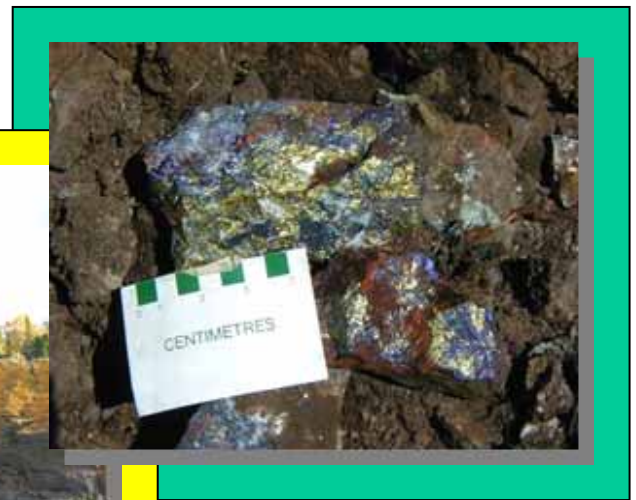


Keweenawan Rocks of the Mamainse Point Area

Field Guide for the 52nd Annual Institute on Lake Superior Geology Vol. 52, Part 5



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MIDDLE KEWEENAWAN ROCKS OF THE MAMAINSE POINT AREA

INTRODUCTION

Mid-Keweenaw mafic volcanic flows, felsic intrusive to extrusive rocks, and clastic sedimentary rocks of the Mamainse Point Formation (MPF) are located about 64 km north of Sault Ste. Marie, along the east shore of Lake Superior (Fig. 1). This area was the subject of a

1989; Nicholson et al. 1997). Although there is only very limited geochronology in the MPF, recent work in the Lake Nipigon area indicates that rift related magmatic activity began at ~1114 Ma (Heaman and Easton 2005) which extends the period of magmatic activity from the ~22 Ma by Davis and Green (1997) to ~28 Ma. This extended period of time is much longer than the 1 to 5 Ma of volcanic activity proposed for more Phanerozoic continental flood basalt provinces by Jerram and Widdowson (2005), but is comparable

to the time periods proposed for Archean age magmatic events possibly related to mantle plumes. This trip will provide an opportunity to re-examine many of the same stops described by Giblin (1974) and Annells (1973).

REGIONAL GEOLOGY

The ~1.1 Ga Midcontinent Rift extends for over 2000 km and is interpreted to be an aborted continental rift (Fig. 1) (e.g. Van Schmus and Hinze, 1985). Seismic profiling of Lake Superior indicates that the rift consists of a series of asymmetric grabens separated by accommodation zones filled with up to 30 km of volcanic and sedimentary rocks (e.g. Cannon et al., 1989). Initiation of rifting has been related to a mantle plume, or hot spot (e.g. Hutchinson et al. 1990; Nicholson and Shirey 1990),

which resulted in the production of < 1 500 000 km³ of volcanic and intrusive rocks (Klewin and Shirey 1992). Rift related volcanic and sedimentary rocks of the Keweenaw Supergroup are generally exposed along the margins of the rift, with the greatest volumes exposed west of Lake Superior (Fig. 2) (Nicholson et al. 1997). Limited exposures are present along the east shore of Lake Superior at Mamainse Point, Cape Gargantua south of Wawa, and Michipicoten Island with a more extensive

