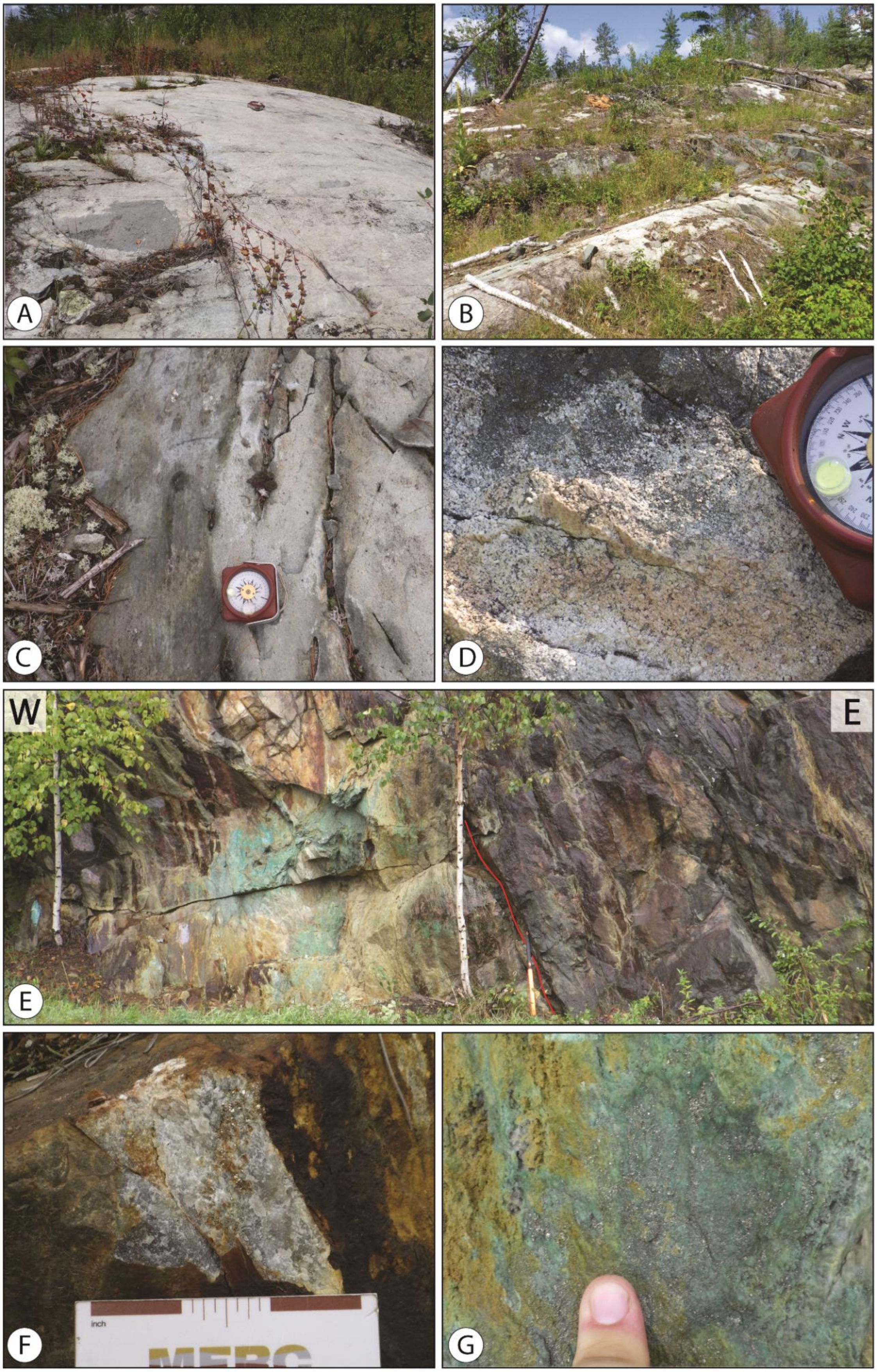
A large quartz-feldspar porphyry (QFP) sub-volcanic intrusion is exposed close to Off Lake. This felsic intrusive complex is characterized by an NE-SW elongated shape (9×4.5 km) and occurs in the upper part of the lower mafic metavolcanic unit of the RRGB. Stop 3a consists of a large exposure of this QFP sub-volcanic intrusion (Fig. 6a). The contacts between the QFP and the mafic country rocks (gabbro intrusions, massive and porphyritic basaltic lava flows) are sharp and can be followed over distances of up to several hundred meters. Numerous enclaves and dikes of metavolcanic rocks can be observed in this intrusive complex (Fig. 6b and 6c). QFP is variably foliated with foliation planes striking NNE and dipping steeply to the east (35/80). The mineralogical composition and the textural characteristics of QFP composing this intrusive complex (Fig. 6d) are similar than those of the QFP dikes-sills occurring in the mafic metavolcanic unit of the RRGB (see stop 2). QFP consists of quartz eye and feldspar phenocrysts of 0.5 cm long and siliceous-aphanitic matrix. The age of the sub-volcanic intrusion and its genetic link with the felsic volcanoclastic units of Burditt and Pinewood Lakes are unknown. Samples for geochemical analyses and geochronology have been collected this summer to address these research topics.

Return to your vehicle to come back to the highway 615 and turn left to go to the stop 3b. Drive along Off Lake until the north end of the lake. There is a small parking area on the left part of the road to park the vehicles. The outcrop is marked by a fuchsite rich zone (UTM: 15U 439904 mE, 5418799 mN).

The QFP is generally homogeneous and unaltered. However, stop 3b exposes a north trending fuchsite rich zone (Fig. 6e), which marks the contact between highly altered and foliated QFP and foliated metagabbro. The QFP is strongly affected by a quartz-sericite alteration and has a high content of sulphides including pyrite, arsenopyrite and chalcopyrite (Fig. 6f). Metagabbro occurring close to the mineralized zone also contains variable amounts of sulphides. The strong deformation of this mineralized zone suggests that this contact could acted as a fault during the regional deformation.

Figure 6 (a) Field photograph showing the quartz-feldspar porphyry sub-volcanic intrusion of Off Lake. (b) Mafic metavolcanic dyke in the quartz-feldspar porphyry intrusion. (c) Contact between the quartz-feldspar porphyry a mafic metavolcanic dike. (d) Textural and mineralogical characteristics of the porphyry. (e) Fuchsite rich zone underlying the contact between the quartz-feldspar porphyry (to

the west) and the metagabbro of the country rock (to the east). (f) and (g) Zoom on mineralized and highly altered quartz-feldspar porphyry.



Stop 4: Felsic pyroclastic unit of Clearwater-Burditt Lake

Return to vehicle and take the highway 615 in the north direction, follow this road until the end (parking close to Burditt Lake). Park vehicle on the parking in front of the lake (UTM: 15U 441422 mE, 5420244 mN).

The felsic volcanoclastic unit of Clearwater-Burditt Lake outcrops extensively on the shores and the islands of Burditt Lake. Stop 4 (Fig. 7) exposes a series of outcrops of monolithic tuff-breccia and felsic lapilli tuff to lapillistone. The tuff breccia are composed of coarse grained (0.5 to 1 cm quartz eye and plagioclase phenocrysts) quartz-feldspar porphyry clasts surrounded by a fine grained strongly foliated matrix (Fig. 7a to 7c). Clasts of QFP were flattened and elongated parallel to the foliation, which strikes NNE and dips to the east (15/55). These clasts are texturally and probably compositionally similar to QFP composing the sub-volcanic intrusive complex of Off Lake (stop 3). This first facies of felsic volcanoclastic rocks could be interpreted as autoclastic rock resulting from autobrecciation related to extrusive volcanism (extrusive domes). The second type of volcanoclastic rocks exposed at this stop consists of lapilli tuff to lapillistone mainly composed of aphyric felsic fragments (Fig. 7d to 7f). These clasts are rounded and less deformed than clasts composing the tuff breccia suggesting a deformation gradient between the two rock exposures. The felsic volcanoclastic unit of Clearwater-Burditt Lake could constitute the effusive expression of the sub-volcanic intrusive complex of Off Lake. To test this hypothesis and constrain the volcanic story of the Off-Clearwater-Burditt Lake area, samples of these different facies of volcanoclastic rocks have been collected for geochemical analyses, mineralogical study and geochronology.

Comparison between the volcanic system of Off-Clearwater-Burditt Lake and the mineralized volcanic center of Rainy River will permit to constrain (i) the overall geological and volcanic context of the Rainy River gold deposit, and (ii) processes involved during the mineralization.

