

56TH ANNUAL MEETING



**INSTITUTE ON LAKE SUPERIOR GEOLOGY
INTERNATIONAL FALLS, MINNESOTA
MAY 19-22, 2010**



**PROCEEDINGS VOLUME 56
PART 2 – FIELD TRIP GUIDEBOOK**



INSTITUTE ON LAKE SUPERIOR GEOLOGY

**56TH ANNUAL MEETING
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**PETER HOLLINGS, PETER HINZ, MARK SMYK,
MARK JIRSA, AND TERRY BOERBOOM
Co-Chairs**

Proceedings Volume 56 Part 2 – Field Trip Guidebook

Edited by Terrence J. Boerboom, Minnesota Geological Survey

Cover photo: Moderately deformed Seine conglomerate containing metavolcanic and granitoid clasts, with clast tilting due to dextral deformation. Hwy 11, 1 km east of Horsecollar Junction

56TH INSTITUTE ON LAKE SUPERIOR GEOLOGY

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Reference to material in Part 1 should follow the example below:

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The editor (Terry Boerboom) would like to sincerely thank all of those who contributed to this field trip guidebook. The time and effort that went into the preparation of the field trip stops and write-ups are greatly appreciated by all.

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Field Trip 1

Mineral Deposits of the Rainy River area, Ontario

N.W. (Wally) Rayner and staff

Rainy River Resources Ltd.
Suite 303 – 1620 West 8th Avenue
Vancouver, BC V6J 1V4



Visible gold in drill hole NR09-446 (returned 1088.45 g/t Au over 1.5 m),
courtesy www.rainyriverresources.com

Field Trip 1

MINERAL DEPOSITS OF THE RAINY RIVER AREA, ONTARIO

B.W. (Wally) Rayner, Rainy River Resources, Ltd.

INTRODUCTION

Rainy River Gold Deposit, Rainy River Resources Limited

(modified from: <http://www.rainyriverresources.com/The-Project/Rainy-River-Overview/default.aspx>)

Overview

The Rainy River Gold Project (RRGP) is an advanced-stage gold exploration project situated in the southern half of Richardson Township, approximately 50 km northwest of Fort Frances (Fig. 1). In June 2005, Rainy River Resources Limited acquired a 100% interest in the project from Nuinsco Resources Limited and has since added approximately 4 million ounces in total gold resources to the deposit. The property has year-round road access, power lines in close proximity and a railway 21 km to the south.

With over \$65 million in its treasury, Rainy River plans to carry out aggressive exploration in 2010. In addition to over 70,000 m of planned drilling, the company will be completing a Preliminary Economic Assessment in the third quarter of 2010. The company is also conducting Metallurgical Testing and Environmental Baseline and Geotechnical Studies. (Portions of the following text have been directly extracted from SRK Consulting's Mineral Resource Evaluation Report dated July 10, 2009.)

History of the Rainy River Gold Project (RRGP)

The Rainy River Project has attracted exploration interest since 1967. Various companies including Noranda, International Nickel Corporation of Canada (INCO), Hudson's Bay Exploration and Development and Mingold Resources operated in the area centered on the RRGp between 1967 and 1989. The Ontario Geological Survey undertook geological mapping in 1971 and again in 1987-88 in conjunction with and a rotasonic overburden drilling program. Nuinsco undertook exploration activities between 1990 and 2004, with Rainy River continuing from 2005 onwards. Nuinsco drilled a series of widely spaced reverse circulation drill holes from 1994 to 1998, defining a 15 km long "gold-grains-in-till" dispersal train emanating from a

thickly overburden-covered, 6 km² "gold-in-bedrock" anomaly. Nuinsco completed a series of diamond drilling programs to assess the mineral potential of the above anomalies which led to the initial discovery of the 17 Zone in 1994. Nuinsco subsequently discovered the 34 Zone in 1995 and 433 Zone in 1997. Between 1994 and 1998, Nuinsco drilled 597 reverse circulation holes and 217 diamond drill holes (49,515 m). These were mostly in the Richardson area. The 34 Zone was further drill-tested between 1999 and 2004.

In June 2005, Rainy River completed the acquisition of a 100% interest in the project from Nuinsco. In the same year Rainy River re-logged key sections of the historical core drilled on the property and then input all of the data into a GIS database. Rainy River subsequently drilled in excess of 100 reverse circulation holes in three phases to better define the "gold-in-till" and "gold-in-bedrock" anomalies.

In 2007, Rainy River discovered the ODM Zone, which is correlated as being the western extension of the 17 Zone. Rainy River completed a fourth phase of exploratory reverse circulation drilling at this time. Between 2005 and 2007 an additional 209 diamond drill holes for 95,340 m were drilled. In April 2008, a mineral resource estimate for the RRGP was completed. At a cut-off grade of 0.5 g/t Au, an Indicated resource of 34,238,000 t at 1.26 g/t Au and an Inferred resource of 67,564,000 t at 1.03 g/t Au were reported.

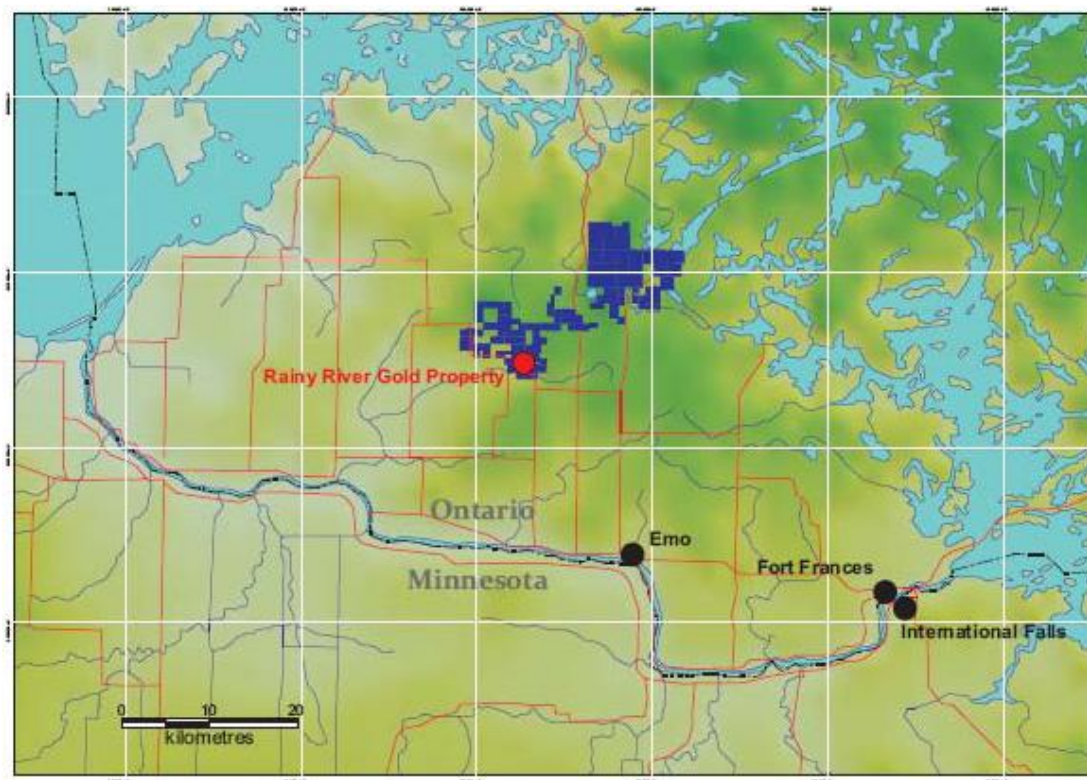


Figure 1. Location of the Rainy River property (from http://www.rainyriverresources.com/Theme/RainyRiver/files/Technical_Reports/July%2010,%202009.pdf)

In 2008, Rainy River drilled an additional 112 diamond drill boreholes for 59,719 m and completed a fifth phase of reverse circulation drilling near the resource area totaling 47 holes. During this time a better understanding of the deposit was gained with additional zones of mineralization recognized, including the HS zone.

The addition of 124 diamond drill holes (68,453 m) from the 2009 drilling campaign has resulted in an overall increase in gold resources to 2.37 M ounces gold in the indicated category and 2.66 M ounces gold in the inferred category. The company's focus of defining mineralization below the limits of the proposed open pit has successfully increased total underground gold resources to 935,000 ounces in all classes, a 298% increase over the 2009 NI 43-101-compliant estimate.

Regional and Local Geology

The Rainy River property falls within the 2.7 Ga Rainy River Greenstone Belt ("RRGB; Fig. 2") which forms part of the Wabigoon Subprovince. The Wabigoon Subprovince is a 900 km long east-trending area of komatiitic to calc-alkaline metavolcanic rocks which are in turn succeeded by clastic and chemical sedimentary rocks. Granitoid batholiths have intruded into these rocks, forming synformal structures in the supracrustal rocks which often have shear zones along their axial planes.

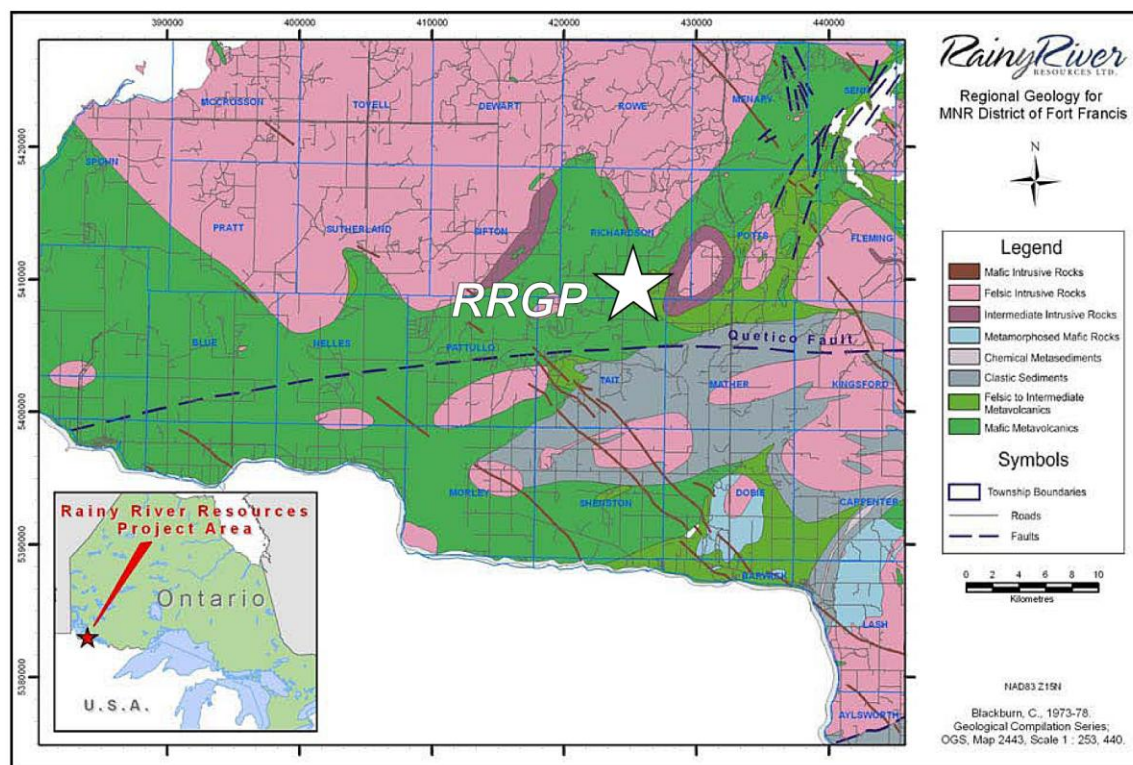


Figure 2. Regional geology of the Rainy River Gold Property (RRGP) (modified from [http://www.rainyriverresources.com/Theme/RainyRiver/files/Technical Reports/July%2010,%202009.pdf](http://www.rainyriverresources.com/Theme/RainyRiver/files/Technical%20Reports/July%2010,%202009.pdf) and from OGS Map 2443)

The Wabigoon Subprovince is host to the Sturgeon Lake volcanogenic massive sulphide (VMS) deposits to the northeast in addition to several other, but smaller, orebodies. It is a very prospective terrain in which to conduct exploration. The Wabigoon Subprovince was locally overlain by Mesozoic (Jurassic and Cretaceous) sedimentary rocks and were subjected to deep lateritic weathering followed by Quaternary glaciation. Limited preservation of the Mesozoic cover sediments and saprolite occurs in localized palaeolows.

The Wabigoon basement rocks and remnant Mesozoic sedimentary rocks are overlain by Labradorian till of northeastern provenance. This till has been found to contain anomalous concentrations of gold grains, auriferous pyrite and Cu-Zn-sulphides. It is overlain by a glaciolacustrine clay and silt horizon and by argillaceous and calcareous Keewatin till of western provenance. The Rainy River area therefore was covered successively by the Labradorean and Keewatin ice sheets.

The Property is centered on Richardson Township with the Sabaskong granitoid batholith to the north and the Black Hawk Stock to the east. A package of metasedimentary rocks is found south of Richardson Township. Wedged in between these lithologies are a conformable series of tholeiitic mafic and overlying calc-alkalic intermediate to felsic metavolcanic rocks. These strike almost east and dip to the south (Fig. 3).

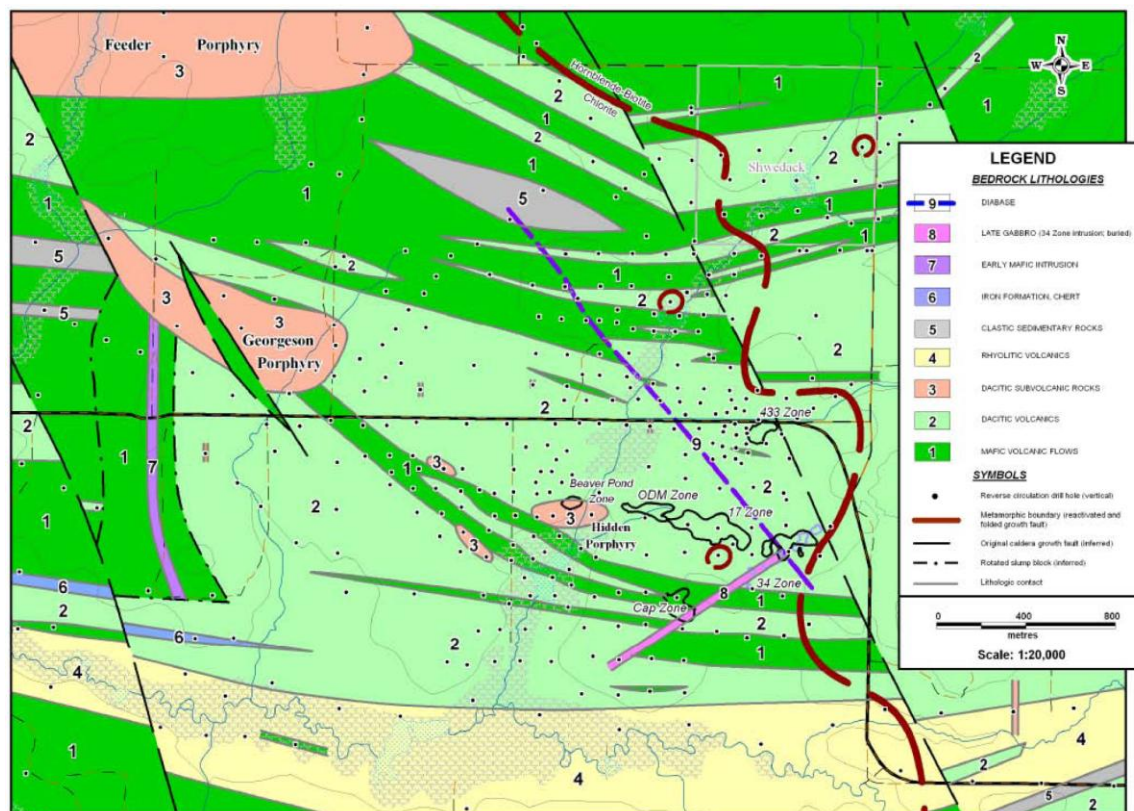


Figure 3. Bedrock geological interpretation for the area surrounding the Richardson caldera (from: [http://www.rainyriverresources.com/Theme/RainyRiver/files/Technical Reports/July%2010,%202009.pdf](http://www.rainyriverresources.com/Theme/RainyRiver/files/Technical%20Reports/July%202010,%202009.pdf))

Intermediate metavolcanic rocks (dacites) host most of the Rainy River gold mineralization. A well-defined penetrative fabric is commonly observed on a regional scale. This foliation is approximately parallel to the trend of the metavolcanic rocks on the Rainy River Property, which strike at approximately 300° and dip 50° to 70° to the south. A steep, southwest-plunging stretching lineation is recorded in all lithologies within the main mineralized zones, with kinematic indicators suggesting south-over-north, reverse-sinistral deformation.

The regional-scale, east-trending Quetico Fault has been interpreted to not extend as far west as the Richardson Township area, not being detected in diamond and reverse circulation drilling programs to date. No other thoroughgoing shear zones have been identified; significant shearing appears to be restricted to gold-bearing rocks that were weakened by the earlier volcanogenic alteration. Late, broadly north-trending, brittle faulting produces small offsets in the mineralized horizons.

Deposit Types and Mineralization

Early exploration work on the Rainy River Project was based on the premise that the gold mineralization was of a shear-hosted, epigenetic type. As exploration activities progressed, a volcanogenic massive sulphide model was proposed. A volcanogenic caldera model (termed the 'Richardson Caldera' model) was proposed in 1997 to explain the gold and sulphide mineralization observed at Rainy River. Recent studies of all available exploration data support a model of sulphide and gold mineralization being of early volcanogenic rather than later epigenetic (shear-hosted) origin, belonging to the gold-rich subclass of the volcanogenic massive sulphide spectrum although the sulphides are mainly disseminated rather than massive.

Several mineralized zones have been delineated by exploration on the RRGF to date (Fig. 4). Gold mineralization is found in the southern Cap Zone, the central ODM/17, Beaver Pond and West Zones and the northern HS and 433 Zones. Recent studies suggest that there are at least two stages of gold mineralization within the Rainy River Project, an early pervasive disseminated stage as well as a later stage of cross-cutting veinlets that often contain visible gold.

The lowest-grade, disseminated gold mineralization is mostly associated with deformed volcanoclastic (permeable) dacites. Zones of higher gold mineralization are often associated with strong silicification and finely layered, foliation-parallel sphalerite and pyrite. Visible gold is typically associated with narrow (<2 cm thick) quartz veinlets, narrow pyrite veins or a sphalerite- / pyrite-rich breccia matrix. Detailed mineralogy studies have revealed that gold and electrum occur as inclusions in pyrite or in close association with sphalerite, carbonates (ankerite) and fine-grained silicates. The gold-bearing pyrite occurs as relict, anhedral grains, whereas the gold-rich sphalerite represents late-stage sulphides that formed rims on or infilled fractures in pyrite.

Magmatic Ni-Cu-Co-PGE-Au-Ag mineralization is found in the 34 Zone which is associated with a tubular, late-stage pyroxenite-gabbro intrusion that crosscuts the ODM/17 Zone. The magmatic sulphides vary from massive to net-textured and disseminated.

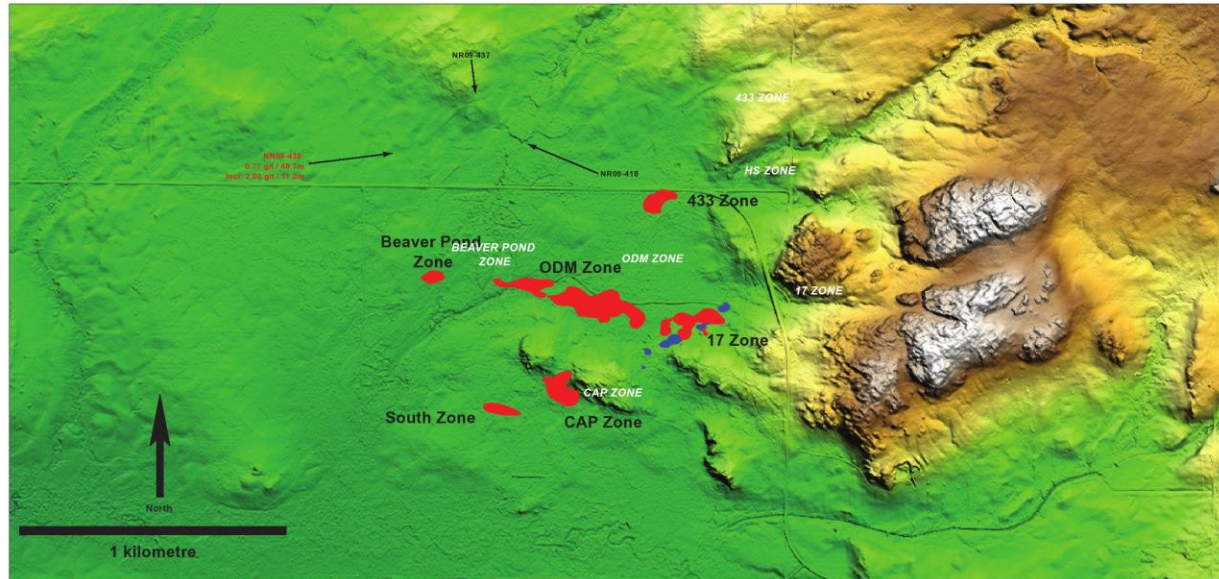


Figure 4. Resource zones location map with Digital Elevation Model backdrop (http://www.rainyriverresources.com/Theme/RainyRiver/files/images/Plan_map_april.jpg)

FIELD TRIP STOPS

UTM Coordinates are nad '83 Zone 15

Rainy River Gold Project – Richardson Twp Ontario

**** Please refer to map at end of field trip stop descriptions****

MAFIC UNITS:

***Stop 1A** UTM- 422272E/5411907N

1B UTM- 422222E/5411941N

Local Information: outcrop mapped by Blackburn (1976) is adjacent to reverse circulation (RC) drill hole #358 and identified as andesite, where as bedrock in RC holes #357 and #358 was identified as dacite, indicating that this first stop is very close to a lithological contact.

Lithology: definite mafic rock containing (>40 % actinolite, chlorite). Southern part of outcrop is thick lava flow while the northern part is partly pillowed. Flows face southwestward and foliation trend is 055deg dipping 85 deg SE.

Comments: The orientation of the lava flow is compatible with the regional strike of the pre-dacite mafic units on the east limb of the Dearlock syncline as shown by Blackburn (1976).

***Stop 2** UTM-425740E/5411640N

Local information: Isolated exposure on the north side of sand and gravel pit.

Lithology: Medium grained mafic rock that can be either part of thick lava flow or intrusion. Pillowed mafics present. Mafics are intruded by several generations of porphyritic, felsic to intermediate dykes up to 2 m wide.

Comments: Part of the pre-dacite mafic basement sequence on the east side of the eastern inner caldera fault. Several 10-20 cm wide fault zones marked by brecciation and increased schistosity trending 040-050 degrees. No stripped outcrop.

Stop 3A UTM 427048E/5411103N

3B UTM 426607E/5411108N

Local Information: Exposures on Roen pasture.

Lithology: Medium grained mafic rock that could be either part of thick lava flow or intrusions. Pillows present locally trend NE and face SE. Minor porphyritic felsic to intermediate dykes.

Comments: Part of the pre-dacite basement mafic sequence, east of the eastern inner caldera fault. The base of the dacite is inferred to be 150m above to the SE of the outcrop area.

***Stop 4A** UTM 425580E/5409350N
 4B UTM 425423E/5409413N
 4C

Local Information: These series of stripped areas follow the strike of a mafic lava flow sequence and metagabbro occurrences within the dacite caldera sequence. 4A was stripped by Nuinsco as a possible site for a portal for underground exploration. 4B and 4C were stripped as part of a Nuinsco exploration program.

Lithology: 4A- mafic lava flows vary between porphyritic and non-porphyritic and have been cut by fine grained quartz phyric intermediate dykes. Flow top breccia zones up to 50 cm thick are observed in the trenches.

4B- mafic lava flow with quartz carbonate and quartz carbonate sulphide veining host the Cap mineralization. Vein sulphides are primarily pyrite along with chalcopyrite and sphalerite.

4C- mafic lava flow in contact with dacite, possible fault contact.

Comments: This mafic sequence is an inter-caldera flow that may have formed a cap on the main dacite sequence hosting the Rainy River Gold deposit. Within the mafic sequence are sills of metagabbro.

***Stop 5** UTM-423174E/5410172N

Local Information: Mafic outcrop exposed on Highway 600 toward Dearlock.

Lithology: North trending ophitic metagabbro sill (possible thick mafic flow) 100 m thick, 400m strike length. Western contact not exposed. On the east, the metagabbro is in sharp contact with massive and pillowed mafic lava flows. Pillow shapes indicate that the flows face westward.

Comments: Attitude of the mafic flows is compatible with the regional structural trend of Blackburn(1976) but is not compatible with the rock units deduced from bedrock encountered by RC drilling by ODM (Averill 1997).

INTERMEDIATE UNITS:

***Stop 6** UTM-426650E/5410563N

Local Information: Davis Pasture, partly cleaned outcrops.

Lithology: Dominantly a subaqueous, felsic-intermediate lava flow characterized by white weathered flow lobes > 10 meters thick, 50 m long at 035 degrees. In the NW corner of the outcrop there is a contact between a felsic to intermediate dyke on the SE and brecciated dacite on the NW at 030 degrees.

Comments: Rusty matrix is probably an autoclastic breccia or hyaloclastite produced by quench fragmentation of felsic magma during the advance of the lava flow under water. The intermediate dyke is only sparsely porphyritic and phenocrysts are generally > 2 mm in size.

***Stop 7** UTM-426148E/5410326N

Local Information: These outcrops occur behind Alvin McClain's residence and on strike with the units at Station #6.

Lithology: The lithologies exposed are complicated by a number of faults. Volcaniclastic conglomerates occur at the north end of the outcrop up to 5 m thick and comprised of 75-90 % sub-rounded to rounded felsic to intermediate clasts in a coarse sandy matrix. Rare fuchsite and chlorite rich pebbles are observed.

Several brecciated lava flows occur in sequence; these units contain rounded-angular lapilli and blocks from 5mm to 10's of cm. Quartz crystal rich dacite is most abundant lithology in this outcrop.

Comments: this is a key outcrop as it exposes a number of lithologies and relationships between them. The brecciated units and the quartz crystal rich dacite may represent a fall deposit or pyroclastic flow. Alternately this area may represent similar quench fragmentation of subaqueous dacite flows as seen at Stop 6 or fragmented lava domes within the caldera complex.

***Stop 8** UTM- 426273E/5409497N

Local Information: A well exposed, cleaned, discontinuous outcrop area south of the drill road. ATV outcrop.

Lithology: Most of the outcrop is quartz crystal bearing dacite that contains about 5% medium grained rounded quartz crystals as well as rare rounded rock fragments. Within this unit are discontinuous beds of sandstone and conglomerate. The massive dacite shows well developed late jointing and minor displacement faulting. The mafic dyke that strikes E-W across the top of the outcrop shows the style of displacement that is observed in drill core along main litho contacts as well as in the surface projection of the ODM/17 zone mineralization.

Comments: this outcrop represents the upper part of the thick dacite unit which is the hanging wall to the main ODM/17 zone mineralization. Based in the presence of sparse rock fragments and the variability in crystal content across the unit, Ayres interpreted this quartz bearing dacite unit as a pyroclastic flow deposit. Drill hole NR97-43 is in this outcrop.

Stop 9 UTM-426074E/5408994N

Local Information: Large lichen covered outcrop west of Highway 600 north of the Teeple farm drainage ditch.

Lithology: Relatively uniform quartz crystal bearing dacite that contains 5% quartz and 15-20% plagioclase crystals of similar size. The unit is intruded by several metagabbro dykes.

Comments: Intermediate unit of upper dacite that occurs stratigraphically above the capping mafic unit to the northwest. This dacite is probably of crystal tuff fall deposit or pyroclastic flow unit.

***Stop 10** UTM-426230E/5409875N

Local Information: West of Highway 600, opposite the junction with Roen Road.

Lithology: Relatively uniform quartz crystal poor dacite. No clast or internal features were observed in this exposure. In the NE corner of the outcrop, there is a 2 m wide zone with strong planar fabric trending 140 degrees. This fabric is parallel to the trend of the inferred east boundary caldera fault.

Comments: Rocks are part of the thick eastern dacite sequence on the east site of the eastern inner caldera fault, but they are relatively close to the inferred location of the fault. This unit is a dacite tuff fall or pyroclastic flow.

Stop 11 UTM-426320E/5409850N

Local Information: Large, lichen covered outcrop east of Highway 600

Lithology: This large outcrop area contains lithologies that are mainly dacite quartz crystal tuff and or flows. Locally pebble to cobble conglomerate units contain rounded felsic to intermediate clasts. The pyroclastic rocks appear to be pumice rich. The dacite is intruded by a number of metagabbro (mafic) dykes that have diverse trends and cut by a number of small scale faults. The faults are in places several metres across and are hosts to diversely orientated quartz veins.

Comments: This unit weathers with positive relief and may represent the up lift part of the eastern caldera block.

Stop 12 UTM-426900E/5410000N

Local Information: Large lichen covered outcrop immediately east of station 11 and east of the junction with the Roen Road.

Lithology: Quartz crystals are ubiquitous and variable abundance, exposures are similar to the outcrop at stop 11. Outcrops in this area weather with higher relief, due to less alteration and the presence of metamorphic biotite and hornblende.

Comments: These rocks probable fall within the metamorphic halo resulting from the emplacement of the Blackhawk Stock.

Stop 13 UTM-427536E/5409453N

Local Information: Large outcrop area north and east of the Teeple farm.

Lithology: Outcrops are mainly quartz and feldspar porphyritic flow and tuffs and autoclastic breccias interbedded with lens of cobble to boulder conglomerate, locally with exotic clasts of unknown origin.

Comments: Ayres mapping in 2005 indicated that conglomerate beds range up to 120m thick, this unit was not located in subsequent mapping of this area.

Stop 14 UTM-427300E/5410175N

Local Information: Series of poorly exposed small outcrops along a highlevel swamp within the same outcrop area as stop 13. Access is from the Clark Road that runs along the east side of the Teeple Farm.

Lithology: Pyritic mafic tuff or flow, possibly hyaloclastite about 50 m thick.

Comments: Strong AEM conductor drilled by Nuinsco. Both pyrite and pyrrhotite occur in this unit and explains the conductive nature of the lithology. This unit is either a mafic flow within the dacite or part of the underlying basement sequence displaced into its current position by unrecognized fault.

FELSIC UNITS:

***Stop 15** UTM-426632E/5408608N

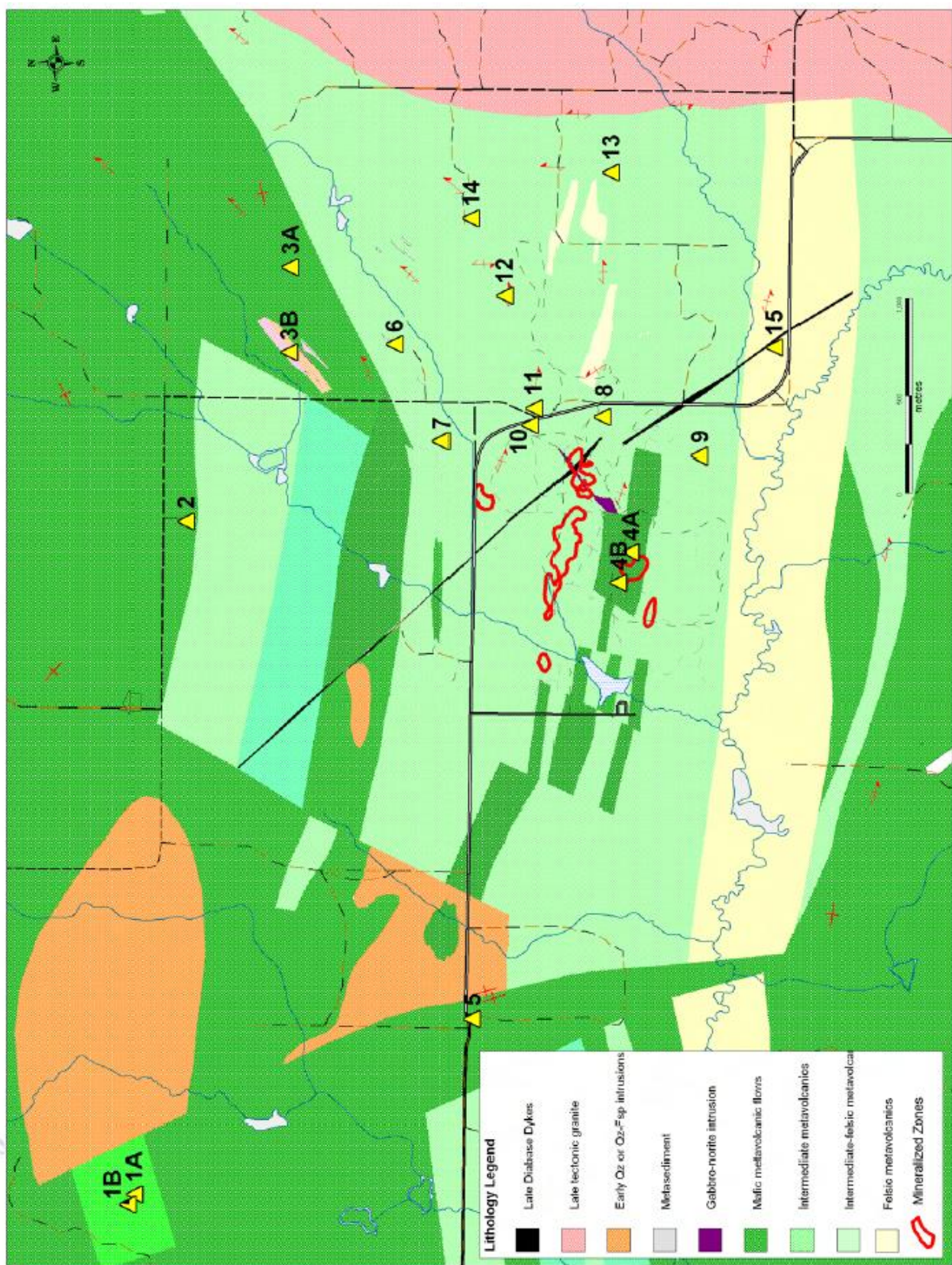
Local Information: Small outcrop in Teeple pasture about 30m north of Highway 600.

Lithology: Quartz and plagioclase crystal bearing unit with no primary structures. Possible felsic lava flow northeast of the dyke.

Comments: Outcrop cut by northwest trending diabase dyke.

Tour note: The stops mark with * are recommended the other are of general interest.

Lunch break for the tour group will be at the core shack where core from the central part of the ODM/17 zone will be on display as well as other polished core of high grade mineralization.



Field Guide Addendum Rainy River Resources OFF Lake

STOP 1: Cunningham Farm (PRIVATE PROPERTY)

Two outcrops in the south part of the OLFC contain extensive quartz vein systems. The vein systems were discovered by Dr. Lorne Ayers in 2006 during the course of geological mapping.

The host rock in both outcrops is a suite of white to pale grey, to pale brown, to rusty weathering, quartz-phyric felsic dikes that contain 1 to 3%, 1- to 4-mm, quartz phenocrysts. Groundmass of the dikes has been recrystallized and is now fine grained. Dikes vary from foliated to massive. The two outcrops may be part of a single vein system.

A. Northern (Lorne's) Outcrop (436670E; 5412250N)

The vein system in the northern outcrop (**Figure 1**), was mechanically cleaned and washed in October, 2007, and has since been channel sampled. This is a relatively small, subcircular outcrop, the cleaned part of which is 35 m (east-west) by 25 m (north-south). On this outcrop, there is evidence of at least three intrusive events, three vein injection events, several periods of deformation and sulphide mineralization.

Felsic dike complex

The first intrusive event was emplacement of felsic dikes. Because of early deformation of the dikes, resulting in a well developed fabric, injection of voluminous quartz veins, and other stages of intrusion, vein injection and deformation, it was not possible to identify more than one phase of dike emplacement on the northern outcrop.

However, based on observations made elsewhere (Ayers, 2007), including the larger southern outcrop, dike emplacement was a multiple intrusive event with some dike emplacement possibly post-dating mineralization. The early fabric, which trends 000° and has a vertical dip, is a combination of sericitic foliation, fractures and <0.5-cm-wide quartz veins.

Mineralization

The quartz-phyric, felsic dikes contain as much as 10% pyrite and minor chalcopyrite. The sulphide minerals occur as disseminated grains and aggregates, which are as much as 1 cm in diameter and in narrow, sericitic, shear zones. Anomalous gold values occur in a sample collected in 2006 (Ayers, 2007). As noted below, sulphide mineralization also occurs in early quartz veins.

Early quartz veins

At the northern outcrop, the felsic dike complex was injected by an early stockwork of pale-grey, glassy, quartz veins that contain <5% pyrite and have localized malachite staining. Most veins are 1 to 5 cm wide and are typically 5 to 30 cm apart, but locally veins are 40 to 120 cm wide; the wider veins appear to be discontinuous pods and/or the result of amalgamation of veins. Although the veins are interconnected to form a stockwork, there is, in most places, a preferred orientation to many veins. Vein orientation ranges from 100° to 160°, and the veins dip between 45° SW and 90°; connector veins are as much as 90° divergent to this trend. Variations in vein trend are a function of both differences in orientation from place to place across the outcrop and warping of veins. The preferred orientation of veins may be a function of a dominant fracture system and associated subsidiary fracture systems, flattening, or a combination of these factors. Some vein deformation is suggested by localized warping of the veins.

In most of the northern outcrop, the early quartz veins range in abundance from 10 to 70%, although there are local areas where only a few veins were observed. Veins are most abundant in the central

part of the outcrop and decrease in abundance toward the southwest and northeast margins. Where veins are abundant, the quartz-phyric, felsic, host rock forms angular, elongated fragments surrounded by quartz.

Where veins are less abundant, vein habit is variable, and this variation is, at least in part, a function of vein abundance:

1. in some places, particularly where vein width is variable, the host rock has a brecciated appearance with rounded to angular, more equidimensional fragments separated by 1- to 5cm-wide veins; <1cm-wide, subsidiary veins extend into, and across the larger fragments; and
2. in other places, particularly where vein abundance is only 10 to 15%, veins have a relatively consistent trend, and few veins deviate more than 20° from this trend; these veins are partly interconnected and, in places, bifurcate and rejoin, surrounding lenticular rock areas, but there is no obvious stockwork or breccia pattern.

On the southwest side of the outcrop, there is a relatively abrupt boundary, with a general trend of 120°, between an area that contains abundant quartz veins on the northeast and an area with only sparse veins on the southwest. This boundary is gradational over 1-2m, and the trend of the boundary is irregular; the irregularities have amplitudes of several metres. From this boundary, the vein zone extends northeastward for 23 m to the edge of the cleaned exposure. On the northeast side of the exposure, vein abundance is less than in the central part of the stockwork zone, but quartz veins are still present in a small outcrop, which was not cleaned, about 15 m northeast of the cleaned exposure.

Near the east side of the outcrop, there are two fault-bounded blocks that are 1 to 3 m wide and contain only sparse, early quartz veins. Boundary faults truncate early quartz veins in adjacent parts of the outcrop. These blocks are wedge-shaped on horizontal outcrop surfaces, consist of the same quartz-phyric, felsic host rock as elsewhere on the outcrop, is 4 m long and 1 m wide; it has a general northerly trend, subparallel to the well developed foliation. A second northerly trending block at least 3 m wide is incompletely exposed in the southeast corner of the outcrop.

Early faults and veins

The early quartz veins are offset along faults that typically trend 020 to 030°; in most places the offset is only a few centimetres. The faults vary from ductile to brittle structures. On the outcrop surface, ductile faults lack obvious fault lines whereas brittle faults have obvious fault lines, some of which are filled by relatively straight, quartz + chlorite veins that are as much as several centimetres wide. Locally, early quartz veins have been dragged and rotated against faults that are now filled by quartz + chlorite veins. The dragging indicates a left-lateral sense of movement and some dragged veins now almost parallel the early faults.

Late quartz veins

On the northwest side of the outcrop, several, white to locally rusty, quartz veins as much as 40 cm wide transect both the early quartz veins and the quartz + chlorite veins; no sulphide minerals were observed in these veins. These late veins have an average trend of 045°, and dip ranges from 40°NW to 70°SE. Vein margins vary from straight to irregular with narrow vein offshoots extending as much as several metres subparallel to the main veins and 40 cm perpendicular to the main veins.

Late granitoid dikes

Two distinct ages of granitoid dikes were intruded into the late quartz veins and all older structures and rock units. The granitoid dikes are distinguished by colour and trend, and they comprise an earlier, texturally variable, pink- to pale-grey-weathering phase and a younger pale-grey- to cream-

weathering phase. Dikes of both phases extend completely across the outcrop. These dikes have not been metamorphosed, and they are probably related to the late tectonic **Finland stock**. As mapped by Blackburn (1976), the margin of this stock is 600 m west of the northern outcrop. Alternatively, the dikes could be related to the **Fleming batholith**, the western edge of which is 1200 m east of this outcrop.

Three, pink- to grey-weathering, leucocratic dikes, ranging in width from 1 to 15 cm, were observed; the dikes are slightly sinuous, but the average trend is 060°, and the dip is 75°NW. The dikes contain at least 25% quartz and <1% mafic minerals, and, texturally, they vary from aplitic to pegmatitic. The pegmatitic dike, which ranges in width from 1 to 3 cm, has a central, 5- to 10-mm-wide, quartz-muscovite zone with a grain size of 5 to 8 mm.

The younger, pale-grey- to cream-weathering dikes have straight to sinuous to zigzag habits, and they trend 020° to 030°. They include a >3-m-wide dike that is incompletely exposed at the southwest corner of the exposure, and two, closely spaced, 10- to 20-cm-wide dikes in the centre of the outcrop; one of the narrow dikes bifurcates, but the second branch terminates within 2 m. These dikes have a grain size of 1 to 2 mm, and they contain 25 to 30% quartz and 5% biotite. The wider dike contains sparse, 1- to 2-cm-wide, unmineralized, quartz veins, and it is weakly foliated parallel to the contact, which is a 2-mm-wide, pinch and swell shear zone.

B. Southern outcrop: (436648E; 5411951N)

In this outcrop, which is considerably larger than the northern outcrop, the quartz vein system occurs along the relatively poorly exposed northwest edge; the vein system has been stripped in a number of places by Joe Hackl and the author.

The quartz vein system is very similar to that in the better exposed northern outcrop. Pale-grey, quartz veins that are generally <5 cm wide, but locally are as much as 50 cm wide, occur in foliated, rusty-weathering, quartz-phyric, felsic dikes. Most veins preferentially trend between 030° and 100°, but the veins are interconnected to form a stockwork within an *in situ* breccia. The vein system is at least 30 m wide, and it was traced about 100 m to the northeast, along a trend of 045°, before disappearing in an area of poor exposure about half way across the outcrop. To the northeast, the vein system appears to decrease in width, and the system here is less obvious because there is less rusty weathering.

On the southeast side of the quartz-injection zone, foliated, rusty-weathering, quartz-phyric, felsic dikes that contain the vein system are in sharp contact with a more massive, quartz-phyric, felsic phase that lacks quartz veins and rusty weathering. The contact is covered by a 1m width of overburden, and it was not actually observed. However, there is good control on the contact location, and the contact trends 030°, subparallel to the vein system. The more massive phase could be a younger intrusion, although still part of the Off Lake felsic dike complex.

The vein system in this outcrop was intruded by two dikes that may be related to the late tectonic, Finland stock. These include:

1. a 30cm-wide, pink-weathering, feldspar-phyric, granitoid dike that contains sparse, 1cm-long, feldspar phenocrysts in a medium-grained groundmass, and
2. a 20cm-wide, zigzag, pegmatite dike. The granitoid dike trends 030° and the average trend of the pegmatite is 060°.

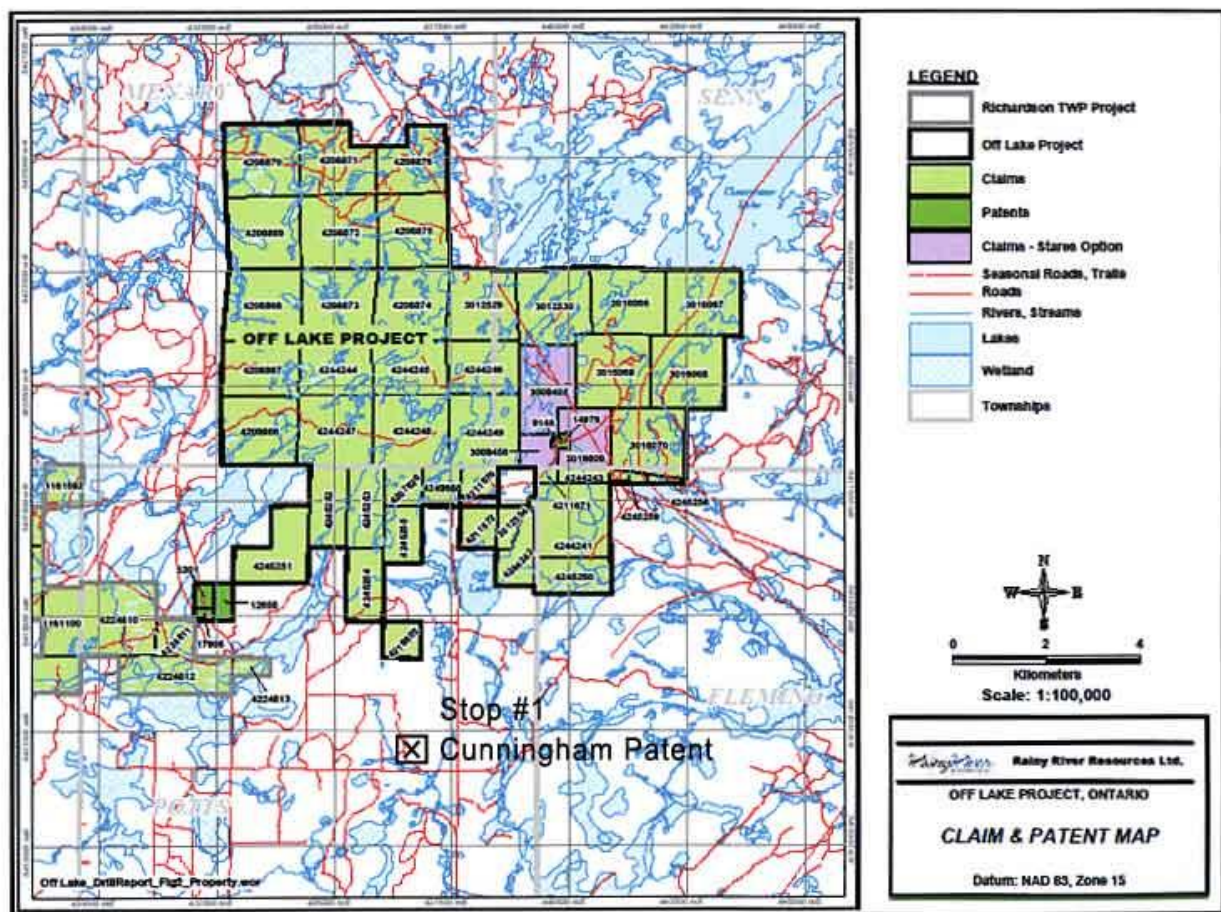
In the southern outcrop, the veins are on the west side of the outcrop and appear to form a generally northerly trending zone as much as 10 m wide; within this zone, individual veins are as much as 1 m wide and have diverse trends.

Genesis of the vein systems

If the pale-grey vein system in the southern outcrop is projected along the apparent trend of the system, as established by the dominant trend of the veins and tracing of the system, it would be close to the early vein system in the northern outcrop, although the vein system in the northern outcrop has a different average trend. This spatial relationship in addition to the lack of vein systems on outcrops farther north suggest that the two vein systems are genetically related.

The early quartz veins predate several generations of later quartz veins, both ductile and brittle faults, and two periods of granitoid intrusions. The early age of the veins and the sharp contact on the southern outcrop between foliated, quartz-phyric, felsic rocks containing the quartz stockwork and a more massive, quartz-phyric, felsic unit that lacks quartz veins suggests that the vein system may be related to emplacement of the Off Lake felsic dike complex.

The only similar quartz stockwork observed to date in the area is associated with the Off Lake fault. The vein system on the Cunningham option has a distinctly different trend to that of both the Off Lake fault, the inferred extension of which is about 800 m to the east, and the Potts fault, which is about 1 km to the south. However, the quartz stockwork on the Cunningham option may be related to an undiscovered early fault in the southern part of the Off Lake felsic dike complex.



Field Trip 2

GEOLOGY OF THE STEEP ROCK GROUP: ANATOMY OF AN ARCHEAN CARBONATE PLATFORM

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Part A – Geology of the Steep Rock Group: Anatomy of an Archean Carbonate Platform.

Part B – Description of Hammond Reef Gold Deposit, Brett Resources Inc.

INTRODUCTION

The Steep Rock Group is located near Atikokan, Ontario where it lies unconformably on Mesoarchean tonalite (Figures 1 and 2). It was first described by Smyth (1881) as consisting from bottom to top of: 1) Conglomerate, 2) Lower Limestone, 3) Ferruginous Formation, 4) Interbedded Crystalline Traps, 5) Upper Calcareous Greenschist, 6) Upper Conglomerate, 7) Greenstones, 8) Agglomerate, and 9) Dark Grey Slate. Lawson (1913) reduced this to four units by combining the upper six into one unit that he described as interbedded crystalline traps. Jolliffe (1966) applied the term Group to the succession, thus changing its status from a Series (chronostratigraphic unit), which it had been termed before, to a lithostratigraphic unit. He also separated the volcanic rocks into a lower Ashrock and an upper assemblage of flows, tuffs and sedimentary rocks. Wilks and Nisbet (1988) were the first to formally define the Steep Rock Group according to the procedures put forward by the International Commission on Stratigraphic Classification outlined in Hedberg (1972, and subsequent publications of the ICSC). Their formal classification remains in place and should be followed when referring to the rock units that were defined. From bottom to top the Steep Rock Group consists of (Wilks and Nisbet, 1988):

Wagita Formation – predominantly conglomerate and sandstone with some pelite (mudstone). It is 0 to 150 m thick and appears to occupy depressions (paleovalleys) in the unconformably underlying Marmion Complex. It is overlain conformably by the Mosher Carbonate

Mosher Carbonate – This unit is composed mainly of calcite with minor amounts of dolomite, ferrian dolomite (ankerite), quartz, pyrite and carbon (in the form of kerogen, Rothpletz 1916; Hayes et al, 1983). It is up to 500 meters thick with an irregular upper surface.

Jolliffe Ore Zone – The lower member consists of the unconsolidated, earthy, Manganiferous Paint Rock Member. It is composed of fragments of goethite, hematite, chert and quartz with a matrix consisting of these minerals plus kaolinite, illite, calcite, gibbsite and pyrolusite (Huston, 1956). It is 100 to 300 meters thick and averages 3.8 % manganese. The Goethite Member overlies the Manganiferous Paint Rock Member. It is composed of goethite (67%) and hematite (21%) with accessory quartz and kaolinite. Where the ore is not brecciated and altered it resembles banded iron formation. This unit is 50 to 100 meters thick and is overlain by the Dismal Ashrock.

Dismal Ashrock – This unit is predominantly a mafic to ultramafic pyroclastic rock. Most clasts are rounded and less than 1 centimeter in diameter but fragments up to seven meters occur. Thin volcanic flows interlayer with the pyroclastics. Lenses of massive bedded pyrite and carbonaceous chert also occur in this Formation and the Jolliffe Ore Zone. The ashrock is 100 to 400 meters thick and is possibly structurally overlain by the Witch Bay Formation.

Witch Bay Formation – Mafic and intermediate volcanic and sedimentary rocks make up this unit. It is extensively deformed with a minimum, and poorly constrained, thickness of 1000 meters. Its lower contact may be a structural discontinuity and it is only tentatively included in the Steep Rock Group. Its upper contact is either intrusive or structural.

All units in the above description have been metamorphosed and the prefix meta is implied to apply to all rock names.