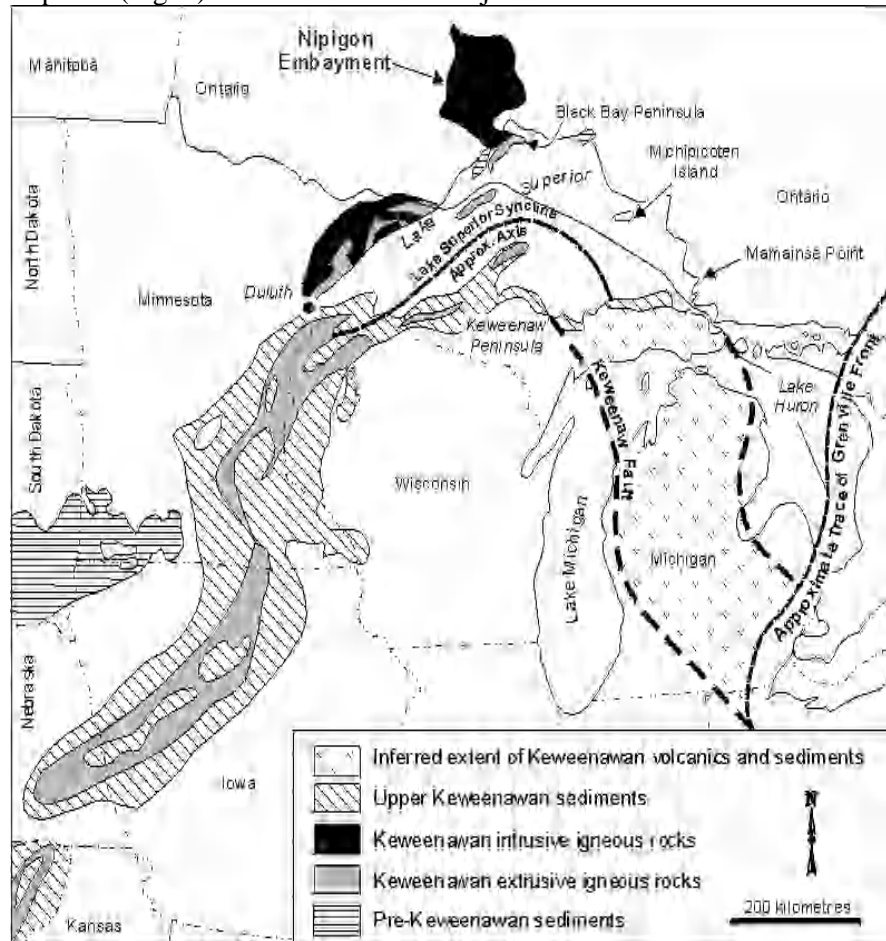


Figure 1. The Midcontinent Rift System and some of the major regional geological features from Lightfoot et al. (1999).

field trip by Giblin (1974) during the Annual Meeting of the Institute of Lake Superior Geology. Since that time, there has been various studies completed on the MPF (e.g. Massey 1980; Klewin and Berg 1991; Shirey et al. 1994; Lightfoot et al. 1999; Walker et al. 2002) and on the rocks in other parts of the Keweenaw Midcontinent Rift (e.g. Green 1983; Cannon et al.