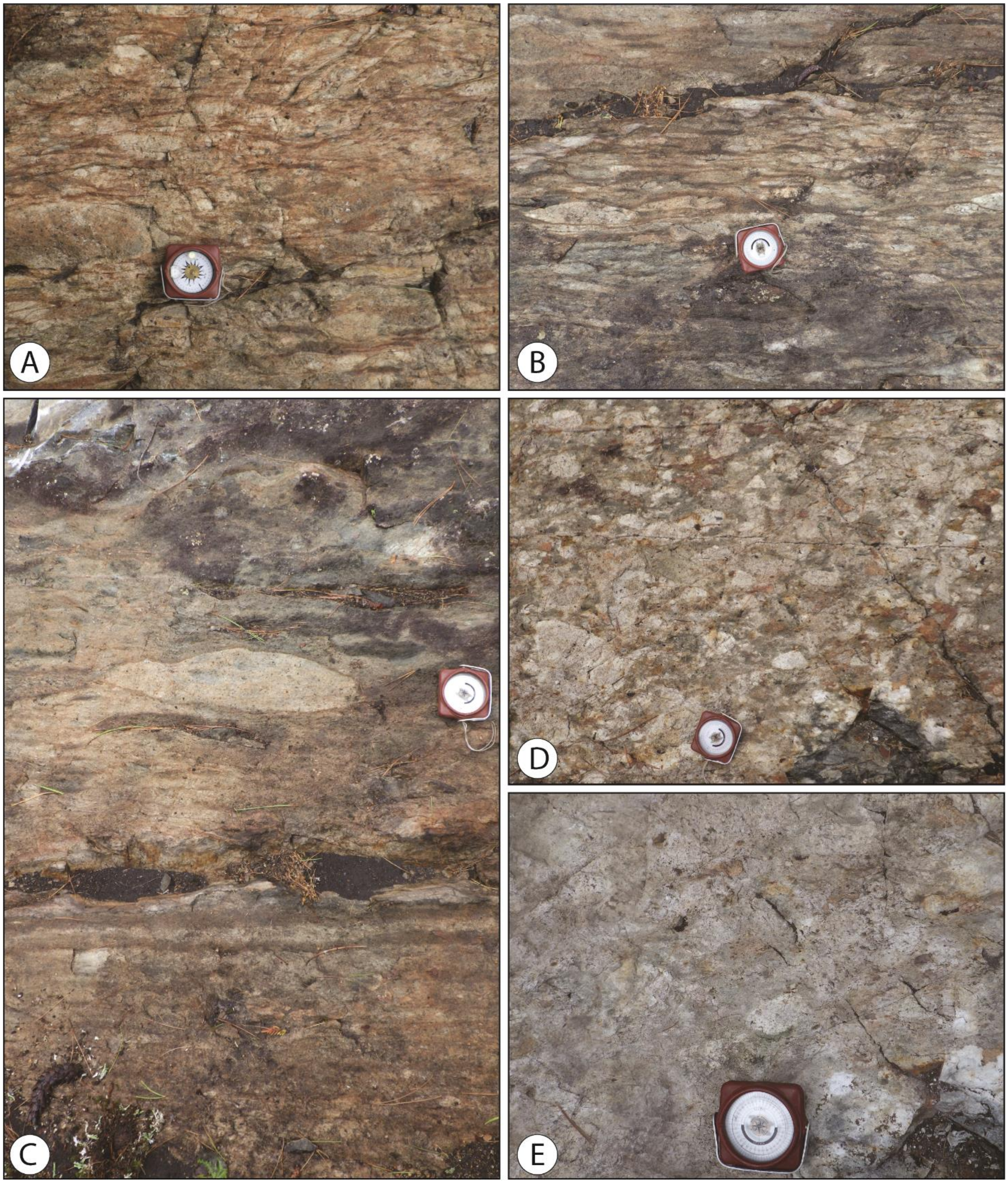


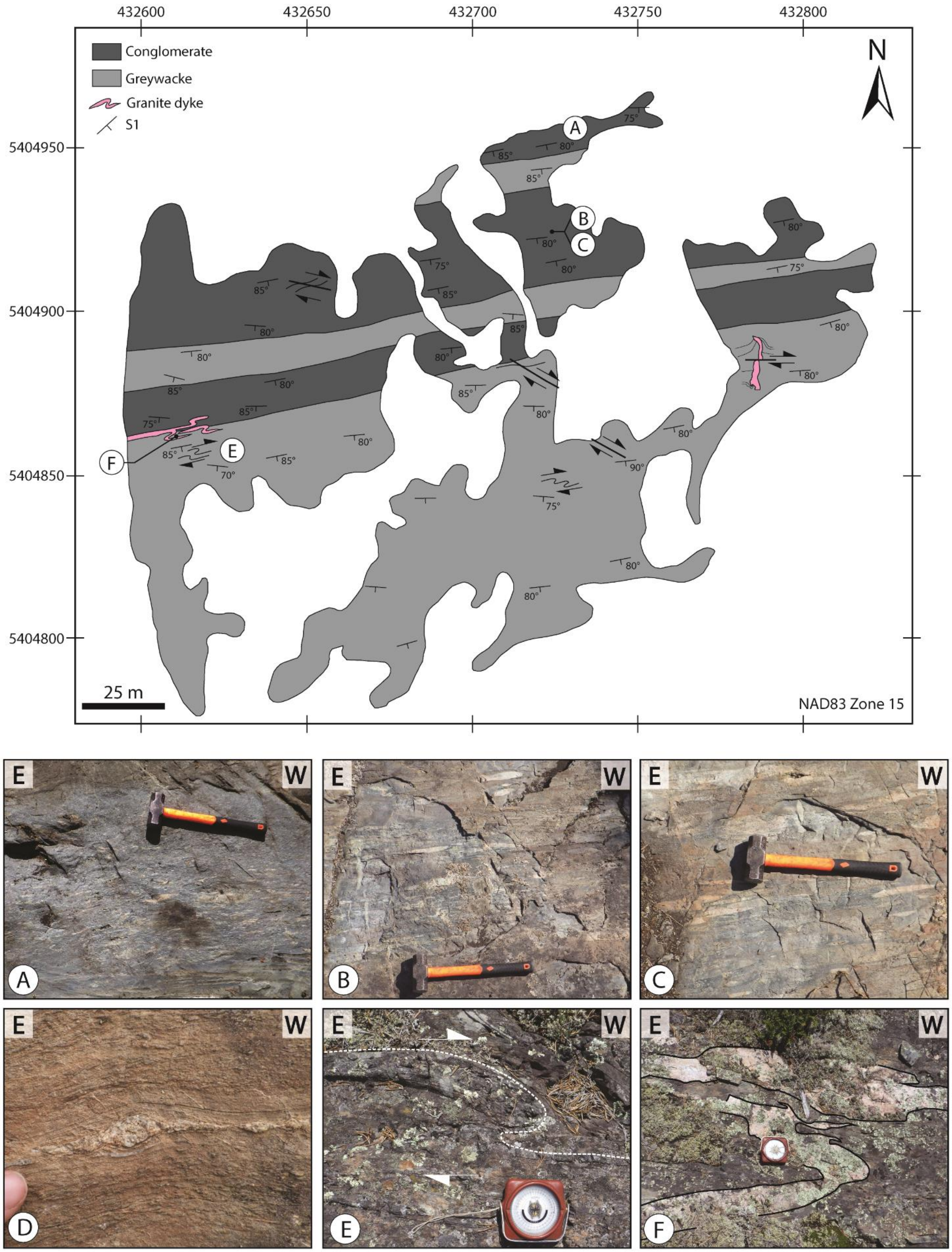
Figure 7 Felsic metavolcaniclastic rocks of the Burditt Lake group. (a) to (c) Bedding view of monolithic tuff-breccia (probable autobreccia) composed of quartz-feldspar porphyry clasts. Note the stretching and the flattening of clasts in the foliation planes. (d) and (e) Outcrops of monolithic felsic lapilli tuff and lapillistone containing slightly deformed and rounded clasts.

Stop 5: Metasedimentary rocks of the Quetico subprovince

Return to your vehicle, come back onto highway 615 and continue on this road for ~17 km. Turn to right at the Off Lake corner, follow this road for ~5 km until the crossroads with the highway 71. Turn on the left on the highway 71 (south direction), continue on this for ~1.7 km and turn on the left (east direction) just after the crossroads with Irvine 2 road. Continue on this dirt road for ~100 m and park your vehicle. Outcrops are exposed on the southern part of the road (UTM: 15U 432722 mE, 5404941 mN).

The Quetico subprovince (QS) consists of an assemblage of metasediments and metasedimentary gneiss, migmatites, and granitic rocks. The boundary between the QS and the WWS was probably initially stratigraphic in nature and is characterized by facies change from predominantly volcanic units to a predominantly sedimentary environment. This boundary was likely a structural weakness, which localized deformation and corresponds now to the regional Quetico fault. In the Rainy River area, the Quetico metasediments consist mainly of a monotonous sequence of interlayered wacke and mudstone interbedded with rare conglomerate layers. Stop 5 is located just to the south of the Quetico fault and exposes a succession of polymictic conglomerate and wacke-mudstone layers (Fig. 8). These metasedimentary rocks are marked by a well-developed foliation, which strikes E and dips steeply to the south (98/75). A steeply WWS –plunging mineral lineation defined by biotite along the foliation planes suggests a vertical component during the regional deformation. Conglomerate layers exhibit a strong planar deformation of pebbles, which were flattened and stretched horizontally and vertically in parallel to the foliation (Fig. 8a to 8c). E-W boudinage of sandstone rich layers and quartz veins in the foliation planes (Fig. 8d) confirms that the sedimentary rocks of the QS were affected by a strong planar deformation related to a N-S shortening. Rare occurrences of E-W trending asymmetric Z-folds (Fig. 8e) indicate dextral strike-slip shearing consistent with the dextral motion of the Quetico fault. These structural features are interpreted to reflect a transpressional strain regime, during which metasedimentary rocks were titled sub-vertically and flattened during the N-S accretion of the QS with the WWS. Occurrences of aplitic dikes and pegmatite folded and boudinaged in the foliation (Fig. 7f) suggest that magmatic activity related to the granitization of the QS was syn-tectonic. Samples have been collected for geochronology to (i) constrain the age of formation of the sedimentary basin, (ii) determine source(s) of these sedimentary rocks, and *in fine* (iii) constrain the geodynamic evolution of the Rainy River area.

Figure 8 Geological map of the stop 5 exposing succession of greywacke and conglomerate composing the metasedimentary subprovince of Quetico (locations on the map correspond to emplacement of photographs). (a) to (c) Layers of polymictic conglomerates displaying strong flattening and stretching of pebbles. (d) E-W boudinage of quartz vein in parallel to the foliation. (e) E-W trending asymmetric Z-folds indicating dextral strike-slip shearing. (f) Folded and boudined aplite.



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Conglomerate
Greywacke
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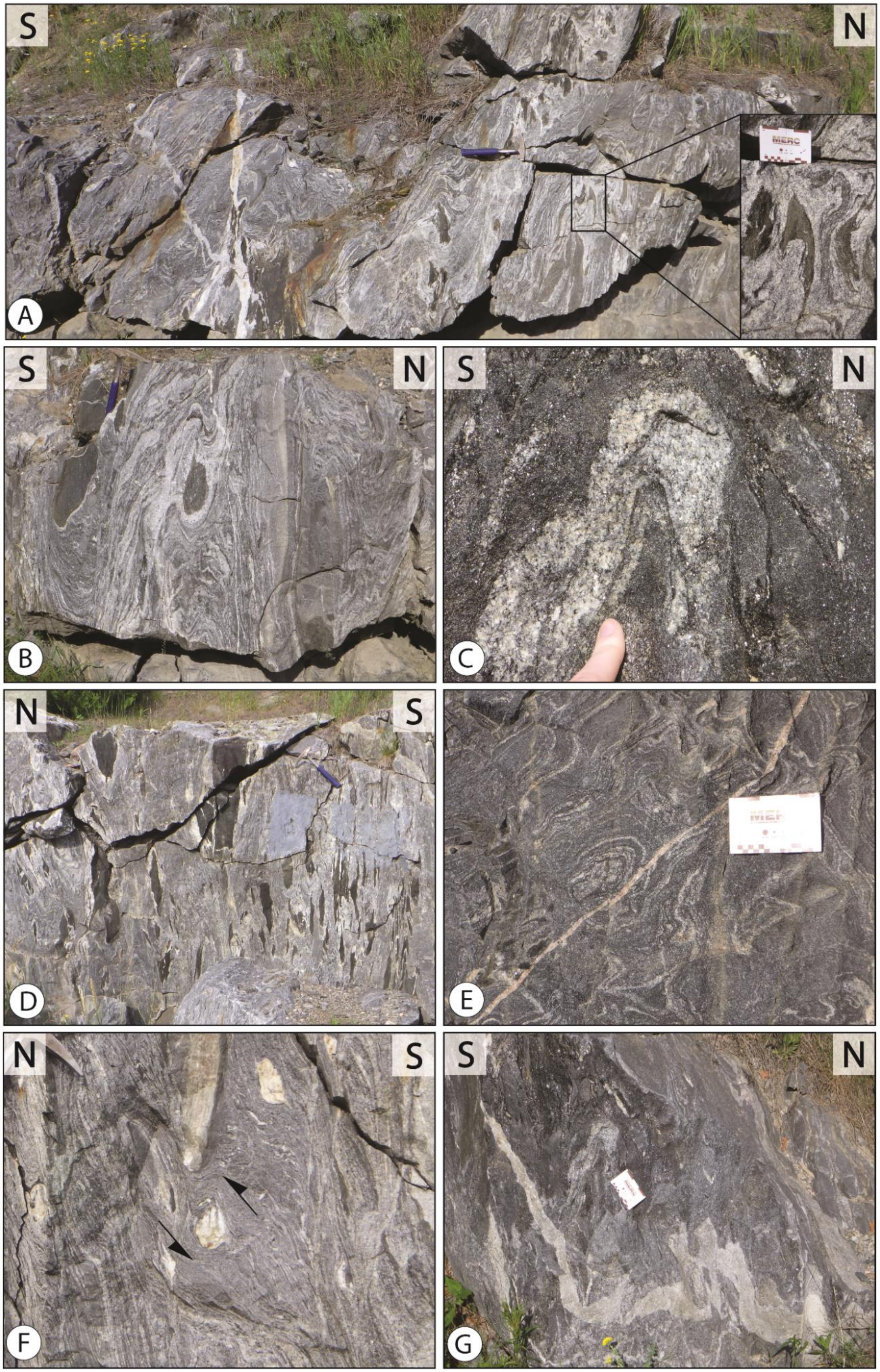
S1
N
25 m
NAD83 Zone 15
A
B
C
D
E
F
E
W

Stop 6: Migmatites of the central granitic zone of the Quetico belt

Return to your vehicle, come back onto highway 71 in the south direction, and continue for ~4.7 km. Turn to left and park your vehicle along the road. Outcrops occur the both sides of highway 71. Please be aware of the traffic and, if possible wear a safety vest (UTM: 15U 432562 mE, 5400139 mN).