Kusky and Hudleston (1999) believe that both the Dismal Ashrock and the Witch Bay Formation are allochthonous, having been tectonically transported to their present positions. They interpret the Dismal Ashrock as a mélange with a ductile high strain zone at its top. They further believe that deposition of the Steep Rock Group began at 3.0 Ga as the Marmion Gneiss Complex rifted, the Jolliffe Ore Zone was formed by the sub-aerial exposure and weathering of the Mosher Carbonate and the Steep Rock Group may have formed a portion of a linear array of 3.0 Ga platform sequences along with the Sachigo and La Grande River Subprovinces. The highly oxidized state of the Jolliffe Ore Zone and its forming under an Archean anoxic atmosphere is difficult to reconcile. This combined with the huge amount of limestone that would need to be dissolved to form a terra rosa up to 300 meters thick make their model for the formation of the Jolliffe Ore Zone untenable. In addition, age determinations obtained since this paper was published throw other portions of their conclusions into serious doubt.

The age of the Steep Rock succession remained conjectural for most of its history in the literature. The first step towards understanding the age relationships occurred in 1988 when

Davis and Jackson published a U-Pb zircon age of approximately 3000 Ma for the Marmion Batholith. This age was refined to 3001.6 ± 1.7 Ma by Tomlinson et al. (2003). A U-Pb zircon age of 2780.4 ± 1.4 Ma was also obtained by Tomlinson et al. (2003) for the Dismal Ashrock, though the age of this zircon may reflect inheritance. Based on correlations between the Steep Rock area and the Finlayson and Lumby areas to the north, which were put forward by Fralick and King (1996), Fralick et al. (2008) bracketed the age of the Steep Rock assemblage between 2828 Ma, the age of volcanics in the Lumby Lake belt that underlie the sedimentary rocks, and 2780 Ma, the youngest zircon in the overlying Dismal Ashrock. Recently age determinations on detrital zircons obtained from basal siliciclastics of the Wagita Formation provided a youngest zircon age of 2779 ± 22 Ma (Denver Stone, O.G.S., personal communication). Unlike age determinations on igneous rocks, where the statistically most likely age is given as the probable age, ages on detrital zircons indicate the unit is probably younger than a specific age and, therefore, the older age of the range is quoted. Thus, the Wagita Formation is likely younger than 2801 Ma. This agrees well with the age put forward by Fralick et al. (2008) of between 2828 and 2780 Ma.

REGIONAL SETTING

The following is taken largely from Fralick et al. (2008).

Examining the Steep Rock Group in isolation, without considering its place within the framework of correlative units in the area does not allow a regional picture to emerge. The Steep Rock Group forms a portion of a once continuous rock assemblage that has been dissected by northeast trending faults (Figures 1 and 2) (Fralick and King, 1996; King, 1998; Wyman and Hollings, 1998; Tomlinson et al., 1999).

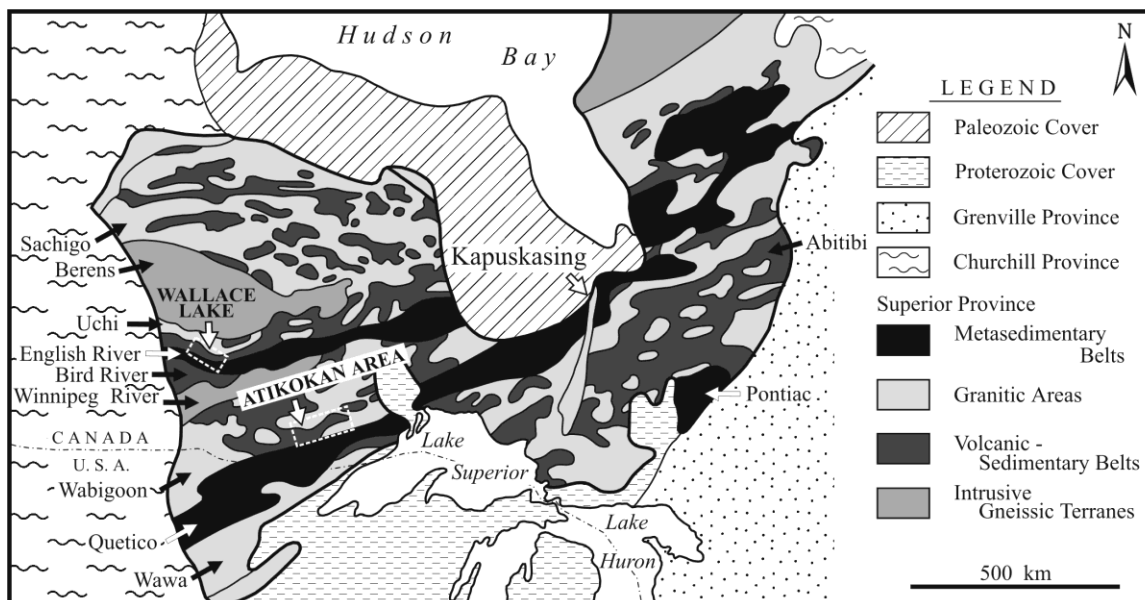


Figure 1. Generalized geology map of Superior Province showing the belt structure and the location of the Atikokan area on the southern edge of Wabigoon Subprovince.

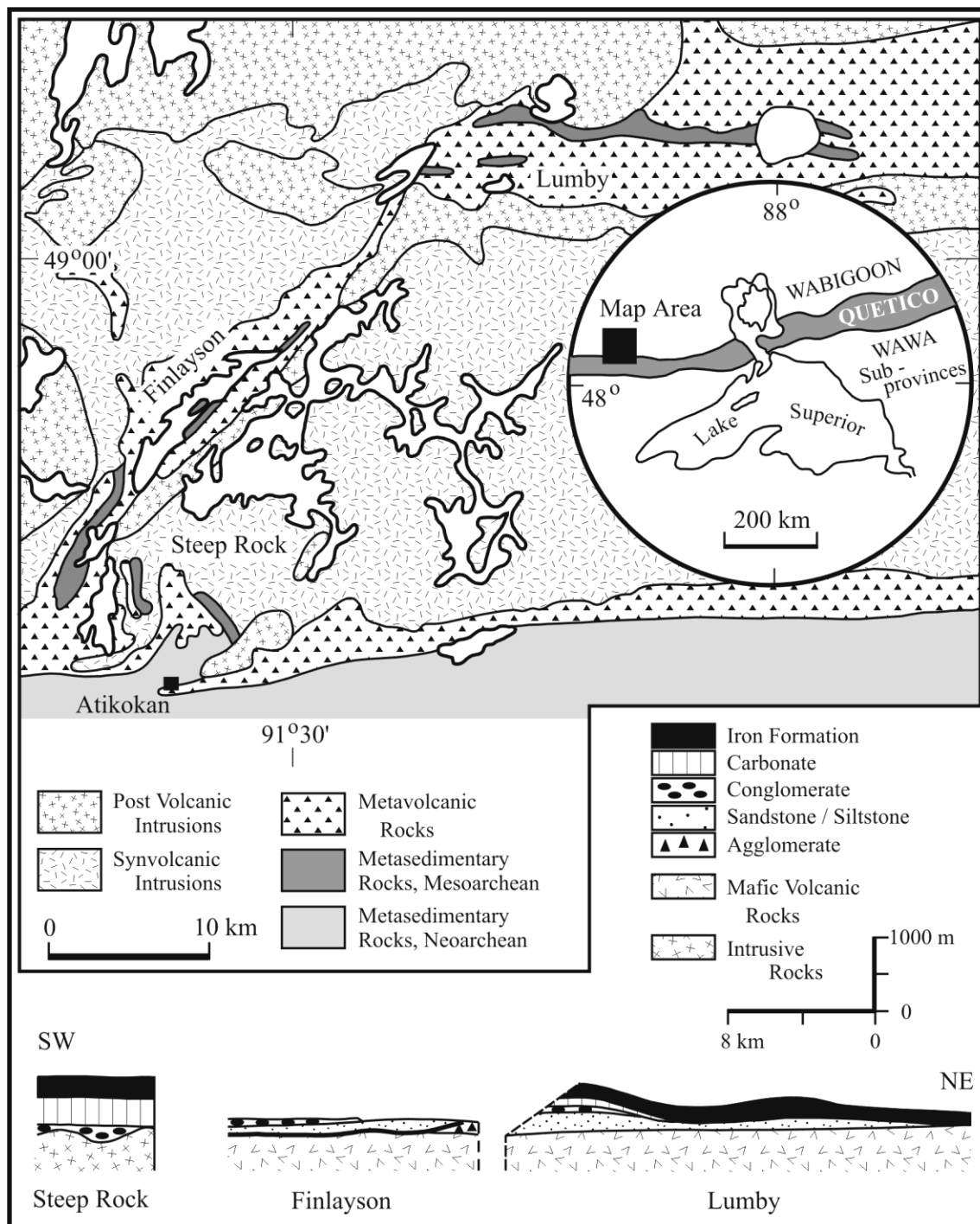


Figure 2. Geology of the Steep Rock region, including correlative units in the Finlayson and Lumby Lake greenstone belts.

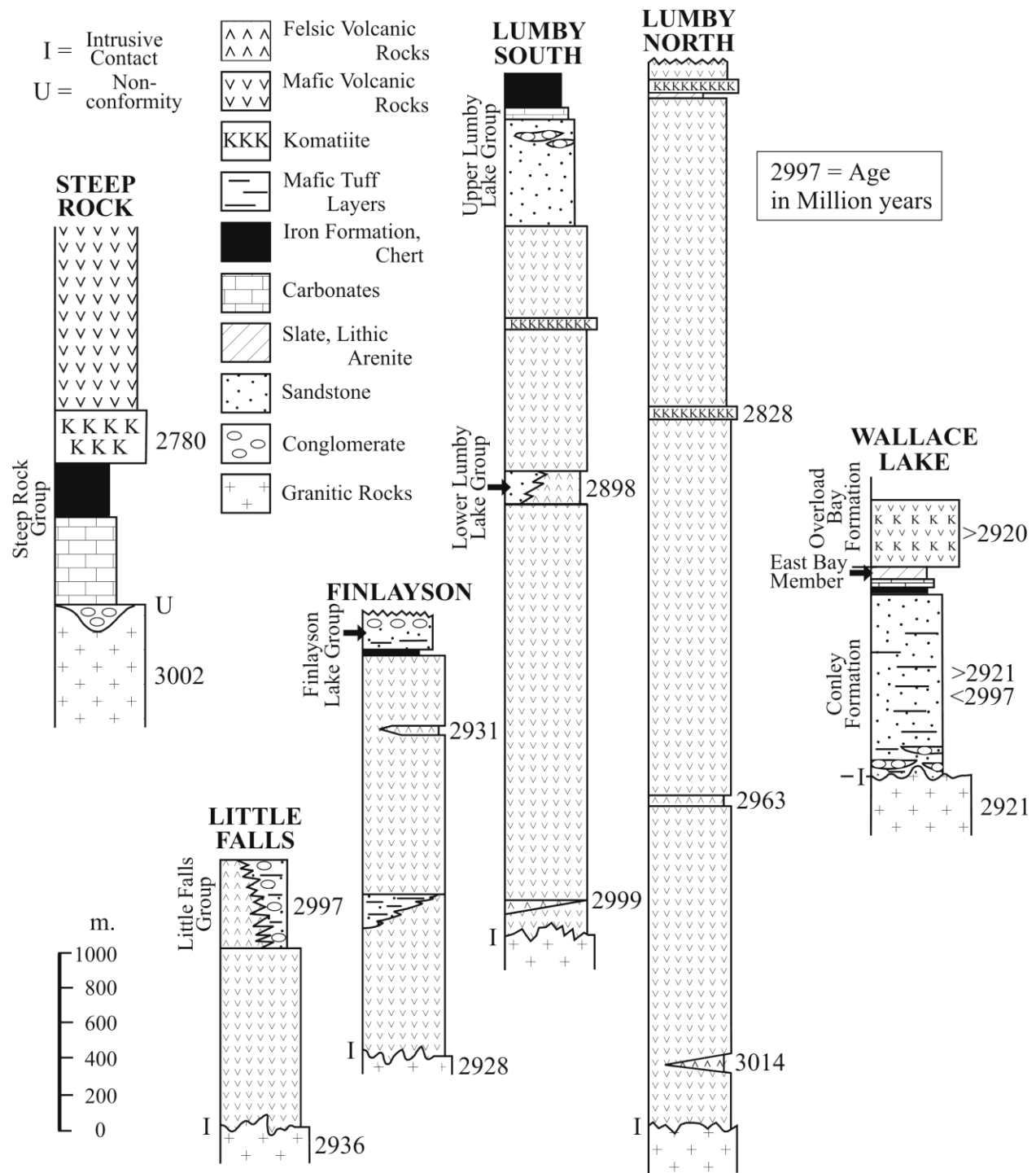


Figure 3. Stratigraphy of the volcanic and sedimentary units in the Atikokan area (ages in millions of years). Consistency of younging indicators throughout the stratigraphic successions is supported by U-Pb zircon age determinations and appropriate stratigraphic position of correlative units in adjacent areas. Units have been tectonically flattened. For sources of age determinations see Fralick et al. (2008).

Sedimentary rocks of the Finlayson Lake Group and Upper Lumby Lake Group overly a thick volcanic succession that began erupting before 3014 Ma (Tomlinson et al. 2003) (Figure 3). Tomlinson et al. (1999) proposed that the mantle source of the Mesoarchean volcanic assemblages in the Steep Rock and Lumby Lake areas was geochemically similar to the source of basaltic rocks that form the Cretaceous Ontong Java oceanic Plateau and that eruption probably occurred in a continental setting following rifting of the crust. Wyman and Hollings (1998) had previously proposed that most of the volcanic units in the Lumby Lake belt have an ocean plateau affinity.

The combination of interpretation of depositional environments with sediment geochemistry and precise U-Pb geochronology of volcanic units enables reconstruction of the paleogeography for this area spanning a 230 m.y. period from the Mesoarchean to the Neoarchean (Fralick et al., 2008). Thick successions of tholeiitic basalt older than 2997 Ma. are present at the base of the Lumby and Little Falls belts. This implies that a sub-aqueous lava plateau existed in the area by 3.0 Ma (Figure 4).

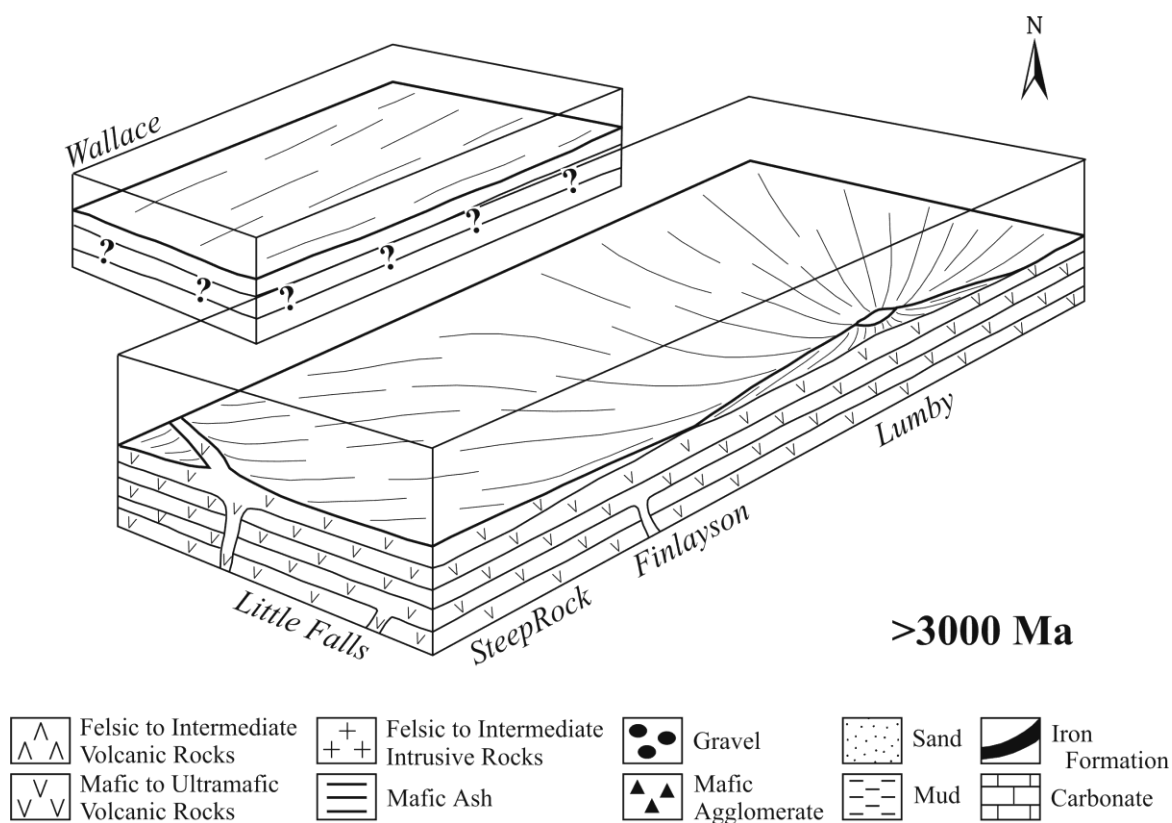


Figure 4. Mafic volcanism in the Steep Rock–Lumby Lake area prior to 3.0 Ga begins building a basaltic plateau.

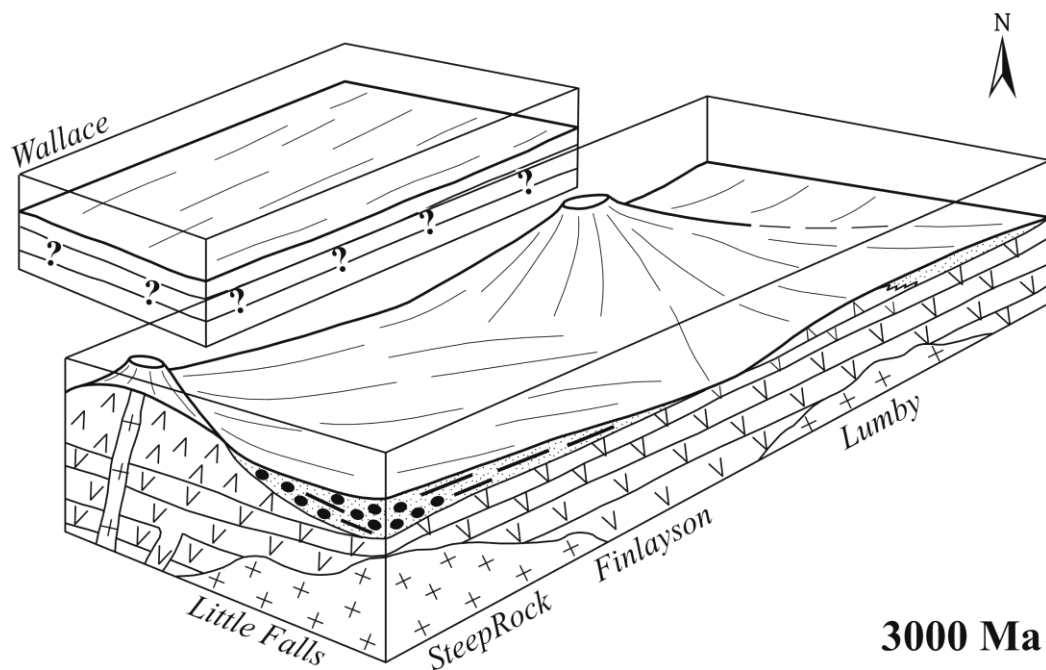
At 3000 Ma tonalitic magmas intruded the tholeiitic basaltic plateau. In both the Lumby and Little Falls areas, Marmion magmas erupted at surface, resulting in felsic volcanism and deposition of clastic aprons surrounding the volcanic centers (Little Falls Group; Figure 5).

Ongoing mafic volcanism throughout this time interval resulted in ash layers from this source interlayered with the felsic volcanic debris. From 3000 to 2920 Ma mafic volcanism continued to thicken the volcanic pile. Periodic bursts of felsic volcanism linked to tonalitic intrusions also occurred (Figure 6).

Throughout the next 100 m.y. mafic volcanism sporadically continued with felsic volcanic pulses, such as the one that erupted the 2898 Ma rhyodacites in the Lumby Lake belt and supplied the sub-aqueous clastic apron forming the Lower Lumby Lake Group. With the cessation of volcanism throughout the area sometime after 2828 Ma, minor block faulting, possibly triggered by adjustment to thermal decay in the region, created localized depocenters for epiclastic sediment in the northern Finlayson area and possibly upraised the tonalities of the Steep Rock area (Figure 7).

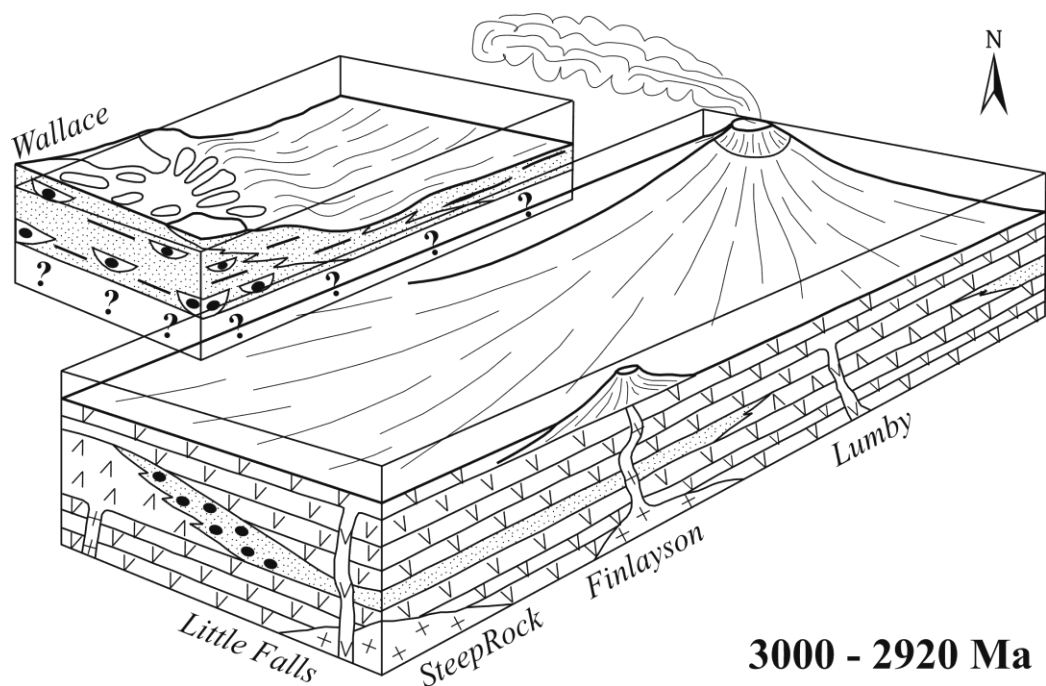
These tonalities and mafic volcanic country rocks underwent erosion, and sediment was channeled through paleovalleys to the shoreline where deltaic deposits accumulated in the shallow areas and mass-flows off the deltas dominated the deeper regions. Subsidence of the area, due to isostatic adjustment to the weight of the ocean plateau, led to submergence of abandoned portions of the delta top, as seen in the upper section of the Finlayson Lake Group. As subsidence and erosion lowered the source area to base-level, the bedrock channel system backfilled, forming the basal Steep Rock clastics of the Wagita Formation, and starved the now largely submerged Finlayson deltaic complexes of sediment. Continued subsidence led to the development of carbonates in the shallower areas, which was succeeded by cherts and iron formation as the area continued to deepen as it isostatically adjusted (Figure 8).

Previously, the sedimentary rocks in the Steep Rock – Little Falls – Finlayson – Lumby Lake areas have been ascribed to a rift setting (Wilks and Nesbet, 1988; Thurston and Chivers, 1990; Tomlinson et al., 1996). The major problem with this interpretation is that some of the volcanic units and associated sedimentary aprons are as old as the supposedly rifted tonalitic basement. This still allows the younger, upper sedimentary units to be rift related. However, recent investigations of the igneous geochemistry have indicated that the mafic to komatiitic volcanic pile associated with the sedimentary rocks was erupted in an ocean-plateau setting (Wyman and Hollings, 1998; Hollings et al., 1999; Hollings and Wyman, 1999). An excellent modern analogue for the evolution of the regional geological setting through time is the Cretaceous of the Kerguelen Plateau off Antarctica. As volcanism ceased in the Kerguelen Plateau 120 m.y. ago (Schlich, 1989) the sub-aerial portion remained above sea-level for 40 m.y. leading to erosion of up to 8000 meters of igneous rock (Coffin et al., 1990; Coffin, 1992). Similar erosive downstripping in the Steep Rock area would account for exposure of the Marmion Batholith. The basal units of the sedimentary succession capping the Kerguelen Plateau are composed of fluvial units analogous to the Wagita Formation. These are overlain by algal limestones, which developed in shallow marine environments (Barron et al., 1989) as sub-aerial deposition failed to keep pace with subsidence driven by isostatic adjustment to the thick volcanic pile. The clastic succession at Steep Rock is capped by stromatolitic limestones deposited after base-level rise flooded source areas. As load and thermal decay induced subsidence continued to outpace sedimentation on the Kerguelen Plateau, the calcareous shallow water successions were succeeded by marine chalk and marl. Deep-water cherts and iron formation record the same



3000 Ma

Figure 5. At 3000 Ma tonalitic magmas, possibly generated by partial melting at depth of the thick plateau assemblage, intruded into the Steep Rock-Lumby Lake ocean plateau. The resultant surface volcanism built positive relief features from which sediment aprons composed of eroded felsic volcanic debris spread out over the plateau.



3000 - 2920 Ma

Figure 6. The Steep Rock-Lumby Lake ocean plateau continued to grow during the 3000 to 2920 Ma time period. Sporadic tonalitic intrusion fed minor intermediate to felsic volcanic events, but the dominant volcanism erupted tholeiitic basalt.

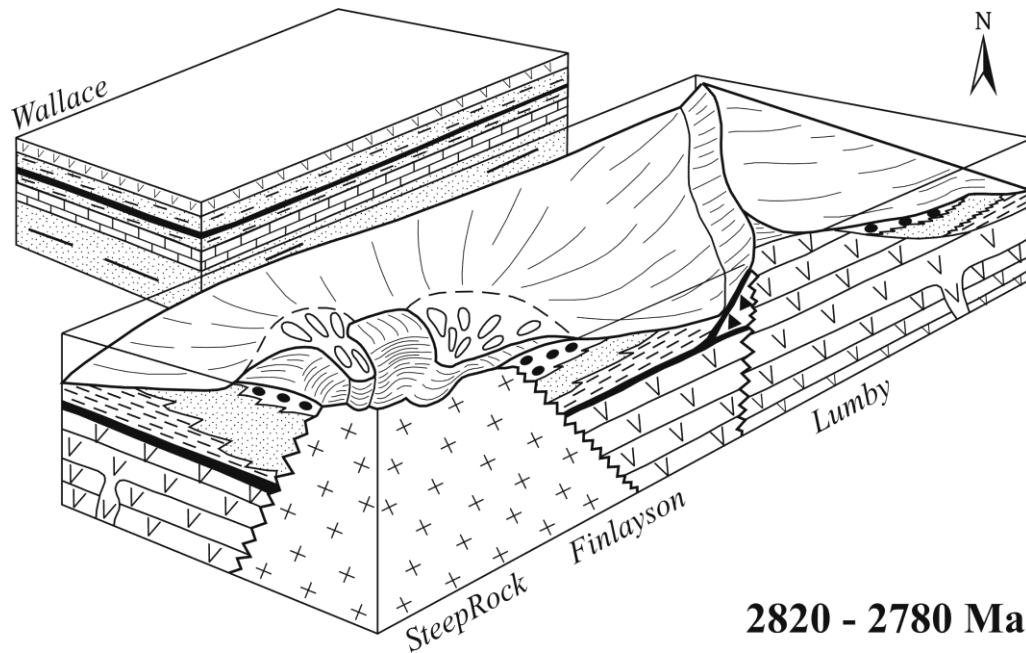


Figure 7. Volcanism ceases on the Steep Rock-Lumby Lake ocean plateau between 2820 and 2780 Ma, and the major sedimentary sequence is deposited. Localized relief produces slope failures and resultant agglomerates in the north Finlayson area. These are overlain by a deltaic clastic wedge prograding from the incised channels of the Steep Rock area.

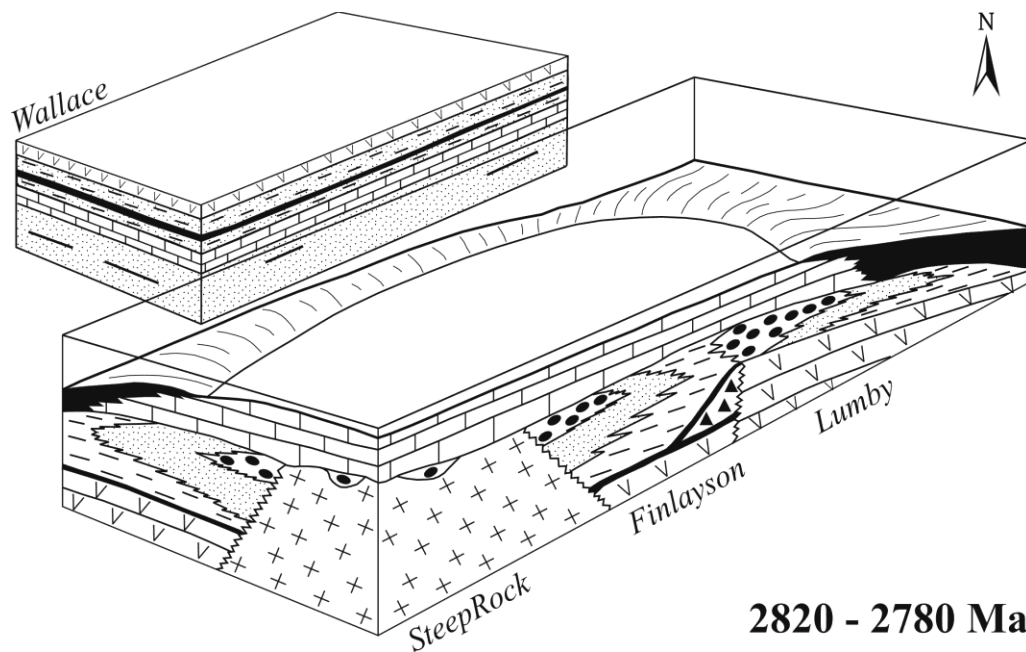
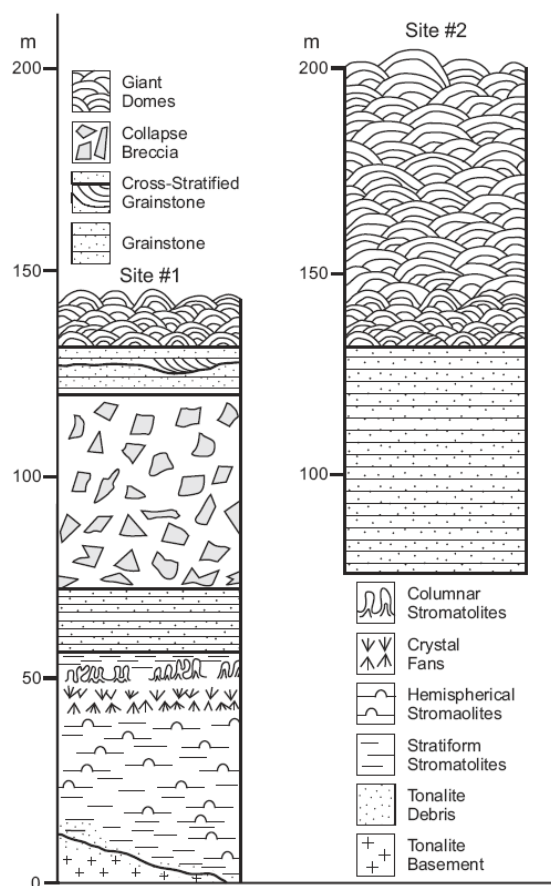


Figure 8. The siliciclastic system depicted in Figure 7 is succeeded by chemical/biochemical deposits as transgression causes clastic sediment starvation. With flooding of the source terrain stromatolitic carbonates developed in shallower areas and iron formation, which had dominated the deeper regions to the north, migrated first over the adjacent siliciclastic deposits and then blanketed the carbonate assemblage as well.

process on the Archean Steep Rock – Finlayson – Lumby Lake Plateau. The striking analogies between the sedimentary units at Steep Rock and the sediments of the Kerguelen Plateau reinforce interpretations based on igneous petrochemistry (Wyman and Hollings, 1998; Hollings and Wyman, 1999; Hollings et al., 1999) that this assemblage represents an oceanic plateau.

THE CARBONATE PLATFORM

Carbonate platforms capping oceanic islands and plateaus are not uncommon in the modern ocean. However, they are rare in the rock record of the Archean. This may be the result of low preservation potential. However, Phanerozoic carbonate platforms suffer from this problem due to their oceanic location and there are still plentiful examples of these preserved in the geologic record. Thus, the Steep Rock carbonate succession represents one of the few opportunities to decipher the paleoecology and paleohydrology of an Archean carbonate platform.



Wilks and Nisbet (1985, 1988) have provided an excellent description of the paleoecology of the Steep Rock platform. The following is largely taken from their work.

Layering within the Mosher Carbonate exhibits a systematic change in form upward through the unit (Figure 9).

The physical and chemical changes in the water mass that must have governed this transition in environments may have been related to a deepening trend from the shoreline environments represented by carbonates on top of fluvial conglomerates and sandstones to the overlying iron formation that was deposited in quite, deeper water (Figure 10) (Fralick et al., 2008).

Alternatively, environmental change may have been related to periods of open versus more restricted circulation of water on the plateau leading to evaporation driven precipitation. We will discuss these possibilities in the field.

Figure 9. Variation in carbonate lithosomes with height in the section.

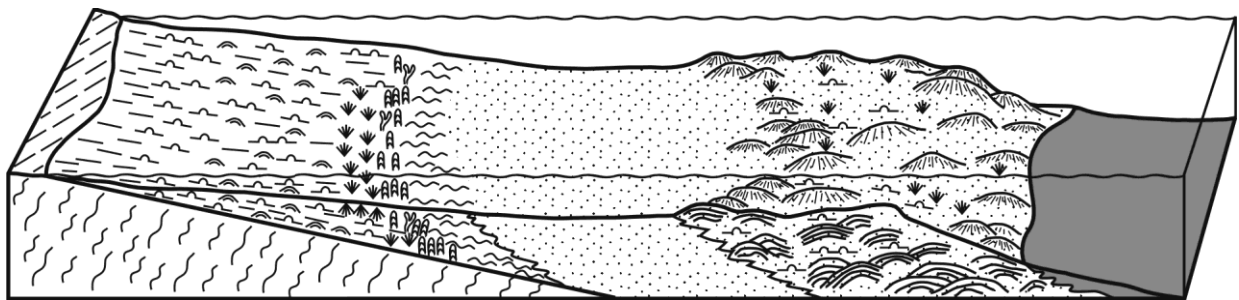


Figure 10. A possible model for organization of carbonate deposition on the Steep Rock ocean plateau. Transgression produced a vertical stacking of the lithofacies. The upward changes in lithosomes present in Figure 9 may be caused by shifts in salinity rather than the lateral variation combined with transgression depicted here.

The carbonate succession begins with an interlayered to sheared originally conformable contact with the underlying fluvial, valley-fill Wagita Formation or the Mesoarchean tonalite gneiss. The best representation of this contact is in an exposure near the bottom of the pit that is now under more than a hundred meters of water. Here decimeter-scale carbonate layers are interbedded with sandstone layers, with similar thickness, over a vertical distance of approximately half a meter. At the first major carbonate outcrop we will visit the basal contact with the 3001 Ma tonalite is sheared, however, pieces of weathered tonalite are present in the carbonate. If the contact is traced laterally it is quite evident that the limestones are onlapping the basement and the tonalitic debris was not carried very far away from the gneiss into the near-shore. The carbonates near the base of the succession have fairly flat layering. The layering is highlighted by changes in organic carbon (kerogen), iron oxides (recent weathering of iron carbonates?) and chert content. What follows, with the exception of the Figures, which are new, is the description provided by Wilks and Nisbet (1985) of the stromatolite succession:

“Near the base of the unit, simple *Stratifera*-like stratiform structures are characteristically present (Figure 11). These have flat to undulatory laminae, occasionally with the development of pseudocolumnar, laterally linked structures, which occur throughout the carbonate member. These *Irregularia*-like pseudocolumnar structures become more common upwards, and columns obtain heights of up to 2 cm (Figure 12A). Above this are hemispherical, laterally linked stromatolites (Figure 12B-D). These cumulate linked structures are similar to those figured by Hofmann (1971) as *Cryptozoon walcotti*. Laminae are wavy and 0.5-3.5 mm thick, and the structures are 5-15 cm high and in basal diameter.

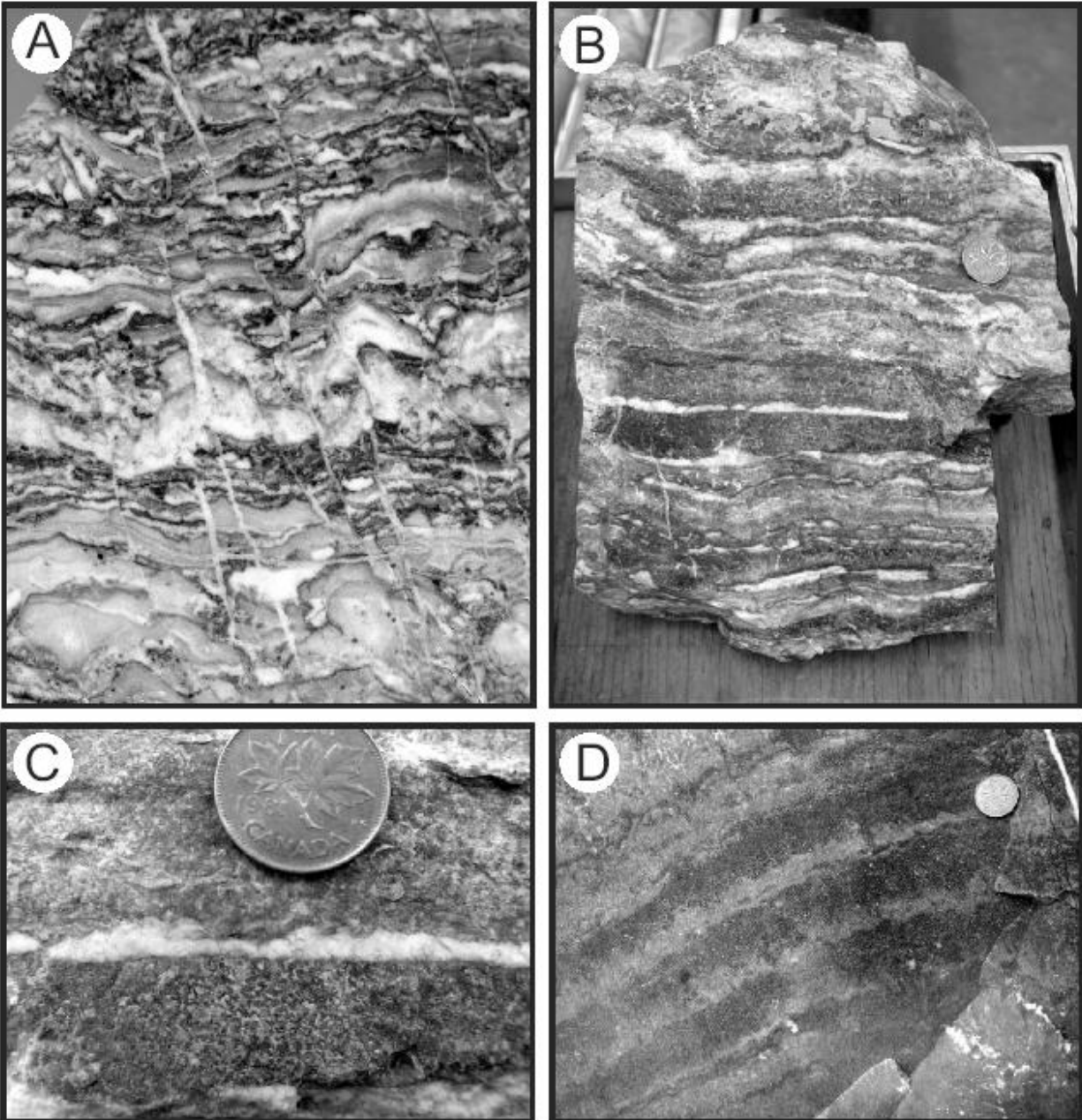


Figure 11. Stratiform layering, which dominates the lowest portion of the section. A) Undulatory, disrupted layering is further disrupted by the small faults. B) This sample has more consistent layering. Note the presence of white cement following some layers. C) Close-up of B. White calcite cement filling void with a flat bottom and undulating top. This shape is typical of gas bubbles that form in present day bacterial mats. D) Laterally consistent layering with small pseudocolumnar stromatolites.

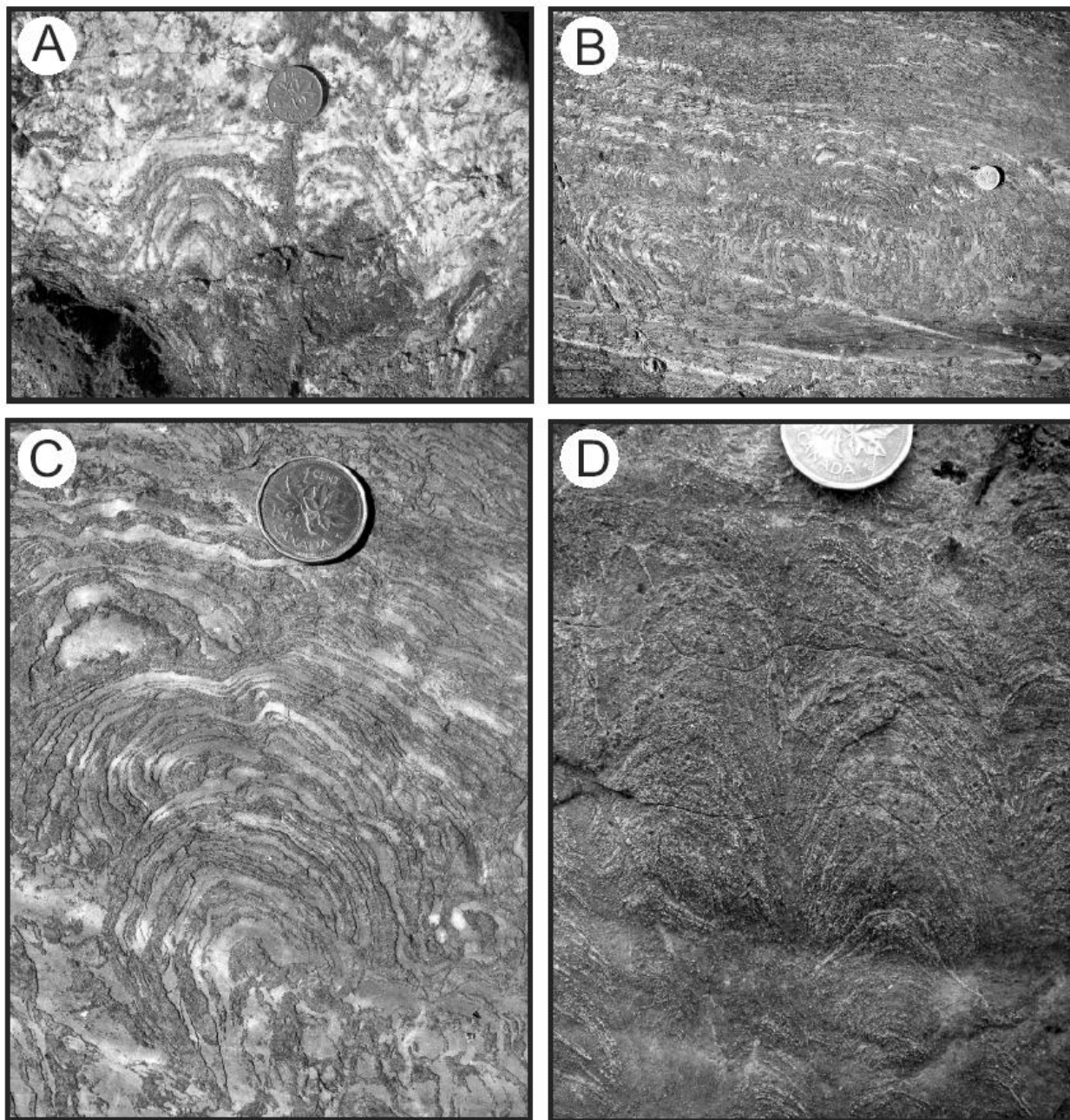


Figure 12. Moving stratigraphically up-section from Figure 11 the stromatolites increase in relief. A) Well developed pseudocolumnar stromatolites. B) Next hemispherical stromatolites begin to appear. C) Close-up of B. Successive hemispherical stromatolites are easily visible growing on top of one another. D) Laterally linked hemispheres in places resemble digitate forms.

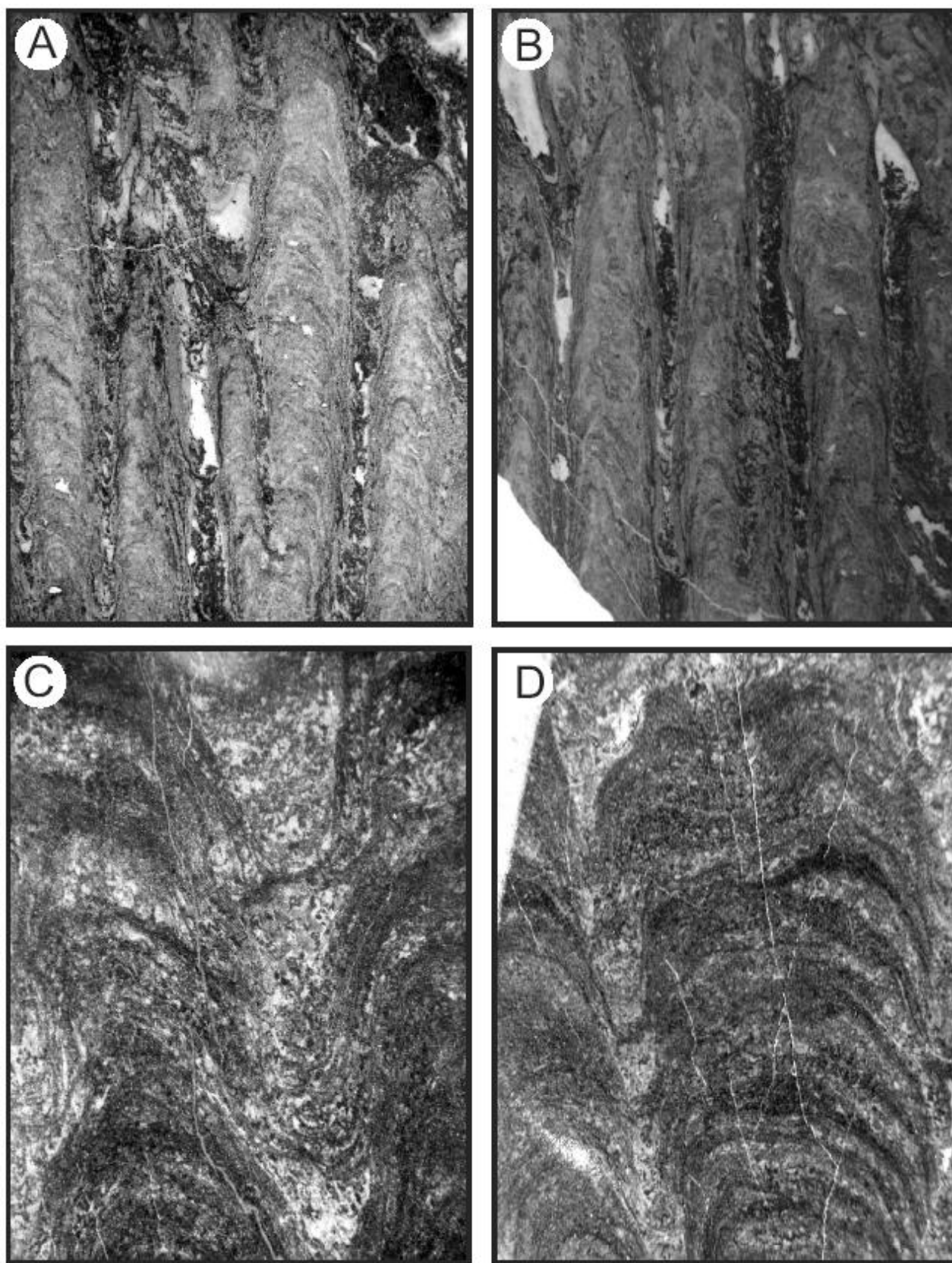


Figure 13. Columnar and branching columnar forms, such as those depicted here, are striking but are only developed in a vertically limited area.

In places these “cryptozoon” structures are succeeded by branching walled and unwalled columnar forms (Figure 13 and 14A).

Branching furcate columns with ragged margins occur with a y style of parallel branching (Walter 1972). Height is up to 20 cm. Above these, simple, small conical structures occur, with diameters of 2-10 cm.” Wilks and Nesbit (1985).

The 3.5 meters below the branching columnar stromatolites contains the first appearance of layers containing the outlines of fans of crystals. In some layers these crystal fans are growing upwards in others they are growing downwards (Figure 14B). The following is a description of crystal fans by Sumner (2000):

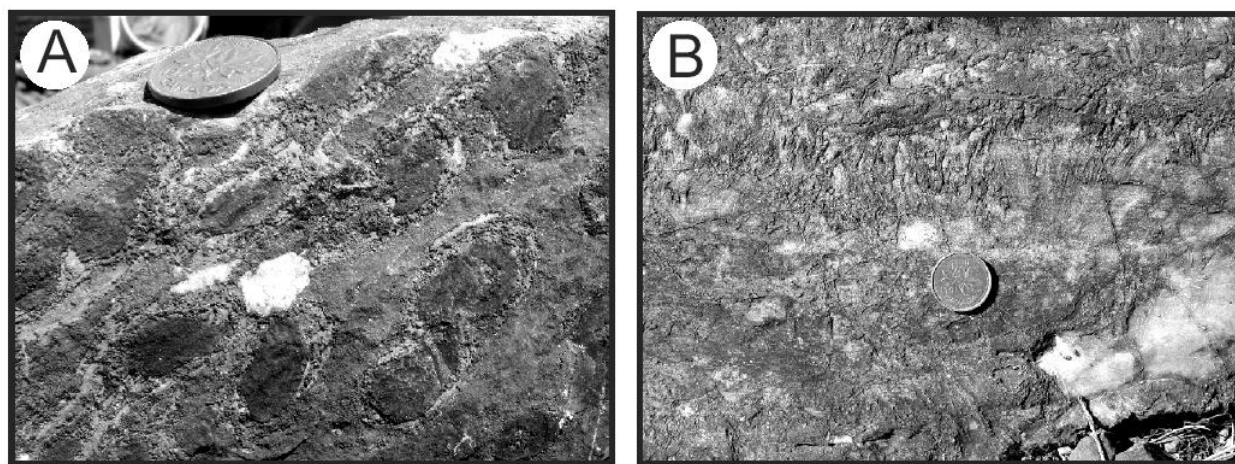


Figure 14. A) Cross-sectional views of columnar forms in outcrop often appear as oncolite-like in shape. B) The first appearance of crystal fans immediately below the columnar stromatolites. Both upward and downward radiating fans are present.

“Microbialites commonly are cross-cut by fibrous mineral pseudomorphs. These pseudomorphs are replaced by calcite, but preserve their primary fibrous character with blunt crystal bundle terminations which suggests an aragonite primary mineralogy (e.g. Sandberg, 1985). The pseudomorphs form fanning bundles of crystals that grew upward. Laterally, neighboring fans of crystals interfered with each other’s growth (Figure 14). Wavy bedding in the microbialites is due to doming of microbialites over areas with abundant fibrous pseudomorphs. This geometry suggests that fibrous mineral precipitation and microbialite growth were contemporaneous (Sumner and Grotzinger, 2000).” Sumner (2000).