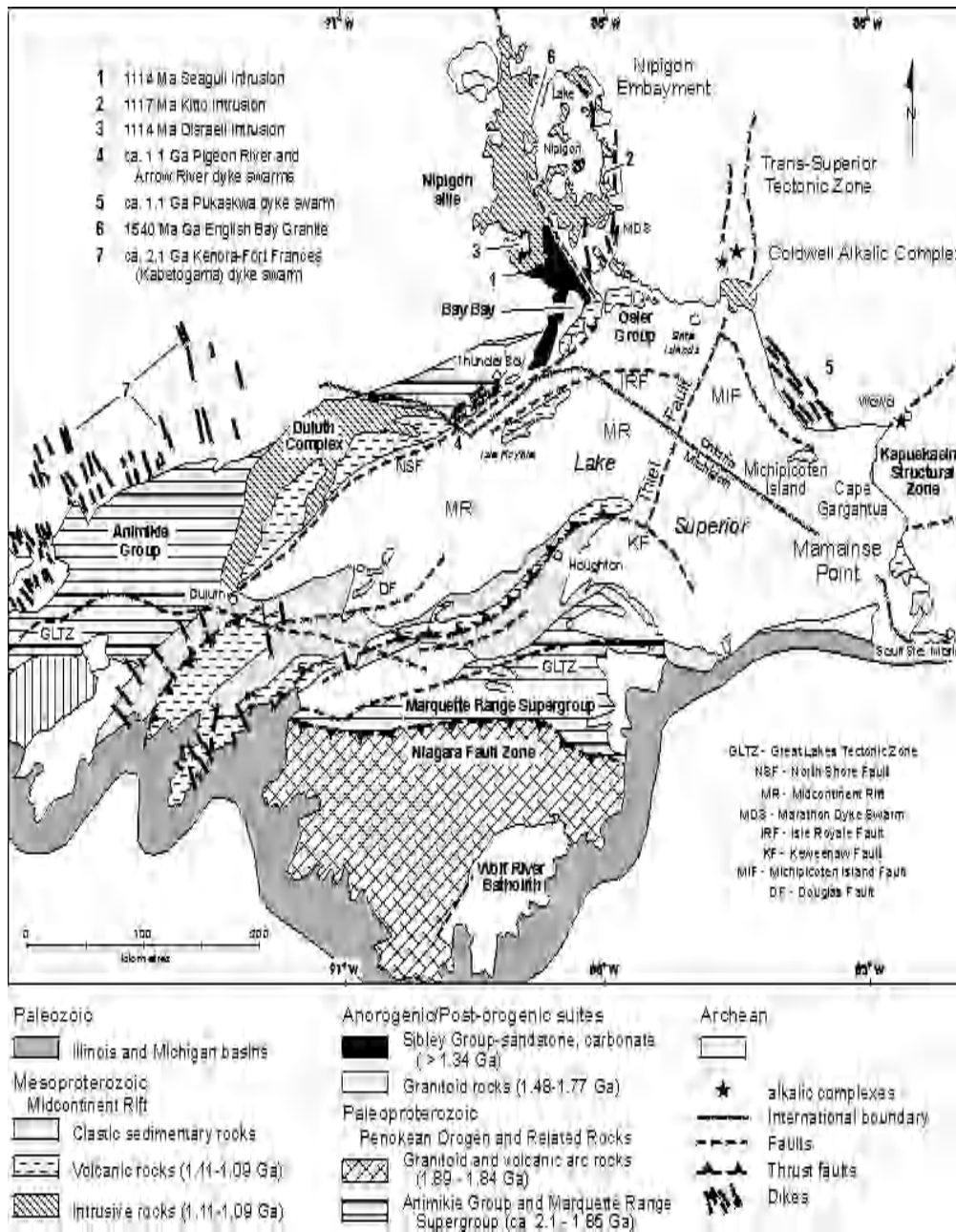


Figure 2. Geological map of the Lake Superior basin after Lightfoot et al. (1999), and modified based on the recent mapping in the Nipigon Embayment (Hart and MacDonald in press).

sequence of volcanic rocks present on Simpson and St. Ignace islands and Black Peninsula near Nipigon (Fig. 2). A rift-wide correlation of the volcanic rocks was presented by Nicholson et al. (1997) (Fig. 3), but the position of the MPF could only be estimated using paleomagnetic data due to a lack of detailed geochronology.

GENERAL GEOLOGY

The Keweenaw rocks are underlain by Archean rocks of the Batchawana Greenstone Belt that consists of mafic to intermediate metavolcanic and minor felsic metavolcanic rocks, and Algoman-type iron formation (Giblin 1974). The Archean rocks strike east, have been metamorphosed to amphibolite facies, and deformed resulting in northeast trending isoclinal folds and penetrative fabric with steep dips.

The Mamainse Point Formation (MPF) unconformably overlies the Archean rocks, and consists of a sequence estimated to be between 4200 and 6000 m thick consisting of sub-aerial mafic flows,

intercalated clastic sedimentary and felsic igneous rocks (Fig. 4 and 5). The mafic flows can be subdivided into lower olivine- and plagioclase-bearing basalts and upper plagioclase-bearing basalts (Annells 1973), which corresponds to a major change in the chemistry of the basalts (e.g. Klewin and Berg 1991; Lightfoot et al. 1999). Clastic sedimentary rocks consist of predominately conglomerates, and the 550m thick Great Conglomerate horizon marks the break between the lower and upper basalts. Minor felsites, quartz porphyry and flow-