The Quetico belt exhibits commonly symmetrical metamorphic zonation from marginal low grade to central high-grade assemblages (Percival, 1988). Metamorphic transformation by recrystallization of wacke and mudstone to biotite gneiss increases with distance south of the Quetico fault (N-S metamorphic gradient). This increase of the metamorphic grade is also accompanied by an increase of the occurrences of granite aplites, quartz-feldspars veins and pegmatites that occur commonly parallel to the foliation of the metasedimentary rocks. Then, the central part of the Quetico belt is mainly composed of migmatites and peraluminous granites. Stop 6 is located to the south of a large NE-SW trending granite intrusion, which marks the central part of an intrusive dome in the Quetico subprovince. This stop exposes beautiful outcrop of migmatitic gneiss, in which paleosome of biotite schist, melanosome (biotite restite) and leucosome (melted part of the metasedimentary rocks) can be clearly identified (Fig. 9). These migmatites exhibit E-W isoclinal folds (fold axis: 260/20) and vertically stretched and boudined paleosome in the fold hinges (Fig. 9c to 9e). Horizontal exposures exhibit complex interference pattern of folding (Fig. 9) resulting from at least two folding events, F1 (NE-SW trending axial plane) and F2 (E-W trending axial plane). Occurrences of quartz veins boudined and rotated in a reverse shear sense, folded and boudined granite aplites and leucosome demonstrate that migmatization and magmatism of the QS occurred during a deformation event involving vertical stretching and N-S shortening. These migmatites attest of the partial melting of the metasedimentary rocks composing the QS during the regional deformation related to the accretion of the QS with WWS. Samples of migmatites and associated leucogranite have been collected to constrain conditions of exhumation of the deeper crust and processes of recycling of juvenile sediments by partial melting of the metasedimentary rocks.

Figure 9 Field photographs showing the main characteristics of migmatites composing the central part of the Quetico belt along the N-S transect. (a) General view of the outcrop of migmatite (b) to (d) Isoclinal folding with vertical boudinage and stretching of paleosome. (e) Horizontal exposure chowing interference pattern of folding (f) Rotated quartz vein with reverse shear sense (g) Folded neosome.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MERC-ME-2019-197g

METAL EARTH

2019 Field Trip Guide

Sturgeon, Ontario

CANADA FIRST RESEARCH EXCELLENCE FUND | APOGÉE CANADA FONDS D'EXCELLENCE EN RECHERCHE

Canada

Geologic overview of the lithotectonic assemblages across the Sturgeon Lake greenstone belt along the Sturgeon transect, western Wabigoon, Superior Craton

Guidebook Authors: Chong Ma[1], Robert W.D. Lodge[2], and Marius Etienne[1]

Field Trip Leader: Chong Ma[1]

1. Mineral Exploration Research Centre, Harquail School of Earth Sciences, Laurentian University, Sudbury ON, Canada P3E 2C6
2. Department of Geology, University of Wisconsin-Eau Claire WI, USA 54701

Meeting Location: The parking lot of the **Silver Dollar Inn** at the intersection of Highway 599 and Highway 642, about 60 km north of Ignace, Ontario. See more information at www.silverdollarinn.com

Meeting Time: 9:00 am, September 11, 2019 (Wednesday)

Notes:

- Please bring lunch and drinking water
- It is strongly recommended to wear hiking boots and high visibility vest

Introduction

One of the goals of Metal Earth is to understand why the Abitibi and Wabigoon subprovinces are significantly different in metal endowment (rich vs. poor, respectively) but geologically similar. This requires understanding the geologic and geophysical characteristics of these greenstone-granitoid belts and their metallogeny of precious/base mineral deposits at regional scale. The Sturgeon Lake greenstone belt in the western Wabigoon subprovince is an example of a poorly endowed Archean greenstone belt.

The Sturgeon transect (Figure 1) is the easternmost of the three north-south transects across the western Wabigoon subprovince of the Superior Craton. It is ~60 km long following Highway 599 and goes through the Winnipeg River terrane and the Sturgeon Lake greenstone belt from south to north. The goals of the Sturgeon transect are to understand (1) the stratigraphy of the Archean metavolcanic rocks of the various assemblages, (2) structural or stratigraphic relationships between the assemblages, (3) nature and timing of deformation, (4) origin and timing of plutonism and volcanism, (5) sedimentary provenances of successor basins, (6) amalgamation of the metavolcanic assemblages and their accretion to the Winnipeg River terrane, and (7) controls of metal endowment.

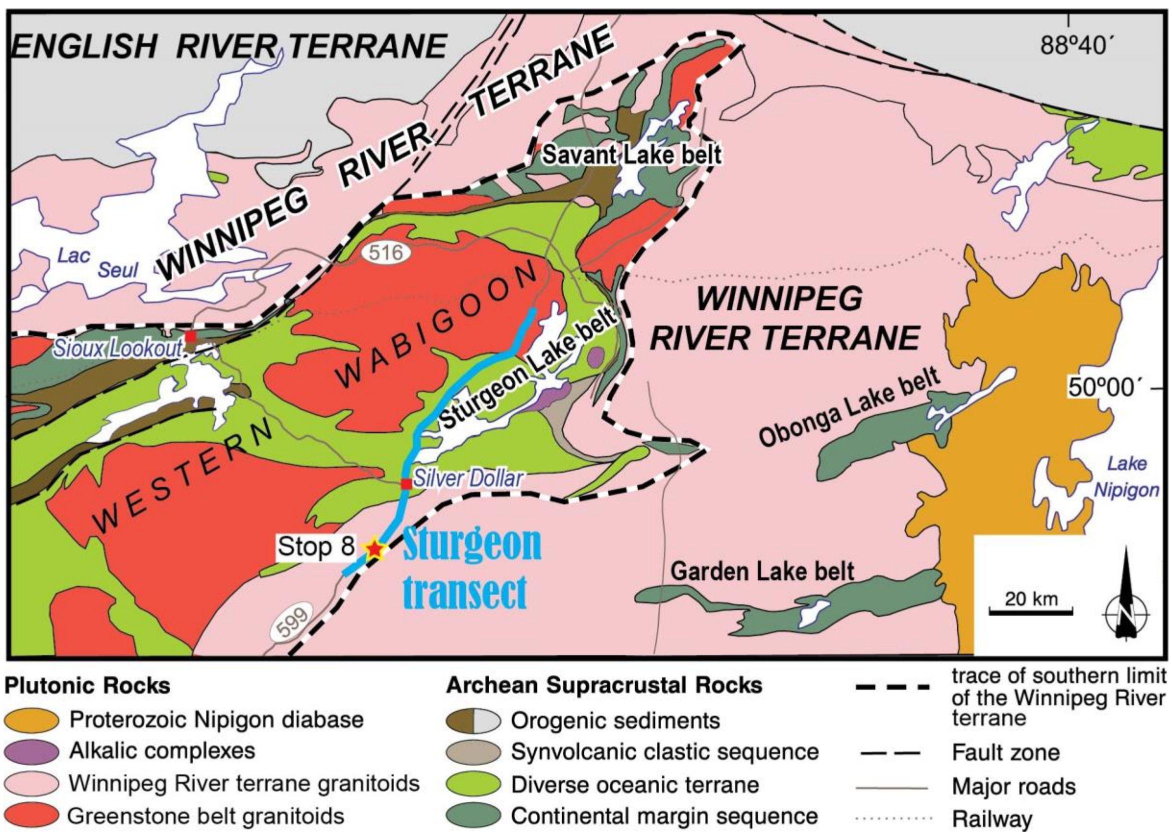

Figure 1. Simplified geologic map of the Sturgeon Lake greenstone belt and the Winnipeg River granitoid terrane (after Sanborn-Barrie and Skulski, 2005).

Mapping and sampling along this transect started in June 2019. The anticipated analytical work includes structural and kinematic analyses, whole-rock elemental and isotopic fingerprinting, zircon U-Pb and Lu-Hf analyses, titanium-in-zircon thermometry, and seismic-gravity/magnetotelluric probing of the lithosphere and upper mantle. All the newly acquired data will be integrated into the regional context on the basis of previously reported data from the region.

Currently, a PhD project is being conducted by Marius Etienne who is focusing on geologic and metallogenic studies of the felsic metavolcanic sequences in the Sturgeon Lake region. He will be investigating the stratigraphy, geochemistry, isotopes, geochronology, and alteration of the felsic sequences along the Sturgeon transect. The dissertation is expected to reveal similarities and dissimilarities in terms of geology and metal endowment among these sequences and to provide insights into the controlling factors of medal endowment. Moreover, three undergraduate projects based at University of Wisconsin-Eau Claire are being carried out, including petrography and geochemistry of felsic plutons, detrital zircon geochronology of the Ament Bay Assemblage, and chemostratigraphy of the Central Sturgeon Assemblage.

Geologic Background

This field trip offers an overview of the lithotectonic assemblages across the Sturgeon Lake greenstone belt and the Winnipeg River terrane along Ontario highway 599 (Figure 1). The trip starts from the Lewis Lake batholith (Figure 2) that is dominated by 2735-2730 Ma biotite granodiorite and biotite tonalite (Whalen et al., 2004). The lowermost Sturgeon Lake greenstone belt is intruded by the Lewis Lake batholith and represented by the ~2775 Ma Fourbay Lake Assemblage (Figure 2) that is dominated by flattened pillow basalts with intermediate-felsic tuff intervals (Davis et al., 1988; Sanborn-Barrie and Skulski, 2005). To the south of Fourbay Lake, the ~2745 Ma bimodal Handy Lake Assemblage is divided into lower, middle, and upper sequences (Figure 2), which generally are characterized by tholeiitic mafic flows, calc-alkaline mafic flows, and intermediate-felsic tuff/lapilli-tuff, respectively (Sanborn-Barrie and Skulski, 1999). The next youngest is the ~2735 Ma South Sturgeon Assemblage (Figure 2) that hosts the Zn-Cu-Pb-Ag volcanogenic massive sulphide deposits in the Mattabi, Sturgeon Lake, Lyon Lake, Creek Zone, and F-Group mines (Figure 2) and is composed of a lower pillowed and massive basalt sequence and an upper intermediate-felsic sequence (Davis et al., 1985; Sanborn-Barrie and Skulski, 2005). The intermediate-felsic metavolcanics are dominated by andesite-dacite-rhyolite flows, quartz-phyric pyroclastic flows, tuff, lapilli tuff, and volcaniclastic rocks (Sanborn-Barrie and Skulski, 2005). The Central Sturgeon Assemblage (Figure 2) contains the youngest metavolcanic sequences (2720–2718 Ma, Davis and Trowell, 1982; Sanborn-Barrie and Skulski, 2005) along the Sturgeon transect, which are unconformably overlain by poorly sorted conglomerates that are dominated by gabbroic- and mafic volcanic-derived pebbles (Sanborn-Barrie and Skulski, 2005).