The upper half of the carbonate succession contains “giant stromatolites” (Figure 15). These are composed of 1 to 15 cm thick layers of crystal fans commonly radiating upwards (Figure 16 A and B). They are overlain by darker layers of fenestrate microbialite. The microbialites consist of stacked, concave-up thin dark lines, which give the appearance of stacks of upside-down fingernails (Figure 16C and D). In some layers the dark filaments forming the stack are supported and separated by thin support columns (Sumner and Grotzinger, 2000; Sumner, 2000).

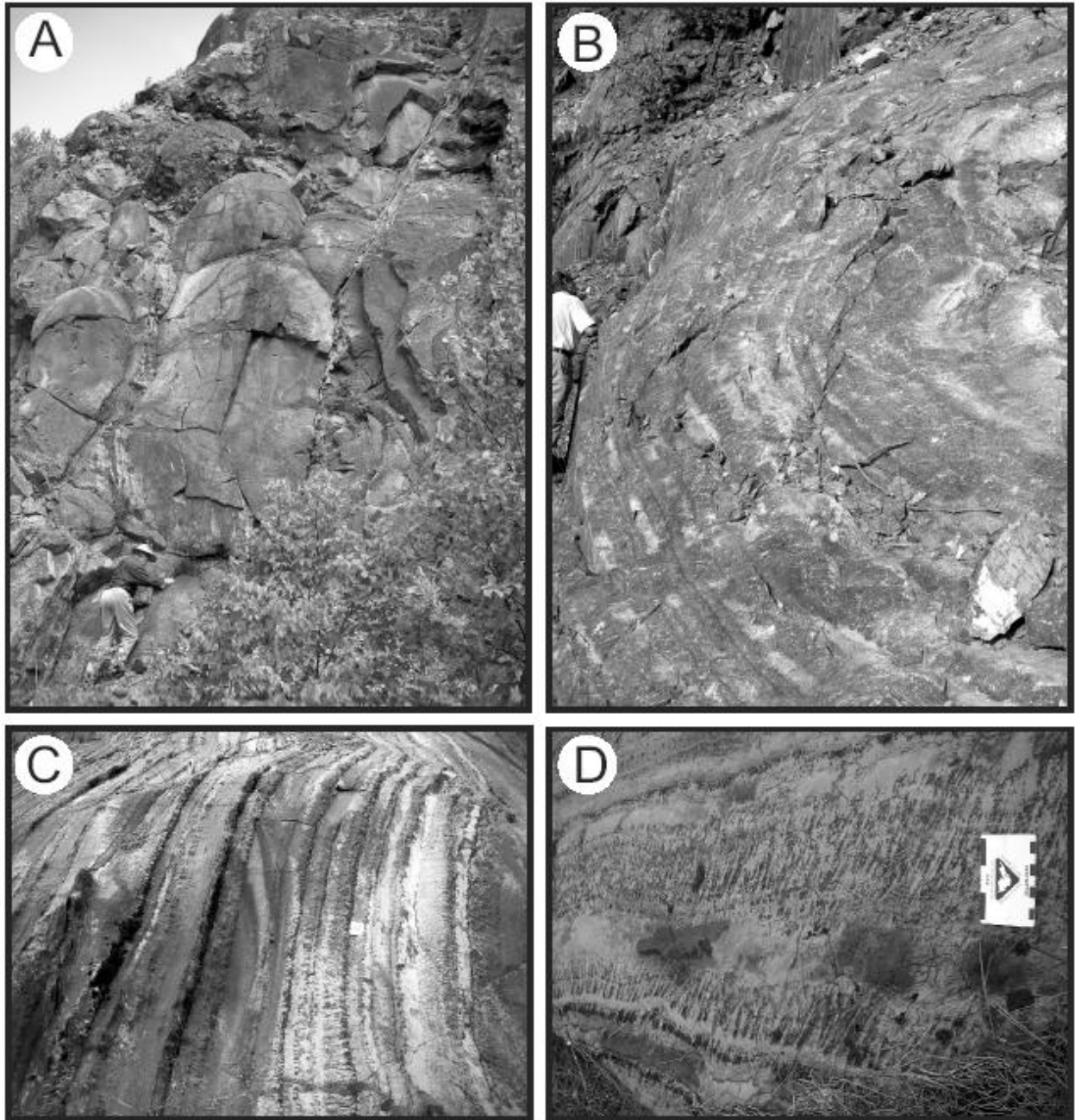
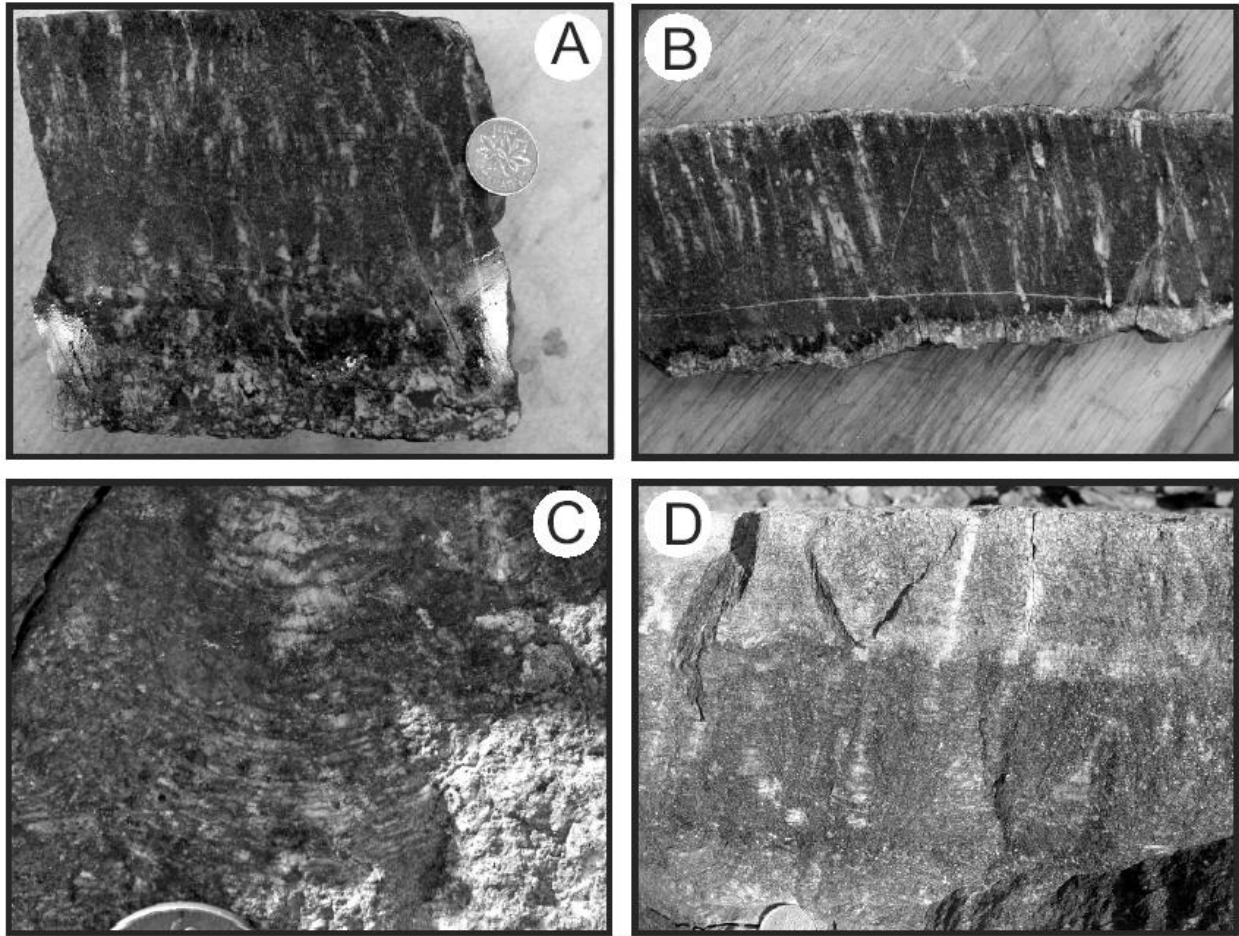


Figure 15. Giant domes in the upper portion of the carbonate succession. A) Giant domes in plan view. Elongation may reflect current activity (elongate parallel to current). B) Giant domes in cross-sectional view. C) Crystal fans dominate this succession and the domal structure, as seen here in cross-section, is very subdued. D) Close-up of silicified crystal fans in C.

The spaces between the microbialite layers are filled with white calcite. Sumner (1997, 2000) believed that the cusate laminae and the support structures were formed by two different microbial communities. Where early calcification of the support structures occurred, the open, net-like morphology with white calcite cement in the pores was preserved (Figure 16D, upper



portion). Where the support structures were not mineralized during formation the structure was *Figure 16*. A and B) Crystal fans underlain by a thin dark layer (iron- and/or organic-rich?). In A the lowest layer appears to be an open-structure microbialite but in B it may be a coarse grainstone. C) Finestrated microbialite with a collapsed structure. D) The lower portion is a finestrated microbialite with a collapsed structure, overlain by one with an open structure.

compacted and the darker layers dominated by cusate layering were formed (Figure 16C and D lower portion) (Sumner, 2000).

The combination of crystal fans and in some layers cusate layering, which appears in places to be draping the fans, produces irregular bed surfaces that have an appearance similar to an egg carton (Figure 17A). In other less common areas, the presence of hemispherical stromatolites in the upper layer of the giant domes creates an upper surface composed of small elongate mounds (Figure 18A).

More rarely, some surfaces are similar to small mudcracks with turned-up edges (Figure 17B). The dominance of the crystal fans in the layers forming the large domes indicates that these structures probably should not be referred to as stromatolites. They do appear to have layering formed through microbial processes, but whether these layers cause the shape of the structures is not known. In areas where microbial layers are not present and crystal fans dominate domes are not well developed (Figure 15C and D), indicating that possibly the organically produced layers are the determining factor in the development of domes.

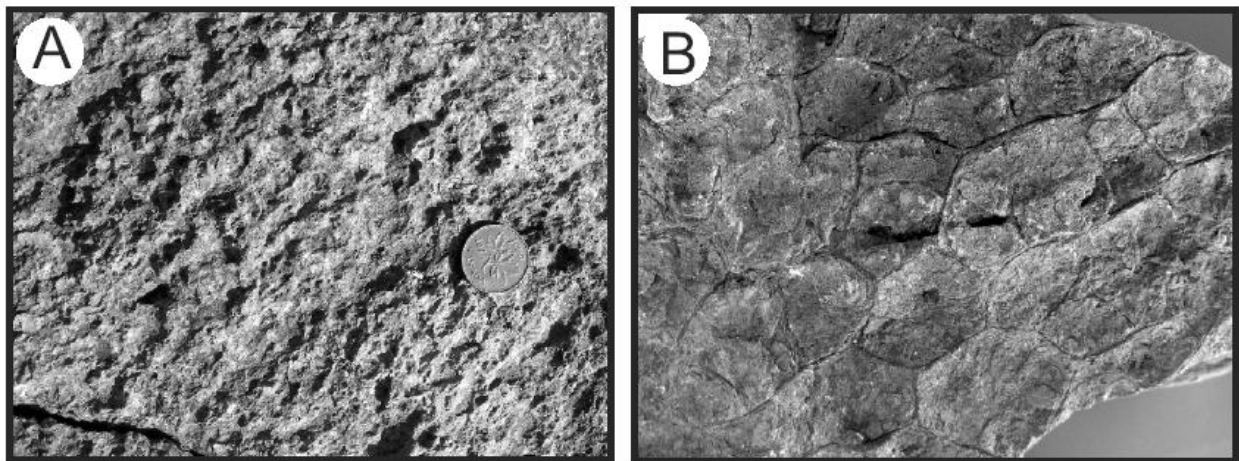


Figure 17. Plane views of bedding surfaces in giant domes. A) The upper ends of crystal fans cause an irregular egg carton-like pattern on most surfaces. B) Much more rarely surfaces have what appear to be mud-cracks (photo is approximately 15 cm across).

Grainstones have not been previously described from the Steep Rock limestones. However, clastic carbonate layers with grainsizes from micrite to granules and small pebbles are present (Figure 18C). They probably dominate the succession between the columnar stromatolites and the large domes. They are also found interlayered with the large domes and forming the base on which some of the fans in the domes are growing. The micrite and grainstone layers are 1 to tens of centimeters thick, massive to parallel laminated and in one instance trough cross-stratified. The clastic beds commonly appear as non-descript, massive continuous, parallel-sided layers and this blandness may have contributed to their non-recognition in the past by researchers primarily interested in the stromatolites.

Though metamorphism and structural deformation in the Steep Rock Group is not intense the carbonates have been subjected to post-depositional alteration. Wegenast (1954), Jolliffe (1955, 1966), Wilks (1986), Kusky and Hudleston, (1999) and Sumner (2000) believed that a karst topography developed on the upper surface of the Mosher Carbonate during sub-aerial exposure. They view the manganiferous paint rock as a residual soil composed of goethite, gibbsite, hematite, and kaolinite with blocks of carbonate and lenses of pisolitic ferruginous bauxite, which formed during this interval. The Jolliffe Ore Zone would represent an iron formation that was deposited on top of the thick soil as marine transgression once again flooded the area. Alternatively, Kimberley and Sorbara (1976) believed that aqueous fluids acidified by the sulfide-rich dismal ashrock were responsible for the alteration. Some serious problems exist with the former more widely held hypothesis. 1) The manganiferous paint rock is consistently described as unconsolidated and earthy, yet authors who believe it is a residual soil that formed upon exposure of the Mosher Carbonate require it to have gone through the Kenoran Orogeny. It is difficult to believe that it was metamorphosed to greenschist facies but not lithified. All other paleosols of this age in the Canadian Shield are lithified and deformed. 2) This same problem applies to the karst collapse breccias as well. Although Kusky and Hudleston (1999) stated that these were weakly deformed the numerous breccias I have examined are not (Figure 18B). The delicate cements formed surrounding the breccia blocks show no evidence of deformation or

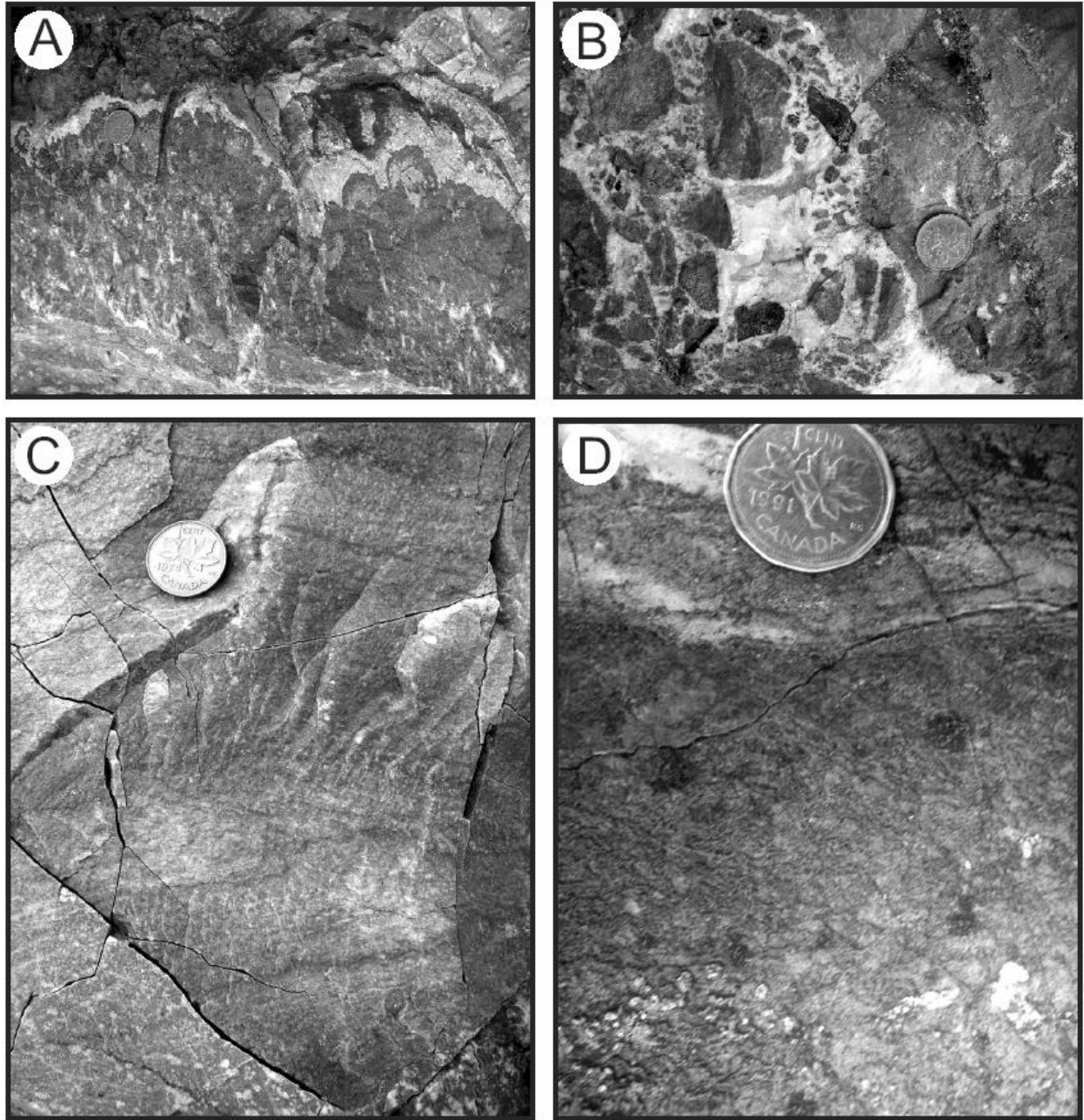


Figure 18. A) Where hemispherical stromatolites are present near the surface of the domes the surface acquires an elongate bulbous appearance. B) Non-deformed breccia with two generations of cement. C) Cross-stratification in a grainstone tempestite layer. D) Iron content increasing towards the top of a layer. This type of iron enrichment is not uncommon.

metamorphism making their existence before the Kenoran Orogeny unlikely. 3) Alteration zones in the carbonate appear to be vertical and some are not associated with the contact. These iron-enriched altered areas are stratigraphically overlain by unaltered carbonate, but the alteration does continue vertically where outcrop allows observation. 4) The type of alteration implies highly oxidizing fluids. As well, the manganiferous paint rock “soil” is up to 300 meters thick. Where did the large concentrations of oxygen come from in the Archean? Certainly not the atmosphere, as other Archean weathering profiles exhibit little to no oxidation. 5) The same succession of siliciclastics with conglomerates and sandstones overlain by carbonates and in turn overlain by iron formation is present in the Lumby Lake area, as previously described. There is no evidence of a period of exposure between the carbonate and iron formation present there. 6) The iron formation overlying the Mosher Carbonate is also brecciated and altered (it has goethite whereas hematite and/or magnetite are standard for oxide facies iron formation in Superior Province). Late mafic and lamprophyre dikes that cut lower units are involved in this brecciation (Shklanka, 1972). Thus, if the paint rock is a soil on a karst two episodes of brecciation substantially separated in time are needed. 7) Lastly, pieces of wood have been found in with the ferruginous pisoliths (R. Bernatchez, personal communication, in Wilks and Nisbet, 1988), and Machado (1987) believed that there was evidence of termite activity during formation of the ore. This placed the age of the ore as younger than Jurassic (Machado, 1987). This evidence overwhelmingly does not support the dissolution and alteration occurring in the Archean, but rather indicates it occurred in approximately the last 100 Ma.

The scenario for the development of the carbonate platform is summarized in Figure 10. Here Walther's Law has been used to juxtaposed horizontally the lithofacies that succeeded one another vertically. This is based on the alteration in the upper carbonate and overlying iron formation developing in the Phanerozoic and the succession representing a transgression culminating in deeper water where the iron formation was deposited. This may not be accurate as the up-section change in lithosomes in the limestone may reflect open circulation evolving to more closed evaporitic conditions leading to precipitation of the crystal fans, but it does reflect a possible scenario. In this depiction the grainstones are in the higher energy areas of the platform close to the deeper water conditions where shoaling waves would be expected. Also, upwelling of deeper water in this zone may have lead to the precipitation of the crystal fans. The stromatolite-dominated lithofacies are in the platform interior where quieter water conditions should have prevailed. Eventually the entire assemblage subsided below the photic zone and deposition of iron formation replaced carbonate precipitation.

FIELD TRIP STOPS

When looking at the carbonate outcrops it is essential to get up close to them. There is a reason sedimentologists usually have their face within a few decimeters of the rock. You will miss most of the detail if you do not do this. As well the outcrops on this trip will seem to be repetitive if you do not look at the detail, and think about what it might be inferring about how the rock formed.

Do not use hammers on outcrops. You can beat and sample loose material all you want.

And, most importantly, **be careful and always mindful of your surroundings.** We will be walking on slopes and near cliffs all day.

BRING YOUR CAMERA

Stop #1: Overlooking northeast end of Hogarth Pit. The basement tonalite is visible at this stop. We will take a few minutes to look at the tonalite and discuss the overall setting of the Steep Rock Group. Special emphasis will be placed on the igneous and sedimentary history of the area from 3.0 to 2.8 Ga, prior to deposition of the Steep Rock Group. This will develop the context of the paleogeographic setting as deposition began in this area.

Stop #2: One quarter of the way down the east side of Hogarth Pit from stop #1 (locations #3, 4 and 5 of Wilks and Nesbit, 1985, 1988). We will probably be at this location from one to two hours. After disembarking from the bus we will walk down a hill towards the pit for approximately 15 minutes. Notice how the small stream following the path changes from precipitating white material to orange material. The white precipitate is a mixture of calcium carbonate with minor aluminum hydroxide. The stream is spring fed and as the water flows onto the surface CO_2 is degassed, which leads to a decrease in acidity by driving the formula: $\text{H}_2\text{O} + \text{CO}_2 \rightarrow \text{HCO}_3^- + \text{H}^+$ to the right. This, in turn, causes supersaturation of the Ca and Al in solution and their precipitation. As the stream continues to flow down the slope the decrease in acidity and the presence of oxygen result in the precipitation of iron hydroxides, causing the orange colour.

A large cliff with boulder debris is present near the bottom of the hill. The rocks forming this cliff are mostly composed of carbonate collapse breccia fragments with calcite or dolomite cement. Some of the cement filling voids is intricately banded. Are there examples of miniature stalactites and stalagmites or dripstone indicating carbonate precipitation above the water table? Is this breccia deformed, i.e. did it go through the Kenoran Orogeny? **Stay back from the cliff as you examine the boulders as loose material periodically falls.**

Next we will walk across the large flat area to the high ground to the south. We need to make our way up the sand and gravel slope to the glacially polished outcrop. The contact between the limestone, which forms most of this outcrop, and the tonalite is exposed to the left (NE). A weak schistosity is developed along it, but if you get up close to it tonalitic debris is visible in the limestone. Actually, the top 60 cm of the tonalite is not tonalite. It is sandy tonalitic debris. If you follow the contact 50 meters up the hill you will notice that it is at an angle to the layering in the limestone and the limestone layers were progressively burying this paleohill. The presence of tonalite debris in the basal limestone and a regolith in the upper tonalite strongly infers that this contact is original not a later structural discordance.

Moving up-section in the lower portion of the outcrop you will be in the stratiform stromatolitic layers for the first 5 meters. Then there is an area where chert replacement has preserved thumb-sized columnar stromatolites growing upwards from the flat-mat forms. Bulbous forms the size of an orange start to appear in this zone. Some of the flat mat layers and bulbous forms have white calcite cement filled vugs that have flat bottoms and arched tops. These are the classic shape of gas bubbles that form and are trapped in leathery mats as the microorganisms rot. They are an indication that flat layering is stromatolitic in origin. The stratiform stromatolites and small mounds continue for 40 meters from the base of section. The first crystal fans appear at approximately the 40 meter mark. They average 5 cm high and are along certain horizons, with the fans in some layers orientated upwards and in other layers downwards. The zone containing columnar stromatolites overlies the area with the crystal fans. These are obliquely growing out towards us so they are truncated forming nests of ellipses. They appear to be composed of ferruginous dolomite (ankerite) or dolomite with hematite. The spaces between columns are filled with white cement, grainstone? and draping microbial laminations. (Grainstone is carbonate sandstone.) This is the only known layer of large columnar forms and can be used as a marker horizon.

Probable grainstones are present approximately 10 meters above the columnar forms. The fine-grained grainstones are approximately 5 cm thick and the granule layers average 10 cm thick. After approximately 20 meters of probable grainstones the layering is disrupted by a zone of iron alteration and brecciation. The breccia varies from clast to matrix support. How did this breccia form? Is it related to Archean karst on the upper surface of a then horizontal Mosher Carbonate or did it form after folding and metamorphism?

Now we will walk around the hill and pick up the section approximately 50 meters higher. **Stay away from the drop-off and aware of where you are relative to hazards at all times.** The outcrop begins with approximately 14 meters of grainstone. A layer approximately 6 meters above the base of this section has possible trough cross-stratification. The large carbonate domes lie on top of the grainstone. Notice that the 1 to 15 cm thick layers are composed of dark (organic-rich), radiating crystal fans, with light calcite cement between individual crystals, overlain by fenestrae microbialite composed of thin dark lines resembling stacks of upside-down fingernails next to one another. These linked concave-up structures are not easy to see. In other fenestrae microbialite the dark lines form a small net design with light calcite cement between the lines. These latter ones display more of the original form as they have not collapsed due to early compaction. Why are the top surfaces of the layers so irregular? From here we will proceed back to the bus.

Stop #3: Southeast end of Hogarth Lake (South Roberts Pit, Site #7 of Wilks and Nisbet, 1988). This is our lunch stop. We will eat our lunch in the clearing next to the road. A path goes to the lowest bench where large domes are exposed, but internal structure is poorly preserved. We will not spend much time at this outcrop.

Stop #4: About 100 meters down the hill from stop #3 a field strewn with boulders and debris piles is down a slope to the left (east). It is a difficult walk down this slope and across the field to the path on the other side but that's where we are going. The path leads to benches overlooking Errington Pit. Once on the path the walking is easy. Take the right fork and after approximately ten minutes an outcrop will appear on your right. The first 45 meters consists of centimeter thick layers of dark and light banded limestone. Then there is a 6 meter thick chlorite-rich diabase dike. This is followed by 9 more meters of the non-stromatolitic, banded limestone, then 15 meters of large (0.75 m high by 1.5 to 2 m across) domes. Some delicate laminations are preserved here. The next 10 meters is sheared with a dike following the fault zone. The rock on the other side of the fault appears to be a repetition of the lower portion of this section with approximately 50 meters of cm- to dm-thick layers of dark limestone with white calcite cement void fills. There is a four meter wide dike in the upper portion of this assemblage. **As you go around the curve in the road keep away from the far edge where there is a cliff going down and do not walk close to the end of the road where it has collapsed into the pit!** Seventy meters of large (5m x 2m x 1.4m high) domes caps this succession. We will need to go to a lower bench to see the top of this assemblage. Smaller cabbage-sized stromatolites and flat layering with white cement lenses are also common in this upper unit. One of the large domes has an overturned edge.

After looking at this section we will walk up the road the way we came in to the flagging tape. Those with a reasonable fitness level can cut through the woods here to the lower road. Those wishing not to climb down a steep slope should continue up the road to the fork and take the fork on your right that we have not yet been down. As we walk through the woods nearing the road to a lower bench the slope of the ground will increase. We will reach a point where we have to carefully pick our way and here a glacially polished outcrop will open up before us. This consists of what were originally fairly flat, sharp-sided, continuous layers. Some of these have silicified upright crystals that are leaning slightly due to deformation. They give the appearance of layer upon layer of 10 to 15 cm tall crystals growing from the bottom. **Be very, very careful at this exposure as the polished surface has small pebbles on it that make it very easy to slip over the cliff below your feet!! Do not go near this outcrop unless you are holding a tree or something similar that will keep you in place if you lose your footing.** The layers curve at one spot showing that relief was developed. Abundant stylolites are also present here. Have a look at the large boulder sitting next to the base of the outcrop as well. It appears that the ankeritic area dropped into the rest bending the layering. Is there another explanation?

The group will reform at the base of this hill on the lower road. We will continue along this road and cut down to a still lower road when we near the pit. **Walk with caution through this area as the various benches all have drop-offs at their outer edges and all eventually end in drop offs. Do not roll boulders, etc., over the edges, you do not know if someone is below.** These lower benches provide access to the best preserved large domes. Here the internal crystal fan

structure is easily visible. Of particular interest is the three dimensional relationship between the domes. Look at where they come together. Are the layers continuous from one to the other? Do the layers in one dome truncate those in another or do the domes bud off one another? Some of the crystal fans are growing from clastic layers of grainstone and rudstone (pebble conglomerate). The fenestral microbialite layers also appear to be rare here, with crystal fans in places overlain by dark micrite. Where microbial layering is present in the upper portion of a layer in a dome note how it controls the surface topography of the bed. Some very good samples of crystal fans in the loose material can be obtained here.

From here we will walk back along the lower road and across the boulder field and up the slope to the bus.

Stop #5: We will drive to the confluence of the roads at the south end of Hogarth Lake, park and walk a very short distance around the bottom of the lake to the south western corner. Here debris of the Dismal Ashrock litters the ground. This unit may be an in situ ultramafic pyroclastic conformable overlying the iron formation or it may be a highly tectonised ultramafic that was caught in the zone of shearing during overthrusting of the Witch Bay Volcanics.

From here we will go back to Atikokan.

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Hammond Reef Gold Deposit, Brett Resources Inc.

Mark Smyk, Ontario Geological Survey
(modified from <http://www.brettresources.com/s/HammondReef.asp>)

INTRODUCTION

The Hammond Reef project is the flagship project of Brett Resources Inc.. In 2006, Brett agreed to earn a 60% option on the property from Kinross Gold Corp. Brett management recognized that this project has significant upside potential. Prior to agreeing to the option, Kinross Gold Corp. outlined a 1.8 million ounce inferred resource on the property. Subsequent to earning their 60% interest in 2008, Brett acquired the remaining 40% of the project from Kinross. In the summer of 2009, Brett announced their second resource estimate for the property - 155 Mt at 1.04 g/t Au in the Inferred category, using a 0.6 g/t Au cut-off, for a base case of 5.2 million ounces of gold. The majority of the ground surrounding the known deposit remains untested by modern exploration methods. Small-scale mining took place on the property directly to the northeast of the current deposit, the Manley area, at the turn of the 19th century and again in the 1930's. Small-scale mining focused only on the free gold found in quartz veins, which records indicate had grades of approximately 0.3 ounce Au per ton.

The Hammond Reef property hosts widespread gold mineralization within a 100 to 300 m wide, northeasterly-trending corridor. Gold mineralization is associated with quartz vein stockworks. Mineralization defined in the current deposit is relatively flat-lying, dipping between 35° to 45° and seems to flatten out at depth. The favourable geometry of the deposit and the fact that 97% of the inferred resource is found within 300 m of surface, makes the deposit amenable to open-pit mining.

LOCATION AND INFRASTRUCTURE

The Hammond Reef Project is located in the Sawbill Bay-Marmion Reservoir area of the Thunder Bay Mining District, approximately 170 km west of Thunder Bay, and 23 km northeast of Atikokan. The property can be accessed both by water and by gravel road and there is a power line approximately 10 km to the west of the property.

GEOLOGY AND MINERALIZATION

The Hammond Reef property is predominantly underlain by the Marmion Batholith granitoid suite, characterized by fresh to intensely altered tonalite-trondhjemite; subordinate, unaltered granitoid gneiss; and minor mafic lenses (typically highly altered). Minor pegmatite dykes and pegmatite segregations are present. Quartz stockwork overprints all phases but is only weakly developed in the mafic lenses. The quartz stockwork hosts the gold mineralization. The stockwork is confined to a broad, anastomosing envelope of alteration measuring up to 6000 m wide on surface exposures and has a northeast strike over a length of approximately 40 km. The trend of the alteration system, major quartz veins, gneissic enclaves, and mafic lenses parallel the dominant east-northeast-trending regional fabric. This alteration comprises a gradual increase in thicknesses of halos of saussurite surrounding fractures. The gradually coalescing halos of alteration, with increased frequency of quartz veining, control the development of pervasively altered granitoid. Gold values show a gradual increase once weak but continuous areas of veining and alteration are observed.

Strong alteration and foliation develops into a schist zone without appreciable veining (Hammond Reef Schist Zone-HRSZ). A discrete zone of strongly foliated Fe-carbonate with variable amounts of sericite, chlorite, hematite, limonite and pyrite lenses is easily mapped and has previously been described as highly foliated, tectonized granitoid breccia or breccia zone.

Veining can be grouped into two styles -- 5 cm to 50 cm wide, straight and generally undeformed "leader" veins and millimetre- to centimetre-thick, densely spaced, randomly oriented "stockwork" veins -- and suggests extensional dilation during formation. The veins are coeval, with no clear crosscutting features or consistent overprinting observed.

The Hammond Reef property exhibits a number of similarities to the Fort Knox deposit in Alaska. Hosted within the Fort Knox Pluton which intrudes the Fairbanks schist, gold occurs in the margins of stockwork veins and veinlets, quartz-filled shear zones, and along fractures within the granite.

RESOURCES

Brett announced an updated resource estimate for the Hammond Reef Deposit (July 23, 2009 news release). Subsequently, on November 12, 2009, Brett announced the results of a Preliminary Assessment Study which uses the new Base Case Inferred Mineral Resource of **259.4 Mt at 0.80 g/t Au, totaling 6.70 million ounces of gold at a 0.3 g/t Au cut-off**. The Preliminary Assessment Study was prepared by Scott Wilson RPA under the supervision of Mr. Richard J. Lambert, P.E., a registered professional engineer and an independent Qualified Person under the standards set forth by National Instrument 43-101.

*The Study is preliminary in nature, it includes Inferred Mineral Resources that are considered too speculative geologically to have the economic considerations applied to them that would enable them to be categorized as Mineral Reserves, and there is no certainty that the Preliminary Assessment will be realized.

A table of the Inferred Resource at various cut-off grades can be found below.

Cut-off Au g/t	Tonnes (000,000)	Grade Gold g/t	Gold Oz (000,000)
1.00	60.2	1.46	2.83
0.90	77.1	1.35	3.34
0.80	98.4	1.24	3.93
0.70	124.6	1.14	4.56
0.60	155.0	1.04	5.19
0.50	188.5	0.95	5.78
0.40	227.0	0.87	6.34
0.30	259.4	0.80	6.70
0.20	281.9	0.76	6.89

METALLURGY

In September 2009, Brett announced the results of a metallurgical test program conducted at SGS-Lakefield Research on samples from both the "A" and "41" Zones. Head grades of the test composites varied from 0.60 to 3.4 g/t Au. The result of the program was a new flowsheet that is simple and will reduce capital and operating costs while improving recoveries:

- Coarse primary grind of 180 microns
- Bulk sulphide flotation to pre-concentrate the gold to a stream of less than 10% by weight of the plant feed with a gold recovery of over 95%
- Fine regrinding of the flotation concentrate
- Cyanidation of the reground flotation concentrate, recovering 97.8% of the contained gold
- Overall gold recovery 93%

All test composites were found to be likely non-acid generating as a result of Acid Base Accounting (ABA) and Net Acid Generation (NAG) analyses. The sulphide sulphur content of the deposit is low, and there appears to be adequate carbonate to neutralize any potential acid generation.

EXPLORATION HISTORY

The Sawbill Bay Gold District has been the focus of intermittent gold exploration since the original discovery of the Hammond Reef property in 1895. Small-scale underground mining and milling occurred between 1896 and 1900, and again from 1937-1941, with the property changing hands several times. Active "modern" exploration programs were conducted at Hammond Reef by Falconbridge Gold in the 1980's and by Pentland Firth in the 1990's. This work resulted in the delineation of two separate low-grade gold mineralized zones, the "A" and "41" Zones, delineated by a total of 83 diamond drill holes (18,060 m). A mineral inventory was prepared by Pentland Firth which indicated that the two zones contained an estimated 88 Mt grading 0.93 g/t Au, for a total of 2.64 million troy oz. gold*. (*This is a historic, non- NI 43-101-compliant resource provided for informational purposes only.)

Since first optioning the property from Kinross in March 2006, Brett Resources has used systematic exploration to expand the known areas of mineralization at the Hammond Reef Project. In 2006, Brett started their work with a geological exploration/sampling program, including geological mapping, prospecting, systematic sampling of outcrops, soil sampling, core sampling for geochemical signatures, and magnetometer surveys.

Initial success came as soil sample results outlined three strong new northeast-trending anomalous gold trends west of Snail Bay area, northeast of the claims known as the Manley Patents. The Manley Patents are the site of at least nine historic shafts mined by small-scale mining in the early 1900's, but were until recently privately held, and have not been subject to modern exploration methods. A trenching program was conducted over the new anomalous gold area and results outlined three separate mineralized zones indicating the presence of a new wide gold mineralized horizon open to the north, and more than 2 km from the A and 41 Zone areas.

An additional 50 to 60 m wide mineralized zone was exposed over 450 m of strike length through trenching on the optioned Sande & Stewart property. It remains open and bears the same orientation and appearance as the mineralized zone north of Mitta Lake.

From the end of 2006 to the end of 2008 Brett completed 34,145 m of drilling at Hammond Reef. Step-out drilling around the A Zone encountered significant new mineralization to the southwest, southeast and northeast. Of particular interest were new intersections to the northeast, indicating that mineralization continued along strike towards the 41 Zone. The continuity both at depth and laterally was found to be remarkably good. In-fill drilling in the 41 Zone confirmed the continuity of the zone on a 50 m spacing, as well as expanded mineralization westward.

By the middle of 2008, Brett had sufficient new drill intersections to complete a NI 43-101-compliant resource estimate for the Hammond Reef deposit, incorporating the contiguous A, 41 and Mitta Lake zones of mineralization. The result was a resource of nearly 5 million ounces of gold in the inferred category (see details in Resources section), nearly double the estimate by previous operators.

Eight holes drilled late in 2008 were not included in the resource estimate, and some holes intersected well developed gold mineralization in areas that will add to the gold inventory in future resource estimates.

The first phase of the 2009 diamond drilling program started in February, with 16 step-out drill holes for a total of approximately 5000 m of core drilling. Results of the spring drilling program were reported in late May, with the program having successfully extended the Hammond Reef resource in three directions: to the west; down-dip by over 150 m; and northeastward by confirming that the strike extent of the gold-bearing structures extend past the Manley Patents by more than 2 km northeast from the currently defined resource.

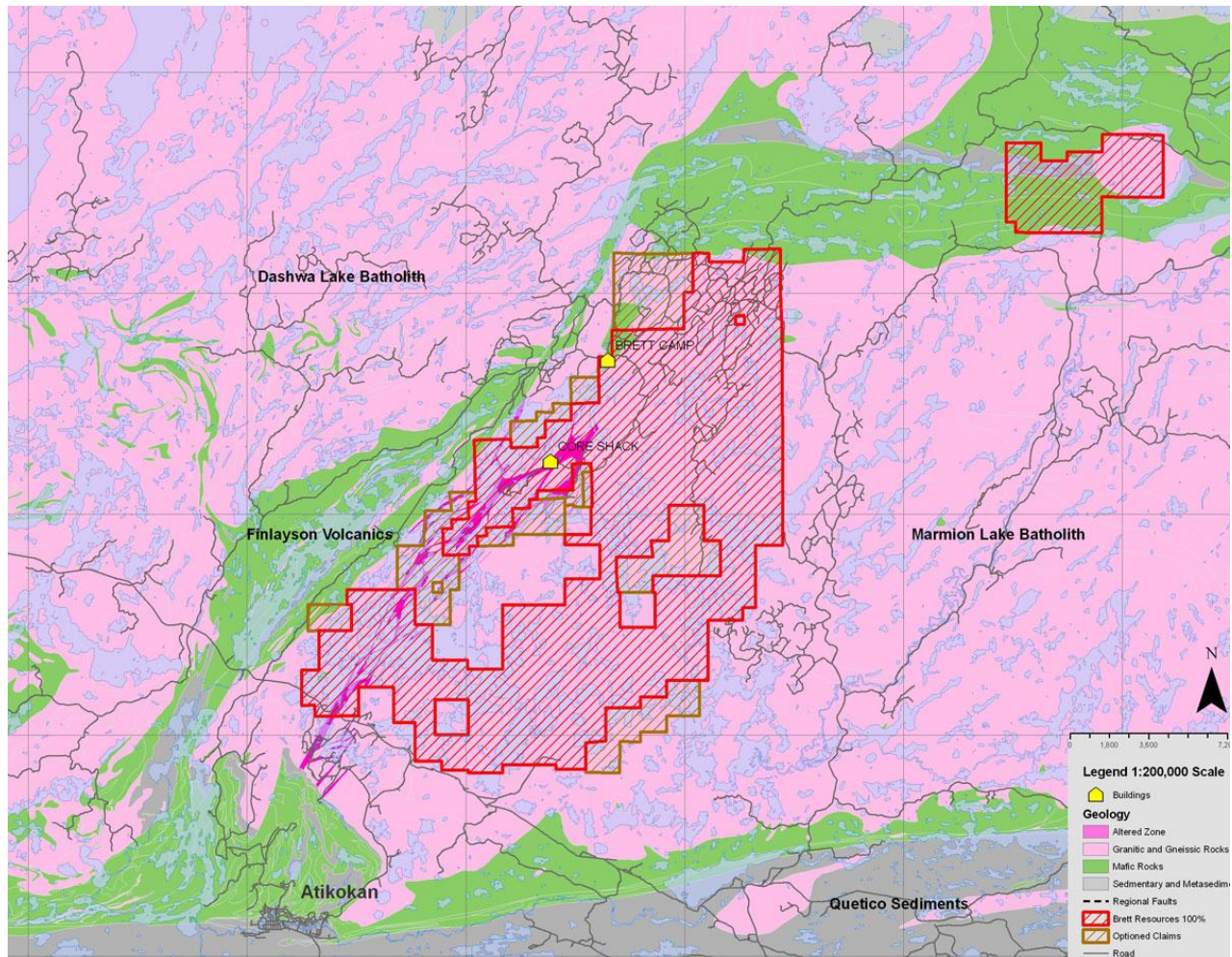
Previous exploration identified broad low-grade mineralization in two surface trenches located in the Snail Bay area, northeast of the Manley Patents and more than 2 km along strike to the northeast of the current gold resource. One of the primary objectives of the spring drilling program was to test the depth extension of the mineralization in these trenches. Two holes were drilled and both holes returned mineralized intersections. These new discoveries of gold mineralization in the Manley area have the same style of mineralization found in the A Zone and remain open along strike and at depth. No modern exploration techniques have been applied to this area and that was one of the main objectives of the exploration program in the summer and fall of 2009.

A second objective of the 2009 spring drilling program was to provide information for a scoping study expected to be completed during the fourth quarter of 2009. In particular, drilling was to test the mineralization up- and down-dip of the currently defined resource area. The holes stepped out from 50 to 275 m along sections and tested both deep and shallow targets and extended the resource at depth by as much as 150 m down-dip to the south. The program has also intersected additional shallow gold-bearing structures that are not in the current resource. These new structures have excellent potential to allow Brett to expand the current resource and positively impact the strip ratio of the pit. The scoping study will incorporate an updated Hammond Reef resource. The best results from the drilling program were from hole BR 126 which intersected 40.5 m of 1.95 g/t Au and from hole BR 127 which returned 159 m of 0.97 g/t Au.

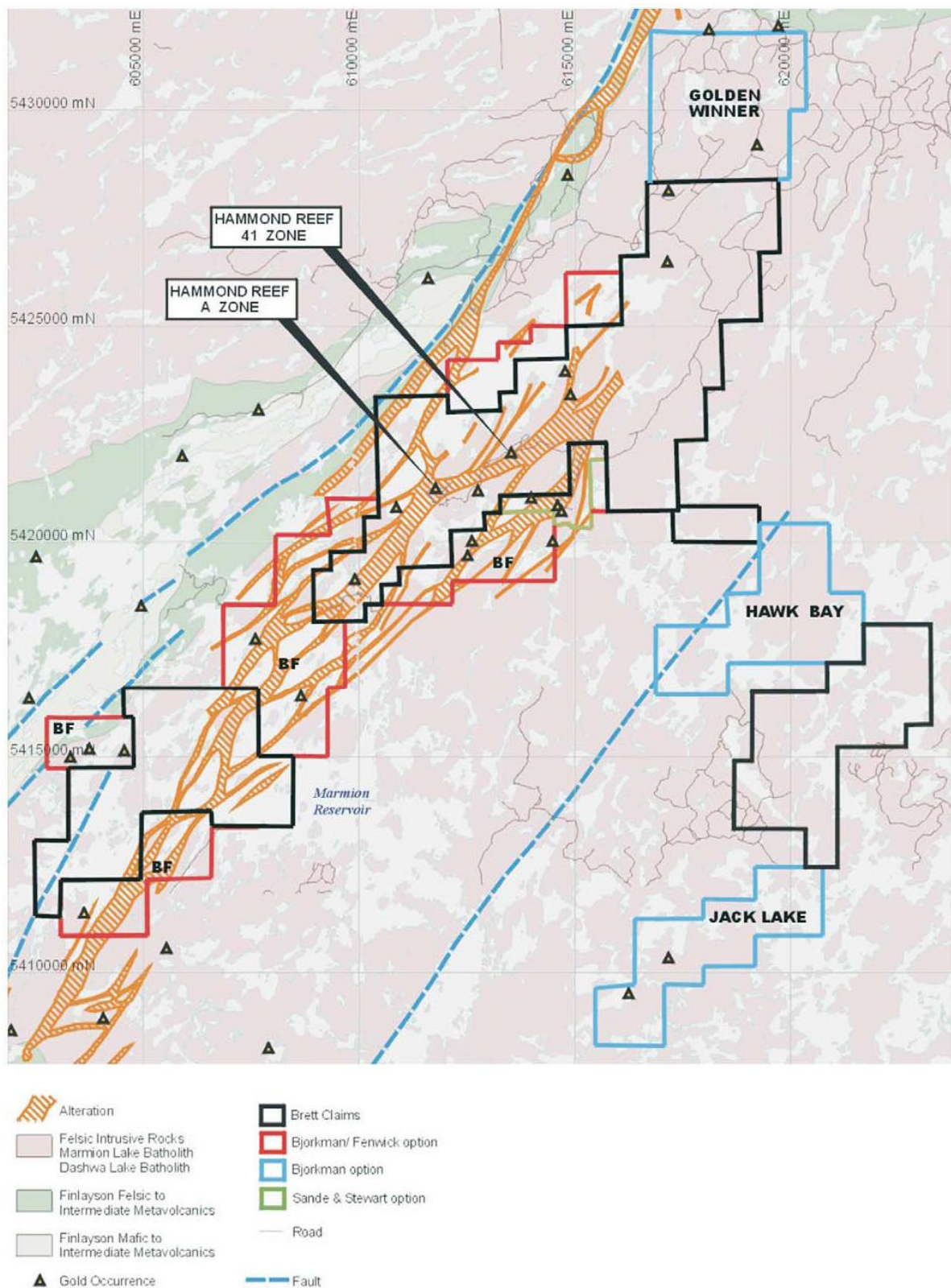
Brett's scoping study will evaluate the economic viability of the Hammond Reef gold deposit. A major part of the study will require engineering reviews of mining methods, pit design and location and processing plant design.

Brett conducted widespread field exploration work at Hammond Reef in 2009. With a combination of geophysics, soil sampling, prospecting, mapping and trenching. Brett hopes to detect new anomalous gold mineralization and to identify new exploration targets for drill investigation.

Brett recently announced that Osisko Mining Corporation mailed shareholders of Brett and filed with the Canadian securities regulatory authorities and the U.S. Securities and Exchange Commission, the offer and take-over bid circular, formally commencing Osisko's friendly offer to acquire all of the outstanding common shares of Brett on the basis of 0.34 of an Osisko common share and \$0.0001 in cash for each common share of Brett (Brett Resources Inc., news release, April 13, 2010). Osisko and Brett entered into a support agreement on March 21, 2010 providing for the terms of the Offer and the agreement by the board of directors of Brett to recommend that Shareholders accept the Offer. The consideration under the Offer represents a premium of 52.5% using the 20-day volume weighted average prices of Osisko and Brett quoted on the Toronto Stock Exchange and TSX Venture Exchange, respectively, for the 20 trading day period ending March 16, 2010.



Hammond Reef property location and regional geology (from http://www.brettresources.com/i/maps/091202_Regional_Geology.jpg)



General geology of the Hammond Reef property, showing location of altered and gold-mineralized zones (from http://www.brettresources.com/i/pdf/2009-11-27_HR_NI43-101.pdf). Each UTM square is 5 km wide.

Field Trip 3

DEFORMATION IN THE RAINY LAKE REGION: A FABULOUS DISPLAY OF STRUCTURES CONTROLLED BY RHEOLOGICAL CONTRASTS

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Consultant, Ottawa



Photo: Flattened Seine conglomerate

1. Introduction

The Rainy Lake area has been the locus of geologic studies for more than a century, starting with the pivotal early work by Lawson (1887; 1913). Over the decades, it has seen its share of controversy from Lawson's classic arguments for the existence of crystalline rock that was demonstrably younger than supracrustal rocks (Lawson, 1887) to the long-lived "Seine-Coutchiching Problem" stemming from cross-border disputes about relative ages of sedimentary sequences (Van Hise et al., 1905; Van Hise and Leith, 1911; Lawson, 1913; Grout, 1925; Tanton, 1927; Hawley, 1930; Gill and Hawley, 1931; Merritt, 1934; Ojakangas, 1972; Wood, 1980). The stratigraphic arguments have largely ceased due to an understanding of the dynamic tectonic framework responsible for the juxtaposition of the disparate rock types (Poulsen et al., 1980; Davis et al., 1989; Poulsen, 2000a) and the application of high precision U-Pb dating to key units (Davis et al., 1989; Fralick and Davis, 1999).

During our fieldtrip, we will focus on analyzing key structural features that will help us understand the kinematics of the regional and local deformation. As the region straddles a significant boundary within the Superior Province, the kinematic history of the area may be used to help elucidate Archean tectonic styles and patterns of continental growth.

The complex juxtaposition of various lithological units makes for intriguing geology in general, and structural geology in particular. The various rock units provide a study in contrasts where the structural styles and strain intensities are largely controlled by the rheological contrasts of adjacent rock types. When a region is tectonically deformed, deformation is preferentially localized in weaker rocks, leaving stronger rocks to remain relatively undeformed with weak to nonexistent deformation fabrics (analogous to embedding a marble into modeling clay and squishing the whole package- all of the deformation is in the modeling clay and the marble stays undeformed). In the field, we can see these rheologic contrasts at a variety of scales, from cm scale pebbles with contrasting strengths in deformed conglomerates, to km scale strong plutonic rocks surrounded by weaker volcanic rocks. Indeed, we can even see evidence for strength inversions. For example, when granites intrude, they are molten and weaker than their host rocks, but as they cool, they gradually become stronger than their hosts, resulting in an inversion in the relative strengths over time. A general theme amongst the stops on this trip will be to evaluate the relative strength, or competence, of adjacent rock types and evaluate how the competence contrasts are manifested into diverse styles of structures.