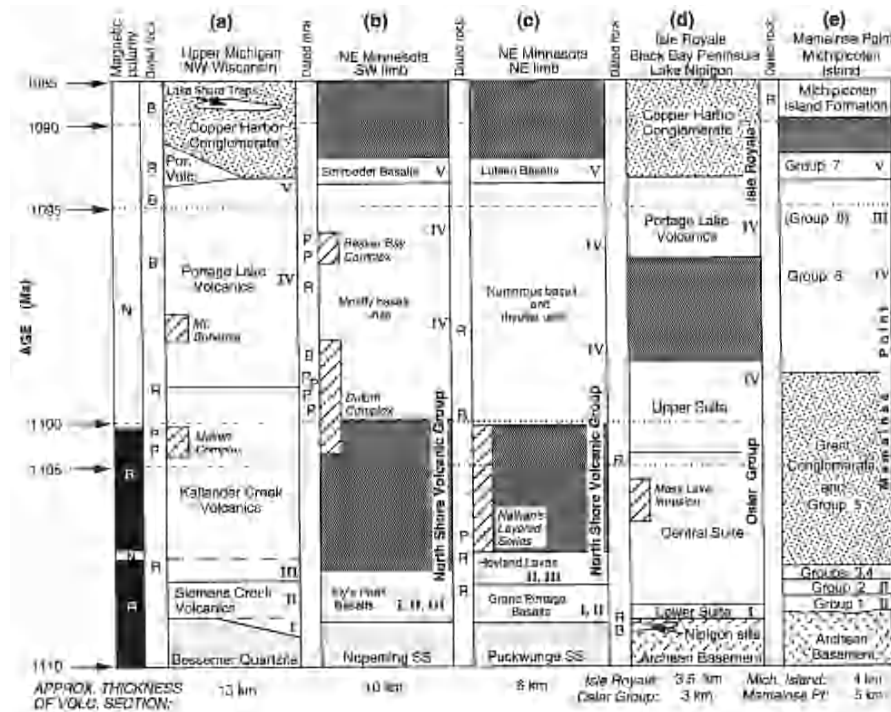


Figure 3. Schematic correlation of MRS volcanic rocks in western and eastern Lake Superior from Nicholson et al. 1997.

banded rhyolites occur as intrusive and possibly extrusive units within the MPF. Felsic dykes, porphyries, and breccias also intrude the Archean rocks to the east, and are considered to be related to the felsic volcanic and intrusive rocks occurring within the MPF. Some of the intrusions host mineralization, with the best examples being the ~1055 Ma breccia pipe hosting Cu-Au-Ag at the past-producing Tribag Mine (Wanless et al. 1968) and several Cu-Mo prospects at the Jogran Porphyry (Tortosa and Moss 2004). The volcanic rocks generally strike to north to northwest with homoclinal dips of 15°-60° to the southwest and are cut by northwest- and northeast-trending faults.

The mafic flows of the Alona Bay area form an about 1300 m thick sequence of basaltic flows with less lithological variation than the MPF, and lacking intercalated sedimentary and felsic igneous rocks (Annells 1973). Located approximately 4 km to the north of the MPF, the Alona Bay flows consist of olivine- and plagioclase-bearing basalts that have been proposed to be equivalent to the lower division of the MPF (Walker et al. 2002; Annells 1973).

Along the north side, the Mamainse Point Formation is unconformably overlain by the Mica Bay Formation which is considered to be the equivalent of the Freda Formation south of Lake Superior (Fig. 4) (e.g. Annells 1973; Giblin and Armsburst 1969). To the south, the Mamainse Point Formation is in fault contact with a red sandstone interpreted to be part of the Jacobsville Formation. Paleomagnetic age estimates by Halls and Pesonen (1982) suggest that both of these units are late Keweenawan.

Mafic Volcanic Rocks

The MPF consists of 300 to 350 individual mafic flows that commonly range in thickness from 1.5 to 9.0 m, with some flows being up to 30m thick and other as thin as 0.15 m (Annells 1973). Many of the flows have upper and lower vesicular zones, with the lower zone vesicles often pipe-like and bent in the direction of flow. Most of the flows have ropy pahoehoe surfaces, but some have clinkery scoriaceous flow tops, and Annells (1973) noted that the olivine-rich flows commonly have scoriaceous rather than pahoehoe flow tops. Prismatic jointing is also common in the olivine-rich flows, but also observed in the finer grained flows.

The mafic flows were subdivided into a Lower and Upper Division by Annells (1973) with the polymictic conglomerates of the Great Conglomerate forming the break between the divisions (Fig.5).

The Lower Division, located along the north side of the MPF, is about 1700 m thick and consists of about 20% flows with olivine phenocrysts and 80% flows with plagioclase and minor olivine and pyroxene phenocrysts. Two volcanic conglomerates and two thin felsic horizons are intercalated with the flows. The Upper Division, located to the south, consists of