Numerous gabbro bodies and granitic plutons are found in the metavolcanic assemblages. The ~2733 Ma Pike Lake Intrusion (gabbro-diorite), the ~2734 Ma Beidelman Bay Pluton (biotite-amphibole tonalite, biotite-granodiorite, and amphibole-biotite-granodiorite), and the coeval Lewis Lake batholith (Figure 2) (Davis and Trowell, 1982; Whalen et al., 2004) are synvolcanic with respect to the South Sturgeon metavolcanic assemblage. A younger phase of magmatism represented by the ~2723 Ma Metionga Lake tonalite (Figure 2) (Whalen et al., 2002) was coeval with the Central Sturgeon metavolcanic assemblage.

The volcanic assemblages and sedimentary sequences along the Sturgeon transect are steeply dipping to the north or south, forming a regional syncline with the Central Sturgeon Assemblage in the hinge and older assemblages on the limbs. These volcanic rocks are predominantly metamorphosed to greenschist-facies conditions, although minor amphibolite-facies rocks occur locally.

The granitoid belt along the southern part of the transect is tentatively assigned to the Winnipeg River terrane based on Sm-Nd isotopes and zircon inherence (Figure 1). Around the Sturgeon Lake greenstone belt, the Winnipeg River terrane is dominated by Neoarchean granitoids containing inherited Mesoarchean components (Tomlinson et al., 2004). The major lithologies along this part of the Surgeon transect are mostly biotite-amphibole tonalite, biotite and amphibole-biotite granodiorite, and bioitite-quartzofeldspathic gneiss, which are crosscut by biotite pegmatites and alkali-feldspar granite dikes.

This field trip aims to show the representative lithology assemblages and related structures as well as some mineralization along the Sturgeon transect. It starts from the north in the Lewis Lake batholith and ends in the Winnipeg River terrane, with six stops in the greenstone belt.

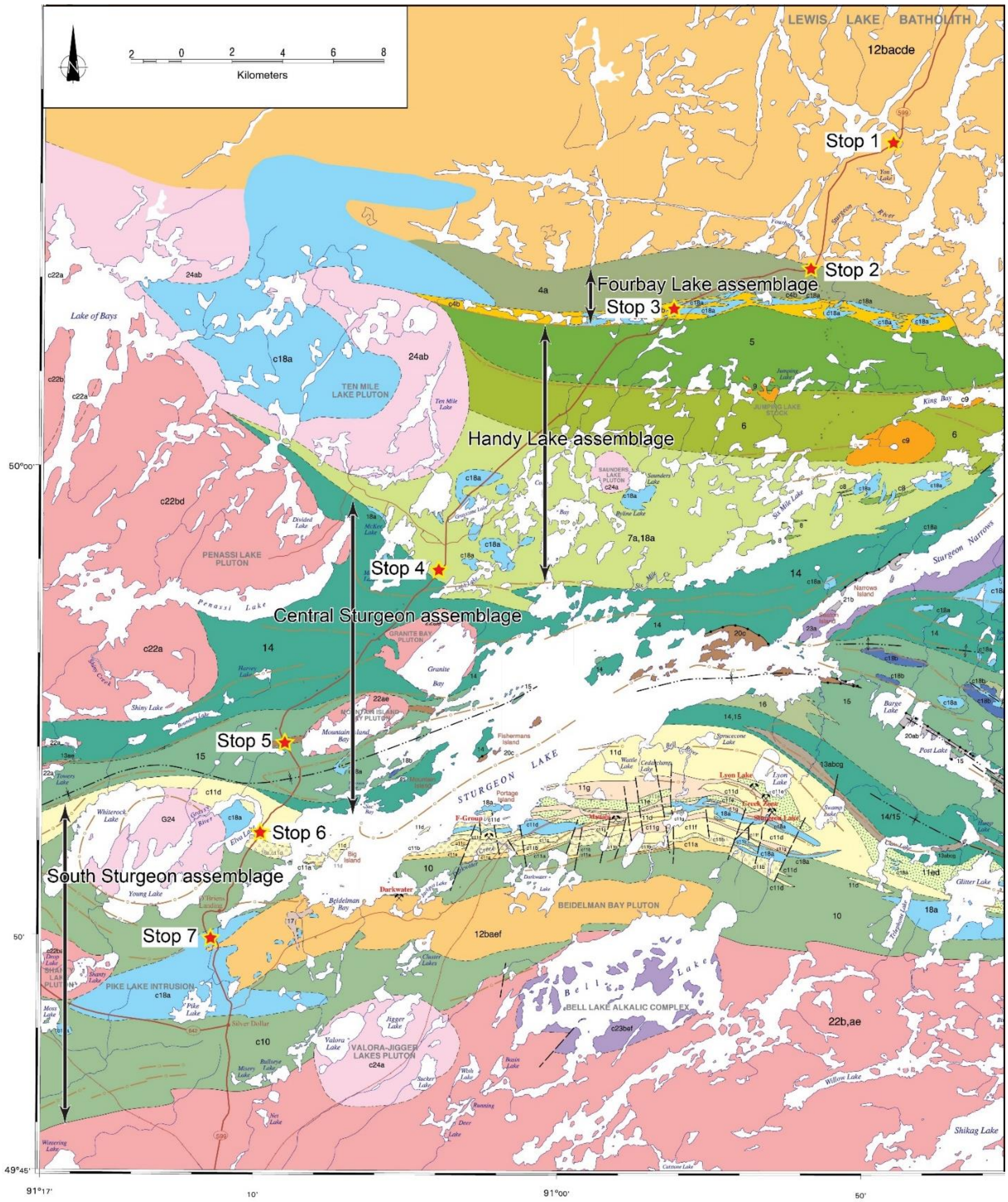

Figure 2. Geologic map of the Sturgeon Lake greenstone belt along the Sturgeon transect with locations of the field trip stops. See legend next page (from Sanborn-Barrie and Skulski, 2005).

LATE- TO POST-TECTONIC PLUTONIC ROCKS

24 — Massive to weakly foliated, relatively unaltered and unrecrystallized granitoid rocks (G denotes geophysically defined).
- a Biotite and amphibole-biotite granodiorite, monzogranite±quartz monzonite±syenogranite.
- b Biotite-hornblende tonalite±trondhjemite±quartz diorite.

ALKALIC COMPLEXES

23
- a Foliated, medium- to coarse-grained syenite with trachytic texture, may be nepheline- or scapolite-bearing.
- b Biotite-hornblende-augite-monzonite, monzosyenite, quartz syenite.
- c Syenodiorite.
- d Fine- to medium-grained, massive, leucocratic syenite (inner central phase).
- e Fine-grained syenitic, gabbroic dykes.
- f Porphyritic.

EARLY- TO SYN-TECTONIC PLUTONIC ROCKS

22 f — Foliated, recrystallized and/or altered granitoid rocks.
- a Biotite and amphibole-biotite granodiorite±monzogranite±quartz monzonite.
- b Biotite-hornblende tonalite±quartz diorite±trondhjemite.
- c Porphyritic.
- d Xenolithic.
- e Dykes.
- f Gneissic.
- g Pegmatitic.

AMENT BAY ASSEMBLAGE

21 — Wacke.
- a Volcanic-derived lithic wacke.
- b Feldspathic to quartzose wacke with pebble beds, commonly crossbedded; minor oxide facies (magnetite) ironstone.

20 — Conglomerate.
- a Poorly sorted, unbedded, gabbroic- and mafic volcanic-derived pebble conglomerate.
- b Poorly bedded gabbroic- and mafic volcanic-derived pebble to boulder conglomerate with rare sandy interbeds.
- c Polymictic conglomerate dominated by volcanic clasts.

unconformity

WARCLUB ASSEMBLAGE

19b — Fine sand size feldspathic and lithic wacke with interbedded chert and oxide facies (magnetite) ironstone.

19a — Polymictic conglomerate (< 2704 Ma).

unconformity

MAFIC INTRUSIVE ROCKS

18b — Serpentinized peridotite.

18a — Gabbro, diorite of different ages; locally amphibolite.

CENTRAL STURGEON ASSEMBLAGE

17 — Porphyritic intrusions including 2720 ± 1 Ma Quest Lake porphyry and 2720.5 +3.5/-3 Ma tonalite (Cu-Mo) intrusion.

16 — Intermediate to felsic calc-alkaline pyroclastic deposits including 2717.9 +2.9/-1.5 Ma rhyolitic tuff.

15 — Upper calc-alkaline mafic sequence: basalt, basaltic andesite, andesite, pillowed to massive, locally plagioclase-phyric.

14 — Lower tholeiitic mafic sequence: pillowed to massive basalt, locally high TiO_2 (>1.5%) basalt.

LOCATION MAP

QUEST LAKE ASSEMBLAGE

13 e — Fine sand size feldspathic clastic metasedimentary rocks.
- a Lithic wacke, feldspathic wacke cut by fine-grained diorite dykes and 2720 Ma feldspar porphyry.
- b Siltstone, laminated to very thinly bedded.
- c Argillite, shale, slate.
- d Conglomerate.
- e Magnetite ironstone.
- f Biotite schist.
- g Graphite, pyrrhotite.

SYNVOLCANIC PLUTONIC ROCKS

12
- a Biotite and amphibole-biotite granodiorite±monzogranite±quartz monzonite.
- b Biotite-hornblende tonalite±quartz diorite±trondhjemite.
- c Porphyritic.
- d Leucocratic.
- e Xenolithic.
- f Dykes.

SOUTH STURGEON ASSEMBLAGE

11 (a, b, e, g) — Intermediate to felsic volcanic rocks host to volcanogenic massive sulphide mineralization (Mattabi).
- a Aphyric rhyolitic pyroclastic flow deposits; rhyolite flows.
- b Megabreccia.
- c Scoria.
- d Intermediate to felsic volcanics including tuff, lapilli tuff, tuff breccia, dacite-rhyolite flows, quartz phyric pyroclastic flows.
- e Andesite lava flows, flow breccias, and hyaloclastite.
- f Quartz porphyry.
- g Volcaniclastic, epiclastic rocks.

10 — Pillowed and massive basalt, associated gabbro (Darkwater sequence).

HANDY LAKE ASSEMBLAGE

9 — Light-weathering, feldspar- quartz (±blue quartz) porphyritic, intrusive/hypabyssal rocks with 20–30% phenocrysts.

8 — Biotite- ±garnet-bearing massive mafic flows.

7
- a Intermediate felsic pyroclastic rocks: 2745 +3/-2 Ma lapilli tuff (Cobb Bay), crystal tuff±hypabyssal intrusive rocks, tuff breccia, pyroclastic breccia, typically sheared and sericitic in Sturgeon Narrows.
- b 2746 +2/-1 Ma massive to quartz±feldspar phyric flows (Morgan Island), rarely spherulitic.
- c Siltstone, lithic wacke interbeds.

6 — Middle calc-alkaline mafic sequence: pillow basalt, locally massive with hyaloclastite; gabbro.

5 — Lower tholeiitic mafic sequence: massive to pillowed, high-Ti basalt, pillow breccia, locally plagioclase-phyric; gabbro.

FOURBAY LAKE ASSEMBLAGE

4b — Intermediate to felsic metavolcanic rocks: 2775 ± 1 Ma, 2775 +5/-2 Ma pyroclastic tuff; minor flows±hypabyssal rocks.