2. Geologic Setting and Geochronology

The large Archean Superior Province (Fig. 1) can be divided into subprovinces based on lithostratigraphy and metamorphic grade (Card and Ciesielski, 1986). The subprovinces were assembled by repeated island arc, microcontinent collisions. Several pieces of evidence are consistent with the island-arc accretion model. First, the microcollisions are evidenced by rocks that can be interpreted as arc sequence subprovinces (metavolcanic rocks of the greenstone belts) and their corresponding accretionary prism subprovinces (metasedimentary rocks) (Langford and Morin, 1976; Hoffman, 1989; Percival and Williams, 1989; Card, 1990; Hoffman, 1990). Second, the ages in the greenstone belts are generally similar along strike, but differ systematically across strike (Hoffman, 1989). Third, the deformation characteristics found

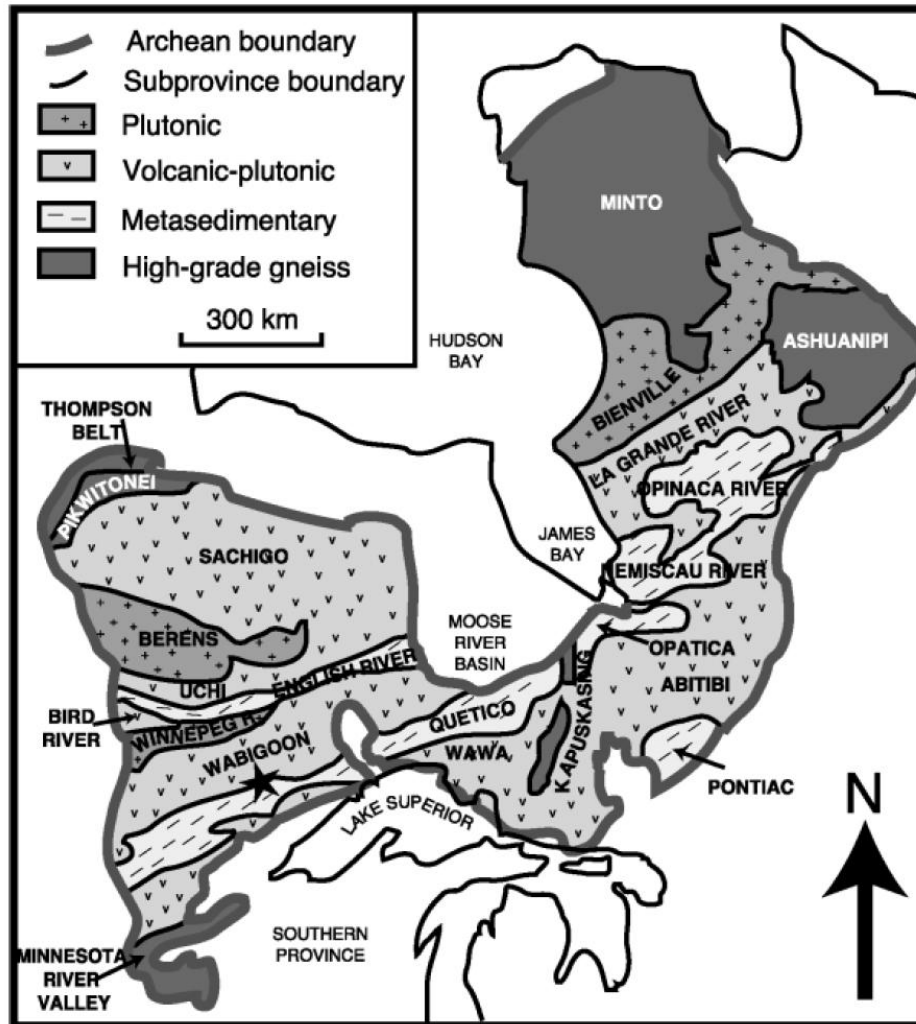
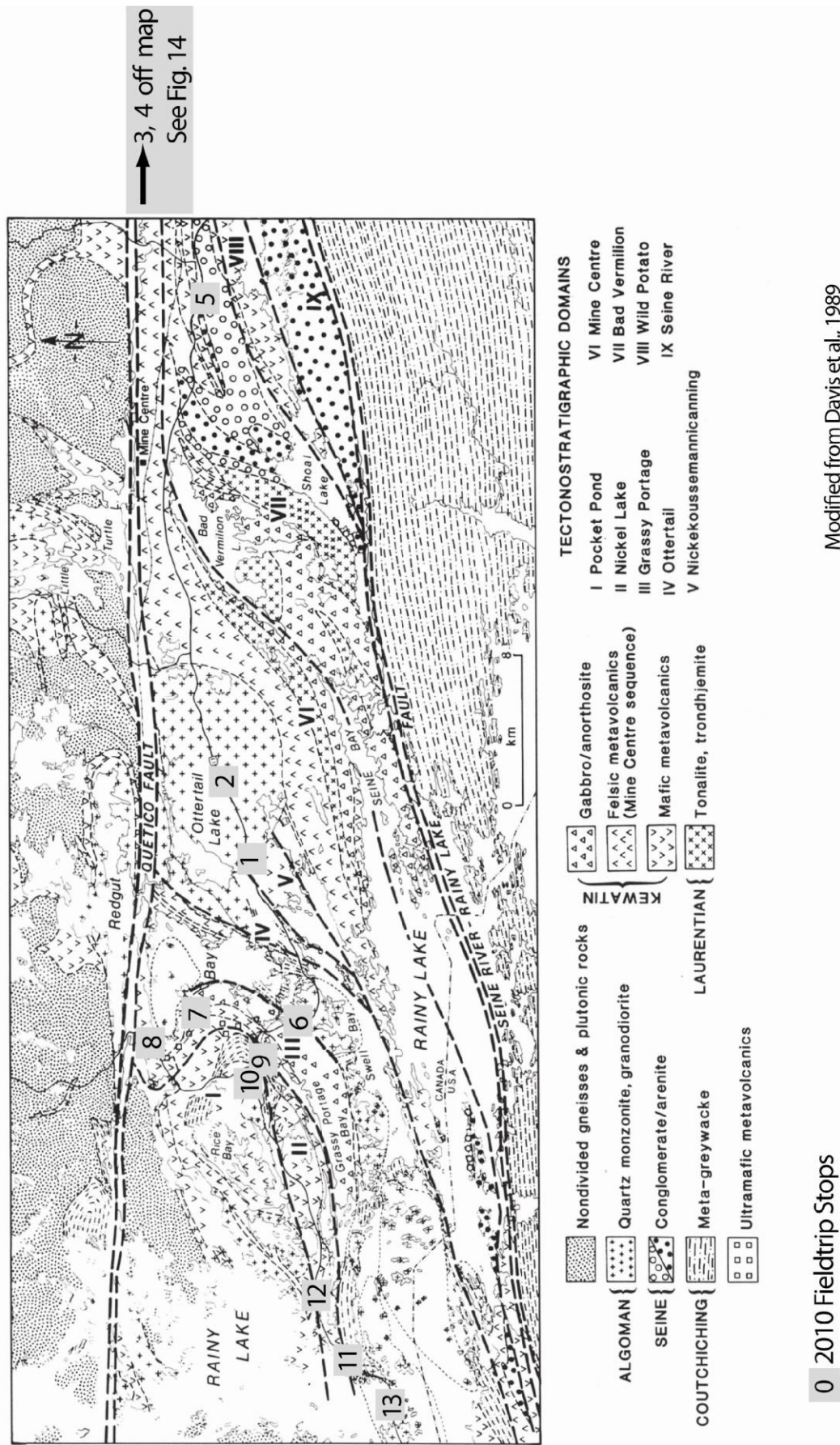


Figure 1. Superior Province based on divisions by Card and Ciesielski (1986).

across the province are best explained by contractional deformation. A history of subduction and southward accretion was responsible for the juxtaposition of Superior Province subprovinces (Langford and Morin, 1976; Percival and Williams, 1989; Card, 1990).

The Rainy Lake zone (Fig. 2) lies on the western part of the boundary between two lithotectonic subprovinces of the Superior Province: the Wabigoon granite-greenstone terrane to the north and the Quetico metasedimentary terrane to the south (Card and Ciesielski, 1986). Oblique collision between the Wabigoon and Wawa volcanic-plutonic terranes during the late Archean approximately 2.69-2.7 Ga (Stockwell, 1982; Davis et al., 1989; Fralick and Davis, 1999) most likely formed the tectono-metamorphic features of this boundary zone (e.g. Poulsen, 1986; Percival and Williams, 1989). The metavolcanic subprovinces (Wabigoon, Wawa) were subsequent island arcs that collided due to ongoing subduction, and the metasedimentary subprovince (Quetico) is comprised from sedimentary basin deposits between the arcs (Percival, 1989; Blackburn et al., 1991; Williams, 1991).



0 2010 Fieldtrip Stops

Modified from Davis et al., 1989

Figure 2. Simplified Rainy Lake region geologic map modified from Davis et al., (1989). Full detailed map is Poulsen (2000c).

Poulsen (1986) recognized the Rainy Lake boundary area as a complex transpressive deformation zone. The area is bounded by two major structures, the Quetico and the Rainy Lake-Seine River faults, which have most likely behaved as both dextral faults and shear zones during their deformation histories (Fig. 2). The two faults/ shear zones converge to the east into a single structure and delineate a wedge-shaped area between them (Poulsen, 1986, 2000a, b, c). Within the wedge, a complex pattern of anastomosing subvertical shear zones and faults wrap around gneissic domes and granitoid plutons (Poulsen, 1986, 2000a, b, c; Druguet et al., 2008). Flattening fabrics combined with the evidence for dextral shearing indicate an overall dextral transpressive tectonic regime with subhorizontal NW-SE shortening (Poulsen, 1986; Tabor and Hudleston, 1991; Borradaile and Dehls, 1993; Borradaile et al., 1993; Poulsen, 2000a, b; Czeck and Hudleston, 2003; Druguet et al., 2008; Czeck et al., 2009).

The main lithological units in the study area can be summarized based on dates obtained by Davis et al. (1989) and Fralick and Davis (1999), as follows:

- (1) Keewatin Group tholeiitic and calcalkaline metavolcanic rocks. These form interlayered sequences of ultramafic to felsic compositions, although basalts and andesites are most common. Crystallization ages range from $2728 \pm 4/-3$ to 2725 ± 2 Ma.
- (2) Metagabbroic rocks with metadolerites and metaanorthosites. They are found as sills and larger intrusions of variable dimensions, generally showing compositional and textural layering. Includes the Seine Bay- Bad Vermillion Complex (2728 ± 2 Ma for the trondhjemitic Mud Lake component) and the Grassy Portage Sill (2727 ± 2 Ma).
- (3) Gneisses. Most gneisses in the region are orthogneisses corresponding to synvolcanic “Laurentian” plutonic rocks, about 2725 ± 2 Ma that vary compositionally from granitic to tonalitic and form the core of the Rice Bay dome and the gneisses near Black Sturgeon Bay.
- (4) Coutchiching Group metasedimentary rocks. These are the sedimentary rocks located south of the Quetico Fault and north of the Seine-River Rainy Lake Fault and are bracketed in age between 2704 ± 3 and 2692 ± 2 Ma by detrital zircon and a crosscutting intrusion. They contain metagreywackes and metapelites, especially biotite schists. They locally contain porphyroblasts of garnet, andalusite and staurolite.
- (5) Quetico metasedimentary rocks. The Quetico turbiditic metasediments are found to the south of the Seine River-Rainy Lake Fault. The age of the youngest analyzed detrital zircon is 2699 ± 1 Ma.
- (6) Seine River Metasedimentary Group. Deposited partly during and after the nearby Coutchiching metasedimentary rocks. The depositional age is bracketed between 2693 ± 1 - 2692 ± 1 Ma, (Fralick and Davis, 1999). This unit formed as one of the Superior Province’s molasse basin-fill units (Corcoran and Mueller, 2007) and includes the Seine River conglomerates, well developed near Mine Centre (Wood, 1980; Frantes, 1987; Czeck, 2001; Czeck and Fralick, 2002; Czeck and Hudleston, 2003; Fissler, 2006; Czeck et al., 2009).
- (7) “Algoman” calc-alkaline granitoids. These are relatively unmetamorphosed and poorly deformed granite, granodiorite, and quartz monzonite rocks that form several individual plutons (age of the Ottetail pluton: $2686 \pm 2/-1$ Ma). They were previously interpreted as

postkinematic and their age of emplacement was used as a constraint for the ending of regional deformation (Davis et al., 1989; Poulsen, 2000a). However, by means of field relationships, microstructural analysis, anisotropy of magnetic susceptibility (AMS), and gravity inversion techniques, Czeck et al. (2006), demonstrated that these plutons formed syntectonically, late within the Archean transpressional event.

3. Structural Framework

Many authors have found evidence for a three phase (D_1 , D_2 and D_3) deformational history (Poulsen, 1986; Davis et al., 1989; Tabor and Hudleston, 1991; Poulsen, 2000a; Druguet et al., 2008). All of these phases are associated with oblique convergence related to the island arc collisions. While the structures are similar in style and sequence to other features found throughout the central Superior Province, the phases are unlikely to temporally correlate across subprovince boundaries, and may not even correlate within the Rainy Lake region due to the dynamic nature of the tectonic setting.

D_1 is characterized by early recumbent folding that produced the inversion of the stratigraphic sequence and S_1 , the first regional schistosity (Poulsen et al., 1980). The combination of several observations including the present-day juxtaposition of adjacent right-way-up and overturned folds (Poulsen et al., 1980; Borradaile, 1982; Poulsen, 2000a), suggest that the original orientations of many of the folds were nappe-like. S_1 is generally subparallel to the layering in the metavolcanic and metasedimentary rocks. A gneissic foliation attributed to D_1 is well developed in the gneiss domes. D_1 is likely to have included significant thrust or oblique faulting that juxtaposed allochthonous units. There is less direct evidence for thrusting, due to a general lack of sedimentary markers that would enable one to recognize duplicated sequences of rock. However, the hypothesis of early faulting is corroborated by the strain patterns within this and other Archean belts, which are generally too low to account for the now largely steeply dipping units (e.g. Schultz-Ela, 1988; Hudleston and Schwerdtner, 1997). This early history of thrusting and recumbent folding can be thought of as “stacking” (Davis et al., 1989; Czeck, 2001; Czeck and Fralick, 2002).

As the crust was “stacked” in D_1 , rocks that were once near the surface became buried. In these rocks, D_1 deformation was followed by D_2 , which is characterized by folding and dextral shearing under a transpressional regime. F_2 folds resulted in steep to subvertical bedding subparallel to a regional subvertical S_2 foliation with a mean ENE-WSW strike. The Seine River Group was deposited in a fault-related basin during early D_2 (Poulsen, 1986, 2000a), which explains their strong D_2 fabrics and minor amounts of internal folding (Czeck, 2001; Czeck and Hudleston, 2003; Czeck et al., 2009). However, it is important to note that the transition of D_1 to D_2 was not necessarily contemporaneous across the Rainy Lake region and the vertical bedding in the Seine is likely a result of initial internal stacking followed by D_2 deformation styles. The Algoman plutons were emplaced and cooled during late stages of D_2 (Czeck et al., 2006). Many leucocratic and quartz veins were emplaced throughout D_2 (Druguet et al., 2008).

D_2 was responsible for the penetrative foliation and lineation fabrics and much of the recorded strain throughout the region. In general, the foliation is subvertical (Fig. 3a), and where strain

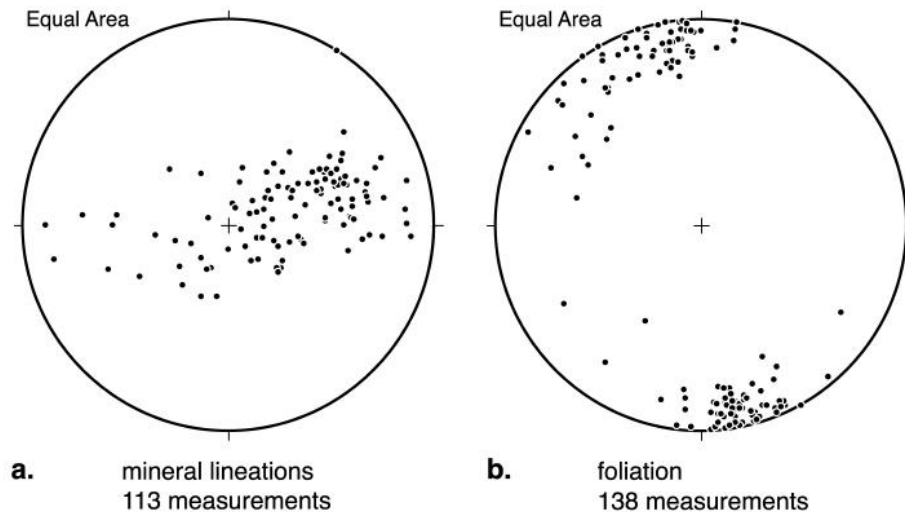
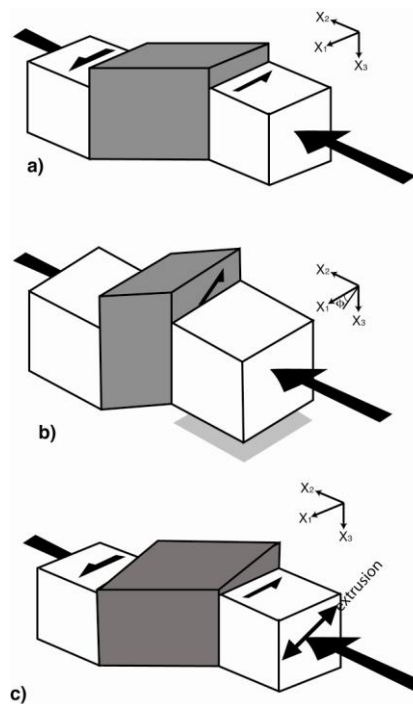


Figure 3. Equal area stereonet projections representing structural fabric in the Rainy Lake region from Czeck and Hudleston (2003). (a) Stretching (mineral) lineations. (b) Poles to foliation.

can be measured, such as within the Seine conglomerates, strain is largely of a flattening type (Czeck, 2001; Czeck and Hudleston, 2003; Fissler, 2006; Czeck et al., 2009). Dextral shear sense indicators in the form of asymmetric folds, conglomerate strain shadows, clast tilting, and other features are often observed on subhorizontal planes regardless of lineation orientation (Czeck and Hudleston, 2003). Most of these fabric features along the boundary are consistent with a type of ductile transpression first described by Sanderson and Marchini (1984). This style of transpression is a mathematical description of a specialized case of “transpression” that in its simplest form just means oblique convergence (Harland, 1971). The style of transpression described by Sanderson and Marchini (1984) involved homogeneous deformation consisting of



orthogonal simple shear and pure shear components with constant volume in a vertically bounded zone (Fig. 4a). Such an idealized scenario has since been termed “monoclinic transpression” (e.g. Lin et al., 1998) and is perhaps most likely to correspond to strain in deep, vertical ductile shear zones during oblique convergence. The structural fabrics for this model include vertical foliations, flattening fabrics, and asymmetric shear sense indicators on the horizontal plane (Fossen and Tikoff, 1993) (Fig. 5). The consistencies of fabrics observed along the Wabigoon–Quetico boundary with the homogeneous transpression model suggest that at least the Wabigoon–Quetico boundary as a whole has undergone quasi homogeneous transpression.

Figure 4. Transpression Models. a) Homogeneous monoclinic transpression (Sanderson and Marchini, 1984). b) Triclinic transpression with oblique simple shear component (Lin et al., 1998). c) Triclinic transpression model with horizontal simple shear component and oblique extrusion direction (Czeck and Hudleston, 2003, 2004).

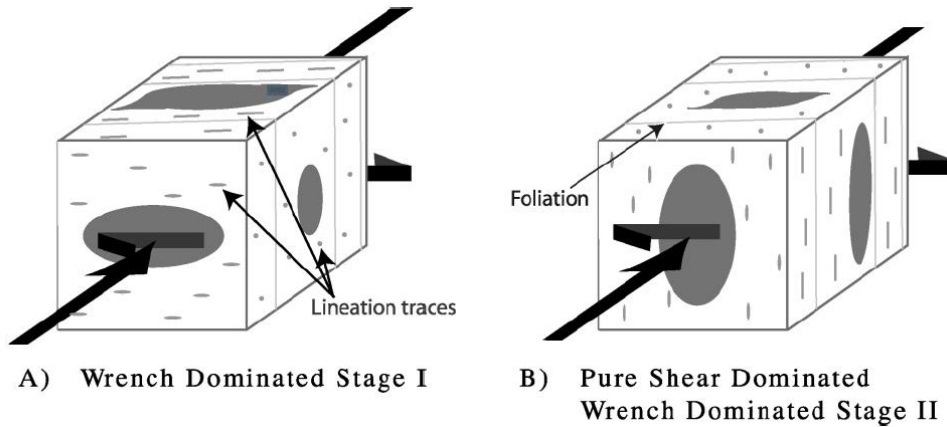


Figure 5. Schematic deformation fabrics and strain predicted for monoclinic transpression (Fossen and Tikoff, 1993). Planes shown are foliations, lines shown are stretching lineations, and schematic “pebble” indicating flattening strain and asymmetric strain shadows from Czeck and Hudleston (2003).

The lineation orientation (Fig. 3b) is one major aspect of the structural fabric in the Rainy Lake region that does not mesh with the monoclinic transpression model, which predicts either vertical or horizontal lineations (Fossen and Tikoff, 1993). The orientations of the stretching lineations, as defined by the preferred orientation of metamorphic minerals, varies at the hectometric scale; they plunge between 0-90° in both east and west directions (Czeck and Hudleston, 2003). The subhorizontal asymmetric shear sense indicators combined with the greatly variable stretching lineation orientations prove to be difficult to explain with most kinematic models. In shear zones that deformed via simple shear, we would expect to find asymmetric shear sense indicators on the horizontal plane, but the lineations should be horizontal. In shear zones that deformed via homogeneous monoclinic transpression models (Sanderson and Marchini, 1984; Fossen and Tikoff, 1993), we would expect to find asymmetric shear sense indicators on the horizontal plane, but the lineations should be only vertical or horizontal depending on the amount of pure shear versus simple shear and the strain magnitude. In many triclinic transpression models that can explain obliquely plunging lineations (Jiang and Williams, 1998; Jones and Holdsworth, 1998; Lin et al., 1998), the simple shear component is no longer horizontal, so the asymmetric shear sense indicators should be found on a corresponding oblique plane (Fig. 4b). For these reasons, most kinematic models for shear zones are incompatible with structures found in the region. The best model proposed for D₂ that explains the subhorizontal asymmetric shear sense indicators and the highly variable stretching lineation orientations is a triclinic transpression with horizontal simple shear and variable extrusion direction (Czeck and Hudleston, 2003, 2004) (Figs. 4c, 6). In the original monoclinic transpression and most subsequent triclinic models (Sanderson and Marchini, 1984; Fossen and Tikoff, 1993; Robin and Cruden, 1994; Dutton, 1997; Jones and Holdsworth, 1998; Lin et al., 1998), material was assumed to extrude vertically upwards. This assumption is logical because, in general, one would expect the direction towards the earth’s surface to provide the least resistance for material movement. However, rocks at depth may have other boundary conditions imposed by anastomosing shear zone geometries or large scale rheology contrasts due to a diverse lithological assemblage that cause localized deviations in the extrusion direction. Certainly, the Rainy Lake region has both complex three-

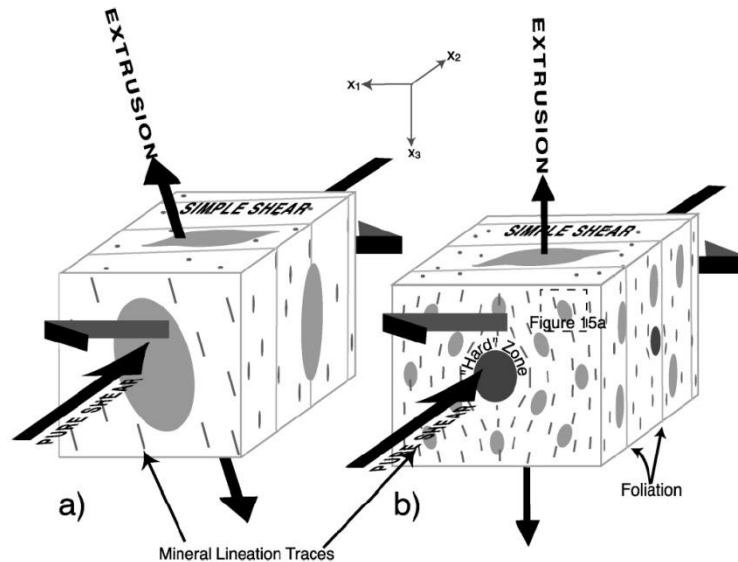


Figure 6. Schematic deformation fabrics and strain predicted for transpression with oblique extrusion from Czeck and Hudleston (2003). Planes shown are foliations, lines shown are stretching lineations, and schematic “pebble” indicating flattening strain and asymmetric strain shadows. (a) Simple view of transpression with nonvertical extrusion. (b) Schematic view of transpression with overall bulk vertical extrusion and localized zones of nonvertical extrusion. Dark colored ellipses represent schematic ‘hard’ zones that influence local extrusion directions. The relative location of (a) is indicated.

dimensional anastomosing shear zones and lithologies with strong competence contrasts that could account for local variation in the extrusion directions.

Domains of higher strain are localized in the relatively incompetent metavolcanic and metasedimentary rocks and channeled around the competent gneissic domes, metagabbros, and Algonian plutons. Two-dimensional strain was estimated using folded and boudined dikes, and the areas of lowest strain are located on the “strain shadow” flanks of the gneiss domes and plutons (Castaño, 2007; Druguet et al., 2008). As a result, the dominant, composite S_1+S_2 foliation displays a complex heterogeneous pattern both in orientation and intensity.

Dextral transpression continued as the rocks were exhumed. It is evidenced by retrograde metamorphism and D_3 structures (Poulsen et al., 1980; Poulsen, 2000a). During D_3 , strain localized along major mylonitized dextral shear zones and faults such as the Quetico and Seine River-Rainy Lake Faults, narrow mesoscale shear zones, and crenulation bands. This late stage of deformation is more brittle-ductile in nature than D_2 , and thus represents rock exhumation. Progressive D_2 to D_3 dextral transpressional deformation was likely controlled by the distribution of lithological units with contrasting competence, the previous structure, and the emplacement of the Algonian plutons. Many of the late quartz veins may have been emplaced during D_3 , but this inference needs to be more rigorously tested.

Some authors note that the final D_3 stage of deformation involved amplification of strike-slip motion along wrench zones (Bauer et al., 1992). The latest brittle faulting has largely been

described as dextral strike-slip motion (Kennedy, 1984), but local late-stage brittle faults associated with N-S shortening also have been observed (Tabor and Hudleston, 1991). In all likelihood, the last stages of deformation associated with the oblique convergence may have been strongly partitioned with the major strike-slip faults accommodating the boundary-parallel motion and the domains between the major faults accommodating the boundary-perpendicular motion (Tabor and Hudleston, 1991).

4. Field Trip Stops

We have arranged the stops in a sequence that will allow us to unpeel the stages of deformation. We will look at the least deformed, youngest rocks first (the Ottertail Pluton), followed by syndeformational metasedimentary rocks (the Seine Conglomerates), followed by older rocks that have seen most/ all of the deformation and, in many cases, are intruded by many generations of syntectonic veins. In this way, we will see rocks with progressively more complicated (and exciting!) structures. There are a few bonus stops at the end in case we have time on our way back to Fort Frances.

The locations of most stops can be found on **Figure 2**. Stops 3 and 4 can be found on Figure 14 which is a map drawn for the entire Seine Basin (overlaps with map on Fig. 2). Stop 5 can be found on both Figs. 2 and 14.

Stops are located by **UTM coordinates based on NAD 83, UTM Zone 15**

Stop 1: Ottertail Pluton Margin

From the Recreation Center in Fort Frances, drive east along Hwy 11 for approximately 45 km. Outcrop located on both sides of road.
(0506850E, 5396300N)

The Ottertail Pluton is one of the calcalkaline granitoids of the Algoman type according to Lawson (1913) that range in composition from diorite-granite. More recent studies have linked them to sanukitoid magma suites (Shirey and Hanson, 1984). They are compositionally distinct from the older orthogneisses in the area, such as in the core of the Rice Bay Dome, which typically have a tonalitic composition (Poulsen, 2000a). All of the Algoman type intrusions have relatively discrete discordant boundaries and are generally semi-elliptical on map view. Although the Ottertail is obviously relatively late as judged simply by looking at the map, the details of how late is a bit more complicated and requires a look at both its margins and interior.

The Ottertail itself is mostly granite to granodiorite. The granites are two-feldspar subsolvus granites, containing both K-feldspar and plagioclase along with quartz, hornblende, and biotite. Across its extent, it has a heterogeneous composition and grain size distribution (Czeck et al., 2006).

At this stop, we will view agmatitic breccias that are common at the margins of the Ottertail (Poulsen, 2000a). Agmatites are defined by breccia-like mesosomes intruded by a leucosome. The breccia-like character implies hydraulic fracturing at the pluton edge

(Kornprobst, 2002). The xenolithic blocks within the breccia are foliated country-rock remnants that were likely deformed during D₁ and D₂.

The Ottertail pluton's composition near the boundaries has significantly higher percentages of chlorite, biotite, and hornblende, presumably input from the country rock. Much of the chlorite is a retrograde reaction product of either biotite or hornblende. Together, the percentages of these three minerals range from 2%–15% in the center of the pluton, grading to 34%–58% along the eastern and western margins (Czeck et al., 2006). Feldspars are more sericitized in these boundary regions (Czeck et al., 2006).

Stop 2: Ottertail Pluton

Continue driving east on Hwy 11 for approximately 4 km. Approximately 1 km east of Pearson's Road turnoff, outcrop is located on both sides of Hwy 11.
(0510221E, 5397524N)

Here we are located in the center of the Ottertail Pluton with the typical granitic chemistry. The rocks appear largely unmetamorphosed in outcrop, but were subjected to low-grade, often hydrous metamorphism (Fig. 7a). Chlorite is the primary metamorphic mineral present, which formed by retrograde metamorphic reactions of biotite and hornblende (Czeck et al., 2006). Trace evidence of other metamorphic minerals including epidote, clinozoisite, and zoisite are often present (Czeck et al., 2006).

The pluton is not highly deformed, but a range of deformation microstructures can be observed throughout, either to subtle or intense degrees (Fig. 7b, c). The amount of grain scale deformation varies non-systematically throughout the pluton. In most samples, quartz microstructures, such as undulose extinction and subgrain formation, indicate that some solid-state deformation accommodated by dislocation creep mechanisms was active (Czeck et al., 2006). In the samples with the most deformation microstructures, a weak to moderate S–C fabric, quartz ribbons, fractured feldspars, and kinked biotites have also been observed (Czeck et al., 2006). Variations in the microstructural assemblages are most likely due to strain localization or possibly different cooling histories. The microstructures indicate that the granite was emplaced and cooled enough to deform in the solid state (in at least some portions) during deformation.

Well-defined planar anisotropy of magnetic susceptibility (AMS) fabrics within the Ottertail Pluton are roughly coincident with the steep foliations measured in the surrounding rocks, indicating that the AMS fabrics were most likely caused by regional deformation (Czeck et al., 2006). Gravity inversion analysis indicates that the pluton is shallow, with a maximum depth of approximately 4.5 km (Czeck et al., 2006). The shallow nature of the pluton supports the conclusion that the steep internal fabrics are unlikely to be purely flow from a feeder zone, but rather a result of the regional strain. The pluton was likely syntectonic, late in D₂. Its geometry is consistent with intrusion into a transpressional setting, possibly into shallow rhombochasm created by en echelon P shears related to the major shear zones or along oblique thrusts (e.g. Tikoff and Teyssier, 1992).

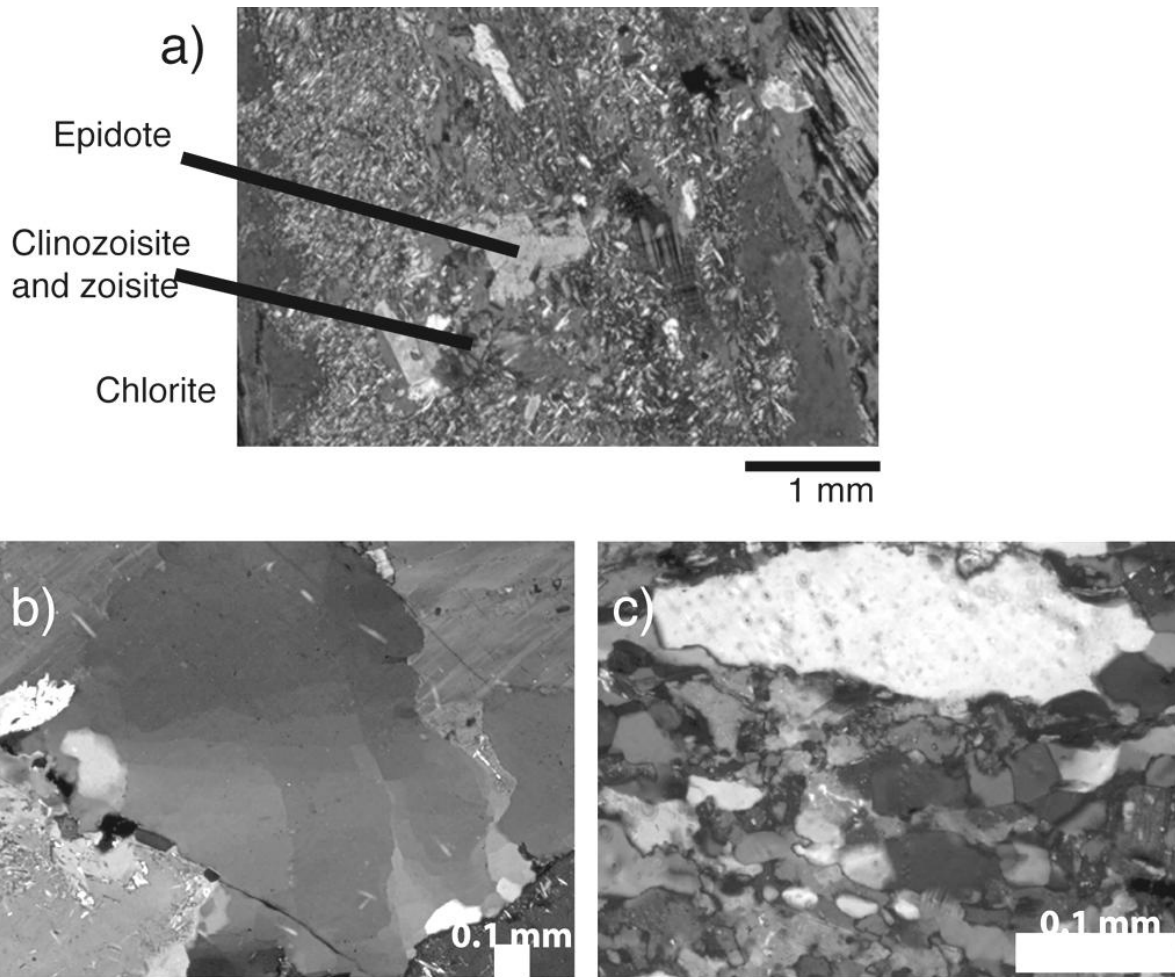


Figure 7. Photomicrographs of Ottertail Pluton from Czeck et al. (2006). a) Typical thin section with low-grade metamorphic mineralogy roughly consistent with regional greenschist-facies metamorphism (cross-polarized light). b) Undulose extinction in quartz (cross-polarized light). c) Subgrain formation in quartz (cross-polarized light).

Stop 3: Moderately strained Seine Metaconglomerates

*Continue east along Hwy 11 for approximately 33 km to Horsecollar Junction . Outcrop located along north side of Highway 11.
(0542130E, 5398538N)*

The Seine Group was interpreted to have been deposited in a fluvial system by Lawson (1913), Wood (1980) and subsequent workers (e.g. Czeck and Fralick, 2002). This formation undergoes a gradual transition from conglomerate dominated near its base to sandstone dominated near its top. The lithofacies found within the Seine match various environments of braided stream systems including channels and bars. Conglomerate dominated longitudinal bar-channel sequences are the most common. However, sandier channel sequences are not rare and gain importance higher in the formation (Czeck and Fralick, 2002). Lawson (1913) suggested the Seine Group was deposited at the site of an ancient fault zone, the strike of which is approximated by the current distribution of the conglomerate and sandstone.

Within the conglomerates, asymmetric shear sense indicators are prevalent. In general, these are either in the form of asymmetric pressure shadows at the ends of clasts, wrapped foliation indicating rotation of the most rigid clasts, and clast tilting. All of these shear-sense indicators suggest dextral shear and are most evident on the subhorizontal plane, *regardless of lineation orientation*. The best model proposed for the deformation in the metaconglomerates that explains the subhorizontal asymmetric shear sense indicators, the dominant flattening fabrics, and the highly variable stretching lineation orientations is a transpression with horizontal simple shear and variable extrusion direction (Czeck and Hudleston, 2003, 2004). The specific clast strain combined with the other structural evidence should allow for a more rigorous test to this model (Fernández et al., in preparation).

The metaconglomerates within the Seine Group provide an excellent opportunity to observe competence contrasts and their effects on deformation. The deformation here is typical of much of the Seine: the granitoid clasts being fairly undeformed while the volcanic clasts reflect significant flattening. Minor amounts of quartzite, BIFs, and other lithologic clast types are also observable.

Czeck et al. (2009) used the clast shapes on the three-dimensional road outcrops to calculate strain within the Seine's various clast populations using the R_f/ϕ method for two-dimensional strain (Ramsay, 1967; Dunnet, 1969; Lisle, 1985), a bootstrap statistical technique (McNaught, 2002; Mulchrone, 2005; Yonkee, 2005), and best-fit three-dimensional ellipsoid calculations (Launeau and Robin, 2003, 2005) (Fig. 8). In most cases, the calculated long axes of the strain ellipsoid match the mineral lineation and short axes are normal to the foliation, indicating that primary clast fabrics have not significantly affected the results. The strain magnitude is strongly dependent on lithology and varies greatly and nonsystematically throughout the region. In general, the mafic and felsic clast populations have similar strain magnitudes at a particular outcrop and granitoid clasts have consistently smaller strain magnitudes. The regional-scale variations in strain magnitude cannot be linked to changes in the concentrations of clast types within the outcrops (Fissler, 2006), but are likely related to spatial proximity to the minor shear zones. Of the 26 outcrops evaluated, 19 have an overall flattening strain, five exhibited a constrictional strain, and two exhibited plane-strain. Flattening dominates throughout the field area while constriction exists in the western and easternmost stations. Strain magnitude does not correlate to strain shape. At this location, long/short strain axes ratios were approximately 2:1 for granitoid clasts, 4:1 for felsic clasts, and 6:1 for mafic clasts.

Czeck et al. (2009) also used detailed finite strain measurements of the clasts to calculate effective viscosity contrasts using established methods (Treagus and Treagus, 2002). The two volcanic clast populations have similar effective viscosities, regardless of strain magnitude, with ratios of felsic/mafic ranging from 0.27 to 2.12 and average ratio of 1.19. The granitoid clasts are significantly more competent than the mafic clasts with effective viscosity ratios ranging from 2.35 to 12.39 and average ratio of 5.61. The results are consistent with a qualitative competence hierarchy of granitoid > felsic $\geq$ mafic, although the quantitative effective viscosity ratios change with strain magnitude: for small strains, granitoid $\gg$ felsic $\geq$ mafic, but for large strains, granitoid > felsic $\geq$ mafic. The variations in these ratios throughout the field area indicate that the effective viscosity contrast between clast types is strain dependent and possibly deformation path dependent (Czeck et al., 2009).

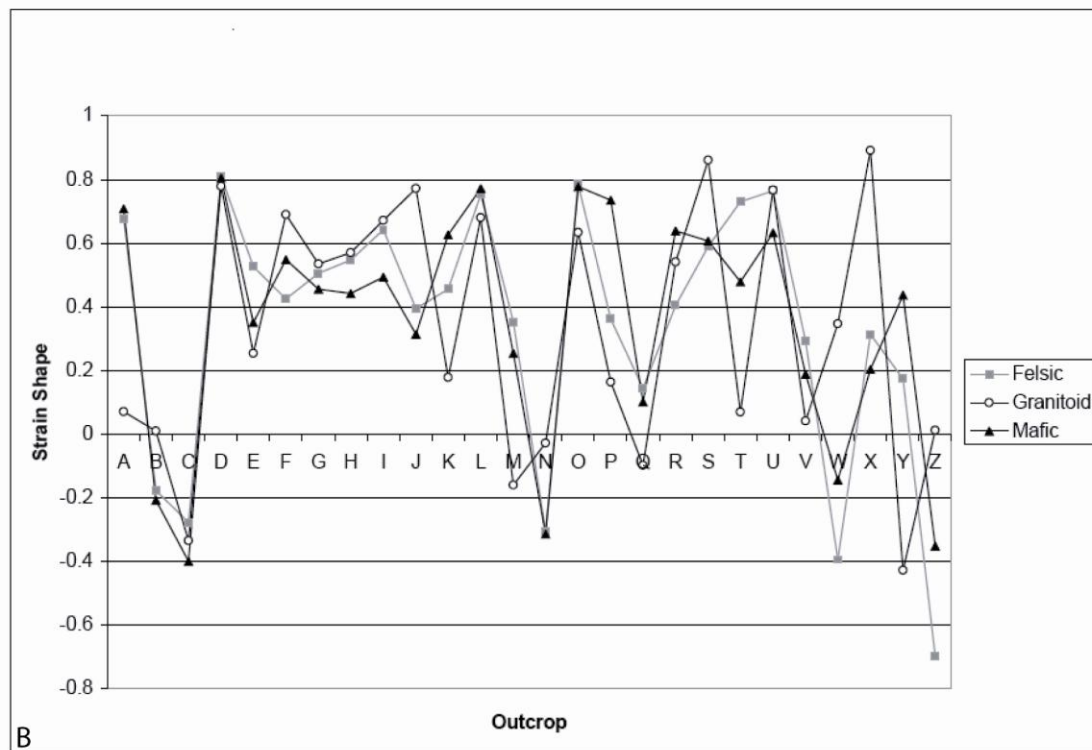
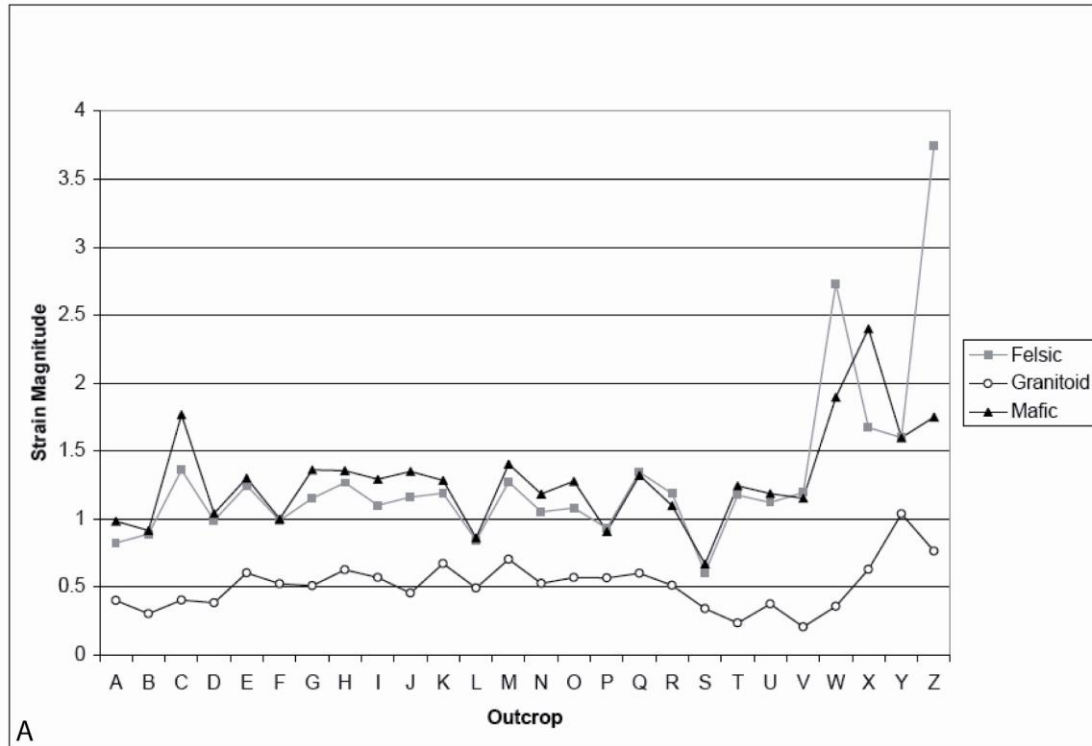


Figure 8. Plots indicating a) strain magnitudes ($\bar{\epsilon}_s$) and b) strain shapes ($\square$) from west to east across basin (stations A-Z) from Czeck et al. (2009).

Stop 4- Highly strained Seine Metaconglomerates

Continue east along Hwy 11 for approximately 19 km . Outcrop located along north side Highway 11.

(0559619E, 5398914N)

The Seine here is extremely deformed (amongst the highest strain found within this unit), reflected in the strained shapes of both the volcanic and plutonic clasts. Many clasts are deformed beyond recognition, giving the rock a striped appearance. Is it possible to accurately estimate strain in a rock that is this deformed? Most likely, all strain estimates are minimum estimates because only the least deformed clasts can be measured. Czeck et al. (2009) estimated strain for the various clast types at this outcrop and found the most disparate strain measurements in their study. Long/short strain axes ratios were approximately 3:1 for granitoid clasts, 11:1 for mafic clasts, and 136:1 for felsic clasts! The errors on the best fit ellipsoids were high, leading to doubts on the veracity of these results (don't put much faith in these numbers!).

The lineation plunges $\sim 44^\circ\text{E}$. While this lineation orientation is the approximate "average" stretching lineation for the Seine, it cannot be thought of as "typical" because the lineation orientations are so inconsistent. This outcrop is a key location to demonstrate that the lineation orientation is not directly related to the amount of strain (Czeck, 2001; Fissler, 2006; Czeck et al., 2009). This is important because most transpression models predict subvertical-vertical lineations in highly strained outcrops, and outcrops such as this one allow us to rule out many kinematic models. Again, the dextral asymmetric indicators are most prominent on the subhorizontal plane which allows us to rule out many triclinic transpression models. The combination of subhorizontal asymmetric shear indicators and variable lineation orientations makes a deformation model of quasi homogeneous transpression with a variable extrusion direction most likely (Czeck and Hudleston, 2003, 2004).

This outcrop also displays some crenulation cleavage. In general, crenulations formed in the Seine when the clasts are strained enough to create a layering effect. Therefore, crenulations formed relatively late within the strain history, probably during D_3 . Crenulations of both dextral and sinistral senses can be observed, indicating that there was likely still a pure shear component to the strain at the time of crenulation formation.

The extensive silica veining and carbonate alteration in this rock suggests that fluids infiltrated the rock during deformation. The relative timing of the carbonate fluid and quartz veins is ambiguous in thin section, suggesting that they were at least at times, coeval (Czeck, 2001). Fluid flow in shear zones is often associated with the possibility of preferential volume loss of soluble material, although the largely constrictional strains measured here (Czeck et al., 2009) are not consistent with typical volume loss apparent strains which fall in the flattening field (Ramsay and Graham, 1970). There was probably a symbiotic relationship between fluid localization and enhanced deformation. With such instances of fluid infiltration in highly deformed zones, people often ask the "chicken vs. egg" question of whether the fluid caused the high deformation through softening of the rock or whether the high deformation caused paths for fluids to infiltrate. We will leave the "chicken vs. egg" question open for discussion.

Stop 5 – Two-dimensional horizontal view of Seine Metaconglomerates

Continue on Hwy 11, turn south on to Forest Tour Road (dirt track overgrown with weeds). (0536650E, 5398850N)

This outcrop allows us to see a large two-dimensional view of the Seine Metaconglomerates with many beautiful examples of clast tiling, asymmetric strain shadows, and other kinematic indicators.

Many sandy beds and channels, often with graded bedding, can be located within this outcrop. Is it possible to determine stratigraphic facing here? As a note of historical interest, A.C. Lawson recognized cross-beds in the Seine sandstones as early as 1911, only a year or so after their significance as a “way-up” indicator was appreciated in younger, flat-lying rocks elsewhere. Lawson’s work in the Seine appears to have been the first use of observed reversals in stratigraphic facing to define traces of folds in a Precambrian setting.

Stop 6- Pseudoboudins

Return west on Hwy 11 for approximately 66 km. Outcrop is located at junction of Hwy 11 and dirt road turnoff (south side of Hwy). Also small outcrop on north side of Hwy. (0497963E, 5393628N)

At this outcrop of pelitic–psammitic schists, we can see fine examples of segmented pegmatite veins resembling boudin trains. Some of these segmented veins are indeed boudins, and they can be distinguished based on: 1) clearly defined edges, often with straight sides formed by fracturing that are oriented at high angle to the host rock fabric and 2) clear fabric deflection of the host rock into the boudin neck regions. However, within other segmented veins, we can see distinct examples of apparent boudinage or “pseudoboudinage” (Bons et al., 2004; Bons and Druguet, 2007; Druguet et al., 2008) (Fig. 9). In pseudoboudinage, a string of pegmatite beads is oriented at a low angle to the foliation and layering. Although resembling boudinage, this structure more likely formed by irregular inflation and collapse during vein intrusion (Bons et al., 2004) or intrusion into dilational jogs (Bons and Druguet, 2007). This interpretation is based on: 1) the irregular “cauliflower” shape of the individual segments and 2) the large amount of extension required to form these structures by boudinage, an amount that is incompatible with strain determined from nearby boudins (Druguet et al., 2008). Subsequent vein-parallel tectonic extension may have produced further separation between segments. Good examples of pseudoboudinage can be seen on the outcrop off of the south side of the highway. Good examples of folded and boudinaged veins can be seen on the small outcrop on the north side of the highway.

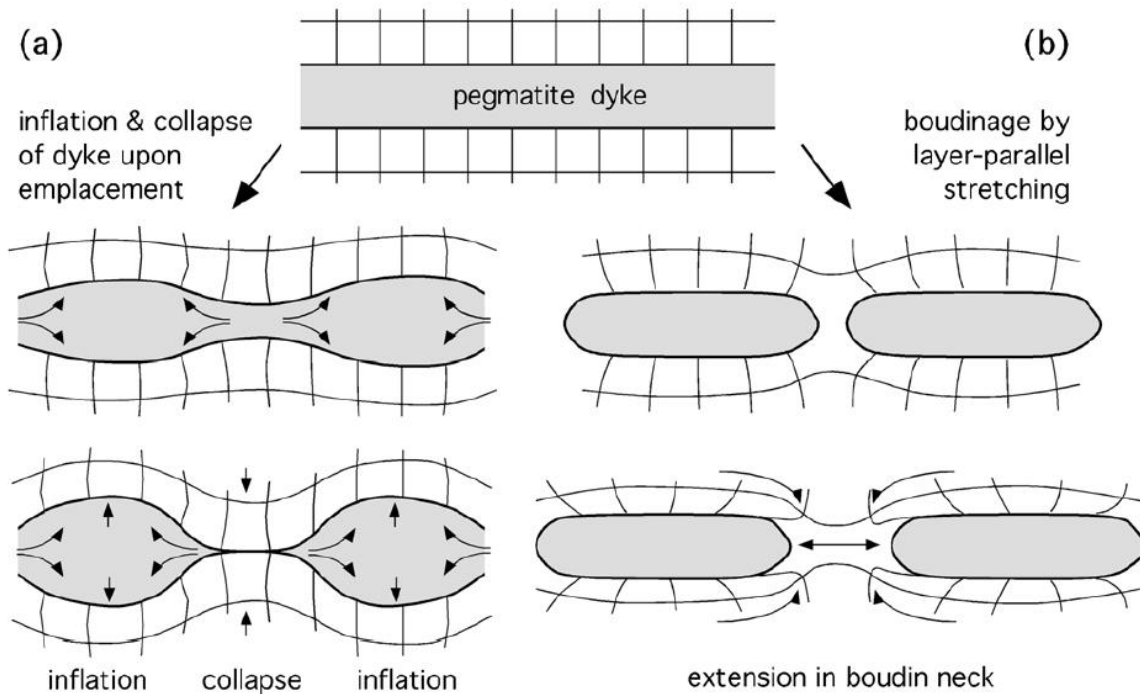


Figure 9. Schematic illustration of geometrical differences between apparent boudinage and actual boudinage from Bons et al. (2004). a) Collapse and inflation of a pegmatite dyke upon emplacement, without any dike-parallel stretching. b) Boudinage of a solidified pegmatite dyke, due to dike-parallel stretching.

Stop 7- Shear zones within the Grassy Portage Sill

Continue west along Hwy 11 for approximately 4 km to the junction with Hwy 502. Turn right and drive north along Highway 502 for approximately 2 km. Turn east along unnamed road and drive for approximately 4.5 km. Outcrop is a small mound on north side of road. (0498897E, 5399146N)

The Grassy Portage intrusion is a large metamorphosed layered gabbroic sill, which is exposed approximately 20 km along its strike. It has been overturned so that it dips steeply to the northwest (Poulsen, 2000a). Within the sill, layering is formed by variations in mineralogy and chemistry, both regionally (km scale) and locally (cm scale) (Poulsen, 2000a). Compositions range from melagabbro to anorthosite (Poulsen, 2000a). The margins have been exploited for disseminated chalcopyrite and pyrrhotite mineralization (Poulsen, 2000a).

We will observe the sill along its base (northwest margin) on a subhorizontal glaciated surface. This lower portion of the sill is dominated by compositions of gabbroic and anorthositic rocks that either may have formed by gravitational setting or autointrusion (Poulsen, 2000a). The metagabbroic rocks range from leucogabbro to gabbro in composition and contain hornblende and plagioclase with minor amounts of chlorite and biotite (Poulsen, 2000a). Most of the gabbros have a poikilitic texture with hornblende megacrysts, but some have an equigranular texture.

Within the sill, the anorthositic rocks are often found as lenticular pods within the gabbros that range in size up to 50 cm maximum diameter. They have adcumulate textures of fine-grained andesine (Poulsen, 2000a). At this particular outcrop, the pods have adcumulate textures, but are composed of fine-grained zoisite. The zoisite textures indicate that they were formed by hydrous alteration of plagioclase as evidenced by some relict plagioclase grains with quartz and minor amounts of calcite (Carreras et al., in press).

The metagabbros contain a wavy pre-shearing weak foliation formed by aligned and linked amphiboles, which strikes approximately 110° with steep-subvertical dip. The orientation of this local foliation is consistent with the prevailing foliation in the immediate region, which is deflected from the typical NE-SW regional strike to a WNW-ESE orientation due to deflection around the Rice Bay Dome.

Both the gabbros and anorthosites are affected by subsequent small-scale (cm-dm) shear zones, defined by deflection and intensification of this prevailing foliation and studied in detail by Carreras et al. (in press) (Fig. 10). They are narrow and discrete bands, with a maximum width of a few centimetres, that define an anastomosed pattern with orientations dominated by NNW-SSE striking, moderately to steeply dipping strands (Carreras et al., in press). Inside the shear zones, the rocks are well-foliated and fine-grained mylonites. The shear zones are preferentially within the gabbros and often localize at the gabbro/pod margins. This prevalence of ductile deformation within the gabbros indicates that the gabbros were less competent than the anorthosites during much of the deformation. However, the shear zones also cut across some pods where they are defined by mylonitic banding with finer grain size and segregated compositional banding.

Through detailed kinematic analysis including foliation deflection patterns and relative timing criteria outlined in their paper, Carreras et al. (in press) determined evolution of the shear zones including the relative timing of initiation and subsequent rotation of the features (Fig. 11). They distinguished two main sets of shear zones, dextral and sinistral, which each exhibit a range of orientations. The final angular pattern between dextral and sinistral shears is not an original feature. Dextral and sinistral shears formed together at nearly right angles, and the angles progressively opened towards the extension direction as a result of increasing strain. The obtuse angles were achieved by the combined effects of continued shearing on newly forming shears and internal deformation of the lozenge-shaped domains of lesser deformed rock. Through time, there was an increasing prevalence of dextral shears over sinistral ones. The studied pattern and sequential analysis indicate that bulk deformation was noncoaxial with a deformation regime evolving from a pure shear-dominated dextral transpression to a higher vorticity dextral transpression (Carreras et al., in press).

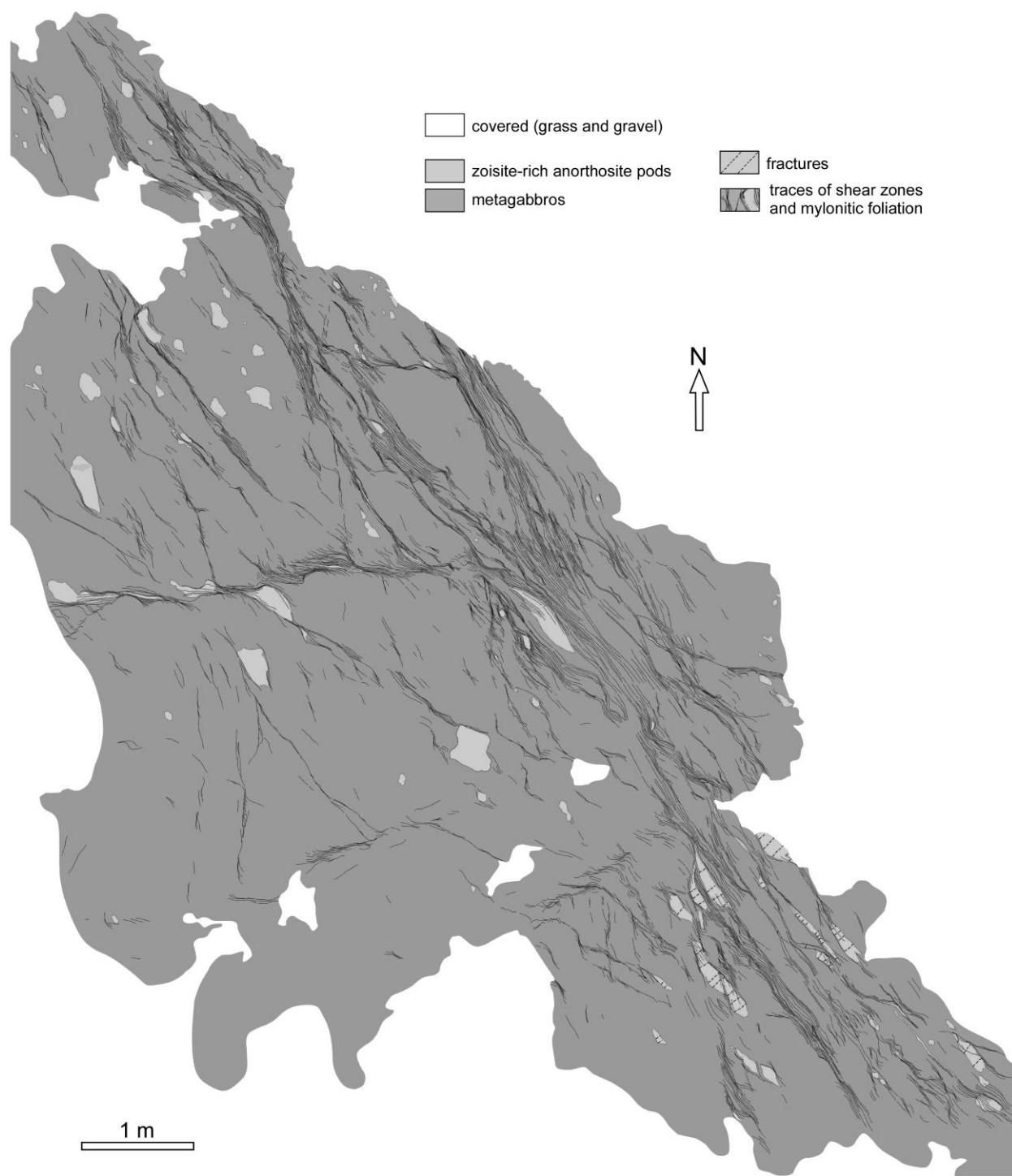


Figure 10. Detailed outcrop map of the shear zones within the Grassy Portage Sill from Carreras et al. (in press).

Fractures are the latest structures, cutting both the foliation and shear zones. They are located exclusively in the anorthosite (zoisite) pods and are chiefly oriented transverse to the mylonitic foliation. The regularity of the fracture orientations suggests that they formed in response to the final state of instantaneous strain because one would only expect them to be subparallel if they formed without any subsequent rotation. They are interpreted as extensional (Mode I) fractures. The incidence of the fractures exclusively within the pods indicates that the pods were relatively more competent than the surrounding gabbros at this final stage of deformation.

Stop 8- Folds and syntectonic veins within mafic metavolcanics

Return to Hwy 502 and drive north for approximately 3 km. Outcrop is located along west side of Highway 502.

(0496149E, 5401196N)

At this stop, we are located in relatively incompetent mafic metavolcanic rocks that are channeled between more competent units: the Black Sturgeon Bay gneiss dome to the northwest, the Rice Bay gneiss dome to the southwest, and the Baseline Bay (Algoman) pluton to the east. The foliation at this outcrop is roughly striking NE/SW, in an orientation that is consistent with the foliation in the incompetent units being channeled around the more competent units. Here, the banded mafic metavolcanic rocks are isoclinally folded (F_2). A sequence of leucocratic veins are intruded into the host rock.

The leucocratic veins are syntectonic with D_2 because many such veins that cross-cut F_2 folds are folded and co-planar with them (axial planes in veins are subparallel to those in the metasedimentary rocks), although in a more open geometry. This relationship reveals that the host rocks underwent folding prior to vein intrusion, but both vein and host rock underwent additional D_2 folding. Druguet et al. (2008) used veins such as these to estimate two-dimensional strain in metavolcanic and metapelitic host rocks surrounding the competent Rice Bay gneiss dome. This outcrop is located in one of the highly strained zones (Fig. 12).

The veins and their host rocks underwent a competence inversion. When the veins were first intruded, they were less competent than the host rock, but as they cooled, they eventually became more competent. We can see evidence for the early less competent veins with cusped margins and irregular vein boundaries. We can see evidence for the late more competent veins with folding.

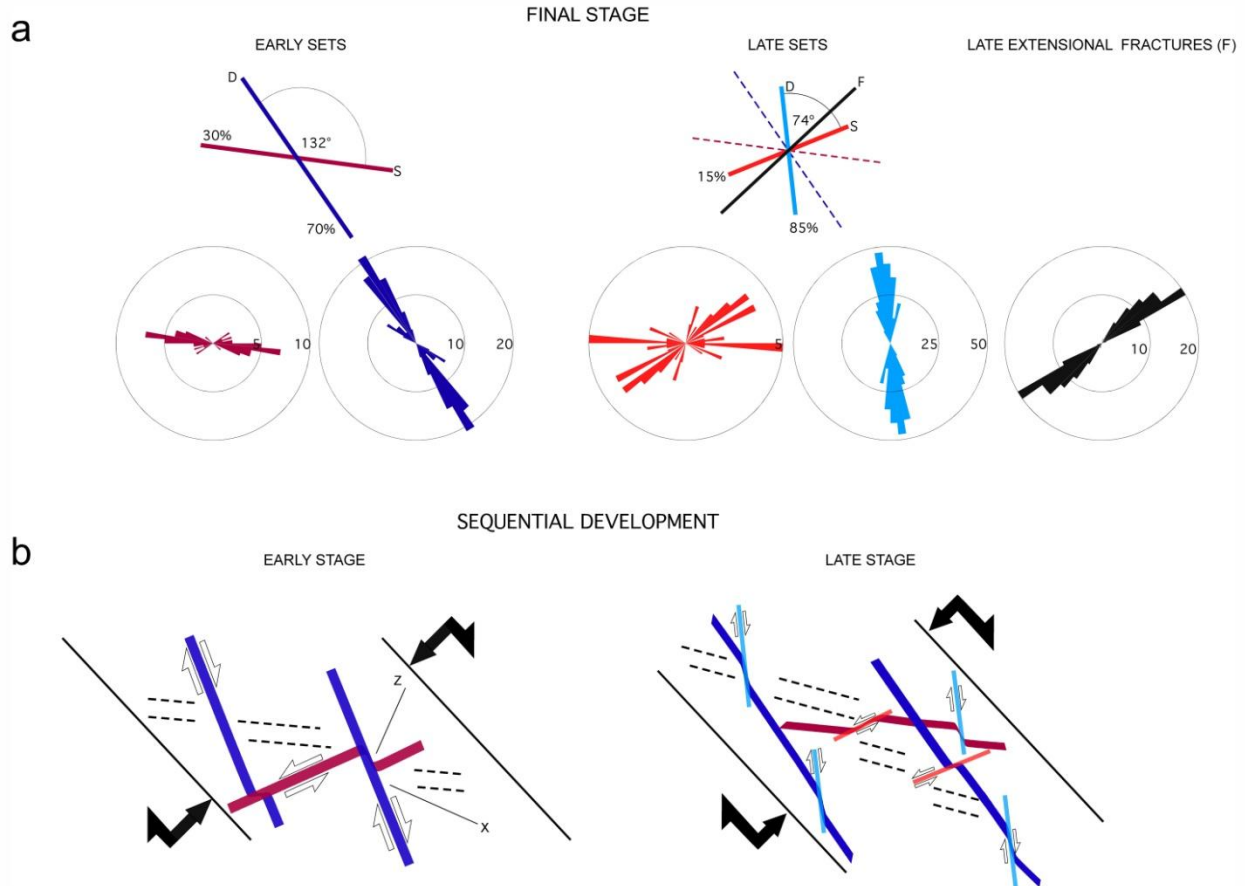


Figure 11. Two-dimensional (horizontal) kinematic model for shear zone set formation from Carreras et al. (in press). a) Mean orientation of the early and late dextral (D) and sinistral (S) sets of shears and corresponding Rose diagrams. The finite bulk shortening direction faces the obtuse angle between the sets. In both stages, there are more dextral shears than sinistral ones. The orientation and corresponding Rose diagram of the late fractures (F) is also included. b) Model for the sequential development of shears, drawn on the XZ plane with north upwards. In addition to shears, the orientation of the bulk X and Z directions, the assumed shear plane and the trend of the pre-existing foliation (dashed lines) have been drawn. It is assumed that the initial angle that faced the bulk shortening direction between sets was $\sim 90^\circ$. As deformation progressed, the two sets rotated in opposite directions, and the angle between them increased. The later development of new dextral and sinistral sets led to complex coalescences and cross-cutting relationships.

Stop 9- Folding and syntectonic veins in alternating pelitic and psammitic schists

Turn around and return south on Hwy 502. Outcrop is located along south side of Hwy 11 immediately east of Hwy 502 turnoff.

(0495680E, 5396171N)

At this stop, we are located in relatively incompetent metasedimentary rocks that are channeled between more competent units: the Rice Bay gneiss dome to the northwest and the Grassy Portage gabbroic sill to the east. The foliation at this outcrop is striking approximately NE/SW, parallel with the map expression of this channeled metasedimentary unit. The rock consists of alternating pelitic and psammitic schists with F_2 isoclinal folds easily seen in the metapsammitic layers and early quartz veins.

There are multiple veins ranging from quartz to leucocratic in a variety of orientations. We can see folding and boudins in the veins depending on their orientation. The folds in the veins have a tighter geometry in the pelitic schists compared to the psammitic schists due to the higher competence contrast between the veins and the metapelites (e.g. Ramsay, 1967; Cruikshank and Johnson, 1993). Based on two-dimensional strain analysis of vein deformation with assumed constant volume, this outcrop is located in a moderately strained zone with long/short axial strain ratios of approximately 2:1 and plane strain (Druguet et al., 2008) (Fig. 12).

Stop 10- Decimeter scale upright folds

Located along north side of Hwy 11 immediately west of Hwy 502 turnoff.

(0495180E, 5396173N)

The next stop is right near the last within the layered metasedimentary rocks. Here we can observe decimeter scale low amplitude folds within the sedimentary layers. Note that the F_2 folds plunge eastward and display an asymmetry consistent with the location on the south-east flank of the Rice Bay Dome. Two outcrop localities convincingly demonstrate downward facing in this metasedimentary (metagreywacke) unit: near Pocket Pond (pillow lavas) and Bear Pass Boat Launch (graded beds) (Poulsen et al., 1980). In both cases, the metagreywackes are structurally beneath, but stratigraphically above the metavolcanics, a relationship that is supported by zircon ages (Davis et al., 1989). Given that these metasedimentary rocks are younger than both the mafic-ultramafic rocks to the east and the felsic rocks in the core to the dome to the northwest, there is a problem in interpreting their configuration prior to development of the F_2 “dome.” The possible solutions are shown in Fig. 13, all resulting in “stacked” tectonostratigraphy. Therefore, in the big-picture view, down-plunge and eastward from this locality is an antiformal syncline.

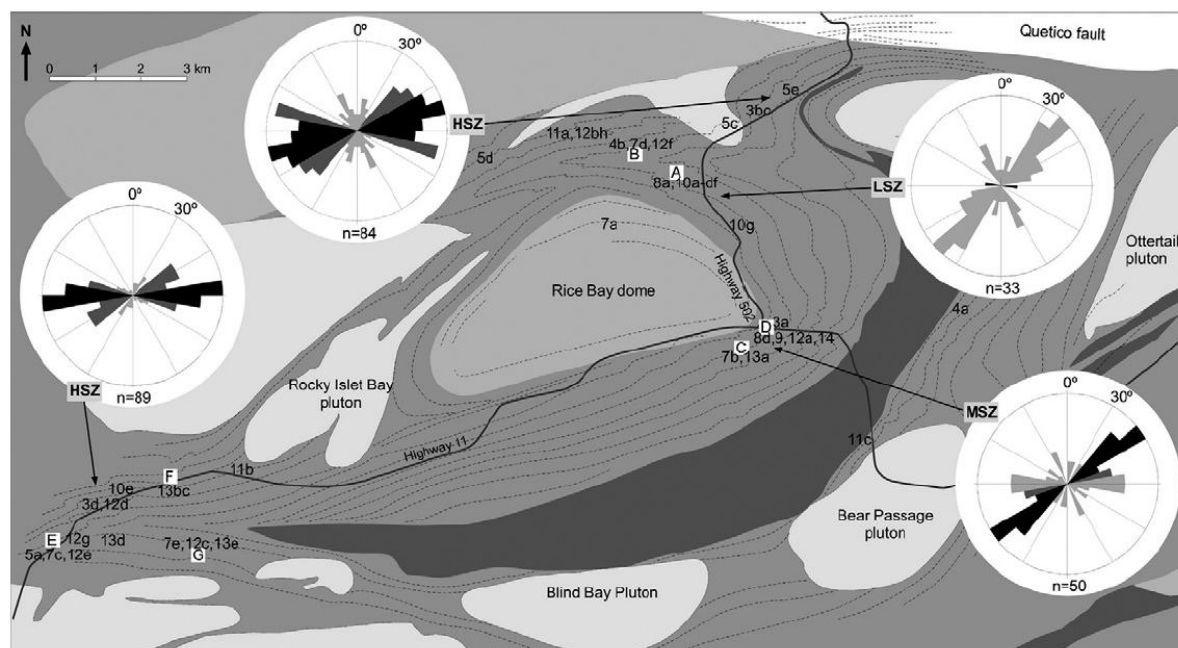


Figure 12. Schematic structural map of the study area from Druguet et al. (2008) with localities where strain estimations were performed (A–G). Diagrams of azimuth distribution of veins from four different areas. Pale grey: shortened veins; black: extended veins and, where possible; grey: shortened and extended veins. (LSZ = from a low strain zone, MSZ= from a moderate strain zone, HSZ = from a high strain zone.). Fieldtrip Stop 8 is from the HSZ at location 5e in the north-central portion of the map. Fieldtrip Stop 9 is from the MSZ at location 8d in the north-central portion of the map. Fieldtrip Stop 11 is from the HSZ at location 5a in the western portion of the map.

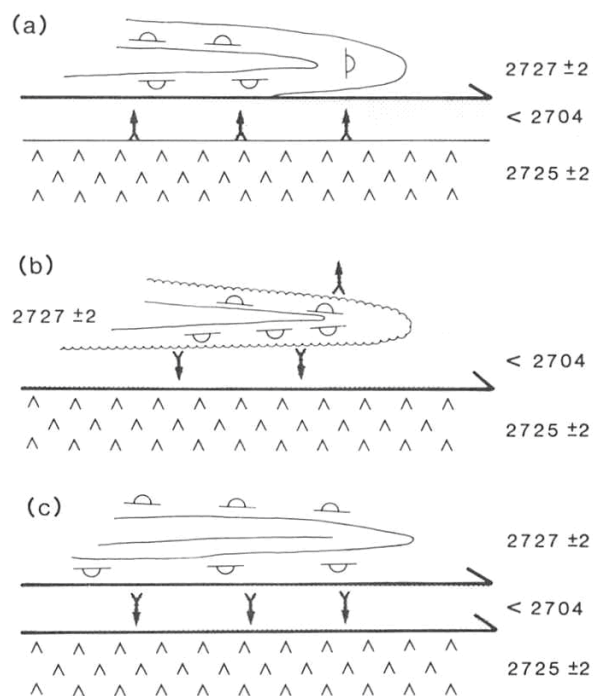


Figure 13. Schematic illustration showing alternative explanations for stacking of tectonic slices in Rice Bay – Bear Pass area. From Davis et al., (1989).

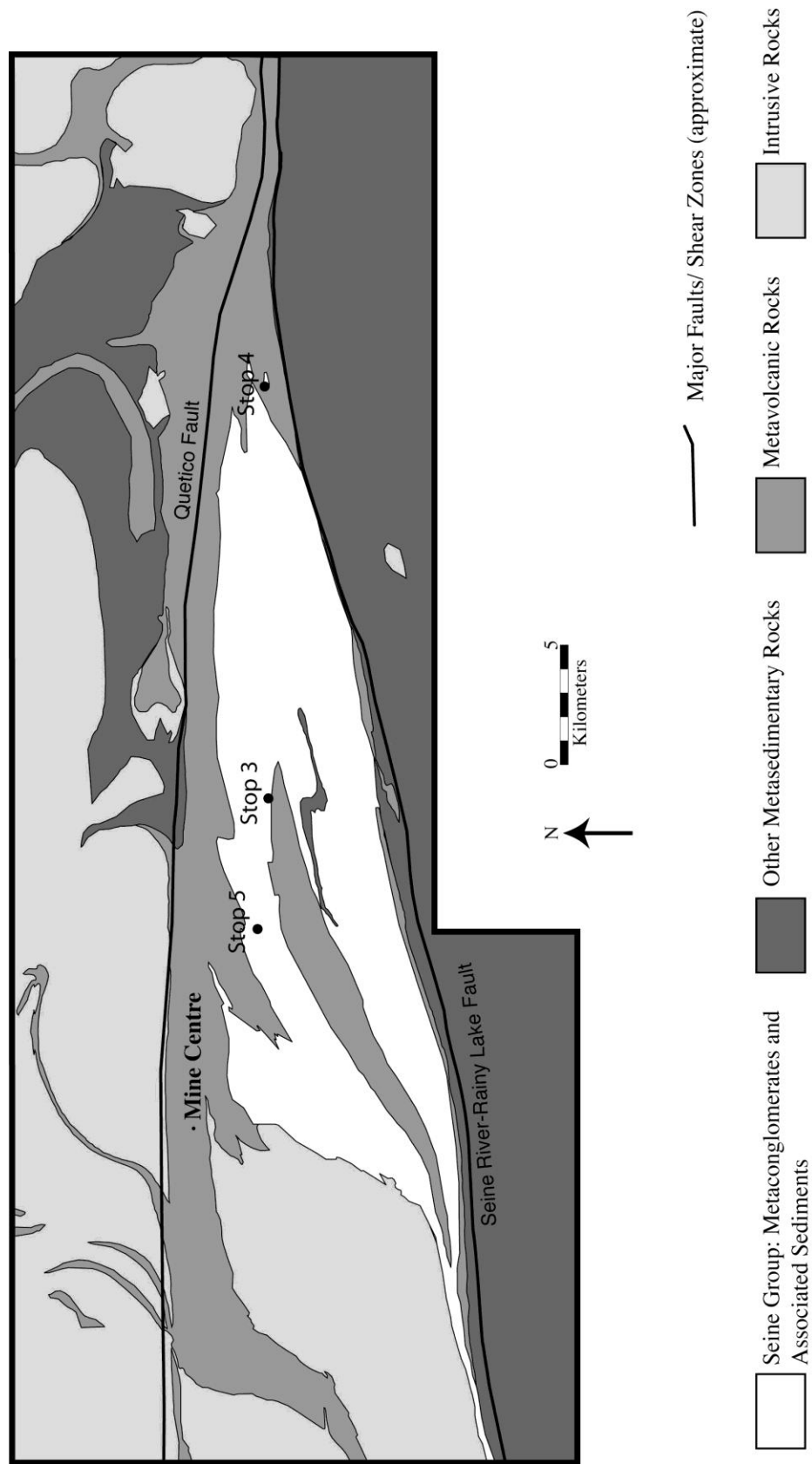


Figure 14. Simplified map of Seine Basin including Stops 3-5. Modified from (Czeck, 2001; Czeck and Hudleston, 2003; Czeck et al., 2009) based on maps from (Wood et al., 1980b, a; Stone et al., 1997a, b) .

Stop 11- Four consecutive sets of strongly deformed leucocratic veins within a foliated metasedimentary rock

Drive west along Hwy 11 for approximately 17 km to junction with Rocky Inlet Road. Outcrop is located on the SE corner of the intersection.

(0479790E, 5391262N)

This outcrop is a strongly foliated metasedimentary rock of the Coutchiching Group located between various Algoman granitic intrusions to the north and south. Four consecutive sets of strongly deformed leucocratic veins intrude the host rock and are boudinaged and folded depending on orientation. When veins intruded at angles higher than 30° with respect to the foliation, they were folded. When intruded at lesser angles, they were boudinaged or folded then boudinaged. There is an increasing measurable strain in progressively older veins, which indicates multiple synkinematic D₂ intrusions (Druguet et al., 2008). Based on two-dimensional strain analysis of vein deformation with assumed constant volume, this outcrop is located in a highly strained zone with long/short axial strain ratios of approximately 5.5:1 and flattening strain (Druguet et al., 2008) (Fig. 12). In this highly strained zone, the folds are tighter than at lesser deformed outcrops. The folds are tight to isoclinal and classified as Class 1C and 2 folds characterized by relative thickening of the hinge zones, which is compatible with flattening strain. Lastly, the veins are offset by discrete brittle faults, primarily ductile, that presumably occurred during D₃.

Bonus Stop 12

If we have time for this stop, it is located approximately 4 km east of Stop 11 on north side of Highway 11, immediately next to convenience store with Bear statues.

(0484020E, 5393045N)

Here, we can observe metabasalts with prominent pillows in three-dimensions. Stretching lineations defined by alignment of mafic minerals and long axes of pillows are near vertical. Strain appears to be constrictional, although detailed strain measurement has not been performed. Leucocratic intrusions have cusped structures that preserve magmatic relationships and weak internal fabrics, suggesting syntectonic intrusion.

Bonus Stop 13

From Bonus Stop 12, drive west along Hwy 11 for approximately 8 km to the western lookout point on north side of Noden Causeway, Hwy 11, immediately under powerlines.

(0477336E, 5388940N)

Here, we can observe well-foliated granitoid rock with large K-feldspars that has been intruded by many felsic and mafic dikes. Fabrics include a foliation oriented approximately N86W, 88NE defined by alignment of plagioclase and a steep (80°W pitch) mineral lineation. The granitoid contains many semi brittle- semi ductile shear zones. The highlights of the stop are exceptional small brittle faults that cut the tectonic fabric and shear zones at a high angle.

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FIELD TRIP 4

ARCHEAN GEOLOGY OF VOYAGEURS NATIONAL PARK AND THE LITTLE AMERICAN GOLD MINE

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Mark Jirsa (Minnesota Geological Survey)

This boat trip through a very small part of Voyageurs National Park highlights the complex Archean geology of the southern Wabigoon and northern Quetico subprovinces of Superior Province (Fig. 4.1). The tour begins at the landing located within metasedimentary rocks of the Quetico subprovince. The boat travels northward, up Black Bay to Little American Island, then northeastward to Dryweed Island. Due to limited time and docking capabilities, the only actual stop will be at the historic Little American Gold Mine—the first and only operating gold mine in Minnesota. Elsewhere the geology will be viewed and interpreted “over the gunnels.” Little American Island lies within the broad zone of dextral shear associated with the Rainy Lake-Seine River Fault, shown by wavy dashed lines on Figure 4.1. Gold-bearing quartz veins on the island were emplaced into variably deformed metabasalt and mafic schist of the Wabigoon subprovince. Dryweed Island, to the northeast, forms a lozenge of comparatively less deformed rocks between the Rainy Lake-Seine River and Tilson Bay fault zones. Most of the exposures on Dryweed Island are components of the Seine Group, a sequence of quartzofeldspathic sandstone, conglomerate, and minor felsic tuff. Stratigraphic facing in the Seine is consistently southward, so this exposure appears to represent a fault-bounded, southward-tilted block. See Jirsa and Hemstad, Field Trip 6, this volume for more details.

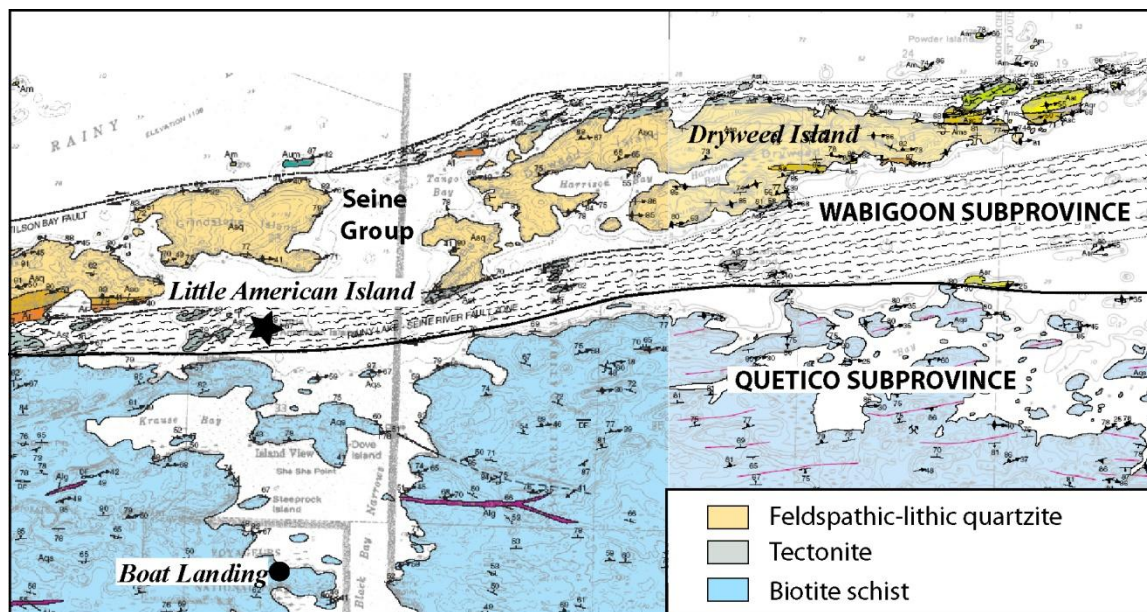


Figure 4.1—Geology of Little American Island and Dryweed Island in Rainy Lake (modified from 1:24,000-scale maps of Hemstad and others, 2000, 2001).

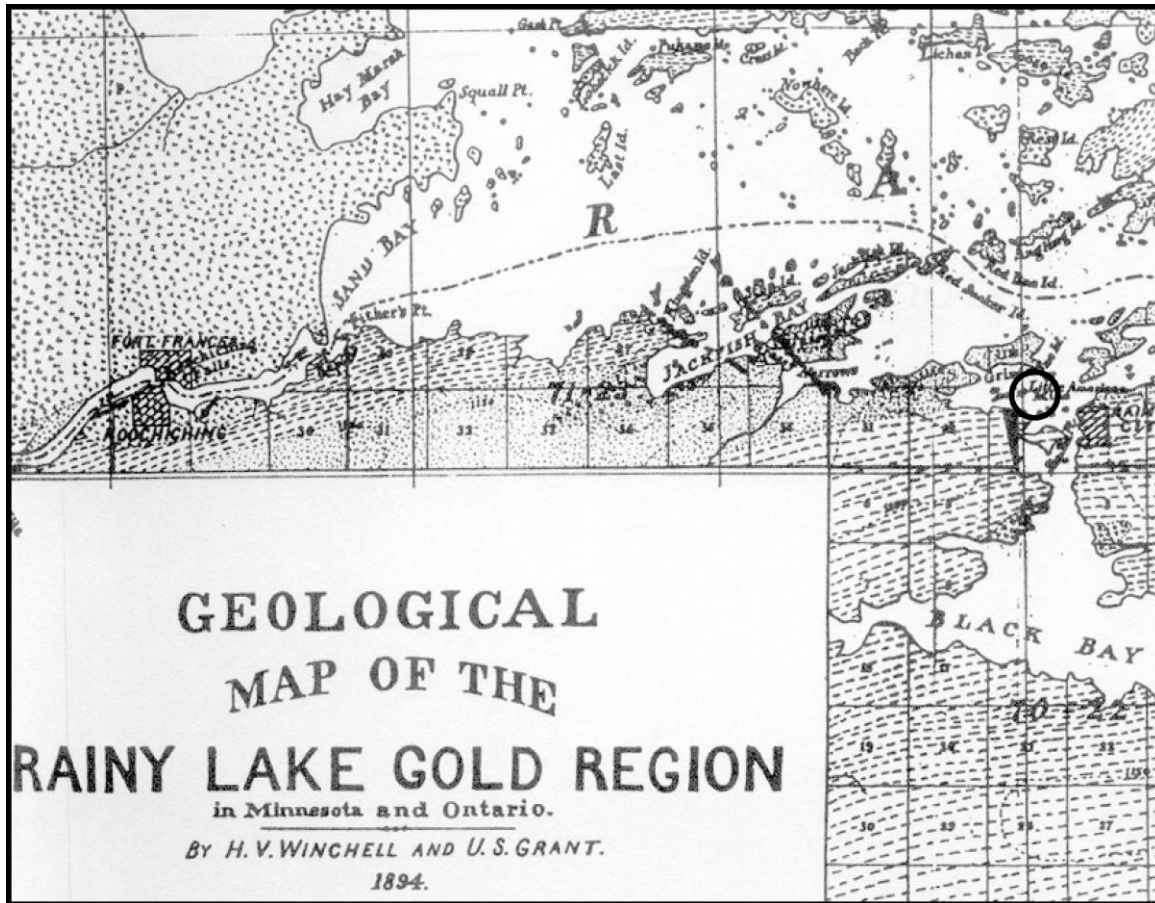


Figure 4.2—Portion of an historic geologic map showing Little American Island (circled), and the town site of Rainy Lake City on the mainland to the southeast (cross-hachured).



Figure 4.3—Plat map of Rainy Lake City and historic photo (from Perry, 1993)

Gold was discovered on Little American Island in 1893 by George Davis, a prospector en route to exploration in Canada, who camped on the well-used spot (Fig. 4.2). There he discovered a quartz vein, cracked some off, crushed and panned it. Later assays returned estimates of gold contents in the range of \$50 to \$100 per ton. The rush was on! Investors from Duluth and elsewhere quickly amassed \$300,000 to capitalize a mining venture. By 1894, Rainy Lake City was platted on the mainland to the southeast, where a mill for stamping and processing the ore was constructed. In a short time, the city had several sawmills, 8 dry-goods stores, 8 grocers, three hotels and restaurants (Fig. 4.3), seventeen saloons, two newspapers, a livery barn, three laundries, a school, a bank, a doctor, and a lawyer (Perry, 1993).

The mine produced \$4,635 worth of gold in 1893 from the 2 meter wide composite quartz vein. However, its operation was plagued with episodes of failing capitol and production calamities. An incompetent amalgamator sent \$10,000 worth of gold into the lake, and the collapse of a loading dock sent a season's ore to the bottom (Perry, 1993). Mining continued intermittently, and the mine eventually reached a depth of 210 feet. At today's prices, an estimated total of \$45,000 worth of gold was extracted during its operation, but the immense cost of transportation and milling brought the mine to a close by 1895. Several attempts to reopen it were made until 1898, when the County seized the property. By that time, the lure of the Klondike sapped much of the excitement from this remote endeavor. The town site of Rainy Lake City was abandoned and dismantled. By contrast, other mines in what was called the "Rainy Lake Gold Region" were very productive, especially those in the nearby Mine Center area of Canada.

Acknowledgement: This boat tour is courtesy of the National Park Service, Voyageurs National Park. We extend our thanks to their staff, including Mike Ward-Park Superintendent and Tawnya Schoewe-Head Park Interpreter, for making it possible.

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FIELD TRIP 5

ASH RIVER NEUTRINO DETECTOR LABORATORY (NOvA) AND THE ARCHEAN VERMILION GRANITIC COMPLEX

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William Miller (University of Minnesota School of Physics and Astronomy)

*This manuscript was not reviewed to conform to editorial standards of the Minnesota Geological Survey

This field trip visits the NOvA project, under construction off the Ash River Trail southeast of International Falls. The project is part of a wide ranging effort to understand the fundamental make-up of matter. The acronym “NOvA” stands for **NuMI, Off-axis, electron neutrino (ν_e), Appearance**. “NuMI” refers to **Neutrinos at the Main Injector** facility at Fermi National Accelerator Laboratory (Fermilab) in Chicago. More than 180 scientists from 28 national laboratories and institutions around the world are working on the NOvA neutrino experiment that will take place at the Ash River site. The experiment will investigate the role of subatomic particles called neutrinos in the origin and shaping of matter in the universe. Fermi National Accelerator Laboratory, which manages the project, will generate a beam of neutrinos to send to a 15,000-ton detector at the new facility. Despite traveling through the earth’s crust (Fig. 5.1), the particles will complete the 500 mile interstate trip in less than a hundredth of a second. Scientists will study changes that the particles undergo as they travel.

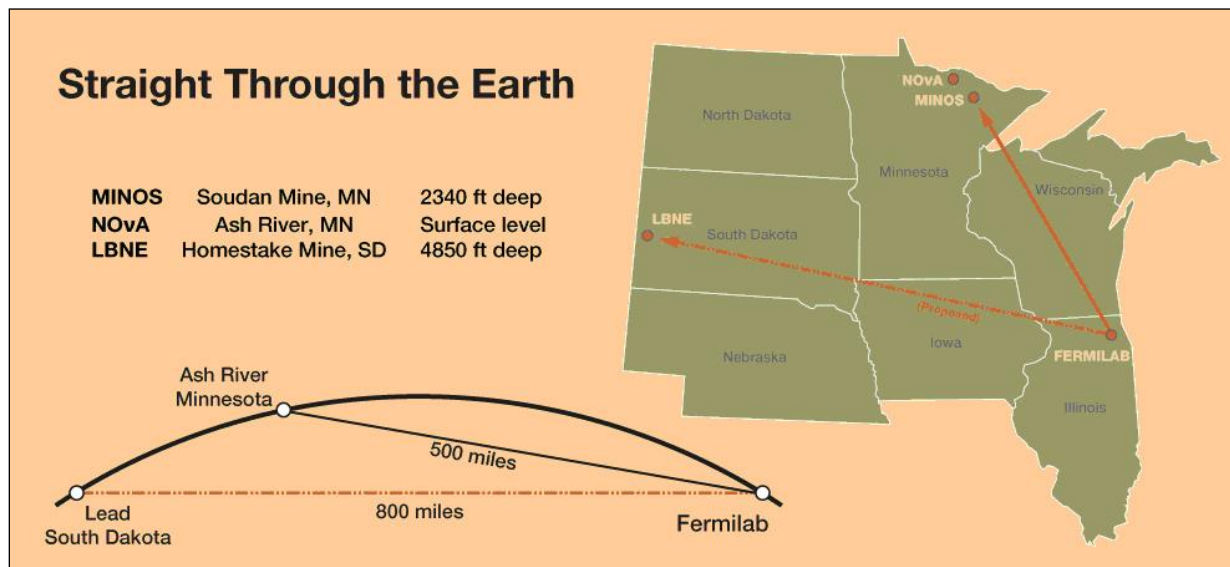


Figure 5.1—Schematic diagram of neutrino trajectories.

The \$278 million NOvA project is funded by the Office of Science of the U.S. Department of Energy and Fermi National Accelerator Laboratory. The NOvA experiment at Ash River will be operated by the University of Minnesota School of Physics and Astronomy. The American Recovery and Reinvestment Act provided \$40.1 million to the project. For more information, contact Bill Miller via e-mail at Miller@soudan.umn.edu or visit the website at www.nova.fnal.gov/fermilab_nova.pdf.

Excavations and outcrops near the NOvA site expose leucogranite-rich migmatite of the Vermilion Granitic Complex in the heart of the Quetico subprovince of Superior Province. See Jirsa and Hemstad, Field trip 6, stop 6-10 this volume for more details. The narrow, darker colored unit shown on the Figure 5.2 near the site is biotite-hornblende diorite.

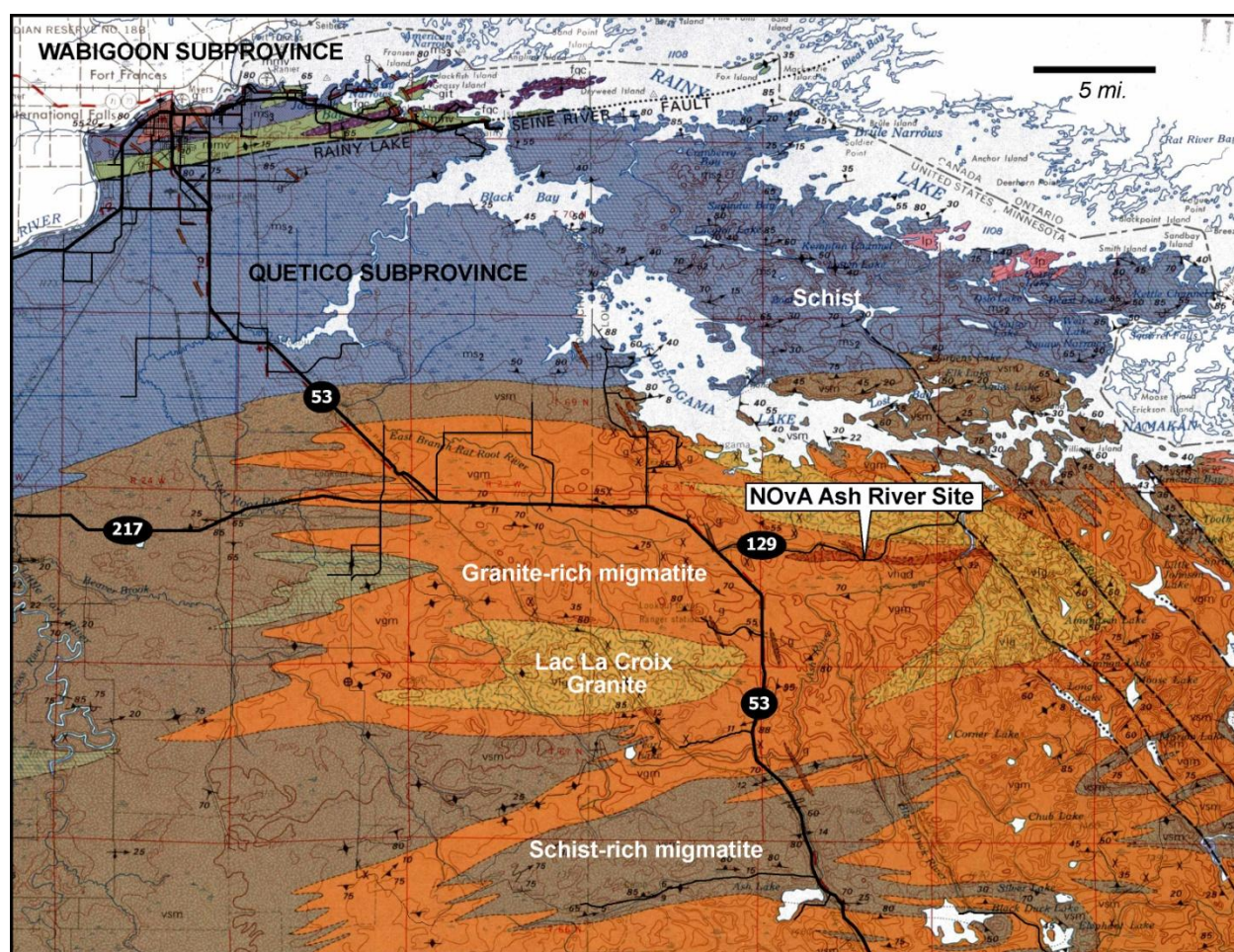


Figure 5.2—Geologic map of the NOvA site (modified from Southwick and Ojakangas, 1979).

REFERENCE

Southwick, D.L., and Ojakangas, R.W., 1979, Geologic map of Minnesota, International Falls sheet: Minnesota Geological Survey, scale 1:250,000.

FIELD TRIP 6

TRANSECT THROUGH THE QUETICO-WABIGOON SUBPROVINCE BOUNDARY

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*This manuscript was not reviewed to conform to editorial standards of the Minnesota Geological Survey

GEOLOGIC SETTING

This trip examines the geology along the boundary between two subprovinces of the Archean Superior Province—the volcanoplutonic Wabigoon subprovince to the north, and the largely metasedimentary and migmatitic Quetico subprovince to the south. The boundary is somewhat transitional, as it is marked by a broad zone of shear associated with the Rainy Lake-Seine River Fault and several other fault structures. The two terranes have contrasting lithologic and metamorphic attributes. The Wabigoon portion of the area consists of tightly folded volcanic rocks and metagraywacke, unconformably overlain by and structurally interleaved with conglomerate and quartzite of the Seine Group and metamorphosed to greenschist facies. The Quetico portion contains biotite schist of graywacke protolith and migmatitic plutonic rocks that are multiply deformed, metamorphosed to amphibolite facies, and intruded by younger granite. Although the subprovince boundary is clearly a metamorphic one, work by Devaney and Williams (1989) on exposures along strike to the northeast implies that the coincident lithologic shift reflects a depositional transition during Neoarchean terrane accretion. The Wabigoon represents oceanic plateau and island arc deposition; the Quetico represents the transition arc to submarine margin and trench-fill deposition. Seismic reflectivity indicates north-dipping structures are present at depth along the subprovince boundary in Canada (Percival and others, 2006). These structures may represent the accretionary boundary that has been over-steepened and segmented locally by subsequent north-south crustal shortening and dextral wrench faulting. The Seine Group, which lies within a fault- and unconformity-bounded block, appears to represent continental sedimentation into one or more successor basins developed along the subprovince boundary. All of these Archean rocks were intruded by diabase dikes of the Kenora-Kabetogama swarm at about 2067 Ma (Wirth and others, 1995).

WABIGOON SUBPROVINCE

Only a sliver of the subprovince is exposed on the Minnesota side of the border, and therefore, much of what is known about it is based on work to the north. Volcanism in the subprovince as a whole occurred in the range of 2745-2720 Ma (Corfu and Davis, 1992); with rare older and younger volcanic sequences locally. Metavolcanic rocks exposed on the mainland and islands in Minnesota are variably schistose and include pillowed, massive, and tuffaceous basalt; felsic tuff, and hypabyssal intrusions. Schistose metasedimentary rocks of apparent turbiditic origin are infolded with the volcanic strata. Plutonic rocks vary from synvolcanic batholiths consisting of tonalite, diorite, and gabbro; to younger granodiorite batholiths and plutons (~2710 Ma), monzodiorite (sanukitoid) plutons (~2698-2690 Ma), and monzogranite (~2690-2660 Ma). Younger clastic successions, including the Seine Group described below, sit with local unconformably on older volcanic strata and typically have ages in the range of 2711-2686 Ma.

Seine Group

The Seine Group exposed in Minnesota (or Seine conglomerate, as it is referred to in Canada) consists of interbedded conglomerate, quartzofeldspathic and lithic sandstone, and minor tuffaceous strata. Although moderately to strongly deformed, sedimentary structures are locally preserved and include trough cross-bedding and normal and reversed grading. Collectively, these characteristics indicate fluvial deposition. Conglomeratic beds contain pebble- to cobble-size, rounded to subrounded, polymictic clasts that include fragments of subjacent rocks and a variably porphyritic volcanic component of intermediate to felsic composition. The contrast between the relatively deep water, pillowed volcanic and turbiditic rocks, and the superjacent quartzose and conglomeratic strata of the Seine is striking and implies that significant uplift by tectonic shortening must have occurred. The unit trends discontinuously northeastward across the mainland and islands and continues into Canada. In Minnesota, it appears to be bounded on the north by the Tilson Bay Fault, and stratigraphic younging is consistently southward. Additional details about the sedimentology and deformation of the Seine conglomerate can be found in Czeck and Fralick, 2002; and Poulsen and Czeck, field trip 3, this volume.

The Seine Group is one of a series of similar deposits throughout the Superior Province represented by subaerial unconformities overlain by fluvial and lacustrine or marine basin-fill sediments. The relative temporal framework of these deposits indicates that they are time-transgressive, generally younging to the south, which is consistent with arc collisional events (Corcoran and Mueller, 2007). Czeck and Fralick 2002 suggested that the Seine conglomerate was deposited following collision of the southern Wabigoon terrane with the Wawa and intervening Quetico terranes. The age of the Seine is bracketed between about 2696 Ma, the age of a clast, and 2686 Ma, the age of an intrusion which cuts the Seine (Davis and others, 1990).

QUETICO SUBPROVINCE

The Quetico is one of a number of east-trending, largely metasedimentary subprovinces in the Superior province. It is bounded on the south by the Wawa volcanoplutonic subprovince, and on the north by the Wabigoon subprovince. It consists of schist derived from turbiditic sedimentary rocks and a complex suite of granitic intrusions and associated migmatite. In northeastern Minnesota, the subprovince displays a roughly symmetrical distribution of metasedimentary rocks on the north and south, that grade irregularly through zones of schist-rich

migmatite, to a central axial zone composed largely of polyphase granitoid migmatite and younger granite. Metamorphic grade mimics this symmetry, with generally higher grade rocks in the central axis and lower grade near the bounding volcanoplutonic subprovinces. The accretionary prism model of Williams (1990) implies sediment deposition by submarine fans and abyssal turbidites. Timing of deposition is constrained by youngest detrital zircons at about 2698 Ma, and intrusion ages of about 2688 Ma (Davis and others, 1990).

The migmatitic and plutonic rocks in the axial zone are known collectively in Minnesota as the Vermilion Granitic Complex (Southwick and Sims, 1980). The migmatite is divided into schist-rich and granite-rich components, depending on the ratio of paleosome to neosome. These can be equated generally with the terms metatexite (low degree of partial melting) and diatexite (nearly complete fusion), respectively, of Sawyer, 2008. Field relationships within the complex (Southwick, 1991) indicate that earliest granitoid phases are leucogranite, granodiorite, and trondhjemite, which make up the leucosome of a broad area of migmatite. The migmatite is interlayered at all scales with paleosomes of biotite schist and amphibolite, and is cut by dikes, sills, and irregular masses of two mica leucogranite with accessory garnet, and biotite granite that contains minor magnetite. The latter forms a large intrusion known as the Lac La Croix granite, and apophosial intrusions that produce aeromagnetic anomalies highlighting broad fold structures. The earlier migmatite was derived from partial melting of a metasedimentary protolith. Southwick (1991) suggested that the younger Lac La Croix-type granite is a further distillation of granitic liquid from partial melting of the older migmatite and metasedimentary rocks. The apophosial intrusions of Lac La Croix granite generally decrease in thickness and continuity westward, suggesting that the western portion of the complex may represent the roof zone of a batholith cored by massive granite.