4a — Mafic metavolcanic rocks: strongly foliated to gneissic pillowed flows and fine- to coarse-grained garnet-amphibolite, rarely plagioclase-phyric equigranular flows; gabbro.

JUTTEN ASSEMBLAGE

3 — Amphibolite; quartzose wacke.

inferred unconformity

VANESSA LAKE ASSEMBLAGE

2 — Quartzose arenite; quartzose wacke; lithic wacke.

1 — Basalt; 2925 ± 2 Ma rhyodacite tuff.

Fieldtrip Stops

Stop 1 (UTM: 15U 656274.24 E; 5553803.05 N)

Lewis Lake batholith with multiple intrusions and molybdenite mineralization

Directions from the Silver Dollar Inn:

From the parking lot in front of the Silver Dollar Inn office, take a right onto Highway 599 toward Savant Lake. Continue on Highway 599 for 51 km to the Whiskey Jack Lodge sign by the highway. Make a U turn at the junction between Highway 599 and the gravel road to Whiskey Jack Lodge. Drive southward on Highway 599 for about 500 meters. The outcrop is a road cut, right after the gentle curve. Park safely on the shoulder of the highway.

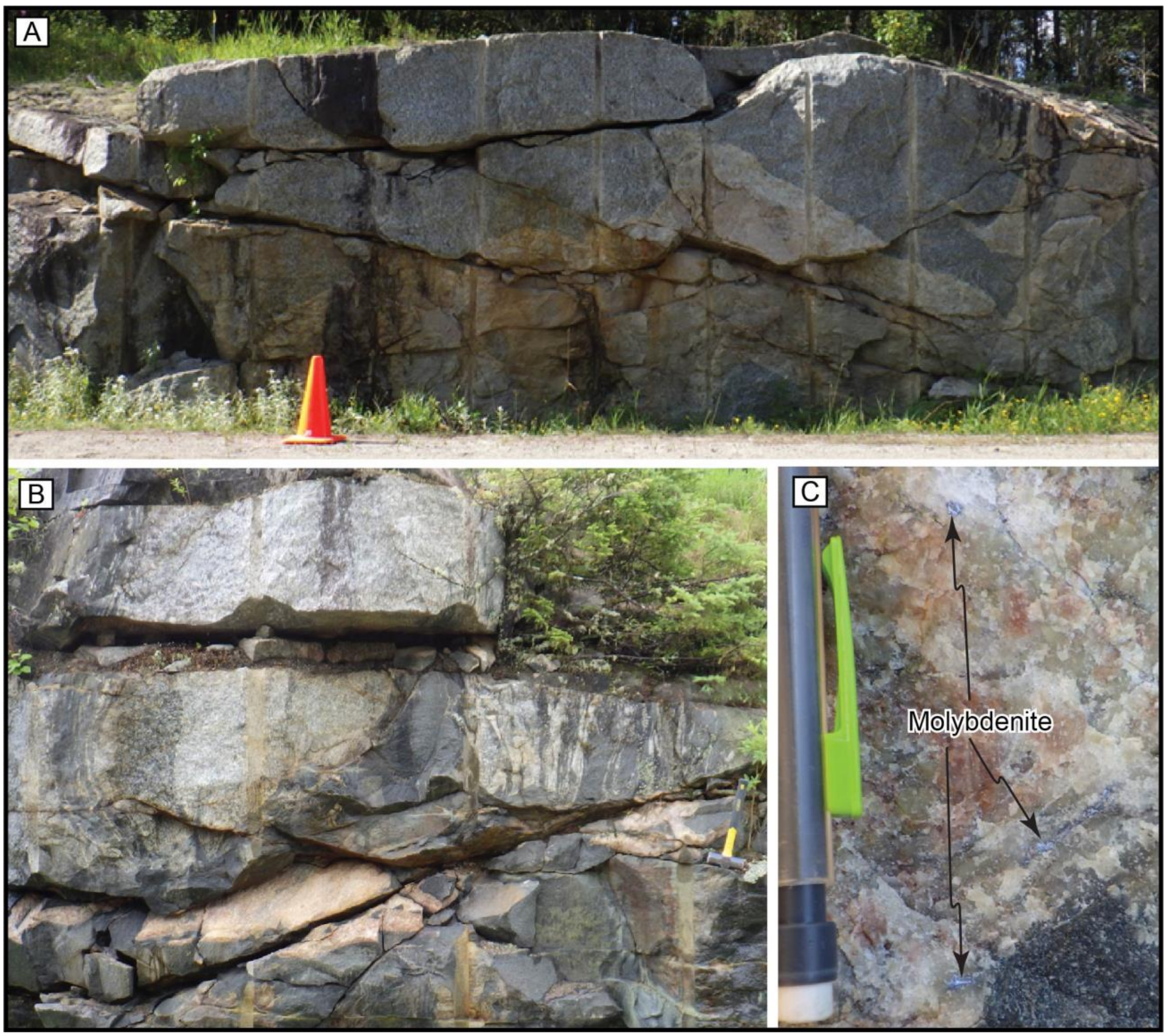

Figure 3. Representative lithologies of the Lewis Lake batholith. (A) Tonalite and granodiorite crosscut by a pegmatite dike. (B) Magma mixing and mingling between the leucocratic tonalite and a biotite-rich tonalite. (C) Molybdenite in a pegmatite dike.

The outcrop of this stop is located at the northern end of the Sturgeon transect in the Lewis Lake batholith (Figure 2) that is the biggest synvolcanic intrusion in this region. The batholith is inhomogeneous, containing multiple phases of intrusions and are variably foliated. A biotite porphyritic tonalite of this batholith has been dated by zircon U-Pb to be 2735 +3/-2 Ma (Whalen et al., 2004). The Lewis Lake batholith, therefore, is interpreted as synvolcanic with respect to the South Sturgeon Assemblage that hosts the Mattabi VMS mine.

The main lithology at this stop is a leucocratic, coarse-grained, equigranular, foliated biotite tonalite to biotite granodiorite. The biotite tonalite is characterized by a steeply dipping foliation that is well defined by subparallel biotite flakes (Figure 3A). The foliation at this location strikes NW-SE but changes to E-W towards the south part of the batholith.

Locally, there are irregular blocks and layers of biotite-rich tonalite found in the leucocratic coarse-grained tonalite, which locally forms textures indicating magma mixing and mingling between the two melts (Figure 3B).

Several generations of felsic dikes crosscut all the tonalite and granodiorite (Figure 3A). The composition of the dikes is granitic consisting of coarse-grained to pegmatitic quartz, K-feldspar, biotite, and plagioclase. Some of the pegmatitic dikes exhibit an apparent foliation concordant with that of the hosting tonalite.

Crystals of molybdenite are shown in some of the pegmatite dikes (Figure 3C). Small amounts of pyrite are mainly disseminated in the tonalite-granodiorite and the pegmatitic dikes. The pyrites are commonly oxidized.

Stop 2 (UTM: 15U 653071.81 E; 5548687.23 N)

The oldest rock of the Sturgeon Lake greenstone belt (the bottom of the Fourbay Lake Assemblage)

Directions from Stop 1:

Continue on southward Highway 599 for 6.5 km. The outcrop is about 50 m north of the junction between Highway 599 and Six Mile Lake Road. Park safely on the shoulder of Highway 599.

The lowermost Fourbay Lake Assemblage near its contact with the Lewis Lake batholith (Figure 2) preserves the oldest supracrustal rock of the Sturgeon Lake greenstone belt, 2775 ± 1 Ma, based on zircon U-Pb ages from a felsic tuff of this assemblage (Davis et al., 1988). This is also the oldest volcanic assemblage in the Wabigoon subprovince.

The outcrop at this stop (Figure 4A) is dominated by strongly foliated pillowed basalt (Figure 4B). Pillows are flattened to oblate shapes, about 3 to 5 cm thick. The foliation of the basalt strikes E-W and dips ~80° towards the north. Locally occurring

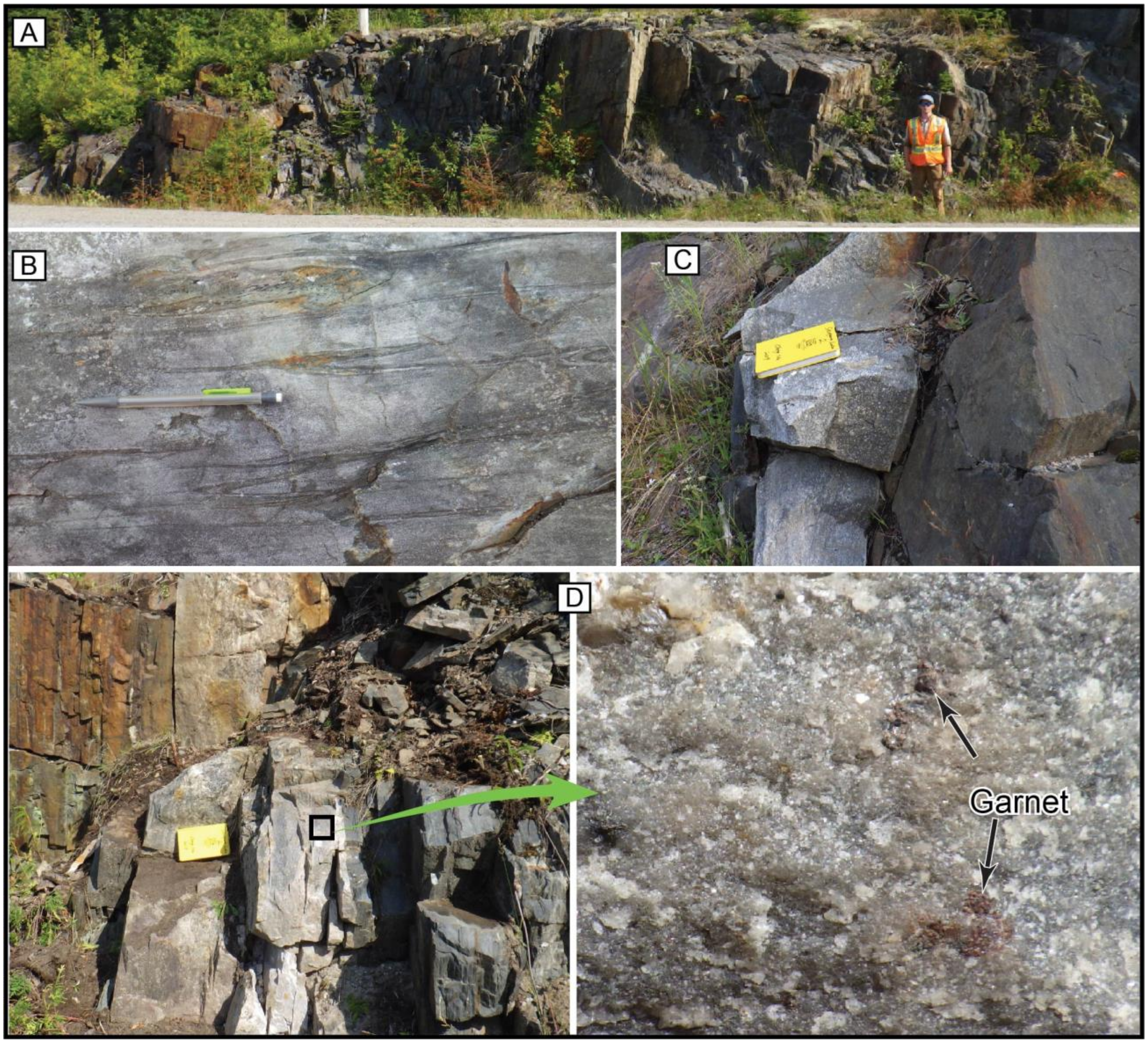

Figure 4. Lithology of the lowermost Fourbay Lake Assemblage. (A) Overview of the outcrop at Stop 2. (B) Strongly foliated mafic metavolcanic flow with local flattened pillow structures. (C) Coarse-grained biotite tonalite dike. (D) Garnet-bearing fine-grained to pegmatitic granitoid dike.

pillowed structures are strongly flattened perpendicular to the foliation. The visible pillow selvages (<1 cm thick) are sub-parallel to the foliation and hydrothermally altered to be quartz-sericite-chlorite. These rocks are intruded by two types of felsic dikes (Figures 4C, 4D).