DEFORMATION AND METAMORPHIC HISTORY

Both terranes have undergone a complex deformation history. As described by Day (1990), three main phases of deformation are recognized. D_1 produced tight to isoclinal, northeast-trending folds plunging to the southwest and locally overturned to the southeast. This event may locally have produced recumbent folds over a broad region (Bauer, 1985; Poulsen and others, 1980). It occurred shortly after deposition and involved burial to produce metamorphic conditions of moderate pressure and temperature (Valli and others, 2004). D_2 deformation was synchronous with peak regional metamorphism to upper greenschist facies in the Wabigoon subprovince and amphibolite facies in the adjacent Quetico subprovince. This is considered low-pressure, moderate temperature conditions by Valli and others (2004); however there is a progressive increase in metamorphic conditions across the Quetico subprovince from 0.2 GPa and 500 C on the west near International Falls, to 0.5-0.6 GPa and 780C in the east. D_2 deformation produced small-scale F_2 folds, and an axial-planar cleavage and schistosity that strikes to the east-northeast. Folds and other asymmetric features indicate that D_2 deformation was a dextral transpressional event, which probably initiated movement along the major faults. D_3 deformation is recorded in the youngest movement along major fault zones. Vertical offset during D_3 or D_4 events, and subsequent differential erosion produced the contrasting metamorphic grades across the Rainy Lake-Seine River Fault. Combining structural, metamorphic, and published geochronologic data, Valli and others (2004) infer ages of tectono-metamorphic events in the Quetico subprovince as follows:

D_1 Moderate pressure and temperature metamorphic event shortly after deposition of turbidites in the range of 2698-2690 Ma

D₂₋₃ Biotite-sillimanite-garnet peak metamorphism (0.6 GPa 700C) during transpression which began ~2689 Ma

D₄ Low pressure, moderate temperature metamorphism in the range of 2671-2667 Ma

According to Fralick and others (2006), clastic deposition in the northern Quetico began about 2698 Ma during D₁ and continued to <2696 Ma, supporting the interpretation of a transition from accretionary wedge to foreland basin deposition. Subsequent deformation during D₁ was associated with accretion of these sediments onto the active Wabigoon arc. Deformation during D₂ and D₃ may represent docking of the Wawa arc from the south.

FIELD TRIP STOP DESCRIPTIONS

This field guide is based on mapping by Hemstad and others (2000, 2001, 2002) and Day (1990), and an earlier guide produced for the Institute on Lake Superior Geology (Ojakangas and others, 1982). Some of the stops described below were also visited during the 1982 meeting and are described in more detail in that guide book—for reference, prior stop numbers are shown in [brackets]. Because of road layout, the order of stops is not necessarily geochronologic. Stops 1-6 and 9 lie within the Wabigoon subprovince (Fig. 6.1); Stops 7, 8, 10, and 11 are within the Quetico subprovince to the south (Figs. 6.1 and 6.2). **All UTM coordinates are given in NAD 83, zone 15.**

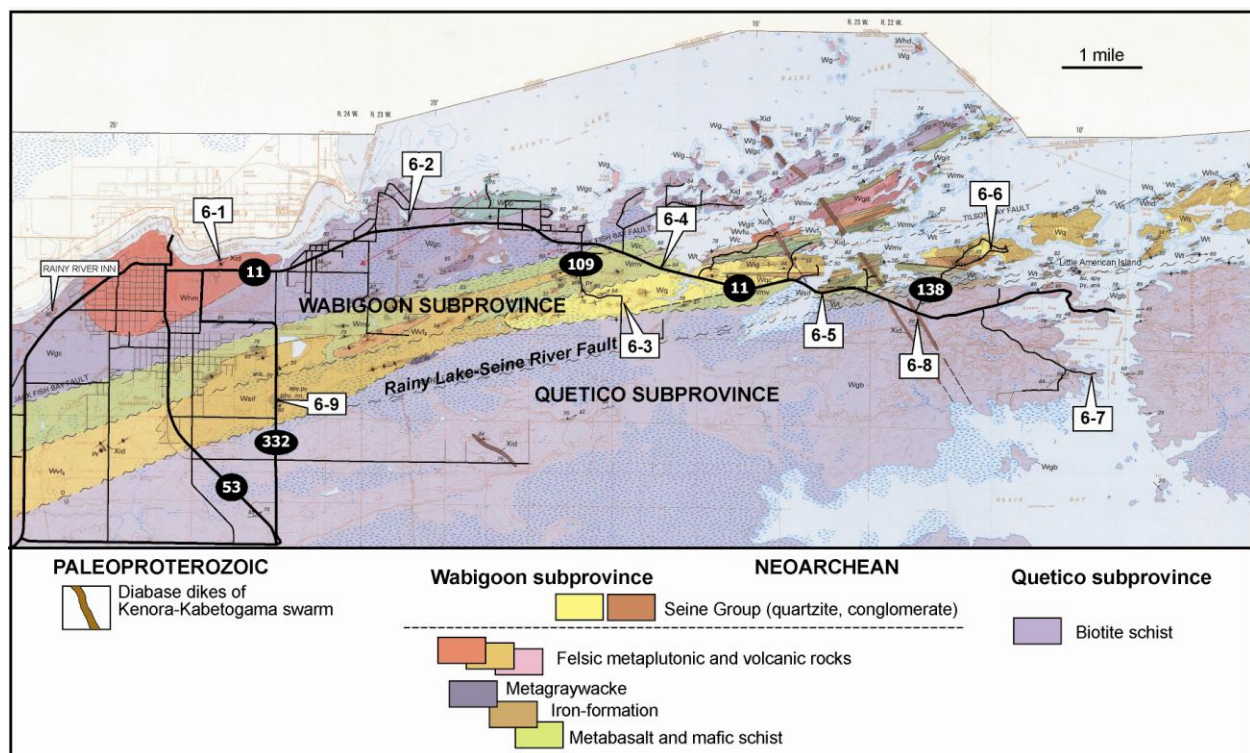


Figure 6.1—Geologic map of the Rainy Lake area, modified from Day, 1990, showing locations of field trip stops 6-1 through 6-9.

STOP 6-1

Archean monzonite cut by Paleoproterozoic diabase dikes

Location: 0.65 miles east of US Hwy 53 on MN Hwy 11; ~500 feet north of Hwy 11 (UTM 471,295E / 5,383,386N).

Description: Pink, coarse-grained, porphyritic hornblende-quartz monzonite. Rock displays a pronounced trachytoid foliation that trends N70E. Unit contains irregular autoliths of monzodioritic to dioritic composition, and rare xenoliths of schistose metasedimentary rocks, which form the country rock into which the intrusion was emplaced. The long axes of inclusions are typically parallel to foliation, implying that foliation is largely magmatic; however, tectonic and metamorphic overprint is also likely.

Note that some of the clasts in conglomerate of the Seine Group at STOP 6-6 have textures similar to this intrusion. Several fine-grained diabase dikes, having varied thicknesses and a northerly trend, cut the monzodiorite.

STOP 6-2

Archean metagraywacke and slate

Location: Just east of village of Rainier; 3 miles east of US Hwy 53 on MN Hwy 11; ~400 feet N of Hwy 11 (UTM 474,888E / 5,384,188N)

Description: This outcrop exposes fine-grained plagioclase-biotite schist of graywacke and mudstone protolith, metamorphosed to upper greenschist facies. Bedding is locally visible and parallels cleavage and schistosity at N68E, dipping 75N. Stratigraphic younging is northward, based on graded bedding and cross-cutting relationships of basal turbidite beds. This is consistent with the outcrop position on the north side of an east-trending, westward plunging anticline that is overturned slightly to the south. Recessed aligned depressions on the outcrop surface generally parallel the foliation and may represent boudinaged carbonate-rich horizons or zones of concretions. The rock is cut by a number of quartz veins emplaced along small-scale faults. NE-trending veins show sinistral offset, NW-trending ones are dextrally offset. Late silicification “veinlets” trending N25W create a ribbed relief on the outcrop surface. The temporal relationship between metagraywacke exposed here and similar but more highly metamorphosed schist in the Quetico subprovince to the south is unresolved.

STOP 6-3

Schistose feldspathic-lithic quartzite of the Seine Group [1982 stop #2]

Location: Approximately 2.5 miles east of Rainier on MN Hwy 11 to County Road 109; turn south on 109 and follow it south and east for about 1.2 miles. Ridge of outcrop trends east from here. (UTM 478,990E / 5,382,630N)

Description: This outcrop ridge extends more or less parallel to bedding and foliation. The rock is medium-grained, light gray to tan. Framework grains consist of quartz and feldspar and are angular to subrounded and slightly flattened in the regional foliation. Matrix consists of sericite, chlorite, and quartz. Beds range in thickness from 5 cm to 1 meter, planar lamination and trough cross stratification are common. This outcrop lies within an irregular belt of quartzite and conglomerate trending to the east-northeast into adjacent Canada. It appears to be fault-bounded on the north by the Tilson Bay Fault, and stratigraphic younging is consistently southward. Though not in evidence here, this unit and that of STOP 6-6, are inferred to unconformably overlie metasedimentary and metavolcanic strata of the Wabigoon subprovince.

STOP 6-4

Metavolcanic and meta-igneous rocks [1982 stop #3]

Location: Return on County Road 109 to MN Hwy 11, proceed east 1.0 mi. to outcrop on north side of highway (UTM 479,745E / 5,383,009N)

Description: At least two rock types are exposed here; a schistose green to gray chloritic tuff containing iron-carbonate, and a coarser grained meta-igneous rock composed of what may have been pyroxenes, now pseudomorphed by amphibole. Both rock types display S_2 schistosity. Though strongly deformed, this exposure is typical of the local greenstone.

STOP 6-5

Tectonite in the Rainy Lake-Seine River fault zone

Location: Continue east on Mn Hwy 11 for 2 mi., crossing Tilson Creek to outcrops and boat landing on north side of highway (UTM 482,770E / 5,382,850N)

Description: These outcrops lie within a broad zone of shearing associated with the Rainy Lake-Seine River fault that separates Wabigoon and Quetico subprovinces. The zone continues eastward to Little American Island, where Minnesota's only gold mine (to date) operated from 1893 to about 1898—see Hemstad and Jirsa, Field Trip 4, this volume for more details. The main part of the fault is represented topographically by the northeast-trending swamp visible just to the south. Outcrops consist of amphibolitic and chloritic schist, inferred to be of basaltic protolith, and minor chert-magnetite iron-formation. Both carry a strong, vertically dipping, N50E-trending cleavage and abundant detached quartz veins in the subparallel shear fabric. The rocks contain minor amounts of pyrite. Some exploration drilling was done near here in the late 1980s (Newmont), to investigate the possibility of more significant mineralization, presumably at junctions of the regional schistosity (S_2) and local shear structures.

STOP 6-6

Conglomerate and quartzite of the Seine Group

Location: Continue east on MN Hwy 11 for 1.2 mi. to Gold Shores Road (County Rd 138), turn NE on 138 and follow it around (one-way) for about 1 mile to roadcuts (UTM 485,876E / 5,383,470N)

Description: This large area of outcrop includes polymictic, clast-supported conglomerate, underlain to the north and locally interbedded with feldspathic lithic quartzite similar to that at STOP 6-3. The conglomerate contains rounded pebbles, cobbles, and boulders of felsic plutonic rocks, mafic to felsic volcanic rocks, chert, biotite schist, and iron-formation. Plutonic clasts are subspherical to elliptical, whereas volcanic clasts tend to be moderately elongated in the regional lineation. The texture of some plutonic clasts is similar to monzonite exposed at STOP 6-1. The schistose matrix is composed of fine- to medium-grained biotite- or chlorite-rich lithic arenite that contains angular to subrounded granules of volcanic rock fragments, intrusive rock fragments, plagioclase, quartz, and chert. Bedding is crude to massive. Subtle, fining-upward to coarsening-upward sequences are common in the conglomerate. Note that some volcanic clasts display pronounced concentric zonation, manifest by color and surface relief. It is unclear whether this represents original mineralogic zonation or metamorphically modified weathering. Similar observations have been made of clasts in other "Timiskaming-type" or successor-basin conglomerates near Virginia, Minnesota (Jirsa, 2000) and in the Ogishkemuncie conglomerate in the Boundary Waters Canoe Area (Jirsa and Starns, 2008).

STOP 6-7

Voyageurs National Park Visitor Center

Location: Return to MN Hwy 11 and continue east for 0.8 mi. to south-trending road to Black Bay visitor center and boat landing (UTM 488,050E / 5,381,191N)

Description: Visitor center displays and restrooms should be open. Several roadcuts along this trail and lakeshore outcrops near the visitor center expose biotite schist of the northern-most Quetico subprovince. This will be the subject of STOP 6-8.

STOP 6-8

Quarry and gravel pit in Quetico metasedimentary rocks

Location: Return to MN Hwy 11 and turn west, follow Hwy 11 ~0.8 miles to Gold Shores Road and walk south to large quarry and pit (UTM 484,630E / 5,382,325N)

Description: Outcrops of fine- to medium-grained, light- to dark-gray schist derived from rhythmically bedded, texturally graded graywacke and shale. The rock is composed dominantly of plagioclase, quartz, biotite, and muscovite; and minor garnet, sillimanite, and hornblende in beds of appropriate bulk composition. Individual beds are typically 5–20 centimeters thick; some sandy beds are as thick as two meters. Outcrop displays folded discontinuous layers of boudinaged concretions, sandy beds, or quartz veins. En echelon gash quartz veins occur locally.

STOP 6-9

Wabigoon subprovince metabasalt and iron-formation [1982 stop #10]

Location: Continue west on MN Hwy 11 for about 9 mi. to MN Hwy 332 near the east edge of International Falls. Drive south and east on Hwy 332 for 2.5 mi. to large road cuts (UTM 472,350E / 5,380,800N)

Description: Schistose rocks of basaltic and iron-formation protolith are exposed on both sides of the highway. Rock is strongly foliated amphibolitic schist, with lenses and layers of tightly folded magnetite-, chert-, garnet- and sulfide-bearing iron-formation. The strong foliation nearly obliterates bedding and other features. Fabric asymmetry indicates much of the fabric is a product of dextral transpression attributed in part to proximity to the Rainy Lake-Seine River Fault just to the south (as at STOP 6-5).

STOP 6-10

Quetico subprovince—granite-rich migmatite of the Vermilion Granitic Complex [1982 stop #15]

Location: Continue south on Hwy 332 for about 1.7 mi. to US Hwy 53. Follow US Hwy 53 south and east for 19.5 miles to large road cut (UTM 493,730E / 5,361,730N) Note: this is 5.4 miles east of Ray at jct. Hwys 53 and 217, and 1.6 miles west of hwy 122 entrance to Kabetogama landing.

Description: This complex and photogenic outcrop is typical of granite-rich migmatite in the Vermilion Granitic Complex (Fig. 6.2). Overall, the unit mapped by Southwick and Ojakangas (1979) as granite-rich migmatite contains between 5% and 25% paleosome inclusions. In this area where granite is dominant, paleosome blocks and slabs up to several meters in size are rafted in neosome. Some paleosome blocks have sharp boundaries characteristic of agmatic migmatite, some have distinct flow fabric of schlieren migmatite, and some have diffuse boundaries representing partial assimilation typical of nebulitic migmatite (vernacular of Mehnert, 1968). The neosome is coarse-grained, light gray to pink, muscovite-biotite granite of the Lac La Croix-type with weak foliation. The paleosome includes biotite schist, amphibolite, tonalite, and early migmatite displaying variable degrees of deformation. The early migmatite

has paleosomes of amphibolite and biotite schist, and neosome of tonalite or granodiorite. Much of the amphibolite has a relict porphyritic texture pseudomorphed by biotite, resembling lamprophyric intrusions exposed in adjacent greenstone terranes.

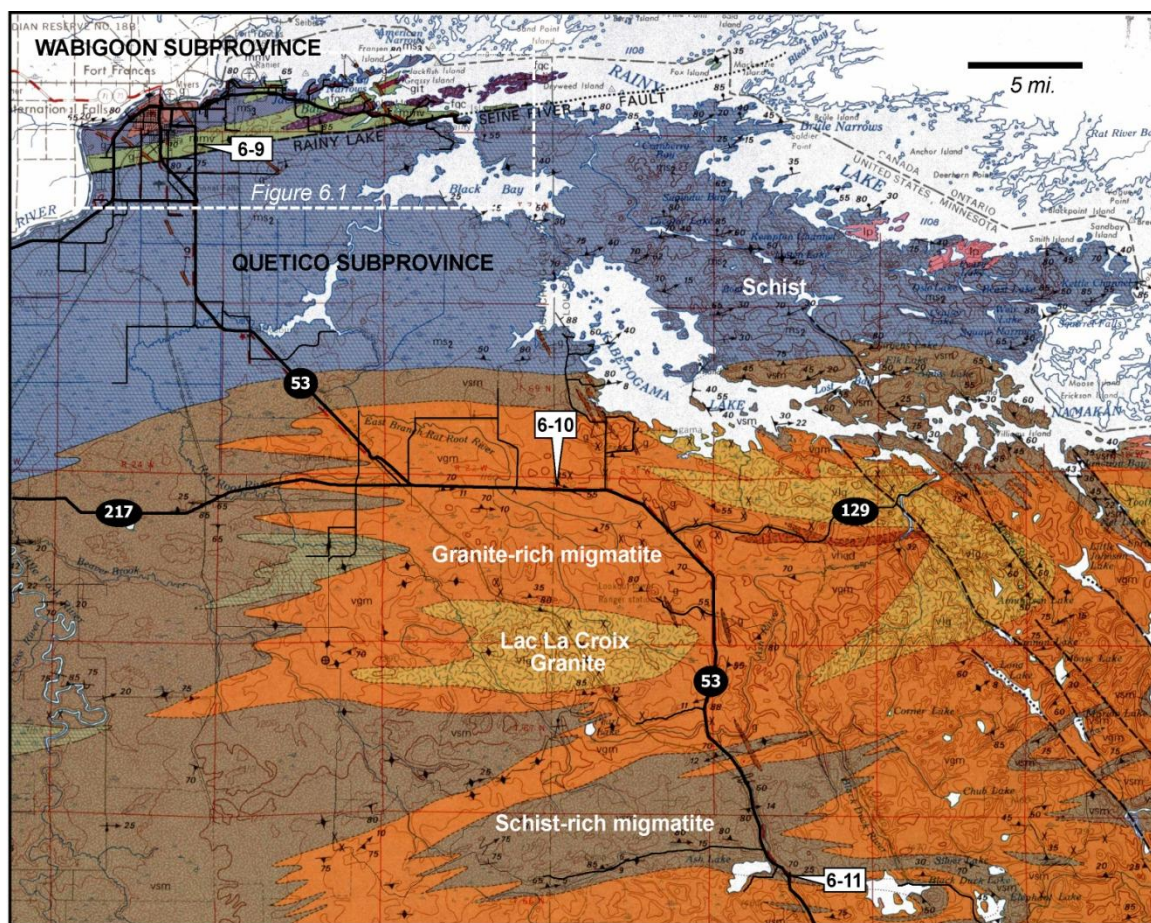


Figure 6.2—Geologic map of the International Falls area, modified from Southwick and Ojakangas, 1979 (original map scale 1:250,000), showing locations of field trip stops 6-9 to 6-11.

STOP 6-11

Quetico subprovince—schist-rich leucogranite migmatite of the Vermilion Granitic Complex

Location: Continue south on US Hwy 53 for about 18.4 miles to road cuts; just southeast of Ash Lake (UTM 507101E / 5,339,900N)

Description: These road cuts expose shallowly dipping schist-rich migmatite of the Vermilion Granitic Complex. According to the mapping convention of Southwick and Ojakangas (1979), the map unit is defined by a leucogranitic neosome content of 10% and 15%. The paleosome consists largely of biotite schist that displays strong metamorphic foliation (S_2 ?) that was deformed by D_3 in broad open folds. No petrography has been conducted from samples of this exposure, so details of neosome composition and metamorphic mineral content are unknown. Nevertheless, it is apparent the schist is cut by a variety of leucogranitic intrusions that are strongly boudinaged and crumpled in planes of S_2 foliation and refolded.

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Field Trip 7

MINERAL DEPOSITS OF THE MINE CENTRE – RAINY RIVER AREA, ONTARIO

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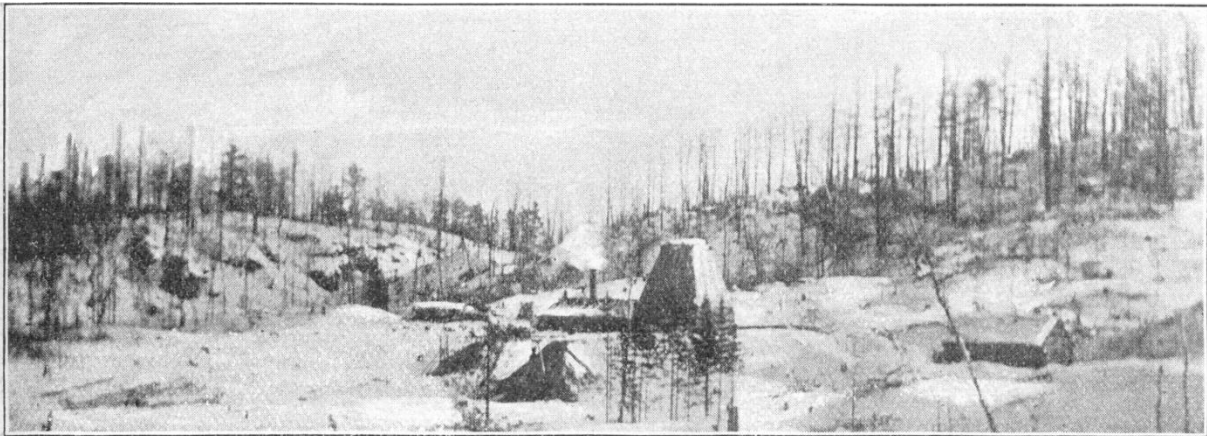
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Shaft and Engine House of the Golden Star Mine, looking toward the hill, p. 73.

Photo of the Golden Star Mine, Mine Centre area, circa. 1898 from the
Report of the Bureau of Mines, Volume VII, First Part, 1898.

FOREWORD

This trip will examine sites containing a variety of mineral deposits in the Mine Centre Area. Historically gold was the primary focus of mineral exploration, development and extraction. However in recent years sub-economic deposits of iron, titanium, copper, nickel and zinc have been identified and are being evaluated by junior exploration companies. The trip will visit four mineral deposit types in the Mine Centre area: lode gold; magmatic copper-nickel, PGEs; magmatic iron-titanium; and pyroclastic-hosted diamonds.

REGIONAL SETTING

Introduction and Tectonic Setting (taken from Czeck and Fralick, ILSG 2002)

The central portion of the Superior province is characterized by alternating subprovinces of metavolcanic-plutonic and metasedimentary natures (Fig. 1).

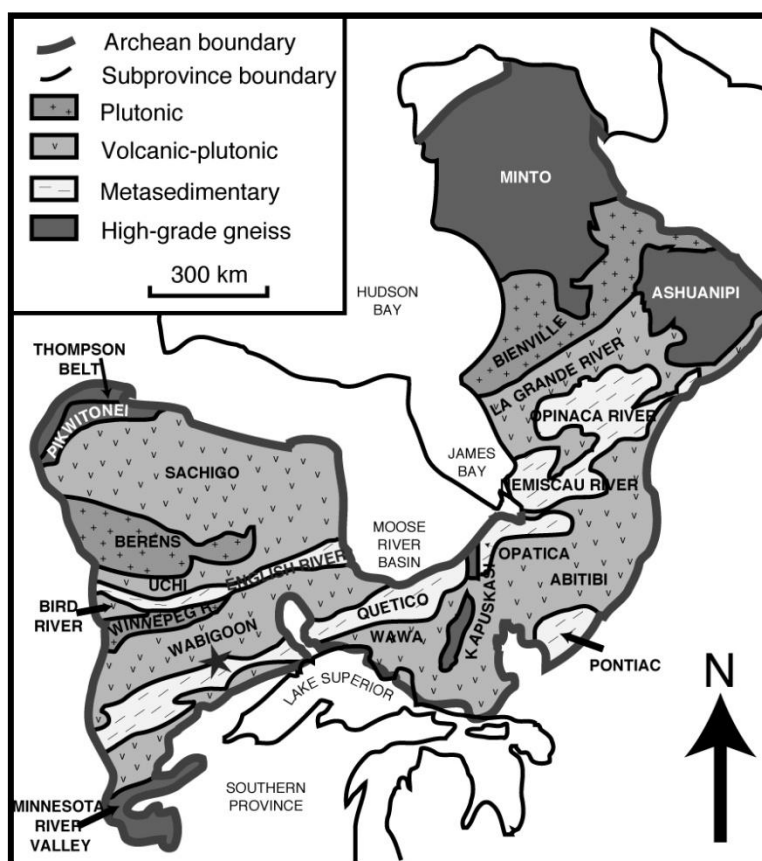


Figure 1. The Superior Province. From Card and Ciesielski (1986).

One popular tectonic interpretation for the central portion of the Superior Province is of repeated island arc, microcontinent collisions. The collisions are evidenced by rocks that can be interpreted as arc sequence subprovinces (metavolcanics) and their corresponding accretionary prism subprovinces (metasediments) (Langford and Morin, 1976; Hoffman, 1989; Percival and

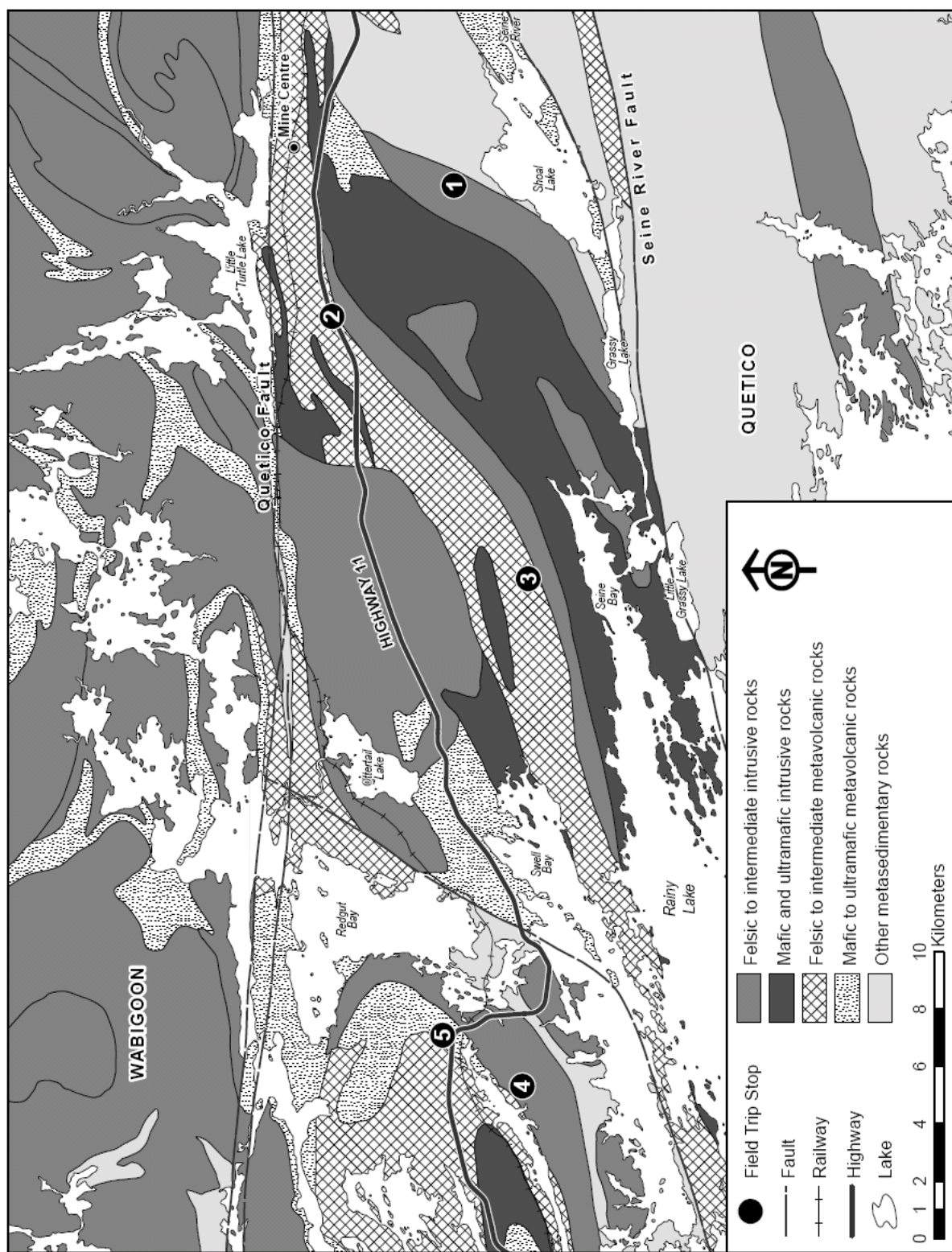


Figure 2. Simplified geological map of the Mine Centre – Rainy Lake area with field trip stops.

Williams, 1989; Card, 1990; Hoffman, 1990). In general, the ages in the greenstone belts are similar along strike, but differ systematically across strike (Hoffman, 1989). This is consistent with the island-arc accretion model. A history of southward accretion has been proposed to explain the juxtaposition of Superior Province terranes (Langford and Morin, 1976; Percival and Williams, 1989; Card, 1990).

The Seine Conglomerate, located in the Rainy Lake region of the western Superior Province, was deposited along the boundary between the Wabigoon metavolcanic/plutonic subprovince and the Quetico metasedimentary subprovince (Fig. 2). The structural observations along the Wabigoon–Quetico boundary are consistent with an oblique island-arc microplate collision circa 2.7 Ga. In this part of the Superior Province, it seems likely that first the Quetico acted as a subduction prism during accretion of the Wawa to Wabigoon. Then, it was effectively shifted from the subduction prism setting to a back-arc setting, as subduction shifted (Percival and Williams, 1989).

In the Rainy Lake region, a series of lithostratigraphic terranes were assembled together along structurally controlled, stratigraphically discordant boundaries during the collisions. The boundary between the Wabigoon and Quetico Subprovinces in this region is divided into three primary blocks by dextral wrench faults (Poulsen, 1986). Each of the small terranes and sub-terrane may have undergone a somewhat unique history of formation and deformation.

The Quetico Fault forms the northern boundary, separating the granite-greenstone terrain of Wabigoon Subprovince from the Couthiching Group argillites and the Seine Conglomerate. The Seine River–Rainy Lake Fault forms the southern boundary of these sedimentary sequences with the Quetico turbiditic metasediments [*sic*] to the south. The wedge-shaped area lying between the two major fault systems is itself dissected by splays off the major east-west [*sic*] faults, which isolate the lithic units, destroying stratigraphic integrity. This problem has resulted in historical speculation on the lateral equivalency of the Seine and Couthiching sediments (Merritt, 1934) and the Couthiching and Quetico (Lawson, 1913).

STRUCTURAL GEOLOGY (taken from Poulsen, Geological Report 266)

The 2 most prominent structural features in the study area are the Quetico and the Rainy Lake–Seine River faults. Both truncate distinctive lithologic units which merge at a low angle with the faults in a manner that suggests a dextral sense of displacement (Map 2525) [*sic*]. The Quetico Fault, up to 1 km wide, strikes east and contains heterogeneous rock types possessing an intense steep foliation that parallels the fault. Mylonite is common and pseudotachylite occurs locally. The mylonite itself is commonly folded into minor folds of dextral asymmetry. Felsic plutonic rocks are the most probable protoliths of mylonites, and protomylonites containing centimetre-sized feldspar porphyroclasts are similar to porphyritic quartz monzonites that are common phases of the Algoman intrusions. This observation, plus the marked truncation of the Ottertail Lake pluton, indicate clearly that the fault postdates the emplacement of the late-stage Algoman granitoid suite.

The rocks of the Rainy Lake–Seine River fault zone contrast lithologically with those of the Quetico Fault. The sharp contact with the Quetico metasedimentary rocks is marked by a zone as little as 50 m wide, composed of chlorite schist and phyllonite. Some of these schists have been

mapped historically as mafic volcanic rocks, but detailed examination reveals that they are commonly heterolithic with enclaves of conglomerate, iron formation and carbonate-rich schist. The nature of this zone is well-illustrated by the changes that occur in metagabbro along the fault near the Scott Islands. Outcrops of gabbro to the north of the fault contain local chloritic shear zones that parallel the trace of the main fault. The width and abundance of these zones increase southward to the main schistose zone, which marks the fault. Small folds superimposed on the steep schistosity and sigmoidal quartz veins in the vicinity of the fault near Neil Point, Minnesota, 3 km southwest of Red Pine Island, indicate a right-hand sense of displacement.

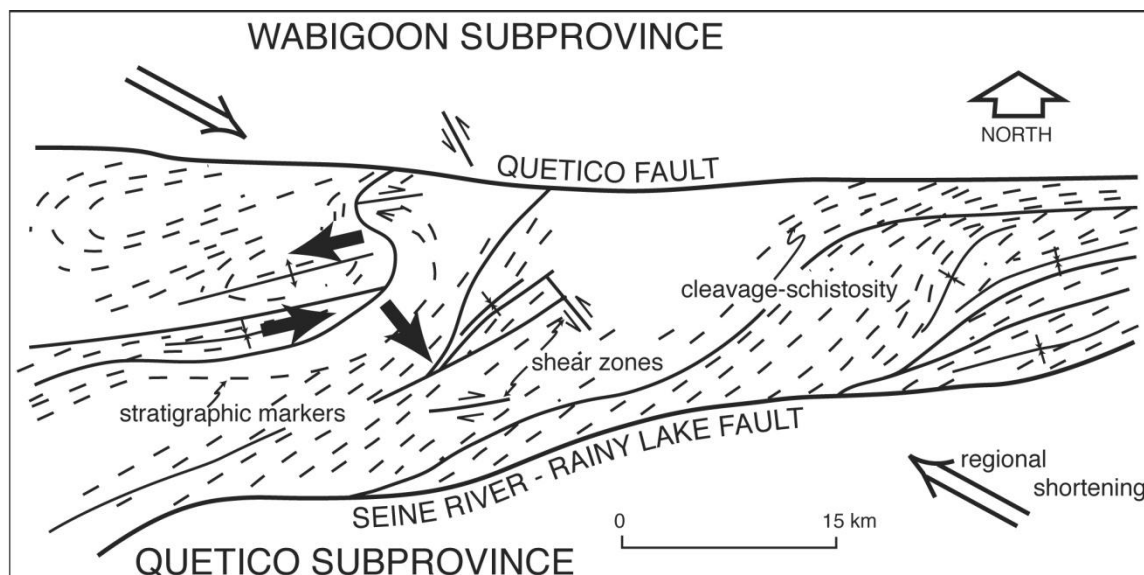


Figure 3. Schematic diagram illustrating structural features of Rainy Lake Wrench Zone. Short solid arrows identify downward facing units. From Poulsen (1986).

Structure

The rocks of the Mine Centre–Fort Frances area contain evidence of progressive deformation involving folds, ductile shear zones and faults. While some of the above features likely formed contemporaneously, there is evidence of a continued transition from ductile to brittle deformation. The attitudes of most structures appear to be dominated by incremental shortening about a subhorizontal axis oriented west-northwest. This imparts a dominant northeasterly trending structural “grain” to the rocks of the area.

Folds, Cleavage And Lineation

Variations in the distribution, attitudes and facing of mappable lithologic units attest to the existence of large folds within the study area. One of these, the Rice Bay Dome, is not a simple structure but can be related to the development of 3 distinctive fold sets (Poulsen, Borradaile and Kehlenbeck 1980). New lithologic mapping of the magnetic ultramafic unit exposed in this area has resulted in further definition of these folds. Early folds (F1) were recumbent and involved substantial inversion of the stratigraphic succession. An early foliation (S1), recognized locally

by extreme flattening of pillow lavas, is probably related to D1. Refolding about axes (F2) that are confined to an east-northeast-striking axial surface (S2) produced a complex interference structure (Figure 8). This superposition results in F2 folds that face structurally downward onto the dome. D2 structures are common and small F2 folds are locally coaxial with pronounced lineations (L2) which result from crystallographic and dimensional orientation of metamorphic minerals. Cleavage (S2) that is axial planar to F2 folds is generally well developed. A third fold set (F3) is accompanied by the development of kink bands and a crenulation cleavage (S3) that strikes northwest. D3 minor structures are particularly abundant in the Bear Passage area.

Away from the Rice Bay Dome, similar sets of minor structures can be recognized. Rarely, 3 discrete cleavages have been observed in a single outcrop. While direct temporal correlation of such cleavages with similar structures in the Rice Bay Dome is unwarranted, the persistence of east-northeast-and northwesterly striking sets throughout the area suggests a genetic relationship to a west-northwest- oriented axis of shortening. These cleavages are commonly axial planar to small folds but their direct relationship to big folds is more ambiguous. In some cases, they appear to transect large structures defined by younging reversals, implying the possible existence of early fold sets such as those mapped at Rice Bay. Minor fold axes and lineations have variable attitudes, but shallow plunges on east-northeast and west-southwest trends are common. Near-vertical stretching lineations are well-developed west of the Rice Bay Dome.

Shear Zones And Faults

The attitude of minor fold axes and cleavage are clearly controlled by proximity to the Quetico and Rainy Lake–Seine River faults. The sigmoidal pattern of cleavage orientation suggests that these faults involve a zone of ductile deformation in which rotation of early-formed structures has taken place. Deflection of marker units indicates right-hand components of displacement for both faults so that the intervening terrane can be considered to be a dextral wrench zone (Figure 3). The orientations and senses of mesoscopic ductile shear zones across the area support this interpretation. Three common orientations exist: 2 sets of right-hand shear zones parallel to each of the major faults can be distinguished from a northwesterly striking, left-hand conjugate set (see Figure 3). The interpreted direction of regional shortening (see Figure 3) is consistent with that indicated by the folds.

Mineral Deposit Types

Poulsen (2000a) proposed the mineral deposit classification shown in Table 1, deposit Type 5, Diamond-bearing ultramafic pyroclastic rocks has been added by the author. The presence of diamonds in the ultramafic pyroclastic rocks had not been identified at the time of Poulsen's field work.

Table 1. Mineral deposits classification, Mine Centre–Fort Frances area

Type 1	Stratabound Mineralization Hosted by Felsic to Mafic Metavolcanic Rocks A. Sphalerite-galena-chalcopryrite associated with siliceous volcanic rocks B. Sphalerite-chalcopryrite associated with intermediate to mafic amygdaloidal volcanic flows, tuffs and breccias C. Sphalerite-chalcopryrite associated with iron formation D. Lean iron formation (mainly chert-magnetite and massive pyrite-pyrrhotite, minor chalcopryrite common)
Type 2	Mineralization Hosted by Layered Gabbroic Intrusions A. Chalcopryrite associated with gabbro and leucogabbro near the base of sills (Northrock) B. Disseminated chalcopryrite associated with siliceous phases of intrusions C. Ilmenite-magnetite-apatite-rutile lenses in the upper portions of the intrusions (Barber Lake property) (Stop 3)
Type 3	Vein Mineralization A. Quartz-gold-sulphide veins in shear zones and cleavage-parallel dilatant zones (Foley Mine, McKenzie-Gray; Stop 1) B. Quartz-molybdenite-pyrite veins and disseminations in unmetamorphosed granitoid rocks
Type 4	Disseminated chalcopryrite-pyrrhotite mineralization hosted by ultramafic metavolcanic rocks (Northrock) (Stop 4)
Type 5	Diamond-bearing ultramafic pyroclastics (Grassy Portage Ultramafic Pyroclastic) (Stop 5)

FIELD TRIP STOPS

(Stops are located by UTM co-ordinates based on NAD 83, UTM Zone 15)

Depart from the Fort Frances Memorial Sports Centre and drive east on Highway 11 for approximately 65 km to the hamlet of Mine Centre. Continue an additional 1.3 km and turn right (south) onto the Shoal Lake Road.

Drive south along Shoal Lake Road for approximately 8.5 km to the entrance of the Foley Mine property, turn right onto the access road. (0526320E 5395406N)

STOP 1– Vein Mineralization - Lode Gold

Q-Gold Resources Limited (Foley Mine and McKenzie-Gray Prospect)

Delio Tortosa

This portion of the trip will be led by Delio Tortosa, Consulting Geologist, Q-Gold Resources Ltd.

Q-Gold Resources Ltd. has mineral rights over a large portion of the historical Mine Centre Mining Camp (Figure 4). Past-producing gold mines and numerous mineral prospects occur in quartz and quartz-carbonate fissure veins oriented north-northwest and dipping steeply. The predominant host rock is the Bad Vermilion Felsic Intrusion that ranges in composition from trondhjemite to tonalite and granodiorite. The intrusion has a sigmoidal shape that is characteristic of the rock units and major faults that occupy the area between the Quetico Fault to the north and the Rainy River – Seine River Fault to the south. Typically, the mineralized veins are laminated and occur within shear zones with a left-hand sense of movement. The quartz contains pyrite, chalcopyrite, arsenopyrite, galena and sphalerite. Free gold is commonly associated with the sulphide-rich zones and displays a strong ‘nugget’ effect along the vein systems.

STOP 1a: Foley Mine Area

The Foley Mine is the best-developed mine in the area with 2.5 kilom of drifting on seven levels to a depth of 260 m. Initial development and mining took place in the 1890’s, and the mine was further developed to greater depth in the 1920’s, with extensive drifting but little gold production. A total of 5,267 ounces of gold was produced between 1893 and 1934. There are two main veins related to the Foley Mine on surface: the Bonanza Vein, which is currently overburden-covered and where the Foley Shaft is situated, and the nearby Jumbo Vein (Figure 5).

The Jumbo Vein is well-exposed west and south of the Foley Mine over a distance of 200 m with a north-northwest strike and steep dip. The wall rocks consist of sheared trondhjemite with the shear fabric displaying a left-hand sense of movement. The Bonanza Vein appears to be a splay off the Jumbo Vein. All the vein systems in the area appear to be interconnected either along strike and/or at depth.

Chip sampling by Q-Gold Resources along the Jumbo Vein resulted in a weighted average of 5 g/t Au, 15 g/t Ag, and 0.33% Zn. Two 25-ton bulk samples taken by Nipigon Gold Resources in 1992 returned 0.5 oz/t Au and 0.05 oz/t Au – reflecting the ‘nugget effect’ for gold in these vein systems.

STOP 1b: McKenzie Gray Prospect

A substantial amount of mineral exploration and bulk sampling was carried out on the McKenzie Gray Prospect between 1984 and 1995. In 1992, Nipigon Gold Resources Ltd. completed 15 diamond drill holes and estimated a mineral resource of 63,000 tons grading 0.17 oz/ton Au, 1.13 oz/ton Ag, 0.25% Cu, and 3.05% Zn (not compliant with NI 43-101). In 1984 the Mine Centre Joint Venture Group processed a 28-ton bulk sample through a local mill resulting in an average grade of 7.2 g/t Au, 112.1 g/t Ag, 10.18% Zn, and 0.11% Pb. A 1995 report by Nipigon Gold Resources, reported that a 204-ton bulk sample from the open pit processed through their on-site test mill returned an average grade of 0.17 oz/ton Au. In 2009 Q-Gold Resources Ltd. completed a diamond-drilling program consisting of 12 NQ holes spaced on sections 15 m apart to evaluate the northwestern extension of the McKenzie Gray vein system. The drill results indicated that the vein ranges in width from less than 1 m up to 7 m wide with weighted assay values of 17 g/t Au, 21 g/t Ag, and 2% Zn. The weighted average grade of all mineralized intersections was 4.7 g/t Au, 30.8 g/t Ag, and 2.9% Zn.

The McKenzie Gray Prospect can be subdivided into two major vein systems: the McKenzie Gray Vein and the East Vein (Figure 6). The McKenzie Gray Vein is thought to be a crack-seal textured vein that crosscuts the East Vein, an extension-type vein (Glidden, 1990). The McKenzie Gray Vein contains much of the Au-Ag-Zn-Cu-Pb mineralization, while the East Vein is noted for its high silver content (possibly argentite).

The McKenzie Gray Vein has a strike of 310° to 315°, dipping 75° southwest to vertically. The vein has an anastomosing character, splitting into two veins and then joining into a wider single vein along strike and down dip. The vein consists of reddish quartz that is bounded by and contains strongly foliated/sheared and altered sections of trondhjemite with the foliation generally parallel to the vein direction.

The McKenzie Gray vein is mineralized with varying concentrations of sulphides that carry significant amount of gold and silver. The most prevalent minerals are: sphalerite, pyrite, chalcopyrite, galena, and a gray metallic mineral (possibly argentite). Gold occurs as 10-micron grains within the sphalerite and as 10-40 micron grains within the quartz (Larouche, 1995).

The East Vein is situated immediately east and on the footwall side of the McKenzie Gray vein. It averages between 3 and 5 m wide and has an irregular shape trending sub-parallel to the McKenzie Gray vein and dipping 60° to 80° southwest. The vein is composed of white to gray quartz and is weakly mineralized, primarily with pyrite and minor amounts of chalcopyrite, and a gray metallic mineral (possibly argentite). The quartz vein contains numerous inclusions of altered trondhjemite.

One of the wider sections of the East Vein intersected by the Q-Gold drilling program consisted of a 6.7 m-wide zone containing 54 g/t Ag, 0.2 g/t Au, and 0.33% Zn. The weighted average grade of all intersections of the East Vein was 35 g/t Ag.

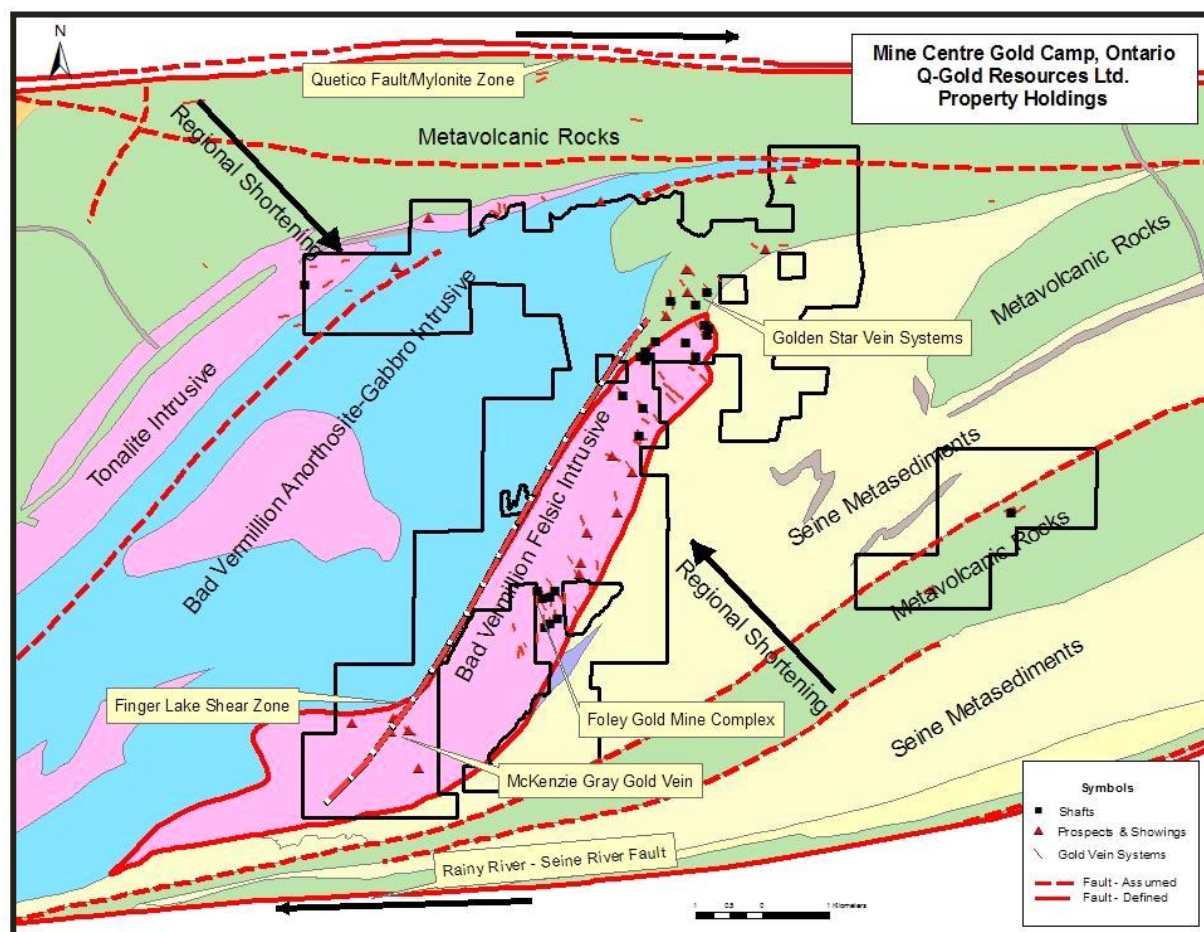


Figure 4: Regional Geology, Gold Mines and Prospects (Internal Company Report, Q-Gold Resources Ltd.)

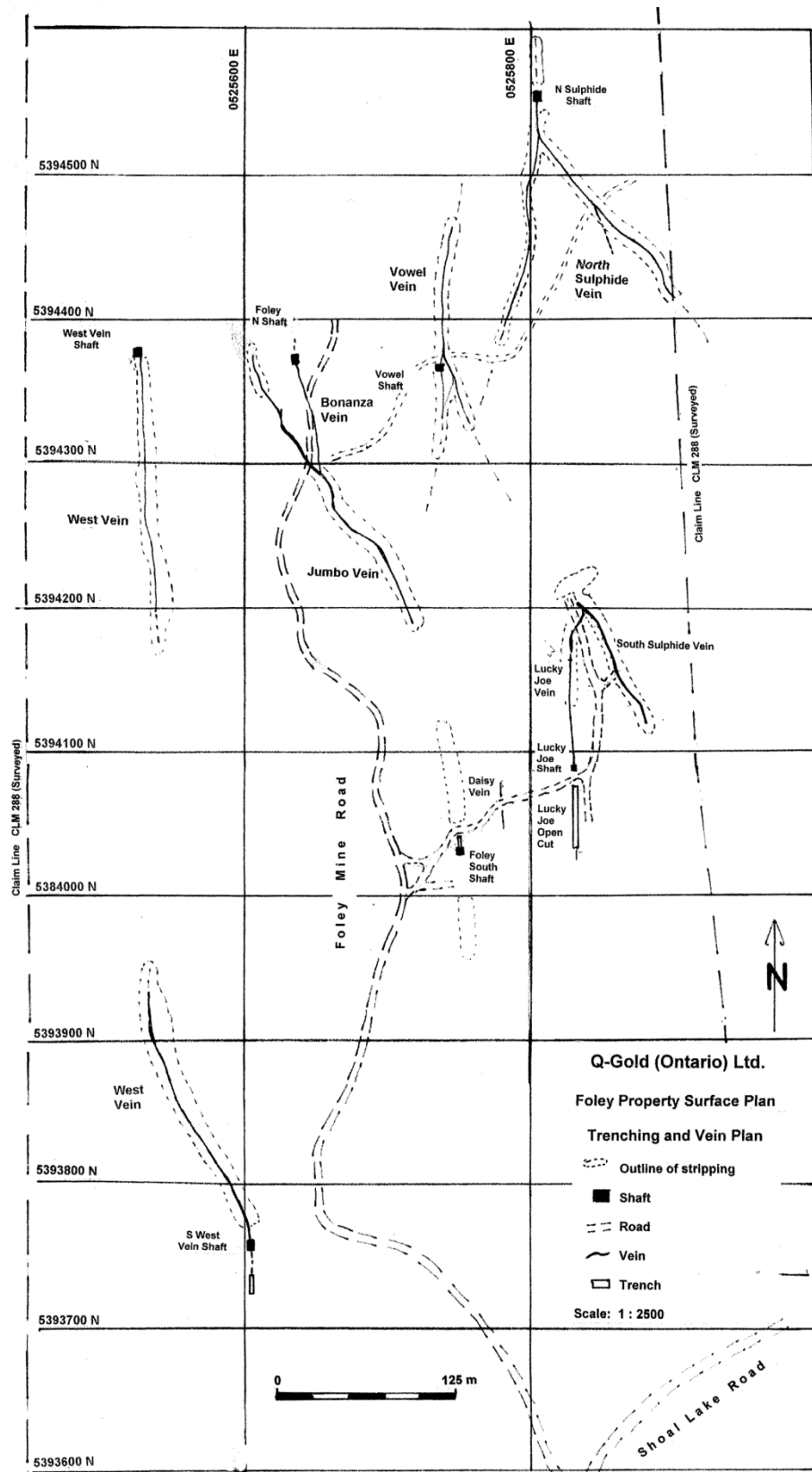


Figure 5: Foley Mine area shafts and veins (Internal Company Report, Q-Gold Resources Ltd.)