The first type is a coarse-grained biotite tonalite dike (Figure 4C) that shows a strong foliation parallel to the foliation within the host basalts and the margin of the Lewis Lake batholith. It is assumed to be associated with the Lewis Lake batholith based on similar composition and texture to nearby outcrops of the batholith and close proximity to the batholith margin.

The second type is a foliated, fine-grained to pegmatitic, equigranular, garnet-biotite granitoid dike (Figure 4D) that is assumed to be metamorphosed with the host mafic rocks.

Stop 3 (UTM: 15U 647697.31 E; 5546917.73 N)

Felsic crystal tuff with graded bedding of the Fourbay Lake Assemblage

Directions from Stop 2:

Continue on Highway 599 southward for 5.8 km. Park on the shoulder of the highway.

The outcrop of this stop (Figure 5A) represents the felsic phase of the bimodal Fourbay Lake Assemblage (Figure 2). The felsic supracrustal rocks here are felsic tuff and lapilli tuff that have been dated to be 2775 ± 1 Ma (Davis et al., 1988) and 2775 +5/-2 Ma (Sanborn-Barrie and Skulski, 2005).

At this stop, the felsic volcanoclastic rocks are rhyolitic-dacite tuff and crystal tuff. The crystal tuff is bedded and shows a variation of the relative abundance of lapilli clasts versus matrix (Figure 5B). The clasts are composed of coarse-grained, angular to subangular quartz and plagioclase, ranging from ~2 to ~10 mm. The matrix is fine-grained, equigranular, mainly consisting of chlorite, plagioclase, pyroxene, and amphibole. A medium-grained basaltic flow occurs as a conformable interval in the felsic volcanoclastics.

Normal grading in the felsic volcanoclastic rocks indicates younging to the south (Figure 5C).

In the southern part of the outcrop, gabbroic bodies are in intrusive contact with the felsic volcanoclastics. The gabbro is homogenous, coarse-grained, massive, and equigranular.

The foliation and bedding of the rhyolitic-dacite tuff and lapilli-tuff are subparallel, generally striking E-W and dipping moderately towards the north. In the gabbro, a thrust fault zone (up to 0.5 m thick) strikes 085°, dips 40° southward, with a lineation trending 160° and plunging 40° (Figure 5D). This thrust fault zone documents shortening along NNW-SSE in a ductile-brittle transitional setting after the formation of the gabbro.

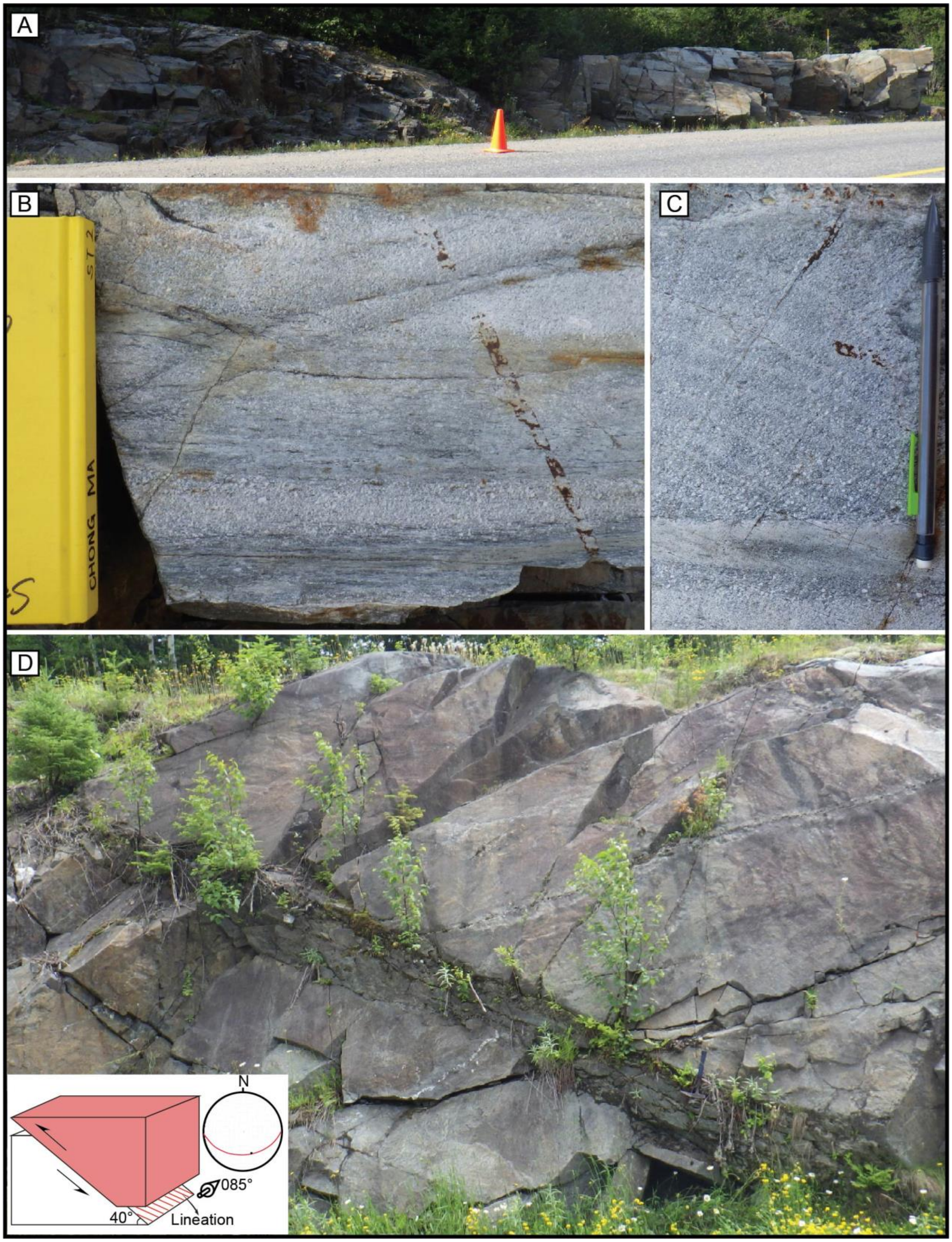

Figure 5. Felsic metavolcanics of the Fourbay Lake Assemblage. (A) Overview of the outcrop at Stop 3. (B) Multiple layers of felsic lapilli tuff. (C) Normal grading of sorted lapilli tuff showing younging to the south. (D) A thrust fault zone in the gabbro.

Stop 4 (UTM: 15U 638701.18 E; 5536428.72 N)

Mineralization in a felsic flow of the Handy Lake Assemblage

Directions from Stop 3:

Continue on Highway 599 southward for 14.9 km. This roadside outcrop is on the west side of Highway 599, the first outcrop south of the junction between Highway 599 and Handcuff Road. Park on the shoulder of the highway.

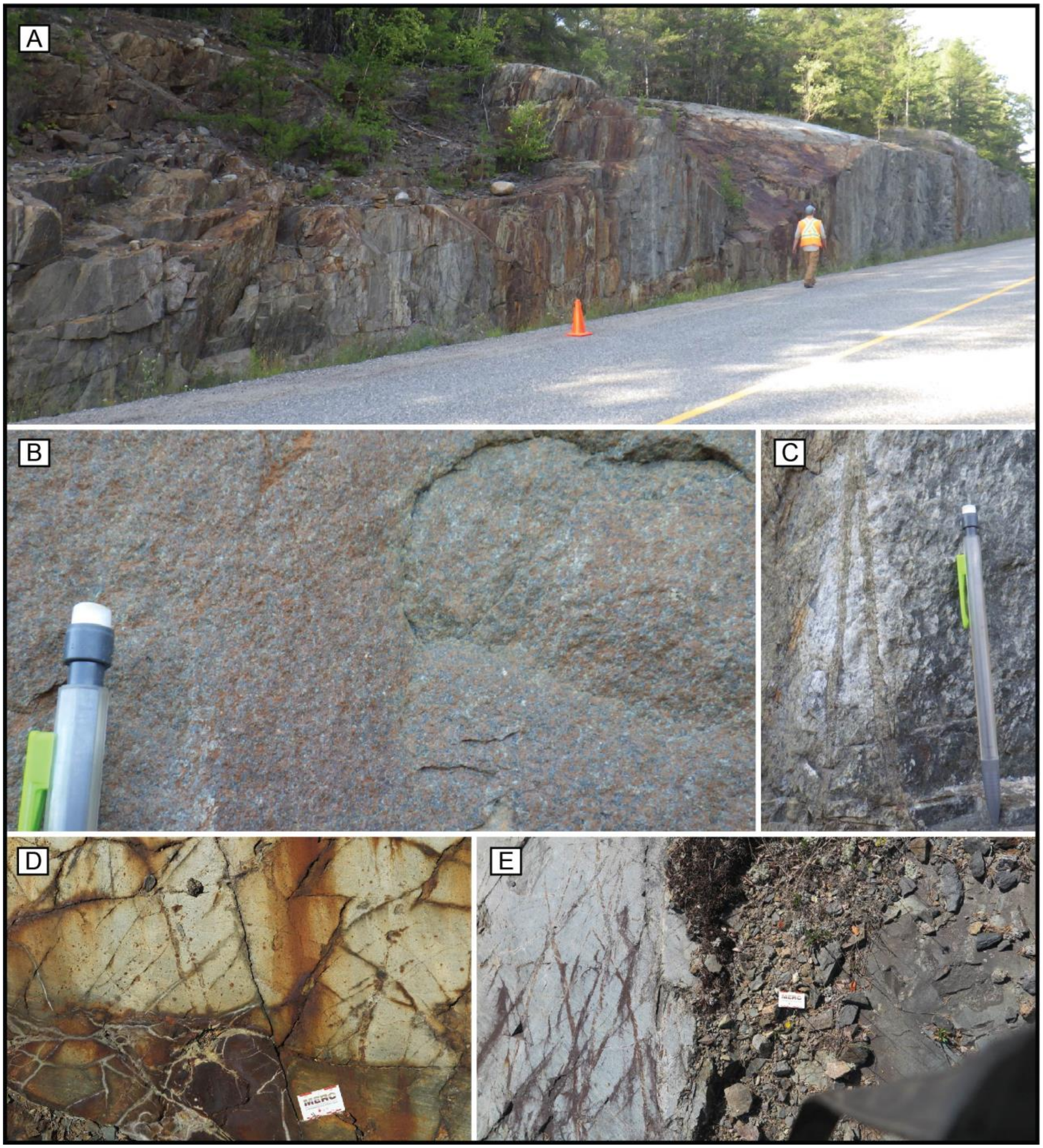

Figure 6. Mineralization and lithology of the Upper Handy Lake Assemblage. (A) Overview of the outcrop at Stop 4. (B) Massive, fine- to medium-grained felsic flow containing blue quartz phenocrysts. (C) Planar quartz veins hosting pyrite and trace chalcopyrite. (D) Representative pattern of the fracture network locally hosting pyrite and chalcopyrite. (E) Contact between the felsic flow and a subvertical gabbro dike.

This stop highlights the felsic volcanic rocks in the ~2745 Ma Upper Handy Lake Assemblage (Figure 2) that is the largest felsic volcanic unit in the Sturgeon transect and the only other major felsic volcanic center on the transect besides the ca. 2735 Ma VMS-hosting South Sturgeon Assemblage (Sanborn-Barrie & Skulski, 2005). Understanding the petrogenesis and mineral potential of the Handy Lake Assemblage felsic rocks will be paramount for addressing regional metallogenic questions for Metal Earth and the Sturgeon transect.

This ~200 m roadside outcrop (Figure 6A) is dominated by massive, fine- to medium-grained flow or hypabyssal intrusion that contains 1-3 mm blue quartz phenocrysts in a light to medium grey feldspar-rich groundmass (Figure 6B). The massive, homogeneous flow at this location is an atypical facies of the Upper Handy Lake Assemblage felsic rocks. Nearby exposures on Handcuff Road and along the shoreline of Cobb Bay are predominantly coarse to fine volcaniclastic facies. The diagnostic feature of these felsic rocks is the subhedral blue quartz phenocrysts that can be observed at this location and within lithic fragments in volcaniclastic facies.

Around the middle section of this outcrop is a 4-5 m subvertical gabbro dike (Figure 6E). The sharp contact between mafic and felsic rocks is best observed on top of the outcrop where differential erosion has highlighted the different lithologies. On the fresh vertical road cut, the contrast in joints/fractures can help highlight the intrusive contact. Mapping in this summer has confirmed observations from several generations of regional maps (Trowell, 1983; Sanborn-Barrie and Skulski, 2005) that documented extensive small mafic intrusive bodies throughout the felsic rocks of the Upper Handy Lake Assemblage.

Pyrite and trace chalcopyrite are hosted in a network 5-15 mm thick planar quartz veins (Figure 6C). On the top of this outcrop, the fracture network is visually similar to polygonal (or columnar) fracture networks (Figure 6D). On the vertical roadside exposure, the mineralized fracture network has steep apparent dips revealing a cross-cutting, box work-like vein pattern. Veins are 30-40% sulfides in smoky quartz matrix and compose up to 15-20% of the rock. Despite the relatively abundant mineralization, hydrothermal alteration of this felsic unit is restricted to some mm-scale zones of sericite alteration at the quartz vein-host rock contact. The planar fractures, lack of foliation in the rocks, and non-systematic orientation of the veins preclude a structural origin to the mineralization, suggesting that it is coeval (synvolcanic?) with the felsic rocks.

One of the major goals of the PhD thesis on this transect is to characterize the volcanology, petrogenesis, and metallogeny of the Handy Lake Assemblage. Mineralized samples from this location will be examined to determine the nature of mineralization (magmatic, hydrothermal, structural, etc). Whole rock major, trace, and isotopic geochemistry will be used to reconstruct the petrogenesis and geodynamic setting of these rocks.

Stop 5 (UTM: 15U 632801.50 E; 5529346.67 N)

Unconformity between the Ament Bay and Central Sturgeon Assemblages

Directions from Stop 4:

Continue on Highway 599 southward for 9.8 km. Park on the shoulder of the highway.

This stop highlights the characteristics of the two youngest assemblages along the Sturgeon transect: The ~ 2720 Ma Central Surgeon and ~2690 Ma Ament Bay Assemblages (Figure 2) (Sanborn-Barrie and Skulski, 2005). The disconformable contact between these two assemblages can be seen on this ~150 m outcrop on the east side of Highway 599 (Figure 7A).

The rocks at this stop are typical of those in the Central Sturgeon Assemblage. This assemblage is composed of tholeiitic to calc-alkalic mafic volcanic rocks and associated mafic dikes and sills, which sits within the hinge zone of the regional syncline of the Sturgeon greenstone belt (Sanborn-Barrie and Skulski, 2005).

At the southern part of the exposure, the outcrop is dominated by intact <1-2 m pillows with thin (2-3 cm) darker colored, and locally pyrite-bearing/rusty selvages (Figure 7B). Many of the pillow cores are pale green caused by epidote-quartz alteration. Further to the south, the pillows are no longer visible, and the mafic rock is mostly massive with an angular in-situ breccia noted by box work-like zones of pale-green, epidote alteration (Figure 7C).

The contact of the Central Sturgeon Assemblage with the Ament Bay Assemblage at this stop is noted by a <0.5 m zone of rusty mafic rock before a “sharp” contact with overlying conglomerate. The entire exposure of the Ament Bay Assemblage here is a narrow ~6 m section with clastic sedimentary rocks comprising interbedded conglomerate and wacke. The subparallel bedding of the outcrop across the contact suggests a disconformity.

The conglomerate beds are composed of charcoal grey polymictic matrix-supported conglomerate with pebble-sized, moderately sorted, subrounded clasts (Figures 7D, 7E). Clasts are mostly chloritic mafic volcanics but locally contains more felsic volcanic clasts. Clasts are supported in a dark grey, fine to medium, poorly sorted

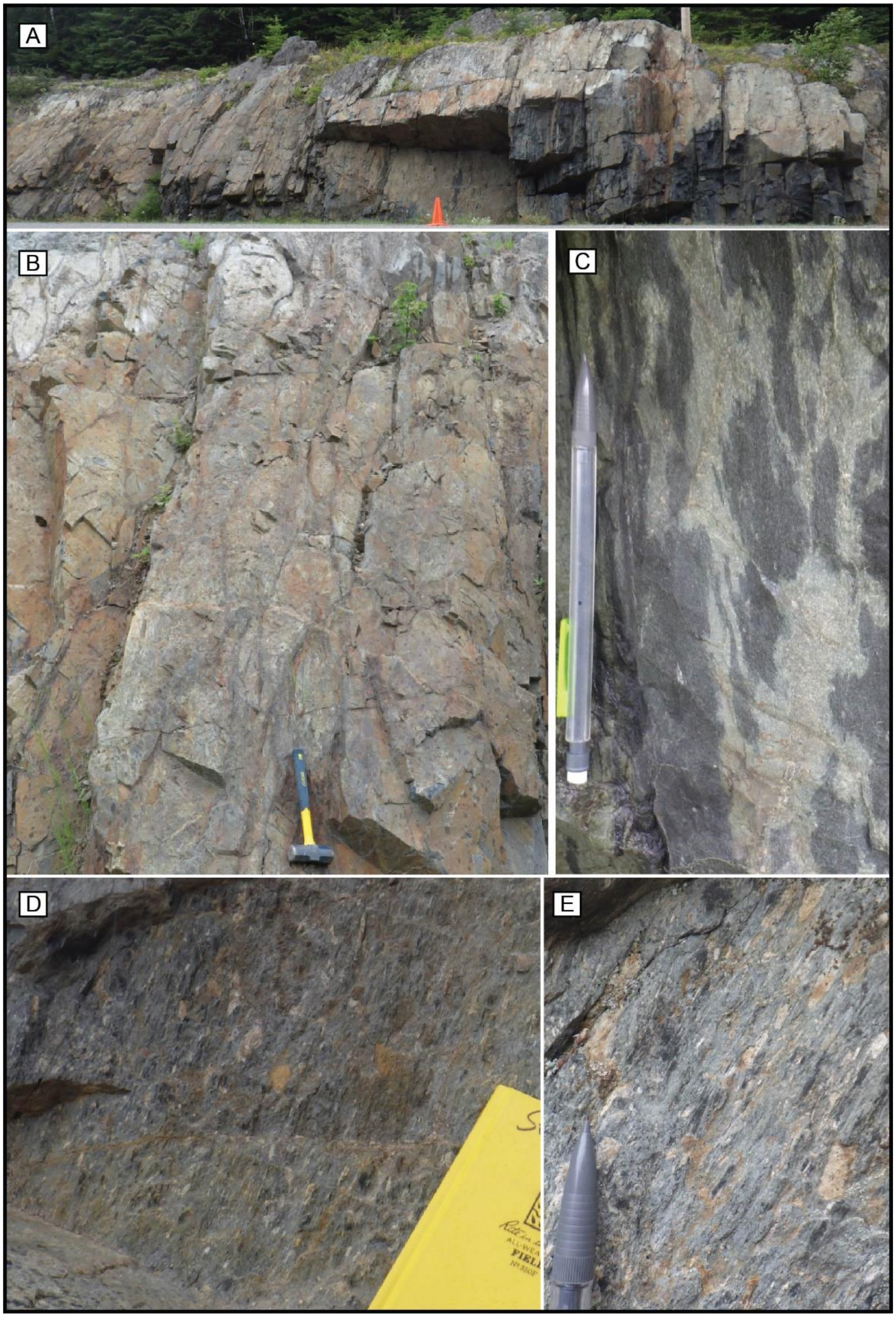

Figure 7. Lithology and contact of the Central Surgeon and Ament Bay Assemblages. (A) Overview of the outcrop at Stop 5. (B) Subvertical pillow structures of the Central Surgeon Assemblage. (C) Epidote-quartz alteration in the massive basalt of the Central Surgeon Assemblage. (D, E) Charcoal grey polymictic matrix-supported conglomerate with pebble-sized, moderately sorted, subrounded clasts of the Ament Bay Assemblage.

sandy lithic matrix. Dark grey wacke interbeds range in thickness from 20-30 cm and have 2-5 cm internal laminations.

The basal contact of younger molasse-type sedimentary deposits of the Ament Bay Assemblage with underlying volcanic rocks of the Central Sturgeon Assemblage is sub-parallel to the northern shoreline of Sturgeon Lake. The linear nature of the basin, sedimentary characteristics, locally-derived clasts, and close spatial association with alkalic magmatism suggests that the Ament Bay unit is a Timiskaming-type assemblage.

The southern boundary of the conglomerate unit is noted by a 10-15 cm zone of fissile rock that is interpreted to be a structural contact between the Ament Bay Assemblage with mafic rocks to the south. South of the contact are a series of small 1-2 m outcrops of a massive mafic unit intruded by a felsic dike, which are interpreted to be part of the Central Sturgeon Assemblage (Sanborn-Barrie and Skulski, 2005).

Pillow basalts of the Central Sturgeon Assemblage immediately to the north and south of this stop indicate that the strata in this section young to the south (Sanborn-Barrie and Skulski, 2005). At this stop, the subvertical pillows are elongated along the foliation and flattened across the foliation (Figure 7B). In the structurally higher Ament Bay Assemblage, deformation is also strong as shown by a penetrative fabric in the conglomerate and commonly stretched clasts (Figure 7E). Rocks of both assemblages share an E-W-trending, subvertical foliation that is parallel to the bedding.

The rocks of this stop are part of two undergraduate research projects at the University of Wisconsin-Eau Claire. Samples from the Ament Bay Assemblage have been collected for detrital zircon U/Pb geochronology and zircon trace element chemistry (Ti, Hf, REE) to probe the magmatic and deformational history of the belt. Samples from the mafic flows and intrusions of the Central Sturgeon Assemblage have been collected to establish a chemostratigraphy and to reconstruct the geodynamic setting(s).