Q-GOLD RESOURCES LTD.
McKenzie Gray Detailed Geology
Nipigon Area Joint Venture Property
Mine Centre, Ontario

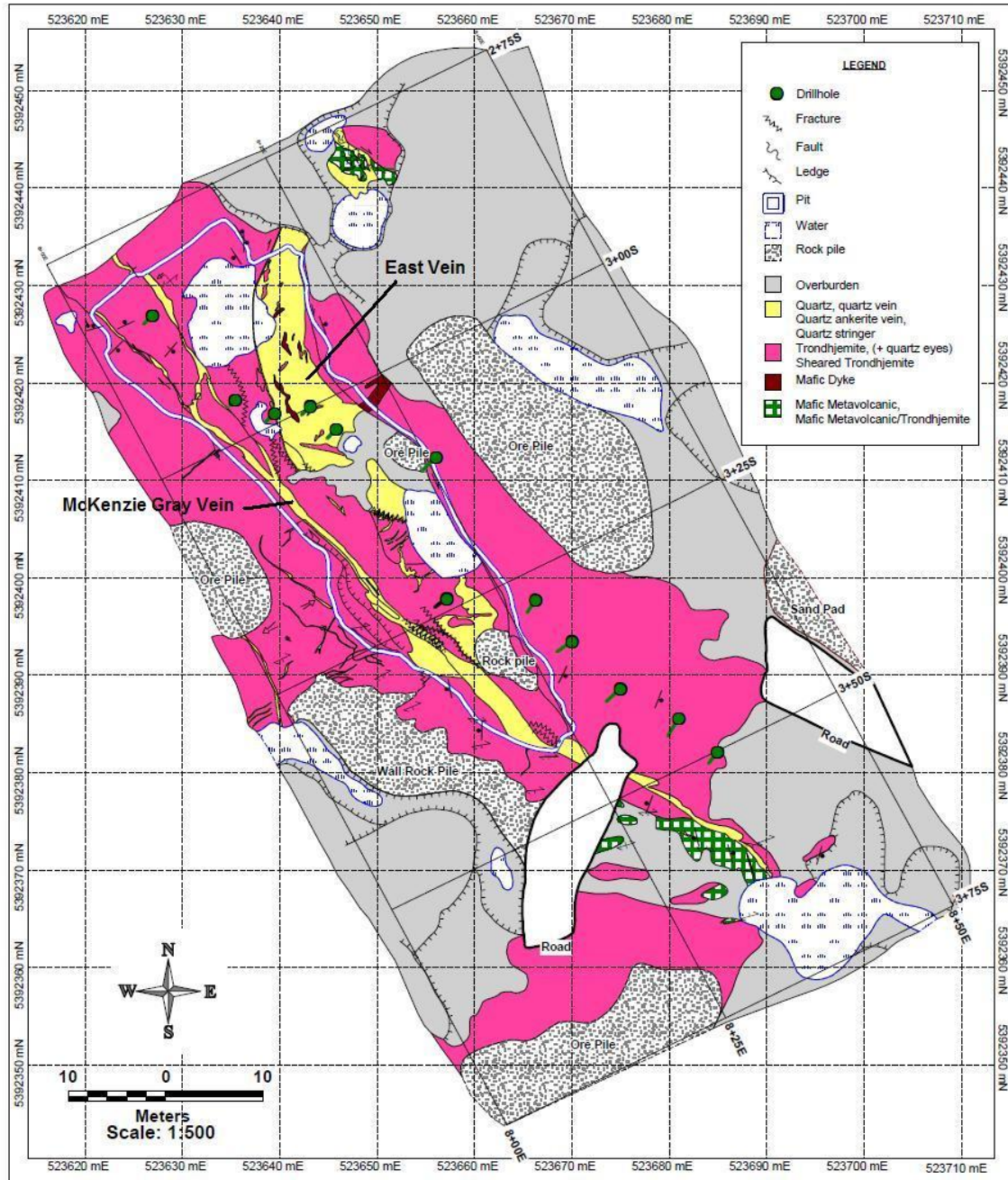


Figure 6: McKenzie Gray Prospect, Detailed Geology (Internal Company Report, Q-Gold Resources Ltd.)

STOP 2 – Historical Stop – Arastra (Optional)

Peter Hinz

Return to Highway 11 turn left and drive approximately 7.1 km west, pull off to the north side of the road. (0522191E 5400245N) If conditions are favourable walk around the perimeter of the wetland to the low concrete structure at the edge of the open water.

The Mine Centre arastra (a.k.a. arrastra) is a historical oddity in northwestern Ontario. An arastra, also known as a drag-stone mill or ‘chili mill’ is a pre-industrial form of a crusher used in South and Central America for crushing vein material. Local residents have told the author that this is one of three known in the local Mine Centre area, it is believed these are the only known arastras in existence in Ontario. A small pile of quartz-carbonate vein material adjacent to the arastra could have come from either the Olive Mine located 2.5 km to the northwest or the Stellar Mine located 1.7 km, both of which host gold in quartz-carbonate veins.



Figure 7. An arastra from the U.S. midwest, circa. 1890's. Image from <http://www.calisphere.universityofcalifornia.edu/>



Figure 8. The author beside the Mine Centre arastra.

STOP 3 – Magmatic Iron-Titanium Mineralization – Numax Resources Property

Paul Albers & Chris White

Continue west on Highway 11 for approximately 3.5 km to the Barber Lake Road,, turn south and drive 15.4 km (0509484E 5390837N). There is a gate located at approximately 10.6 km.

This portion of the trip will be led by Chris White and Paul Albers, Numax Resources Ltd.

Introduction

Numax Resources, Inc. (Numax) holds a 100% interest in the Mine Centre Fe-Ti-V Property. The property comprises 45 contiguous mineral claims totaling 5,188 ha in the Kenora Mining Division and is situated along Seine Bay of Rainy Lake and Bad Vermilion Lake (Fig. 1).

The Mine Centre Property has been the focus of Numax's exploration efforts dating back to the summer of 2004. The property was previously explored by Hunter in 1911, Goodwin from 1917-1918, Butler Brothers in 1943, and Stratmat Limited from 1956-1958. While relatively inactive at the Mine Centre Property for numerous decades, Numax commenced field work in 2004 that included grid line cutting, two ground geophysical surveys (magnetic and electromagnetic), extensive trench excavation, channel sampling of trenches, field sampling, diamond drilling, and prospecting. During the fall of 2009, geologic mapping (Scale 1:5000) was conducted across a majority of the property. Along with this, ten trenches were mapped in detail (Scale 1:400).

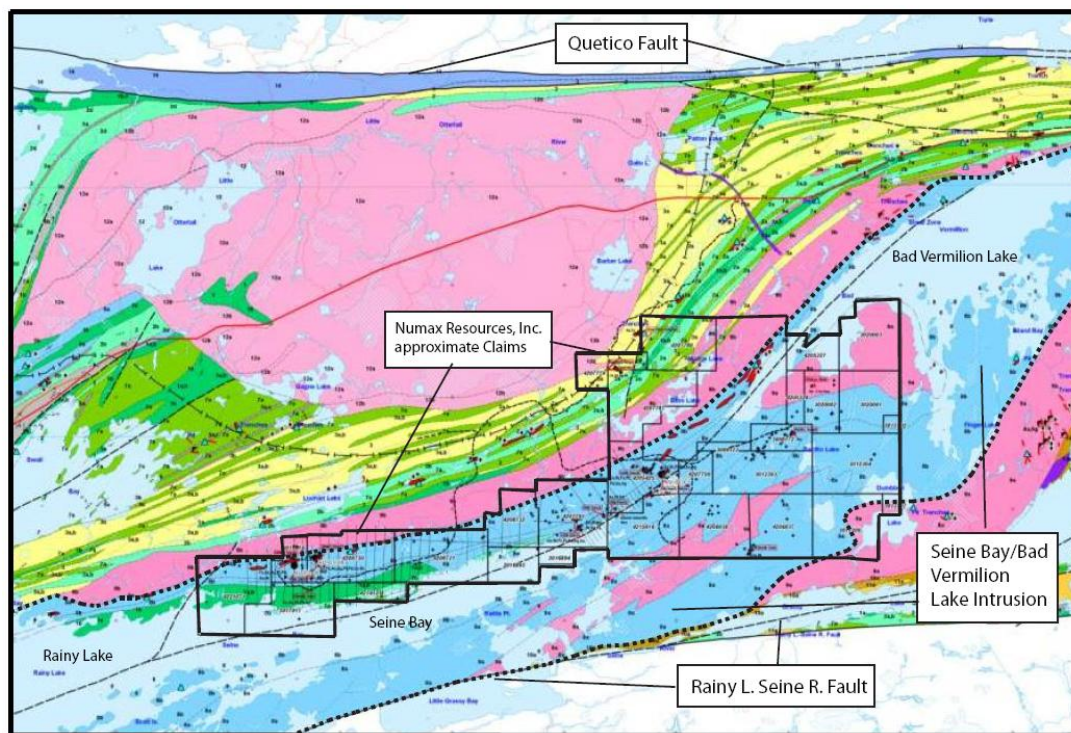


Figure 9: Location of the Numax Resources, Inc., Mine Centre Property, modified from Poulsen, 2000.

Local Geologic Setting

The igneous stratigraphy of the Seine Bay/Bad Vermilion Lake intrusion features interlayered anorthosite, gabbro, melagabbro, pyroxenite, semi-massive oxide, and massive oxide. The intrusion has been rotated such that layers are now oriented sub-vertically in the west, and dipping at 30-60° in the east. Layers generally strike easterly in the west, and northeasterly in the east, with a bend in the intrusion near the Snake Lake area. Graded modal layering of silicate minerals indicates that layers top to the north and northwest, respectively.

Zones of massive and semi-massive oxide demonstrate the geologic expression of, and correlate with magnetic anomalies discovered during Ontario Geological Survey airborne geophysical surveys (2009, 1980), and a ground magnetometric survey conducted by Numax (Simoneau, 2008). These massive and semi-massive oxide zones are present as discrete, continuous to semi-continuous layers of magnetite, ilmenite, and titaniferous magnetite, covering a strike length of at least 10 km, and likely extend in both to the east and west.

The Seine Bay/Bad Vermilion Lake intrusion is uniquely situated between two major fault zones (the Quetico Fault to the north and the Rainy Lake-Seine River Fault to the south; Fig. 1). Though the gabbros and anorthosites of the intrusion appear to be largely undeformed, numerous discrete (metre-scale) shear zones exist within the intrusion, typically trending in a general easterly direction. It is quite possible that deformation within the intrusion has been largely accommodated by zones of massive oxide as the contacts between massive oxides and gabbroic rocks locally exhibit an obliquely trending (to the contact) mineral lineation emanating from the massive oxide into the gabbro, which dominantly features Fe-Ti-oxide smearing into the gabbro. Additionally, several large shear zones have been identified within the intrusion; a fault displaces barren anorthositic rocks in contact with oxide- and sulfide-bearing gabbroic rocks.

In the area of Numax's Mine Centre Property, the Seine Bay/Bad Vermilion Lake intrusion is sandwiched between metamorphosed felsic intrusive rocks to the north, and mafic meta-volcanic rocks to the south, which largely underlie the northern shore of Seine Bay. However, mafic intrusive rocks of the Seine Bay/Bad Vermilion Lake are again present to the south of Seine Bay (Poulsen, 2000). The exact natures of both the upper and lower contacts of the intrusion are not completely understood at this time.

The felsic intrusive rocks to the north display a distinct equigranular texture with spherical quartz eyes. Occurrences of quartz eyes (1-3 mm in size), can be observed locally in the mafic intrusive rocks of the Seine Bay/Bad Vermilion Lake intrusion, proximal to the upper contact. Additionally, interlayers of felsic and mafic intrusive rocks can be found locally near the upper contact.

The mafic meta-volcanic rocks exposed on the northern shore of Seine Bay could be a very large inclusion block within the intrusion, or more likely could be related to the regional faulting in the area. The contact between mafic metavolcanic rocks and mafic intrusive rocks appears intrusive, as it is extremely heterogeneous and features pegmatitic gabbro intermixed with mafic metavolcanic rocks. Closest to the mafic meta-volcanic rocks, apophyses of gabbroic melt migrate downward into the mafic volcanic rocks; while closer to the gabbro above, blocks (1-3 m) of mafic metavolcanic rocks occur as inclusions within the gabbro.

In the eastern part of the property a shear zone displaces pegmatitic gabbroic rocks adjacent to anorthositic rocks. This shear zone is within 10-20 m of the lower contact with mafic metavolcanic rocks. Quite possibly, this shear zone has displaced the far western extent of the intrusion eastward, causing the intrusion to become “stacked,” and displacing a portion of the mafic meta-volcanic footwall to its current position within the intrusion.

Description of Map Units

The lithologic units present in Numax’s Mine Centre Property are remarkably correlative in outcrop and exposed trenches, generally along an easterly strike. Figure 2 displays a simplified geologic map of the central Seine Bay/ Bad Vermilion Lake intrusion as it relates to Numax’s Property. The lithologic units present on the property include:

Felsic volcanic undivided (FVu) – Felsic volcanic rocks (undivided), typically interpreted as inclusions or groups of inclusions within the Seine Bay/Bad Vermilion Lake intrusion, typically very fine-grained, fresh and weathered surfaces white to light pinkish – beige, locally contains fine- to medium-grained disseminated chalcopyrite up to 1% found in both the Heat-Sink Trench and the Trenches on Line 28.

Massive and Semi-massive Oxide (MOX) – Massive (90-100% Fe-Ti oxide) and Semi-massive (30-90% Fe-Ti oxide) mineralization of iron – titanium oxide, typically hosted by medium- to coarse-grained pyroxenite, fresh surfaces are metallic black to dark purple, weathered surfaces are rusty orange to brown, magnetic strength varies from moderate to very strong, typically contains trace to 2% disseminated and massive sulfide (1-2 cm thick) consisting of pyrrhotite + chalcopyrite + pyrite, sulfides are typically fine- to very fine-grained, oxides are typically medium- to coarse-grained.

Mafic Intrusive, oxide-bearing (MIox) – Oxide-bearing (5-30% Fe-Ti oxide) mafic intrusive rocks, typically consisting of homogeneous, medium- to coarse-grained gabbro, melagabbro, pyroxenite, and rare leucogabbro, fresh surfaces are medium grey, and weathered surfaces are medium grey to brown, magnetic strength typically moderate to strong, contains lenses and layers of massive oxide that are <1 m thick, clinopyroxene is locally ophitic, but is typically intergranular, locally contains rare to trace disseminated sulfide mineralization, alteration dominantly includes moderate chlorite after pyroxene.

Mafic Intrusive (MI) – Non-oxide-bearing (<5% Fe-Ti oxide) mafic intrusive rocks, typically consisting of homogeneous, coarse- to medium-grained anorthosite and leucogabbro, and locally gabbro, fresh and weathered surfaces are light grey, locally displays modal layering between plagioclase and clinopyroxene, typically consisting of layers <1m thick that top to the north-northwest.

Mafic and Felsic Intrusive undivided (MFIu) – Undivided mafic and local felsic intrusive rocks, assumed from Poulsen, 2000.

Simplified Geologic Map of the central Seine Bay/Bad Vermilion Lake Intrusion

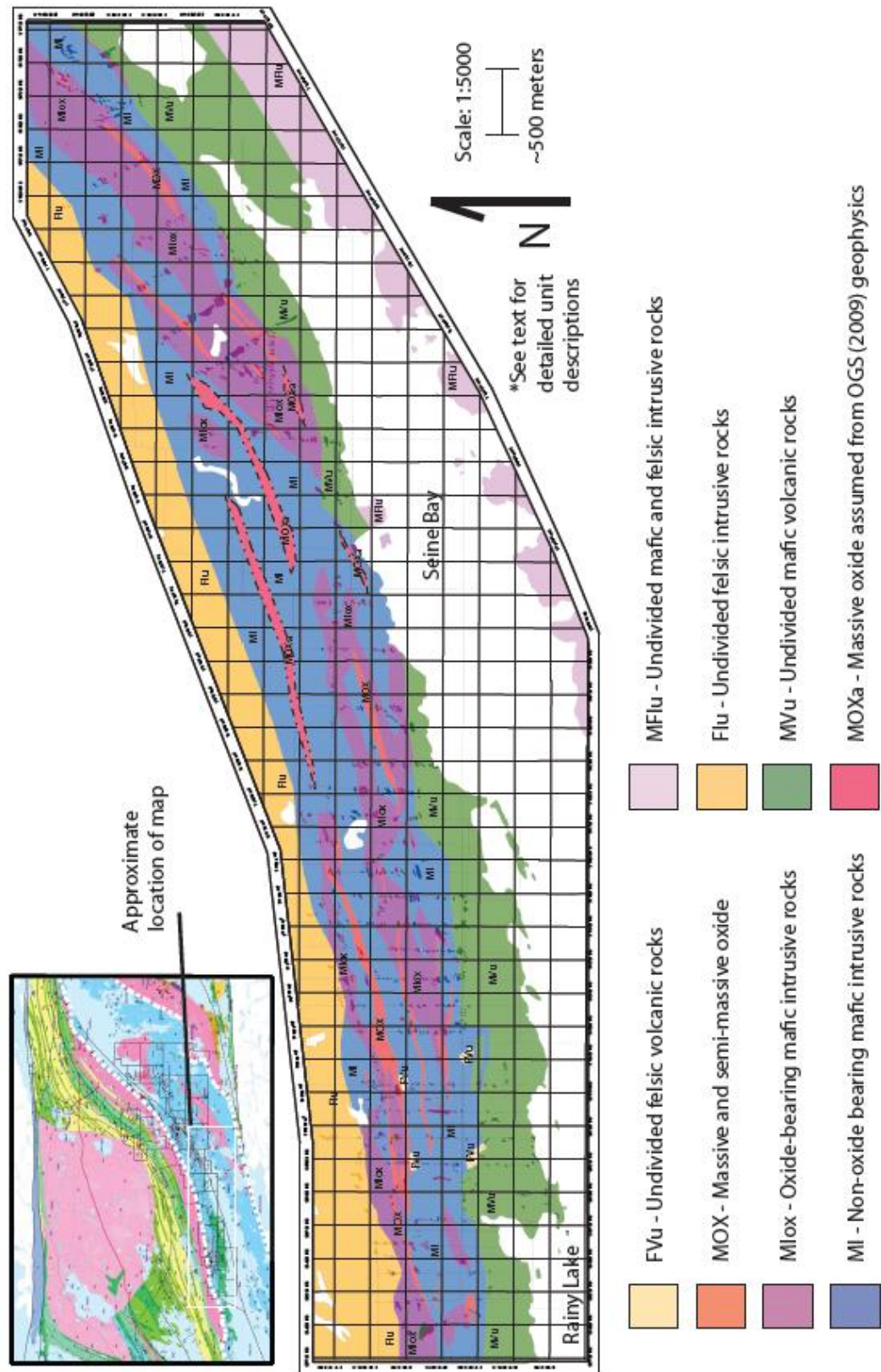


Figure 10: Simplified geologic map of the central Seine Bay/Bad Vermilion Lake intrusion, modified from Albers and White, 2010.

Description of Map Units, continued

Felsic Intrusive (FI) – Felsic intrusive rocks dominantly consisting of granodiorite, quartz diorite, tonalite, and trondhjemite, typically medium- to coarse-grained, these rocks typically display the effects of contact metamorphism largely demonstrated by the texture of quartz, forms the hanging wall to the Seine Bay/Bad Vermilion Lake intrusion in the map area.

Mafic Volcanic undivided (MVu) – Undivided mafic volcanic rocks, typically consisting of homogeneous, massive, fine- to very fine-grained basalt, typically displays contact metamorphism to hornfels, locally plagioclase-phyric, locally displays pillows, local sulfide mineralization, occurs both as inclusions within the Seine Bay/Bad Vermilion Lake intrusion, and as an extensive “finger” occurring across the length of the intrusion in the map area, an extremely heterogeneous intrusive contact is observed in the Discovery Zone and Discovery Zone North Trench between the basalt “finger” and the Seine Bay/Bad Vermilion Lake intrusion in which prominent sulfide and oxide mineralization is displayed.

Massive and Semi-massive Oxide assumed (MOXa) – Massive and Semi-massive oxide, assumed from Ontario Geological Survey (2009) airborne geophysical survey (approximate).

Field Trip Stop

The field trip consists of one stop, which will traverse a complex of trenches excavated on section line 28. The trenches include Beaver Dam, Buck, and Doe trenches. Figure 3 displays a geologic map of these trenches with accompanying Fe_2O_3 and TiO_2 assay data profiles, as well as a profile of the ground magnetometric geophysical survey data (Simoneau, 2008).

Ten distinct lithologies, which display correlative stratigraphy through the complex of trenches and outcrops on section line 28, and with adjacent trenches and outcrops at least 600 m to the east and west, are displayed. Detailed lithologic descriptions that correspond to Figure 3 are documented below (from north to south).

A) Melagabbro: Medium- to fine-grained, weakly to non-magnetic, weak chlorite alteration, locally verges on pyroxenite; silicate modal mineralogy is as follows: 68-88% clinopyroxene, 5-15% plagioclase, and 5-15% olivine, trace disseminated and veinlets of very fine-grained chalcopyrite + pyrrhotite (<0.5%), <2% iron oxide, olivine seems to occur as clusters with plagioclase and weathers to rusty brown creating a pock-marked appearance, weathered surface is medium slate grey, fresh surface dark slate grey, cut by a dike of felsic to intermediate composition which is very fine-grained, non-magnetic, and contains tiny phenocrysts of white alkali feldspar, clear to white quartz, and 1-2 mm needles of hornblende, weathered surface is white, fresh surface is medium blue/grey, upper contact buried beneath overburden/swamp, lower contact gradational, at least 33 m thick.

Simplified Geologic Map of Trenches on Line 28 with accompanying Geochemical and Geophysical Profiles, Numax Resources, Inc., Mine Centre Property, Mine Centre, Ontario

- *A: med-fn-gr, Melagabbro
- *B: med-cs-gr, layered, Melagabbro
- *C: fn-gr, Oxide Pyroxenite
- *D: med-gr, Oxide Melagabbro to Oxide Pyroxenite
- *E: med-fn-gr, Massive Oxide
- *F: med-gr, Oxide Gabbro
- *G: med-fn-cs-gr, sheared-lineated-folded, Gabbro
- *H: med-fn-gr, Massive Oxide
- *I: med-gr, Felsic Volcanic
- *J: fn-gr, Intermediate/Felsic Dike

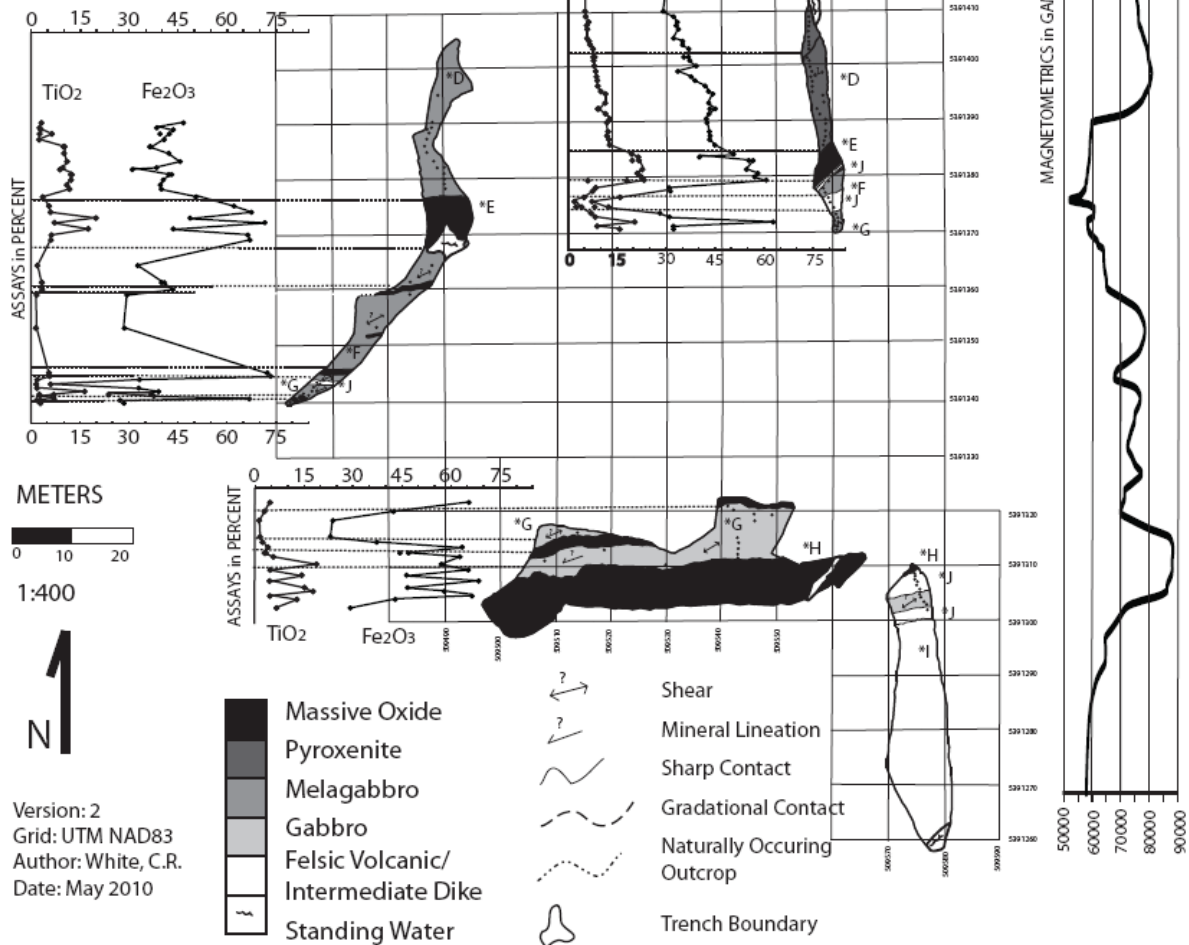


Figure 11: Geologic map (Scale 1:400) of the Trenches on Line 28 with associated Fe_2O_3 and TiO_2 profiles from channel samples, and walking magnetometric geophysical survey profile.

B) Melagabbro (layered): Similar in composition to the melagabbro above (A), but contains less olivine and is medium- to coarse-grained, displays prominent modal layering between plagioclase and pyroxene, layers are typically <1 m thick and in many instances thinner layers (<10 cm thick) stack on top of thicker layers, plagioclase-rich tops are typically 1-4 cm thick, layers are very consistent with sharp contacts and local fault off-sets (<10 cm), layers dip subvertically and strike at $\sim 245^\circ$ with a topping to the northwest, lower contact is gradational over ~ 3 m and displays a zone with thin fractures or shears (1 mm to 2 cm thick) filled with chlorite and skirted by plagioclase-rich gabbro that abruptly dissipates back to melagabbro, fractures are irregularly spaced (1 cm to 0.5 m apart) with a subvertical dip and strike of $\sim 240^\circ$, ~ 43 m thick.

C) Oxide Pyroxenite: Fine-grained, weakly to non-magnetic, strong chlorite alteration, $\sim 5\%$ iron oxide which is clumped together with very fine-grained plagioclase, trace very fine-grained chalcopyrite + pyrrhotite, weathered and fresh surfaces are pale green and purplish, lower contact abrupt, ~ 8 m thick.

D) Oxide Melagabbro to Oxide Pyroxenite: Medium-grained, weakly to moderately magnetic, strong chlorite alteration, <3% very fine-grained granular olivine, 5-15% iron oxide, trace fine-grained disseminated chalcopyrite + pyrrhotite, local patchy veining or fracture fillings of chlorite <0.5 m thick and discontinuous with pinching and swelling, local very distinct change in weathering: broken-up and sheared with a strong foliation dipping sub-vertically and a general southwest trend (too magnetic to obtain strike), near the bottom of this unit is a thin sub-vertically orientated band of fibrous-fanning amphibole (2 mm to 1 cm thick) generally striking southwest (too magnetic to obtain strike), lower contact is sharp to gradational over 3-4 m, ~ 25 m thick.

E) Massive Oxide: Medium-to fine-grained, strongly magnetic, strong chlorite alteration, hosted by pyroxenite, rare fine-grained disseminated chalcopyrite, vague localized modal layering displaying as thin bands (1 mm to 3 cm thick) of chlorite (very soft with blue-green color) semi-continuous and flat-lying, sub-vertical generally trending southwest (too magnetic to obtain strike), spaced 10-20 cm apart commonly occurring as pairs with a thinner layer (2-4 cm thick) overlying a thicker (10-20 cm thick) layer, 4-9 m thick, lower contact is sharp with a 0.5 m thick lens or dike locally cross-cutting the contact between this massive oxide and the gabbro below, dike contains 1% fine-grained disseminated chalcopyrite and stringers of chlorite, weathered and fresh surfaces are white (felsic volcanic?), ~ 4 -10 m thick.

F) Oxide Gabbro: Medium-grained, weakly to non-magnetic, strong chlorite alteration, $\sim 5\%$ iron oxide, rare fine-grained disseminated chalcopyrite + pyrrhotite, thin sinuous and continuous laminations of <1 mm thick plagioclase and chlorite occur in within 0.5 m of upper contact, contains local layers (<10 cm thick) of massive oxide oriented normal to strike of upper contact, lower contact is abrupt over ~ 1 m, with lineated iron oxide emanating obliquely to contact ($\sim 30^\circ$) into oxide gabbro from massive oxide below showing a somewhat boudinage appearance, dipping sub-vertically (too magnetic to obtain strike), 3-25 m thick.

G) Gabbro (lineated/sheared/folded): Fine- to medium- to coarse-grained, locally weakly magnetic, strong chlorite alteration, pyroxene and iron oxide are typically lineated and stretched

in direction of lineation (too magnetic to obtain trend), local pervasive folding with up to nine folds observed in a single structure, typically folds are rimmed with chlorite (2 mm to 2 cm thick) and dominantly composed of quartz and plagioclase with local iron oxide, locally strongly foliated dipping sub-vertically and striking southwest (too magnetic to get strike), but foliation is normal to mineral (iron oxide) lineation at contact above, numerous layers (10 cm to 1.5 m thick) of massive oxide dipping sub-vertically with strike normal to upper contact, contacts between massive oxide and gabbro are sharp and irregular, massive oxide is hosted by pyroxenite with local olivine and displays sub-vertically oriented laminations (1-2 mm thick) of chlorite striking normal to contacts, locally grades to oxide gabbro toward lower contact, lower contact sharp, up to 45 m thick.

H) Massive Oxide: Medium- to fine-grained, strongly magnetic, strong chlorite alteration, hosted by pyroxenite, weathered surface is brown/rusty-orange to dark-deep-reddish/purple, fresh surface is metallic dark-purple/black, local silver-white staining generally as small (several cm) sinuous patches, local discontinuous sinuous bands of massive pyrrhotite + pyrite + chalcopyrite (<2 cm thick), local lenses that form a discontinuous layer of strongly chloritized sheared gabbro (1 m thick x <3 m long), lower contact consists of a 1-2 m cliff face plunging beneath the overburden, at least 7-10 m thick.

I) Felsic Volcanic: Strongly metamorphosed and altered, massive appearance, weathered surface is pinkish/orange to beige with intermixed patchy blue-green, fresh surface is generally pale blue-green-grey, mafic phase is strongly altered to chlorite, local pale-yellow epidote alteration, local thin (<1 mm thick) folded bands that show a somewhat preferred orientation with strike (~270°) of contact, local foliation and shearing toward top of zone, rare fine-grained disseminated pyrite and possibly chalcopyrite, could be the same as dikes above, lower contact buried beneath overburden and standing water, at least 37 m thick.

J) Dikes and/or Felsic Volcanic Inclusions: Very fine-grained, non-magnetic, locally contains up to 1% fine-grained disseminated chalcopyrite, local phenocrysts (1-2 mm in size) of white alkali feldspar, clear to white quartz, and needles of hornblende, local irregular-shaped clasts of beige to light reddish/orange quartz (1-15 cm long), weathered surface is white to light blue-grey, fresh surface is medium to light blue-grey, contacts are generally sharp, 1-4 m thick.

Iron-titanium-oxide geochemical data collected from continuous channel sampling through the trenches display very distinct profiles that correlate remarkably well with the geology observed in the trenches (Fig. 3). Restricted (<1.5 m) zones or layers of massive oxide within gabbroic rocks show spikes in Fe_2O_3 and TiO_2 , while felsic to intermediate dikes display corresponding decreases in Fe_2O_3 and TiO_2 values. The profiles are most interesting through units C, D, E, and F. Here the profiles display a steady increase from north to south through the pyroxenite and oxide pyroxenite, hitting a peak of roughly 60% Fe_2O_3 and 25% TiO_2 in unit E (massive oxide). The profile of the ground magnetometric geophysical survey (Simoneau, 2008) along section line 28 is also quite correlative with the observed geology (Fig. 3). The survey profile displays spikes of >80,000 gammas in zones of massive oxide, and corresponding decreases in unmineralized gabbro and felsic rocks to <60,000 gammas.

As discussed above and presented in Figure 3, the geology, geochemistry, and geophysics of the trenches on line 28 are remarkably correlative. The igneous stratigraphy of the Seine Bay/Bad

Vermilion Lake intrusion throughout the Numax Mine Centre property also correlates remarkably well, with both geologic mapping, and airborne geophysical surveys (Ontario Geological Survey, 2009), showing continuous to semi-continuous layers of massive oxide through the property for a strike length of at least 10 km, and likely up to 15 km. An extensive drilling program focused on confirming and defining this enormous Fe-Ti prospect is both warranted and forthcoming.

Return to Hwy 11 turn left and drive west for 24.4 km, turn left (south) on the bush road and drive 2.25 km to the Y-intersection. Take the right branch and continue for 1.95 km to the Beaverpond Zone (0495043E 5394021N)

STOP 4 – Magmatic Copper-Nickel-PGE Mineralization – MetalCORP Limited – North Rock Property **Peter Hinz**

NOTE: This portion of the field trip guide is taken from the MetalCORP website www.metalcorp.ca.

MetalCORP Limited's 100%-owned North Rock Property is located approximately 25 km east of Fort Frances and is easily accessed via Highway 11 and then 4 km via a gravel road. The property consists of 370 claims or 5,920 ha (14,800 acres).

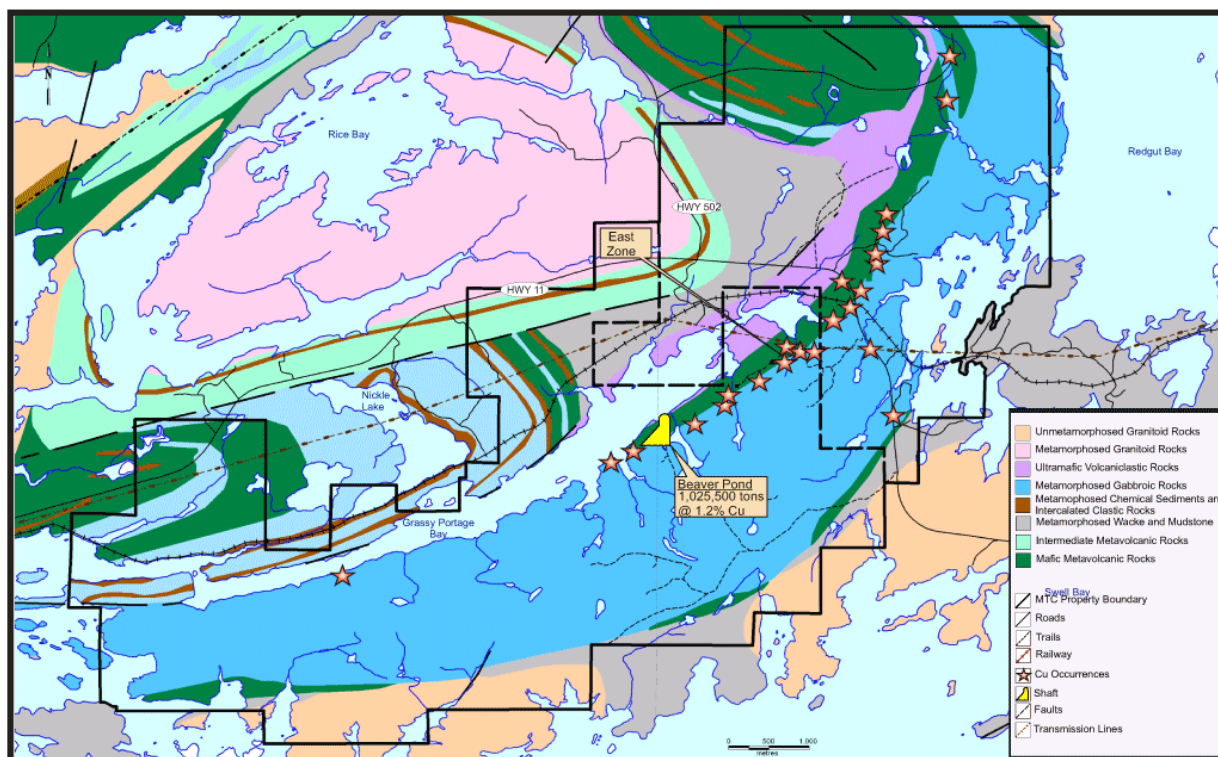


Figure 12. Property outline and generalized geology, North Rock property, MetalCORP Resources Ltd. From MetalCORP website www.metalcorp.ca.

The Property is underlain by the 20 km long Grassy Portage layered mafic intrusion and hosts four known zones of magmatic copper-nickel sulphide mineralization; the Beaver Pond, the Main South, the East and the West zones all of which occur at or near the base of the intrusion, along its western contact.

GENERAL GEOLOGY:

The property is underlain by mafic and ultramafic metavolcanic rocks, which are in contact with the Grassy Portage gabbroic intrusion (Figure 20). The ultramafic rocks are tuffs and lapilli tuffs that are generally actinolite-rich and intensely magnetic. Metabasaltic flows overlie these to the south, and pillow shapes indicate southward facing. The contact of the pillow lavas with the Grassy Portage intrusion is sharp, and is occupied by a 20 m thick unit of coarse-grained, hornblende-rich melagabbro. The melagabbro grades south-eastward to medium- to coarse-grained gabbro composed of subequal proportions of hornblende and plagioclase. Layers of anorthosite composed of andesine intrude the gabbro at the southern margin of the property, where they are spatially related to masses of magnetite-actinolite amphibolite. Numerous mafic to intermediate dikes cut the gabbroic rocks.

Copper-Nickel Mineralization

The most significant of the zones is the Beaver Pond Zone, which was discovered by Noranda in 1958 and subsequently explored from underground via a 90 metre deep shaft and one drift on the 70 m level. Resource estimates for the Beaver Pond Zone, reported by Bergman (1973) range (depending on the cut-off grade) from 1,020,458 tons grading 1.17% Cu to 265,230 tons grading 2.08% Cu. The resource estimate was calculated to a depth 90 m and the deposit appears to remain open to depth. One drill hole intersected 2.21% Cu over 36.5 feet at a vertical depth of 175 m. (Note that these historical resource estimates are not current and should not be relied upon as they were not prepared in compliance with National Instrument 43-101.)

Other significant drill intersections reported by Noranda from within the Beaver Pond Zone include: 4.3% Cu over 8.1 m, 4.1% Cu over 7.8 m, 3.4% Cu over 8.0 m, 1.5% Cu over 21.3 m, and 1.0% Cu over 55.5 m. (These Noranda assays have not been verified and as such should not be relied upon). There is no record of any further mineral exploration work having been conducted on or near the Beaver Pond Zone, or on any of the formerly leased claims in the area, since the underground program was concluded in 1973.

Very little historical data exist regarding the abundance and distribution of nickel, cobalt, platinum group metals (PGM) or gold in the magmatic sulphide deposits on the North Rock Property. However, recent grab sampling of a 10,000 ton surface stockpile of material recovered from underground development of the Beaver Pond Zone yielded assays of up to 8.9% Cu, 0.8% Ni, 0.05% Co, 1.6 g/t Pt, 0.7 g/t Pd and 0.7 g/t Au. Although grab sample assays are typically not representative of the overall grade, these results do confirm the presence of significant nickel, cobalt, PGM and gold values associated with the copper mineralization.

Regional Geology and Occurrences

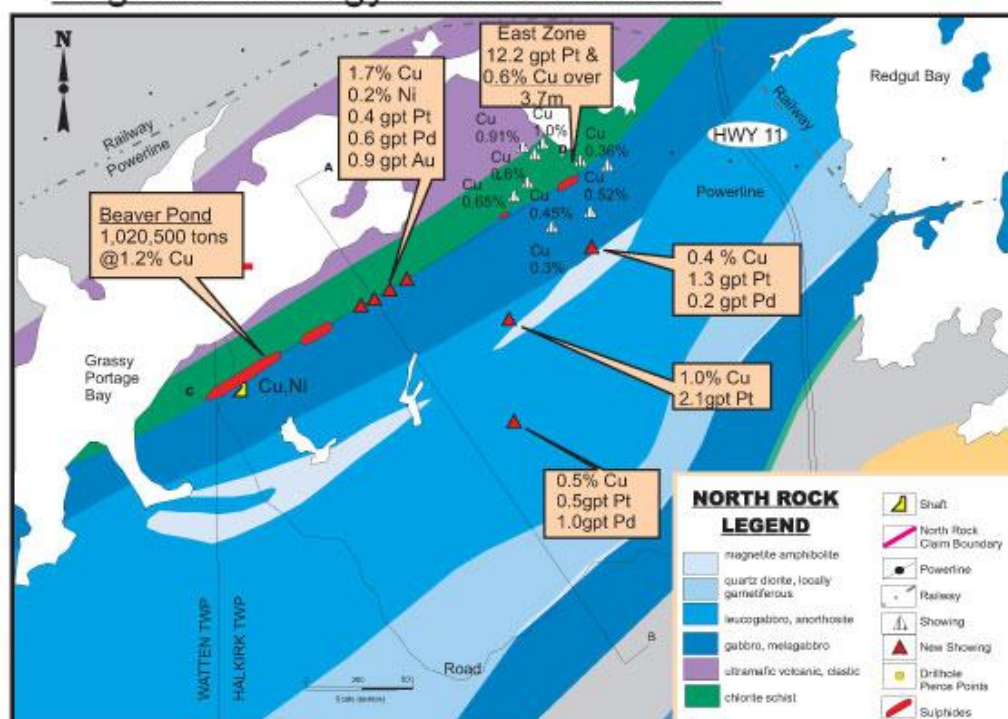


Figure 13. Mineralized zones and assays, North Rock property, MetalCORP Limited. From MetalCORP website www.metalcorp.ca.

The three other known sulphide zones are less-explored and occur over a 1.5 km strike length along the base of the intrusion extending northeast from Beaver Pond Zone. These areas, as well as several other sulphide occurrences higher up in the intrusion, are all considered highly prospective for hosting additional magmatic nickel-copper (+/- PGE's, Co) sulphide mineralization.

MetalCORP conducted surface exploration, an airborne magnetometer/electromagnetic survey and three phases of drilling on the Property from 2005 to the end of 2007.

The first phase of drilling was carried out in 2005 and consisted of 14 diamond drill holes totaling 3,906 m. Phase 1 drilling was designed to test the depth extension of the known copper mineralization at the Beaver Pond Zone. All drill holes intersected widespread, varied amounts of net-textured copper-nickel sulphide mineralization similar to that reported by previous drilling by Noranda. Hole 4 appears to have intersected the core of the zone returning 1.5% copper over 13.7 m. The drilling also intersected a hanging wall Platinum Group Metal (PGM) zone that can be traced for 500 m along strike and to a depth of 200 m. Assay values as high as 3.7 g/t Pt + 7.1 g/t Pd over 0.8 m were reported.

The Company completed an airborne magnetic/EM geophysical survey over the property which detected several anomalies with a 1 km long anomaly coincident with the East zone which is 1.2 km northeast and along strike of the Beaver Pond zone. Mapping and sampling confirmed the

presence of PGM mineralization at the East zone and a Phase 2 drilling program was set up to test the mineralization. The Company drilled 21 holes totaling approximately 4,000 m with several holes intersecting PGM mineralization. Hole 20 intersected 3.7 m (2.5 m true width) from 151.9 to 155.6 m grading 1.2 g/t Pt, 0.1 g/t Pd, 0.1 g/t Au, 0.6% Cu and 0.2% Ni (see March 6 and April 19, 2006 news releases) www.metalcorp.ca.

In June 2007 the Company announced a Phase 3 diamond drilling program of 25 holes totaling approximately 8,000 m to test several airborne EM conductors over a 20 km strike length on the entire Property. Drilling in the Belacoma area, approximately 4.0 km northeast of the Beaver Pond Zone, intersected platinum and palladium mineralization as well with the following values: 3.5 g/t Pd over 2.8 m, 1.2 g/t Pt and 1.0 g/t Pd over 1.0 m, 2.9 g/t Pd over 0.9 m and 1.6 g/t Pd over 0.9 m. A number of other airborne EM conductors were tested, with the majority explained by pyrrhotite veins and/or sulphide iron formation. The sulphide iron formation in the Nickel Lake area was found to be zinc-rich, with the best assay from hole #57 of 0.5% Zn over 19.6 m.

Return to Hwy 11, turn left and drive for 2.7 km, pull off to the right into the small bush lane. Walk through the bush 120 m to the northwest to the outcrops on the south side of the beaver pond (497137E/5396262N)

STOP 5 – Diamonds in the Grassy Portage Ultramafic Pyroclastic – MetalCorp – GUP Property

The Grassy Portage Ultramafic Pyroclastic (GUP) is located approximately 33 km east-northeast of Fort Frances. The property straddles highways 11 and 502 and extends out into Grassy Portage Bay, Rainy Lake (Figure 14). Portions of the property are accessible by road or boat. The property is held by MetalCORP Limited under option from Messrs. R. Cousineau, L. Cousineau and K. Desjardins, all of Fort Frances.

The general geology of the area is described by Poulsen (2000):

The rocks of the Rainy Lake area are part of the Archean Superior Province and form a fault-bounded wedge between 2 subprovinces, the Wabigoon granite-greenstone terrane to the north and the Quetico metasedimentary terrane to the south. The Quetico and Rainy Lake-Seine River faults define this wedge, which is interpreted to be a dextral wrench zone and which displays distinct stratigraphic, structural and metamorphic relationships.

Poulsen (2000) also described the GUP:

A unique ultramafic unit occurs in the Redgut Bay-Grassy Portage Bay area. Rocks from this unit have distinctive textures as well as a magnesian chemical composition; samples plot as basaltic komatiites. Locally, the rock consists of angular to subrounded fine-grained clasts, up to 5 cm in diameter, set in a fine-grained chlorite-tremolite matrix. The rocks are moderately to strongly magnetic and, where visible fragments are not present, they are fine-grained magnetic tremolite schists. As a whole, this ultramafic unit strongly resembles the "ashrock" unit (Joliffe 1955) that overlies the iron ore horizon of the Steep Rock Group north of the Quetico Fault at Atikokan.

The author collected 15 samples from various parts of the property during the 2000 field season; all samples plotted at the boundary between basaltic komatiite (BK) and picritic (ultramafic) komatiite (PK) on a Jensen Cation plot (Jensen 1976) (Figure 15). A plot of total alkalis ($\text{Na}_2\text{O} + \text{K}_2\text{O}$) versus silica (SiO_2) (Le Maitre 1989) shows that the majority of samples plot within the komatiite or meimechite field (see Figure 16). The differentiation between the two rock types is based upon titanium oxide content, meimechite having greater than 1% TiO_2 , and komatiite, less than 1% TiO_2 . Meimechite is defined as, "...the extrusive equivalent of kimberlite" (Mitchell, 1985).

Schaefer and Morton (1991) conducted research on both the GUP and the Dismal Ashrock of the Steep Rock Group. Their work indicated that "GUP is divided into komatiitic lapilli tuff and komatiitic volcanic breccia. Both pyroclastic units contain cored and composite lapilli, evidence of explosive volcanism. Locally, some of the lapilli fragments are highly vesicular (up to 30% by volume), greater than reported for any other komatiite."

A variation in clast composition was noted at various locations in the GUP. Cored clasts up to 10 cm across were noted on the shoreline (495819E/5395232N) and islands (499902E/5394822N) of Grassy Portage Bay. At the Beaver Pond Occurrence (497137E/5396262N) clast-dominant GUP is seen to be in contact with a fine-grained matrix-dominant GUP. The contact between the two units suggests that the younging direction is roughly to the east. This is based on what is interpreted, by the author, to be scouring of the fine-grained tuffs during passage of a pyroclastic debris flow.

The majority of clasts appear to be ultramafic in composition with <2% of exotic origin. At all locations the clasts range from subangular to subrounded, with a maximum dimension of 15 cm.

Rocks of the GUP contain only trace amounts of sulphide minerals (pyrite $\pm$ pyrrhotite). Some sections contain appreciable amounts of euhedral magnetite, visible to the naked eye. A bronze-coloured mica was observed on a small island in Grassy Portage Bay and identified as phlogopite in the field; X-ray diffraction analysis confirmed the presence of phlogopite/biotite. Talc was also noted in some sections.

Shaefer and Morton (1991) and Poulsen (2000) concurred that the GUP has undergone amphibolite-grade metamorphism. Only late-stage, weak carbonatization was noted by the author. Schaefer and Morton (1991) commented on the structure of the area: "GUP outcrops form an arcuate fold interference pattern, are strongly deformed ...". However, outcrops visited by the author display very little deformation, the only structural fabric was a weak foliation observed at the Beaver Pond occurrence. This apparent lack of deformation is supported by observed clast morphology, which ranges from subangular to well-rounded.

The property and surrounding area has undergone extensive exploration at various times since the late 1800s for copper, zinc, nickel, PGM, gold and iron. Prior to 2000, no record of diamond exploration is documented in the area. Under an agreement with the property owners, INCO Ltd. conducted a sampling program on the property in 2003, with samples being analysed by Lakefield Research (L. Cousineau, Prospector, personal communication, 2003). One sample collected by INCO was reportedly identified as a hypabyssal kimberlite.

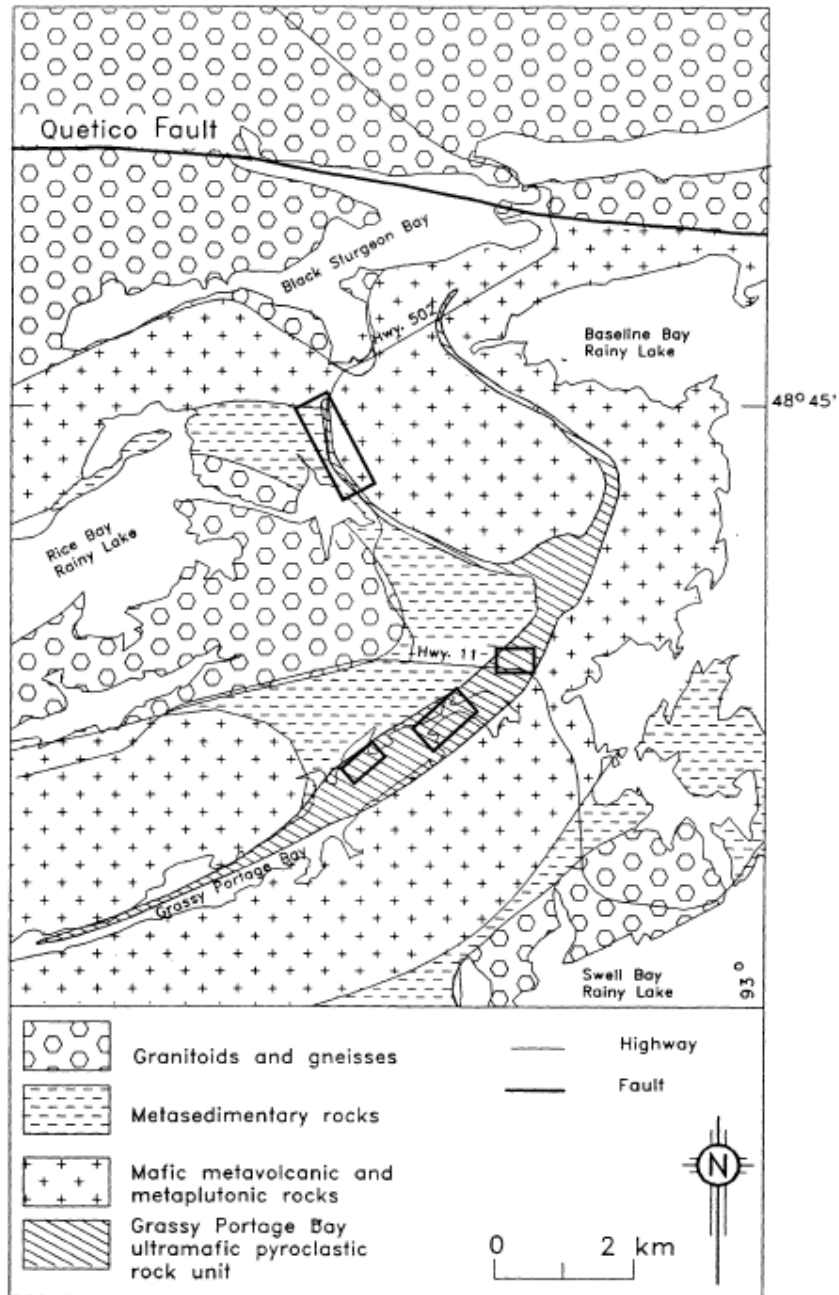


Figure 14. Geology of the Grassy Portage ultramafic pyroclastic (modified from Schaefer and Morton 1991). Rectangles represent sample areas. (From Lichtblau et al. 2004).

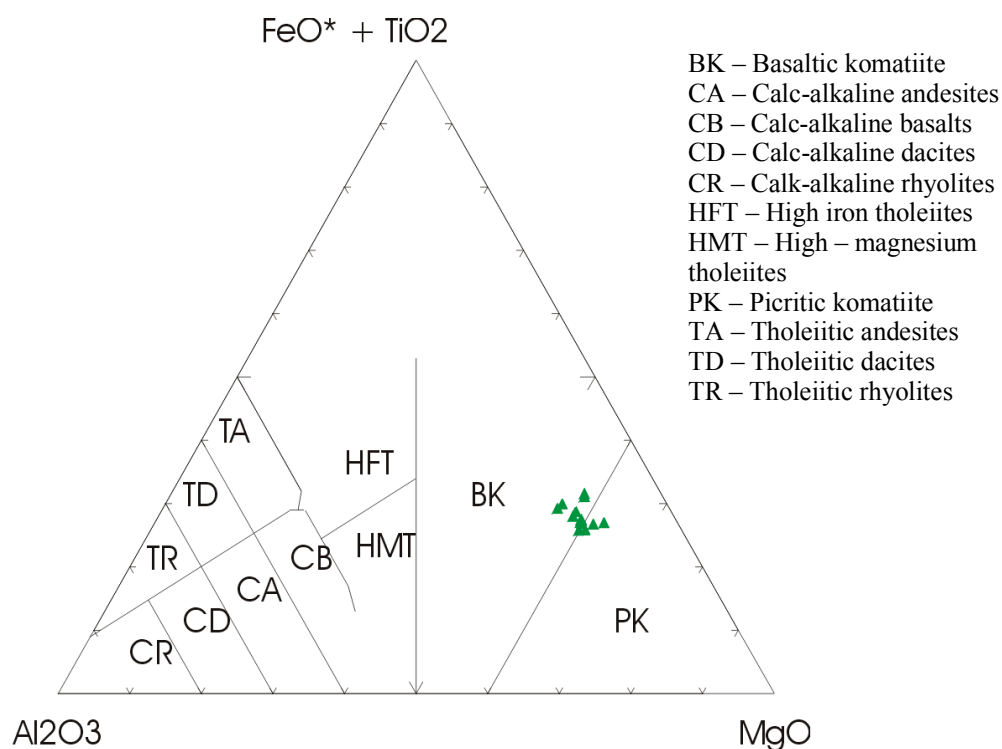


Figure 15. Jensen cation plot (Jensen 1976) for samples collected from the Grassy Portage ultramafic pyroclastic. Triangles represent sample plots, this study.

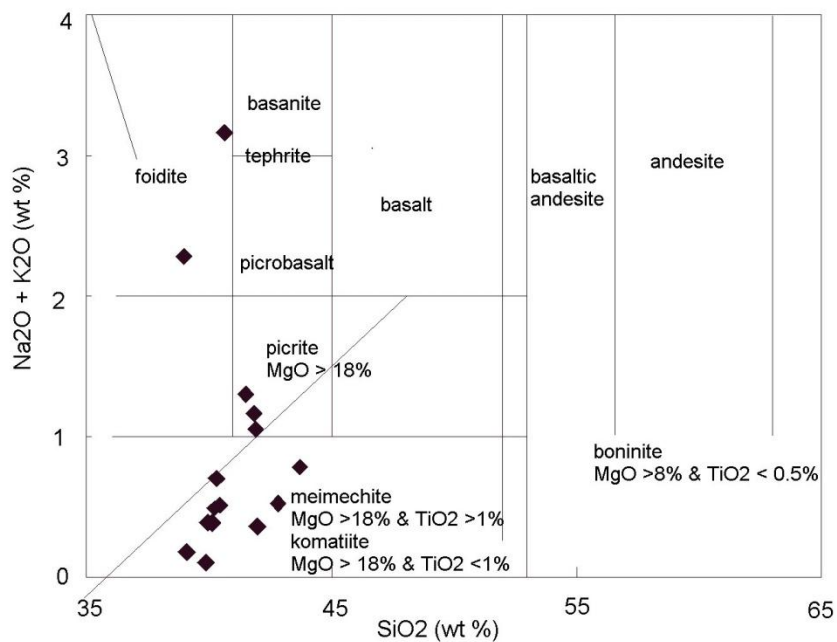


Figure 16. Alkali versus silica plot (LeMaitre 1989) for samples collected from the Grassy Portage ultramafic pyroclastic. Diamonds represent sample plots, this study.

As part of its ongoing exploration program MetalCORP announced in February 2008 the discovery of micro-diamonds on the property in the Grassy Ultramafic Pyroclastic. The Company took a 100 kg sample and sent it for processing by Kennecott Canada Exploration Inc. ("Kennecott") in its Mineral Processing Laboratory, located in Thunder Bay, Ontario. A total of six diamonds were recovered with one sitting on the 0.212 mm sieve, three were on the 0.106 mm sieve and two were less than the 0.106 mm sieve size. In December 2008 Kennecott and MetalCORP signed an option agreement to explore for diamonds on the property but in September 2009 MetalCORP was advised by Kennecott that it had completed processing a 1,200 kg sample taken during its summer exploration program and, based on the results, concluded that the diamond potential is very low. Accordingly, Kennecott terminated its program and its option and returned the property to MetalCORP.

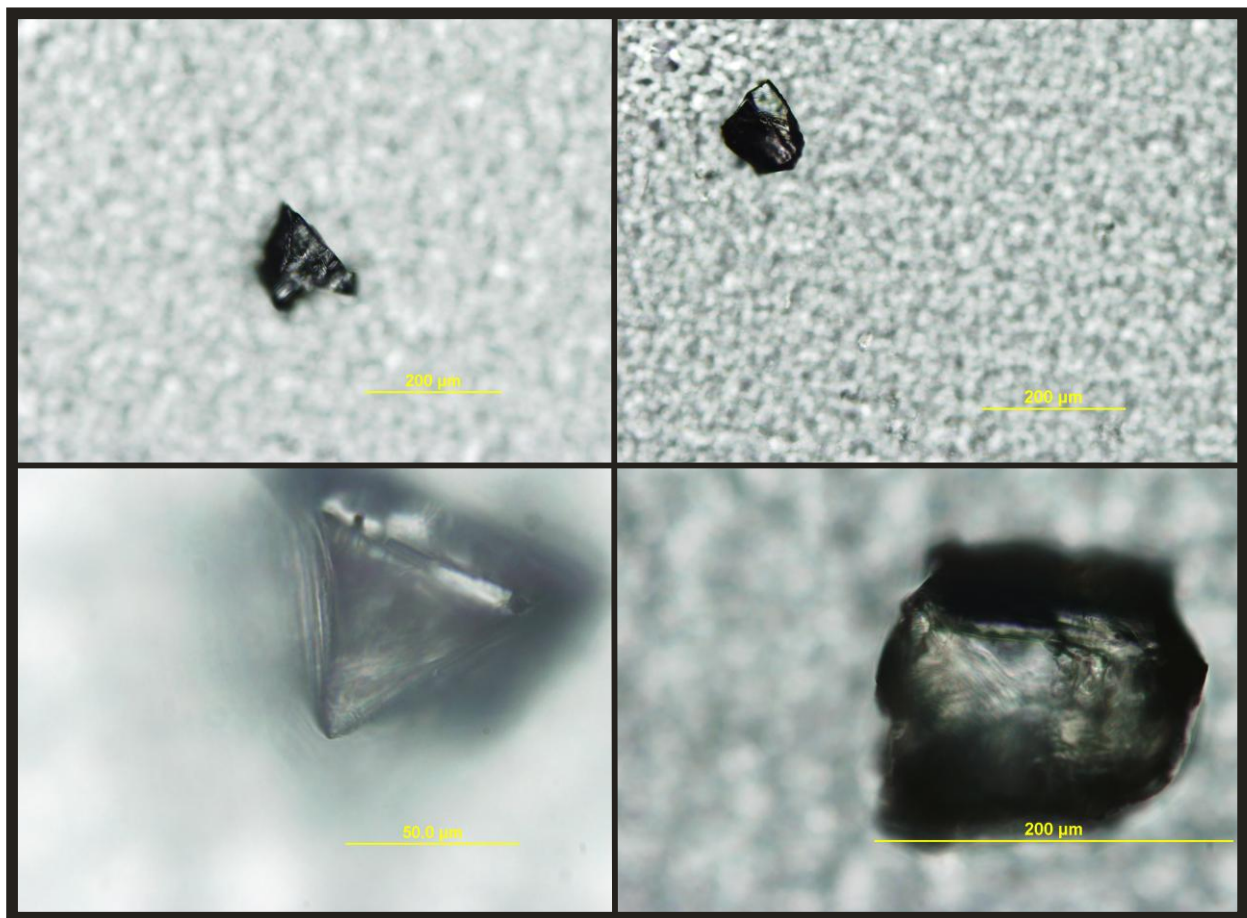


Figure 17. SEM images of four of the six diamonds recovered by MetalCORP from the Grassy Portage Ultramafic Pyroclastic.

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Field Trip 8

GEOLOGY AND ENVIRONMENTAL ISSUES OF THE STEEP ROCK MINE

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View from north rim of the Hogarth Pit during the late 1970's. Courtesy J. Baechler)



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Introduction

Flooding since 1979 of the decommissioned Steep Rock iron mines open pits north of Atikokan, Ontario has lead to the formation of the joint Hogarth-Roberts', Errington and Caland pit lakes (Fig. 1). Currently, the two largest pit lakes, Hogarth and Caland, have maximum water depths of 200 m, with waters levels expected to rise another 90 m, reaching the overflow elevation of 390 m (the original lake water level elevation). Overflow has been estimated to occur as soon as 2030 (Van Crook, 2005), but other estimates indicate overflow will take place around 2060 or later (Jackson, per. comm., 2007; Mikkeleson, unpublished data). Consequently, the overflow of the pit lakes is predicted to flow into the West Arm and possibly into the Seine River system, which flows into the International Boundary Waters of Rainy Lake and Lake of the Woods. The main issue with the waters from the pit lakes is their elevated sulphate contents (up to 1500 mg/L SO_4^{2-}), which have been shown to be acutely to chronically toxic for aquatic life (McNaughton; 2001; Goold, 2008; Godwin, 2009). In addition to water quality issues, it is anticipate that Crown, municipal and private lands and roads, a section of Provincial Highway 622 and portions of the Ontario Power Generation Atikokan Generating Station site will undergo varying degrees of flooding. Consequently, Steep Rock is currently one of the top three hazardous environmental sites in Ontario (Laderoute, pers. comm., 2008).



Figure 1. Map showing the locations of pit lakes at the former Steep Rock iron mine site (image from Google Earth).

In 1988 the Steep Rock mine site was returned to the Province of Ontario where the Ministry of Natural Resources (MNR) has managed the risks to public safety and the environment in accordance with the 1991 MNR Steep Rock Management Plan. However, this plan did not anticipate the water quality issues, which were identified by researchers from Lakehead University, nor did it anticipate a recent proposal to use pit lakes for tailings disposal. Remediation work conducted on the site has been sporadic. However, in 2000 Ministry of Northern Development Mines and Forests (MNDMF) spent \$650,000 to remove industrial buildings under the Province's Abandoned Mine Hazard Abatement Program. Furthermore, all PCB materials were removed from the site by 2008 for treatment at approved waste disposal facilities, as well as the removal of some of the buried metal waste.

Owing to the environmental concerns of the Steep Rock site, in 2008 the MNR received approval to commence the development of a long-term management strategy that will address issues related to surface and ground water quality and hazardous lands. The Steep Rock Mine Rehabilitation Project, a multi-year effort to develop a sustainable long-term management plan for the site has been initiated. This project is governed by a Project Steering Committee with director-level participation from: Ministry of Natural Resources (MNR), Ministry of Northern Development Mines and Forests (MNDMF), Ministry of Energy and Infrastructure (MEI), Ministry of Municipal Affairs and Housing (MMAH), Ministry of the Environment (MOE), Ministry of Transportation (MTO), and Cabinet Office. As part of the Steep Rock Mine Rehabilitation Project, the potential for contaminant release and/or discharge of impaired water from the pit lakes will be examined and remedial strategies developed to ensure that the downstream waters of the Seine River and Rainy Lake remain protected.

History

Preceding mining, Steep Rock Lake, host of the Steep Rock Mine, was a large, 2050 ha, M-shaped lake located north of the town of Atikokan in northwestern Ontario (Fig. 2). Although iron was discovered as early as 1891, several engineering challenges owing to the nature of the ore body, being located beneath the lake, prevented its extraction. However, following the increasing demands for iron ore during World War II, the Canadian Government declared the development of the Steep Rock Iron Mine as a project "essential to the war effort" under "The War Measures Act".

To mine the ore, it was necessary to divert the Seine River that flowed through Steep Rock Lake around the middle and eastern arms of the Steep Rock Lake (Fig. 3). This large river, draining a watershed of approximately 5000 square km, was diverted north around the mine through Finlayson Lake to the northern end of the West Arm of Steep Rock Lake that ultimately retained the flow of the river. This diversion required the construction of two dams that served to separate the West Arm from the rest of Steep Rock Lake. Following the construction of these two dams, work to expose the ore body began. This required draining of the middle and east arms of Steep Rock Lake and the removal of approximately 15 million m³ of lake-bottom silt and varved clay that were ultimately pumped into the West Arm.



Figure 2. Steep Rock Lake prior to mining and diversions (courtesy of the Ministry of Natural Resources).

In 1944, the first ore was mined from Errington Pit with subsequent ore bodies having been developed in the Hogarth and Roberts' pits ca. 1950. During the removal the lake bottom sediment of the latter two ore bodies, a massive release of approximately 4 million m^3 of colloidal silt and clay into the Seine River system and ultimately into Rainy Lake (located 145 km downstream) prompted a second diversion of the Seine River system. This diversion required the transformation of the West Arm of Steep Rock Lake into a closed-system settling basin (Fig. 4) where the once 60 m deep lake now has an average depth of 3 m owing to the deposition of nearly 90 million m^3 of silt and clay sediment.

In 1955, a second major dredging project was underway to access the ore body located along the east arm that was still under 30 m of water and 120 m of fine glacial silt and clay. Marmion Lake, now divided in half through the construction of several new dams, served as catchment of the approximately 120 million m^3 of dredged sediment from the dredging project. The newly accessible deposit became the Caland Pit, which started production in 1960.

The Steep Rock ore was predominantly hematite, and at 63% iron, could be shipped directly to steel mills and loaded into blast furnaces following the reduction of the material into 6-inch chunks and smaller. A more highly processed, finely crushed ore rolled into marble-sized balls and fired to produce transportable pellets later replaced the previously used "direct shipping" of the ore. No chemical processing was used on the Steep Rock mine site.

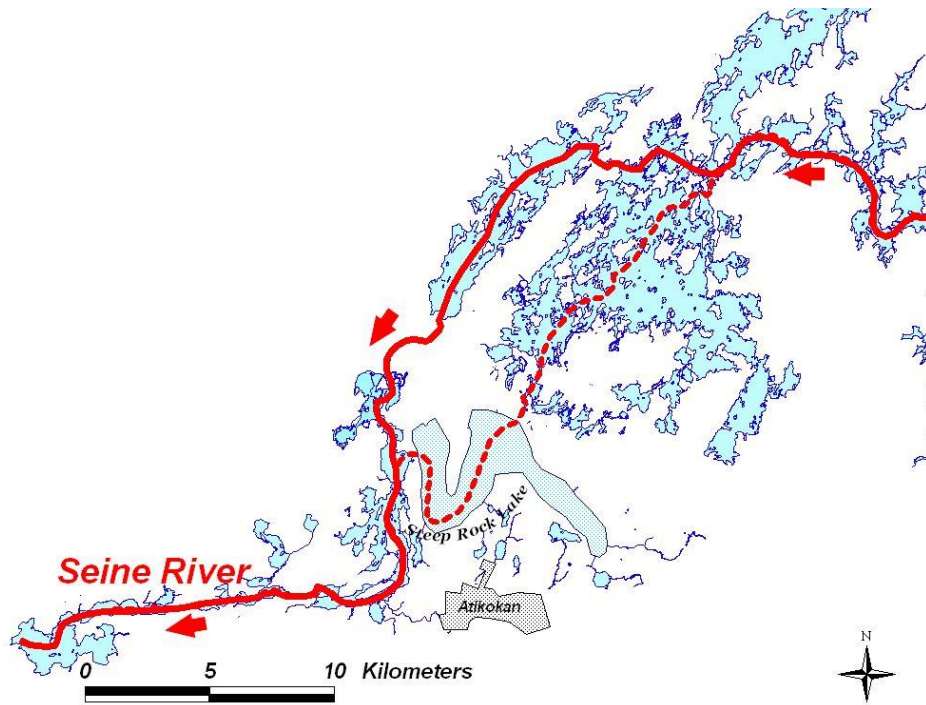


Figure 3. Seine River flow following first Steep Rock diversion (1940's). Dash line shows the original flow pattern through Steep Rock Lake (courtesy Ministry of Natural Resources).

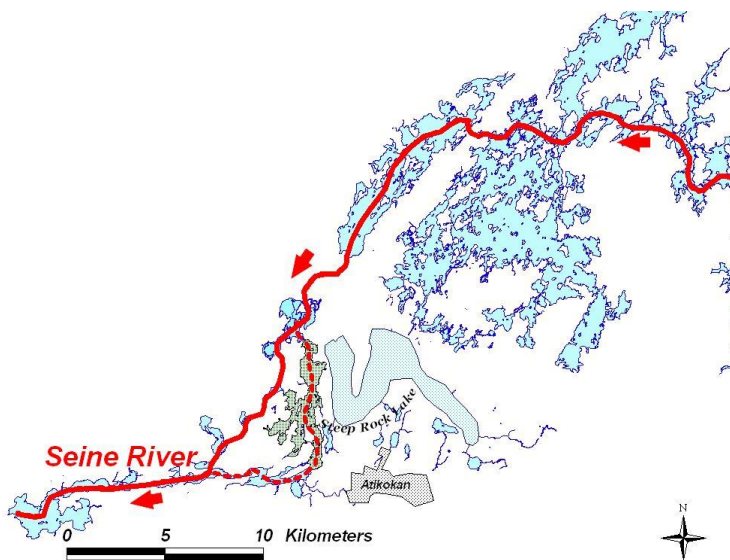


Figure 4. Seine River flow following the second Steep Rock diversion (1950's). Dash line shows the flow pattern of the 1940 diversion (courtesy Ministry of Natural Resources).

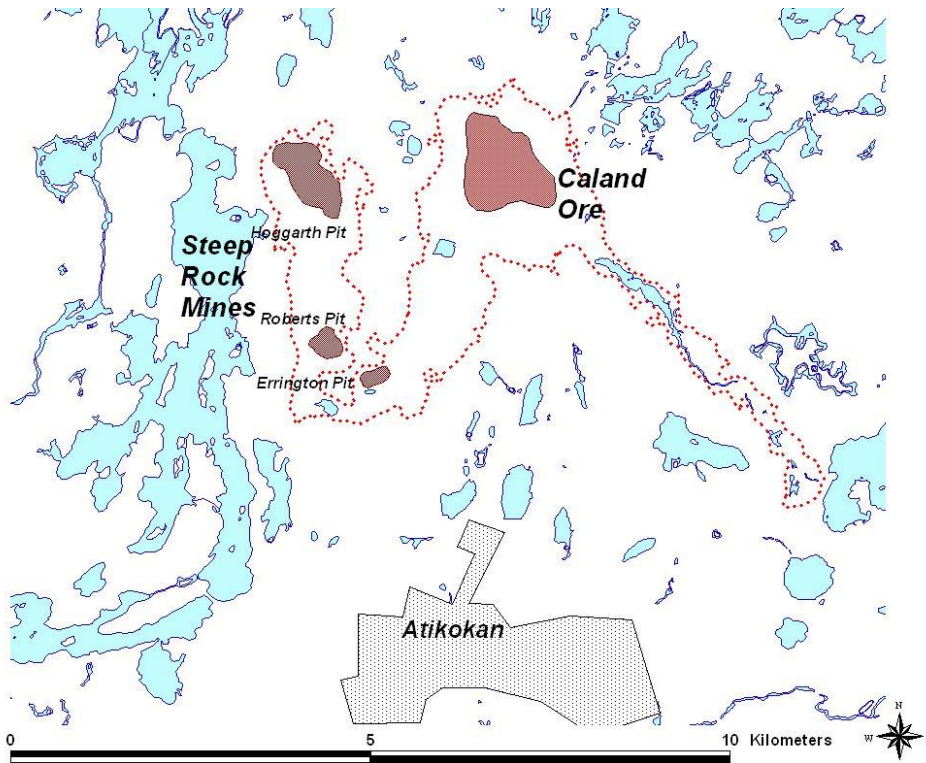


Figure 5. Location of open pits (1955-1979; courtesy Ministry of Natural Resources).

Open pit mining continued until 1979 when both Steep Rock (operating the Errington, Roberts', and Hogarth Pits) and Caland reached the bottom of their conical pits and could no longer reach the deeper ores (Fig.5). Following the termination of mining, Steep Rock and Caland had removed 53 million tons and 35 million tons of ore, respectively. Following the closure of the Caland open pit, Caland Ore returned their leased lands to Steep Rock Iron mines.

By 1985, Steep Rock Mines determined that no further development was expected, informing the Ministry of Natural Resources (MNR) of their intention to return their mining lands to the Province. At the time of surrender there were no specific regulations regarding mine closures and hence Steep Rock Iron mines were under no legal obligations regarding site remediation. However, Steep Rock Iron mines paid nearly a half million dollars to the MNR to defray any current and immediate future costs associated with mine site management as well as ownership and responsibility of two PCB sites (currently under Control Orders issued by the Ministry of the Environment). Over the years, obsolete mining equipment was either removed or buried with hundreds of thousands of dollars spent on removing structures and materials that the Province did not want. On April 1, 1988, Steep Rock Iron mines and the MNR signed the Surrender Agreement at which point the Province of Ontario regained ownership and management of the Steep Rock site.

Following the surrender, the Steep Rock site was largely left alone, allowing the pits to slowly fill with water where maximum water depths currently exceed 200 m. Between 1988 and 2009, the Caland pit hosted the Snow Lake Fish Farm and today the site is largely utilized as an unofficial recreation facility for the residents of Atikokan.

Geology

The Steep Rock area is in northwestern Ontario within the Superior province, on the southern border of the Wabigoon Subprovince adjacent to the Quetico Subprovince (Kusky and Hudleston, 1999; Shklanka, 1972; Card, 1990; Stone et al., 1992). The rocks in the area are structurally repeatedly folded and faulted. Three major metamorphic events resulted in three major periods of deformation. These coincide with the major orogenic events known as Kenorian, Hudsonian, and Grenville (Shklanka, 1972).

The geology of the Steep Rock area is comprised of the Marmion Gneiss Complex, the Steep Rock Group, the Dismal Ash Formation and the Witch Bay Formation (Kusky and Hudleston, 1999; Fig. 5).

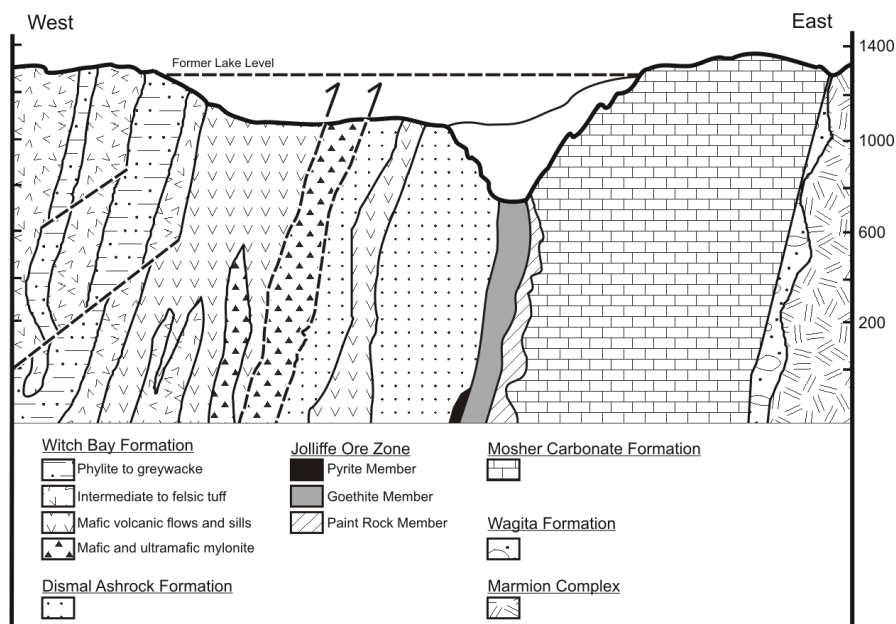


Figure 5. Geological cross-section of Errington Pit (after Kusky and Hudleston, 1999).

The Marmion Complex is part of a regional belt of arc-type plutons and volcanics in the central Wabigoon Province (Kusky and Hudleston, 1999). It consists of several different units with ages between 3001 Ma and 2928 Ma (Stone et al., 1992). These units consist of mafic tonalitic gneiss, a more leucocratic tonalite containing amphibolitized remnants of mafic rocks, and several units of felsic and intermediate tuffaceous rock, all intruded by granodiorite and gabbro dykes (Kusky and Hudleston 1999; Stone et al., 1992).

Overlying the Marmion Gneiss Complex is the Steep Rock Group, consisting of the Wagita Formation, the Mosher Carbonate Formation and the Jolliffe Ore Zone. The Wagita Formation consists of metamorphosed siliciclastic rocks ranging from argillaceous rocks to conglomerate (Shklanka, 1972; Wilks and Nisbet, 1988; Stone et al., 1992; Kusky and Hudleston, 1999). It is 0 to 150 m thick and not well exposed on the Steep Rock property (Kusky and Hudleston, 1999). The Mosher Formation of the Steep Rock Group overlies the Wagita Formation and is up to 500 m in thickness. It was deposited at ca. 3.0 Ga on the rifted arc margin of the Marmion Complex (Kusky and Hudleston, 1999). The formation consists of primarily of dolostone and

limestone, which is often brecciated, and in some localities is characterized by geologically significant and well developed, giant stromatolite mounds (Wilks and Nisbet, 1988; Kusky and Hudleston, 1999). The Jolliffe Ore Zone is 100 to 400 m thick and overlies the Mosher Formation and is composed of (in ascending stratigraphic order): the Paint Rock Member, Geothite Member and Pyrite Member (Kusky and Hudleston, 1999; Jolliffe, 1966). The Manganiferous Paint Rock Member has large blocks of carbonate rock, while the brecciated Geothite Member resembles a banded iron formation (Tanton, 1926, 1941a, 1941b, 1946; Bartley, 1939; Smith, 1942; Wilks and Nisbet, 1988).

The Dismal Ashrock Formation unconformably overlies Jolliffe Ore Zone and consists of mafic to ultramafic volcanic and pyroclastic rocks, which range in thickness from 100 to 400 m (Schaefer and Morton, 1991; Kusky and Hudleston, 1999). The Dismal Ashrock Formation occurs as a series blocks and lenses of komatiitic volcanic breccia, mafic pillow basalt, komatiitic volcanoclastic rock, carbonate, tonalitic gneiss, and goethite-hematite-rich rock surrounded by a matrix of fragmental komatiitic volcanoclastic rock (Kusky and Hudleston, 1999).

Overlying the Dismal Ash Formation is the Witch Bay Formation, which consists of a complex assemblage of metamorphosed mafic volcanic and volcanoclastic rocks that are approximately 2932 Ma in age (Kusky and Hudleston, 1999). The Witch Bay Formation displays physical characteristics of island-arc deposits while being geochemically similar to mid-ocean ridge basalts (Kusky and Hudleston, 1999; Tomlinson et al., 1995). These rocks are correlative in terms of age and lithology to meta-volcanic rocks in the Finlayson belt (Kusky and Hudleston, 1999).

Previous Environmental Studies

Lakehead University undergraduate and graduate students have been studying the two pit lakes since 1998, and in cooperation with the Ministry of Natural Resources from 2002 to 2009. Work by Lakehead University has largely involved seasonal sampling for water quality assessment of Hogarth and Caland pit lakes, and it was through these studies that the water quality issues were first identified. McNaughton (2001) conducted a limnological study of the two pit lakes to determine the potential of developing an aquaculture facility on Hogarth similar to the one on Caland. Vancook (2005) used GIS mapping to predict the path and timing of overflow of Caland into Hogarth and subsequent outflow into the Seine River system. Through the integration of mineralogy, geochemistry and stable isotope geochemistry, MacDonald (2005) determined that the high sulphate levels originated largely from inflowing ground waters rather than contaminated surface waters. Cockerton (2007) explored the influence of water-rock interactions in the two pits and found that the main cause of the difference in water chemistry between the two pits is the apparent higher pyrite content of the Jolliffe ore zone below Hogarth. Goold (2008) determined that the toxicity of Hogarth is due largely to the elevated levels of dissolved sulphate and less so to heavy metals which are present in very low concentrations in both lakes. Perusse (2009) conducted the first groundwater survey, investigating water quality issues of two tailings impoundments. Godwin (2009) used experimental water-rock interaction experiments coupled with toxicity identification and evaluation studies in order to predict water chemistry and toxicity at the time of outflow. Current research continues with a complete hydrodynamic

model being developed by L. Mikkelsen and a bioremediation investigation into the use of permeable reactive barriers to promote sulfate reduction being conducted by S. Shankie.

Water Quality – Pit Lakes

Caland exhibits classic meromictic conditions with a dichotomy in water quality versus depth forming a mixolimnion of oligotrophic water for a depth of 20 m and a sulphate-saline, anoxic monimolimnion for the remaining 180 m. Sulphate levels in the monimolimnion reached up to 450 mg/L. Freshwater inflow has created the thinning mixolimnion.

Hogarth has uniform water quality throughout its 200 m depth except for a very shallow, recently forming, freshwater surface layer. Sulphate levels in Hogarth often exceed 1500 mg/L. The entire Hogarth water column is sulphate-saline and aerobic. McNaughton (2001) determined that water from Hogarth was acutely toxic and there were no apparent signs of aquatic life in the lake; however, a recent study (Goold, 2008) found that it now appears to be chronically toxic. Snails and minnows were observed in shallow littoral zones of the lake during the summer of 2006 (Godwin, 2009). In 2004, Hogarth merged with Roberts' pit at the south end and appears to have a very similar chemical profile to Hogarth.

The concentration of dissolved ions in Caland is lower than that of Hogarth particularly with respect to major cations (Ca^{2+} , Mg^{2+} , Na^{2+} , K^{+}) and dissolved sulfate. All of these parameters increase with depth in each lake. Goold (2008) found that chronic toxicological affects produced by water from the Hogarth pit were likely caused by the elevated levels of dissolved ions especially sulfate (SO_4^{2-}). As a consequence, Hogarth has higher concentrations of dissolved ions compared to Caland, and subsequently higher conductivity, hardness, and TDS (total dissolved solids) levels. Likewise, these parameters all increase with depth in both pit lakes. The pH of the two lakes is circum neutral to slightly basic. The pH in Caland is on average 8.05 at 2 m and decreases with depth to an average of 7.50 near bottom, whereas Hogarth has an average pH of 7.80 at 2 m and decreases with depth to 7.10 near bottom. The alkalinity is greater in Caland (130-173 mg/L CaCO_3) than in Hogarth (94-126 mg/L CaCO_3) and values increase with depth in both lakes.

As a consequence of the Snow Lake Fish Farm on Caland, levels of certain organic constituents are greater throughout the water column in Caland as compared to Hogarth (Godwin, 2009). Caland water has higher dissolved organic carbon (DOC) concentrations than Hogarth (Caland: 2.9-3.2 mg/L; Hogarth: 1.0-1.3mg/L). Curiously the maximum DOC contents in Caland occur at 18 m whereas, at the same depth, Hogarth displays the minimum value. However, the average total nitrogen (Caland: 0.42-0.50 mg/L; Hogarth 0.40-0.75 mg/L) and total phosphorus (Caland: 0.032-0.037 mg/L; Hogarth: 0.029-0.037 mg/L) values from 2005-2008 do not differ greatly between the two pit lakes.

The isotopic composition of dissolved sulphate is depleted relative to pyrite from the submerged ore zone and surface waste rocks ($\delta^{34}\text{S} = -1.5$ to 10%) and other pit wall rocks ($\delta^{34}\text{S} = -1.6$ to 4.9%), consistent with oxidation of ore zone pyrite and subsequent fractionation due to precipitation of saturated sulphate minerals from the water column. The oxygen isotopic composition of dissolved sulphate indicates that Hogarth sulphate is produced by anaerobic oxidation of pyrite, whereas the oxygen isotope composition of Caland sulphate is consistent with aerobic oxidation of pyrite (Fig. 6a).

The near neutral pH of both pit lakes is the result of interactions with carbonate wall rocks. The carbon isotopic composition of DIC from Hogarth is similar to that isotopic composition of the carbonate wall rocks ($\delta^{13}\text{C} = -4.0$ to 0.6‰ ; Fig. 6b). However, DIC in Caland pit water is more depleted and suggests either isotopic exchange with isotopically depleted DOC generated by fish farming activities or atmosphere exchange.

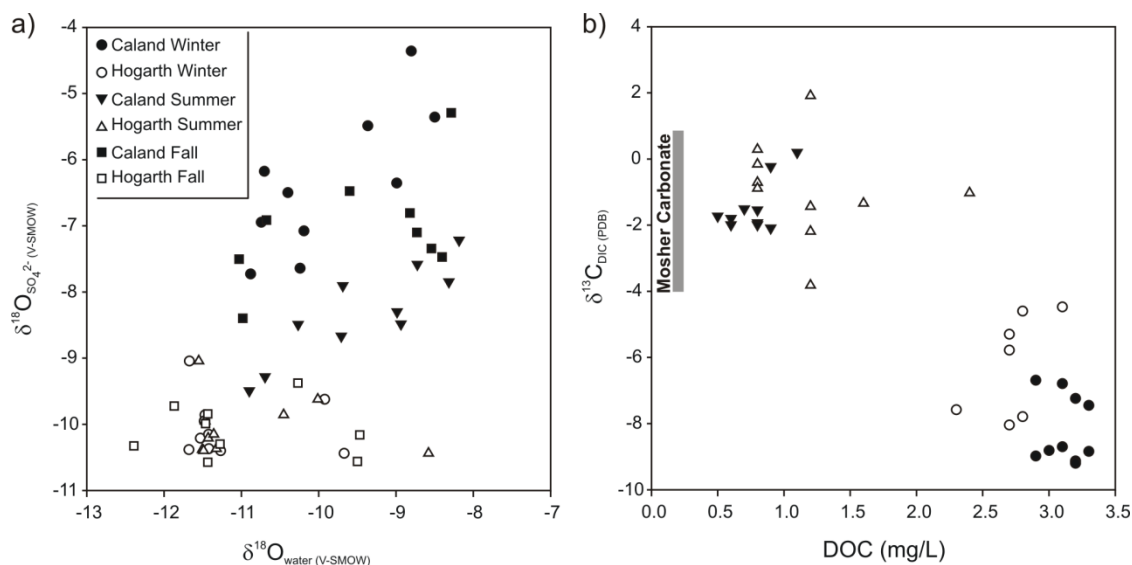


Figure 6. a) The $\delta^{34}\text{S}$ and $\delta^{18}\text{O}$ isotopic composition of dissolved sulphate, and b) $\delta^{13}\text{C}_{\text{DIC}}$ and DOC composition of Hogarth and Caland pit lakes (from Conly et al., 2008).

Water Quality – Ground Water

Figure 7 shows the average composition of major anions and cations, Fe, Mn, total metals and pH for all ground water monitors and selected surface waters. Shallow ground waters contained within pyrite-quartz and goethite-hematite-quartz tailings/waste rock are sulphate-dominant, whereas the one regional ground water is chlorine-dominant. Interactions with pyritic waste rock produces ground waters with elevated sulfate (>3000 mg/L), low pH (<6) and high Fe (>95 mg/L). Fe-oxide + quartz tailings produce pH-neutral ground waters with moderate to high concentrations of sulphate (200-1000 mg/L) and are Fe-depleted (<1 mg/L). The difference in pH, sulphate and Fe levels reflects the following: i) the relatively insoluble behaviour of goethite and hematite in pH-neutral waters; ii) possible occurrence of soluble Fe-sulphates; and, iii) the relative abundance of pyrite and the rate at which it is oxidized. Surface waters parallel the observed trends for ground waters. However, for both sites anion and cation abundances are typically lower, and likely reflect dilution from surface run-off and precipitation.

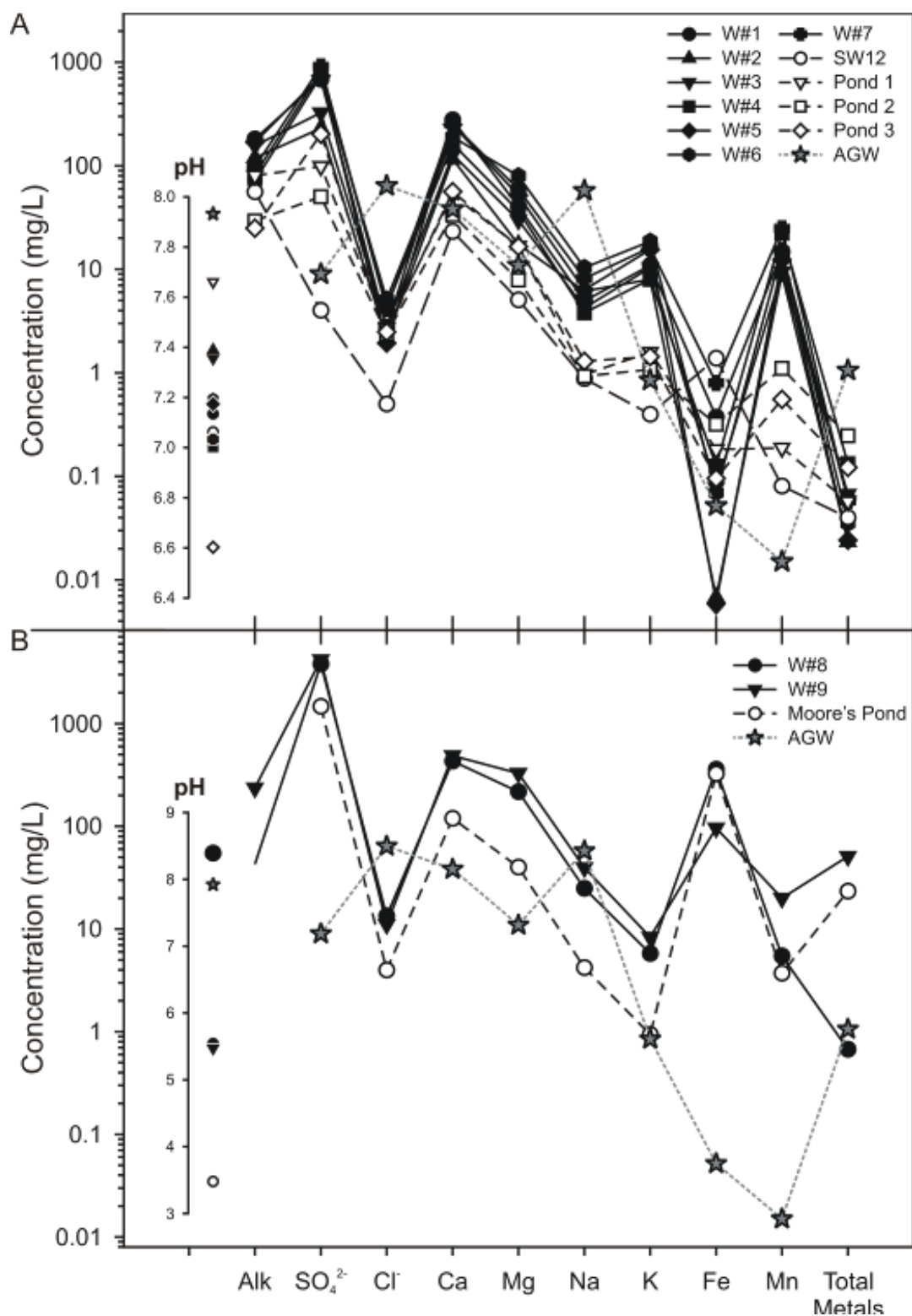


Figure 7. Schoeller diagrams, with pH (inset), showing the average compositions for ground water and surface water from sites 1 (A) and 2 (B). Abbreviations: Alk – alkalinity; AGW – Atikokan ground water (from Conly et al., 2009).

Figure 8 shows the variation in carbon and sulphur isotopes for Steep Rock ground water and surface water. $\delta^{34}\text{S}$ ratios for ground water from both sites are within the reported range for the two pit lakes, and indicate that the dissolved sulphate is produced from the oxidation of pyrite. Ground water from pyritic materials displays a narrow range in $\delta^{13}\text{C}$, and is within the range reported for the two pit lakes, and reflects exchange with atmospheric CO_2 and carbonate dissolution. In contrast, the $\delta^{13}\text{C}$ of ground water from Fe-oxide tailings is both more depleted and variable. Such values are interpreted to reflect isotopic exchange with CO_2 released from buried organic-rich (bog) soils. Ground waters that are both highly depleted $\delta^{13}\text{C}$ and enriched $\delta^{34}\text{S}$ reflect methanogenesis and bacterial sulfate reduction, arising from interaction with organic-rich (bog) soils from below.

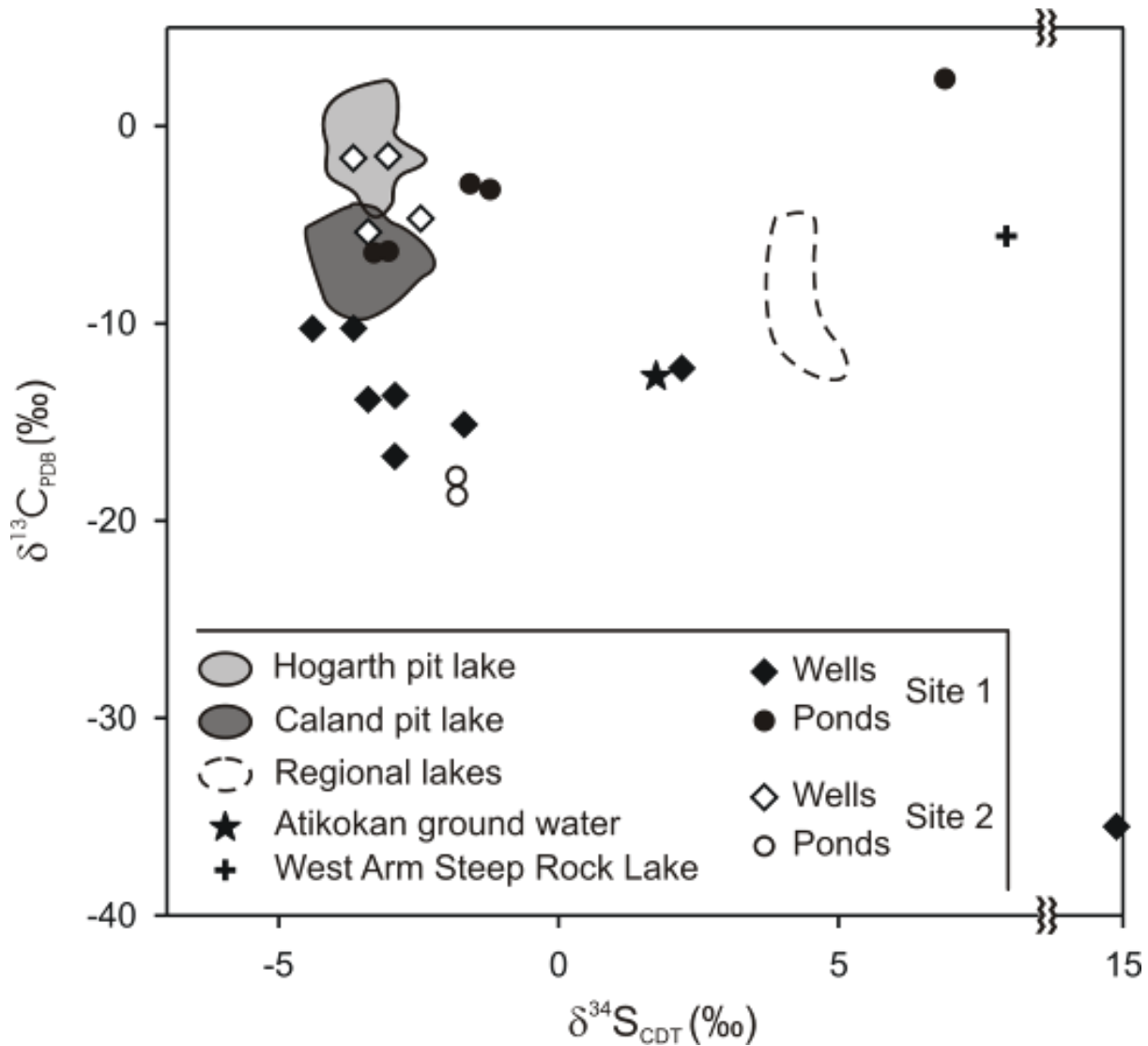


Figure 8. Variation in $\delta^{13}\text{C}$ and $\delta^{34}\text{S}$ of ground water and surface water (from Conly et al., 2009). Data for other waters (excluding regional water; unpublished) from Conly et al. (2008).

Field Trip Stops

Stop Number	Location	Details	UTM Coordinates Zone 15, nad'83
1	Hardy Dam	• Largest earthen dam owned by the Province of Ontario • Originally constructed in 1944 • Holds back Rawn Reservoir, former flow into Steep Rock Lake directed into Atikokan River through a series of tunnels to the southwest • Highway 622 will be under approximately 5 m water.	606391E 5403980N
2	Caland Lookout	• Triangulation Island • Snow Lake Fish Farms (now defunct) • Caland Flats (flooding) • Water quality, sulphate, TDS, meromictic conditions • Rock slope stability	603135E 5408000N
3	Red, Green and Moore's Ponds	• AMD causing low pH • pH buffered by carbonate host rocks • elevated sulphate, high TDS • pyritic waste rock piles • slope stability	600055E 5405046N
4	Errington Pit	• First open pit mined • Pit floor approximately 180m below current water level • "Green Pond shows evolution of water quality • "Yellow Creek" • Fe pptn on creek bed	600133E 5405282N
5	B-2 Shaft Building	• PCB Storage site • Forced entry, public safety	599167E 5405329N
6	Roberts Pit	• Pit lake 180 m deep • Water quality • Slope stability	599206E 5405782N
7	"Party Point"	• Narrows Dam, inundation scenarios • Slope stability • Water quality, sources of impacts	600118E 5407376N

Stop Number	Location	Details	UTM Coordinates Zone 15, nad'83
8	SR Pelletizing Plant	• Soil impacts (As, metals) • Relict structures • Closure activities • Underground openings	600365E 5408468N
9	A-2 Shaft Remnants	• Public safety • Unauthorized salvage operations in underground workings • Unknown infrastructure	599630E 5408685N
10	B-1 Shaft/Vault	• Overlook of pit, "Road to Nowhere" • Water Quality • Slope stability	598614E 5408105N
11	Narrows Dam	• Original diversion • Flooding/inundation • Pyrite rich material • Mobilisation of sediments in West Arm	598931E 5407490N
12	West Arm Dam	• Repairs 2007 • Changes to Steep Rock Lake • Settling Basin • Ongoing risk	597854E 5402450N

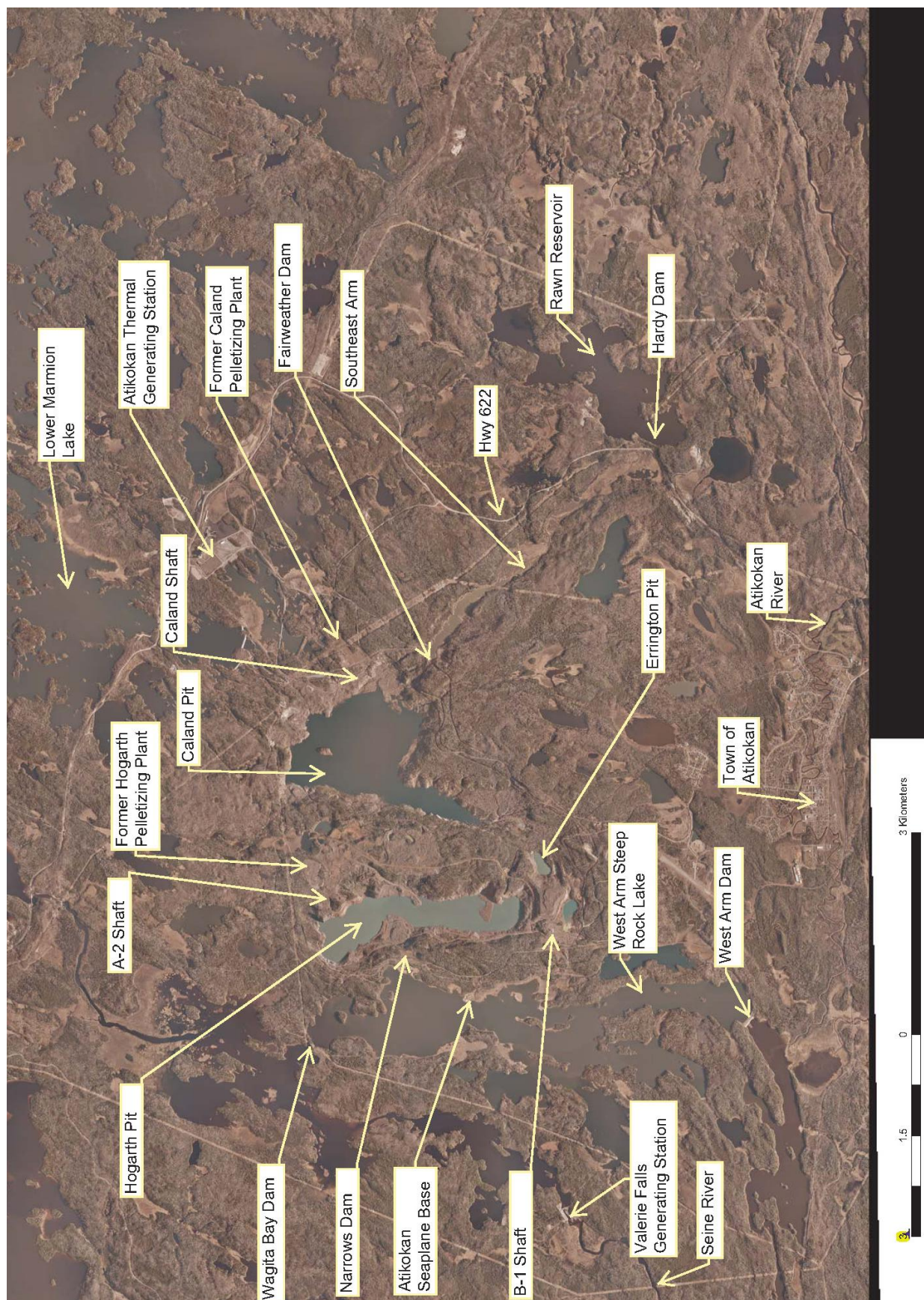


Figure 9. LIDAR ortho map showing field trip stops and other points of interest.

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