Stop 6 (UTM: 15U 635722.26 E; 5526919.55 N)

Pyroclastic flow from the South Sturgeon Assemblage that hosts Zn-Cu-Pb-Ag VMS deposits

Directions from Stop 5:

Continue on Highway 599 southward for 4.4 km. Park on the shoulder of the highway.

The South Sturgeon Assemblage felsic volcanic rocks host several Zn-Cu-Pb-Ag volcanogenic massive sulphide deposits in the Mattabi, Sturgeon Lake, Lyon Lake, Creek Zone, and F-Group mines (Figure 2). This stop displays the only outcrop (Figure

Figure 8. Felsic pyroclastic flow of the South Sturgeon Assemblage. (A) Overview of the outcrop at Stop 6. (B) Stratified lapilli tuff. (C) Lapilli clasts with well-developed reaction zones around the rim. (D) Pumice clasts in the groundmass.

8A) along the transect that is equivalent to the VMS-bearing felsic volcanic sequences of the South Sturgeon Assemblage.

The South Sturgeon Assemblage is composed of a ~9 km thick bimodal metavolcanics of basalt and rhyolite (Sanborn-Barrie and Skulsky, 2005) and has been interpreted as a ~30 km wide caldera complex (Morton et al., 1991). This assemblage generally incudes a pre-caldera sequence of massive to pillowed basalt and a ~2735 Ma caldera-fill sequence of rhyolitic ash-flow, dacitic domes, and andesitic flows that host the Zn-Cu-Pb-Ag VMS deposits (Davis et al., 1985).

The dominant lithology at this stop can be described as a felsic pyroclastic flow. Lapilli clasts vary from 5 mm to 10 cm in size and are dominated by silicified “cherty” lapilli (Figure 8C). Pumice lapilli clasts (Figure 8D) are common in the southern part of the outcrop but not in the northern part. Some lapilli clasts show well-developed reaction zones that form distinctive rims (Figure 8C). This indicates that the groundmass lava was hot during the formation of this volcanic sequence. The fine-grained, greenish gray to black groundmass is dominated by chlorite+quartz and preserves abundant vesicles. The locally stratified lapilli tuff defines a bedding striking NW-SE and dipping steeply to the NE.

In the middle section of the outcrop, a fine-grained mafic interval is enclosed by the felsic flow. In the southernmost part of this stop where the rocks occur as smaller outcrops, the lithology is dominated by greenish tuff generally without lapilli clasts.

Stop 7 (UTM: 15U 630130.04 E; 5521615.77 N)

Lithology and contact of the Pike Lake Intrusion and the Beidelman Bay Pluton, and representative structures in the southern part of the Sturgeon transect

Directions from Stop 6:

Continue on Highway 599 southward for 5.0 km. Park on the shoulder of the highway.

The ~2734 Ma Beidelman Bay Pluton and the Pike Lake Intrusion (Davis and Trowell, 1982) are synvolcanic with respect to the South Sturgeon Assemblage that hosts the Mattabi, Sturgeon Lake, Lyon Lake, Creek Zone, and F-Group mines. These two intrusive phases are immediately beneath the VMS-bearing felsic sequences of the South Sturgeon Assemblage.

This stop (Figure 9A) shows (1) the main lithology of the Pike Lake Intrusion, (2) the contact between the Pike Lake Intrusion and Beidelman Bay Pluton, and (3) representative structures in the southern segment of the Sturgeon transect.

The first lithology is a massive, medium-grained quartz gabbro (biotite, amphibole, plagioclase, blue quartz, and chlorite) that is mapped as the Pike Lake Intrusion (Figure 9B). The second lithology is a leucocratic, massive, coarse-grained,

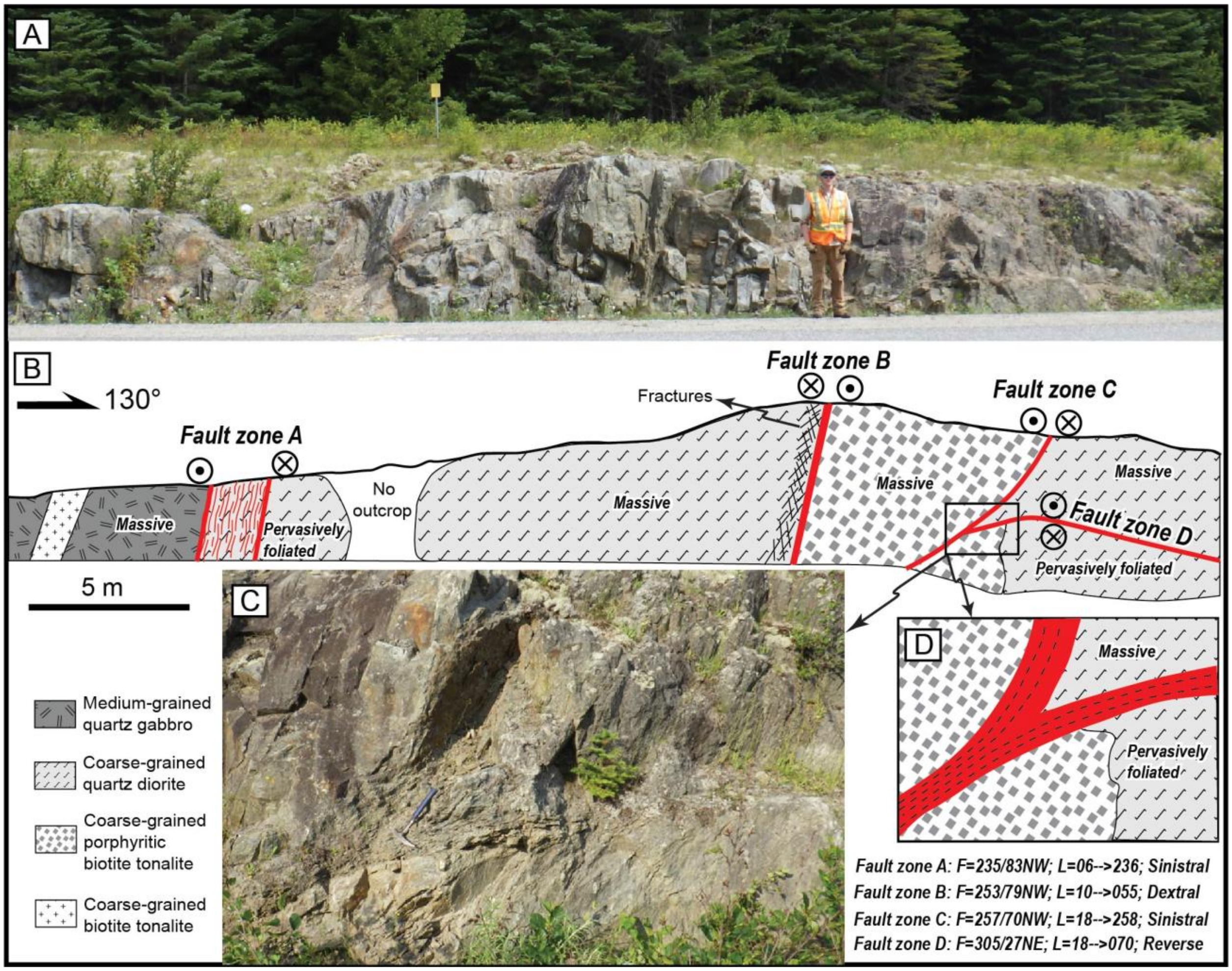

Figure 9. Lithology and structure of the Beidelman Bay Pluton and the Pike Lake Intrusion. (A) Overview of the outcrop at Stop 7. (B) Cross section of the outcrop showing the intrusive and structural contacts between different units. (C, D) Picture and sketch of two merged fault zones.

biotite tonalite dike (quartz, plagioclase, biotite, and minor amphibole needles) in the quartz gabbro. The third lithology is a coarse-grained, massive to strongly foliated quartz diorite (plagioclase, biotite, amphibole, blue quartz, and chlorite). The fourth lithology is a coarse-grained, massive, porphyritic biotite tonalite (Phenocrysts: feldspar, quartz, 0.5 to 2 cm, 60%; Groundmass: plagioclase, quartz, biotite, medium-grained, 40%). The last three lithologies are mapped as the Beidelman Bay Pluton. The spatial relationships of these lithologies are shown on the cross section of Figure 9B.

The contact between the Pike Lake Intrusion and the Beidelman Bay Pluton at this stop is marked by a lithology change from quartz gabbro to quartz diorite, which coincides with a high-strain zone (i.e., Fault zone A on the cross section, Figure 9B) developed along the northern margin of the Beidelman Bay quartz diorite.

Three strike-slip fault zones with subhorizontal lineations and one reverse fault zone are preserved in this outcrop. The structures and kinematics of these fault zones represent the general deformation in the southern part of the Sturgeon transect. From north to south (see the cross section for location), they are denoted as fault zone A, sinistral strike-slip, ductile; fault zone B, dextral strike-slip, ductile-brittle transitional; fault zone C, sinistral strike-slip, ductile-brittle transitional; and fault zone D, reverse, ductile-brittle transitional. The fabrics of the fault zones C and D merge together without crosscutting each other (Figures 9C, 9D), which suggests that these two fault zones were coeval and kinematically related.

Stop 8 (UTM: 15U 627027.28 E; 5505856.08 N)

Representative lithologies of the Winnipeg River terrane along the Sturgeon transect

Directions from Stop 7:

Continue on Highway 599 southward for 17.3 km. This stop is the first outcrop south of a little bridge on Highway 599. Park on the shoulder of the highway.

The Winnipeg River terrane is defined by two plutonic domains: a >500 km NE-SW belt of Paleo- to Mesoarchean metaplutons variably intruded by Neoarchean plutons to the north of the western Wabigoon, and a Neoarchean domain containing scattered remnants of Paleo- to Mesoarchean crustal components to the east and south of the western Wabigoon (Tomlinson et al., 2004; Sanborn-Barrie and Skulski, 2005).

One third of the Sturgeon transect extends into the possible Neoarchean domain of the Winnipeg River terrane (Figure 1). The last stop of this field trip (Figure 10A) shows three major lithologies and their spatial relationships, which may characterize the Winnipeg River terrane in this area.

The first lithology is a biotite-quartzofeldspathic gneiss containing biotite-dominated blocks and layers that are locally foliated. Some of the interesting features include: (a) gneissic banding and folding; (b) felsic melt patches and network; (c) spatial relationship between the gneissic banding and the felsic melts; and (d) biotite dominated blocks/layers.

The second lithology is a biotite-pegmatite that intrudes the gneiss and contains blocks of the gneiss. The pegmatite is undeformed and crosscut by a pink granite dike that represents the third lithology. The pink granite dikes also crosscut the gneiss and are undeformed.

Crosscutting relationships indicate that the biotite-quartzofeldspathic gneiss is the oldest, then is the biotite-pegmatite, followed by the pink granite. Samples have been collected from these units for zircon U-Pb geochronology, which is expected

Figure 10. Representative lithologies of interpreted Winnipeg River terrane. (A) Outcrop overview. (B) Felsic melt patches and network in biotite-quartzofeldspathic gneiss. (C) Folded gneissic banding cut by pegmatite veins. (D) Massive biotite-pegmatite in the gneiss and is cut by a massive K-spar granite dike.

to reveal the absolute ages of these lithologies. Geochemistry and isotopic data will be obtained to reveal the composition and origin of these rocks and the Winnipeg River terrane in this region.

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