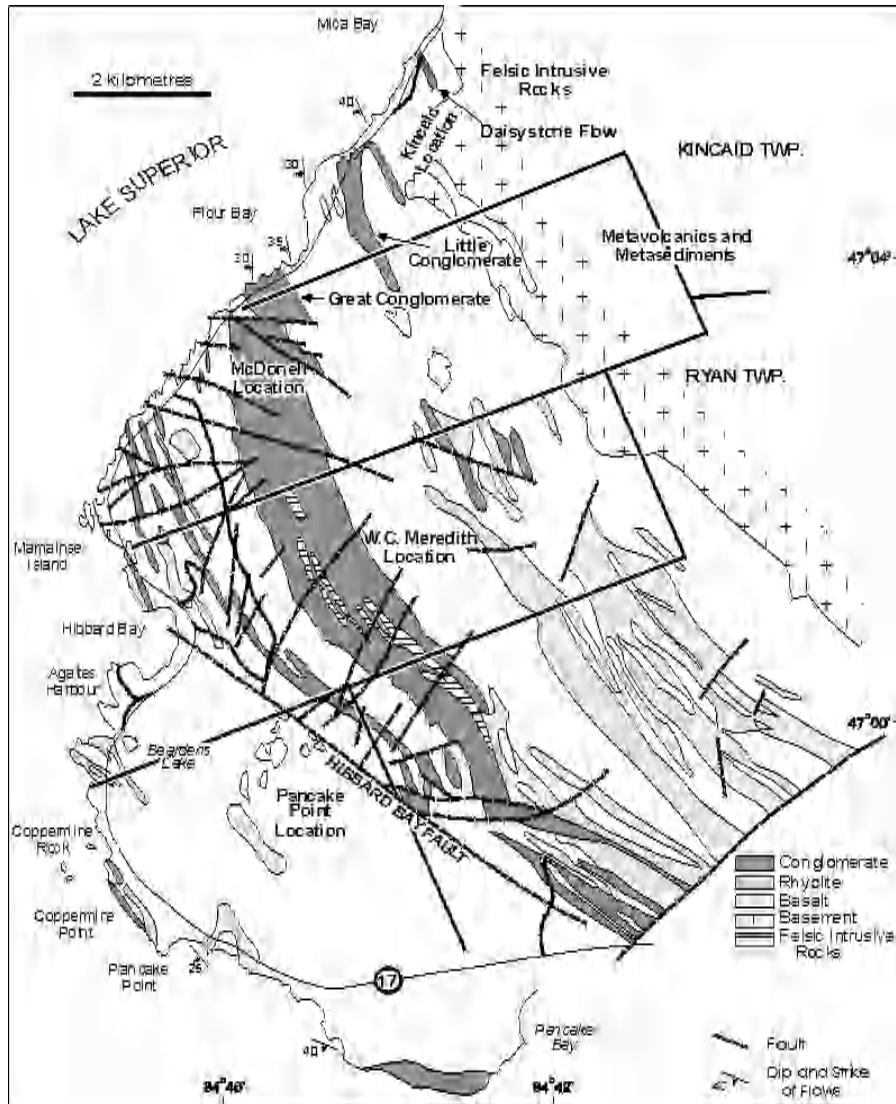


Figure 4. Geological map of the Mamainse Point Formation. Based on OGS Map 2251 (Giblin and Armburst 1969) and modified after Lightfoot et al. (1999).

about 3000m of fine-grained to aphanitic, subophitic to ophitic flows. There are a number of clastic sedimentary and felsic horizons intercalated with the Upper Division flows.

The plagioclase glomeroporphyritic “daisy stone” flow is a distinctive unit towards the base of the Lower Division and contains radiating calcic plagioclase laths, up to 5 cm across (Annells 1973). Annells (1973) also described a flow in the Mamainse Point area, near the base of the Upper Division, as containing a 3.25 m zone of large euhedral plagioclase up to 10 cm long. Annells (1973) also notes that there is a flow with similar textures in the Cape Gargantua sequence

about 65 km to the north. These flows also resemble a plagioclase-rich ponded flow in the Osler Volcanic Group volcanic rocks which is exposed on the southeast corner of St. Ignace Island, in the Thunder Bay area (Sutcliffe and Smith 1988). The top of that flow has a texture resembling the glomeroporphyritic “Daisy Stone” while the core of the flow consists of plates of feldspar up to 5 cm in width.

Felsic Rocks

Generally rhyolitic in composition, the felsic igneous rocks in the MPF have been classified as felsite, quartz porphyry and flow-banded rhyolite. Many of these rocks occur as plugs, dykes, and sheets intruding the mafic flows commonly with auto-brecciated zones centimeters to tens of centimeters in width containing clasts of basalt and felsite and occasional agglomeratic zones

suggesting there may be eroded rhyolitic domes (e.g. Annells 1973; Giblin 1974). The depth of intrusion is not known, or whether some of these units may have formed high level cryptodomes that may have breached surface.

These rocks are commonly reddish brown to pink to grey-white, and vary from fine-grained and massive to quartz and/or feldspar porphyritic, with the groundmass and massive portions composed of quartz, altered feldspar, mica, chlorite, and epidote. Some units may be flow banded with the best exposed examples located along the margins of one body exposed at Cottrell Bay (Fig. 3). This flow banding shows tight asymmetric isoclinal folds with bands that are generally parallel to the contact. The quartz porphyries commonly form small plugs or thin intrusive sheets with paramorphed b-quartz

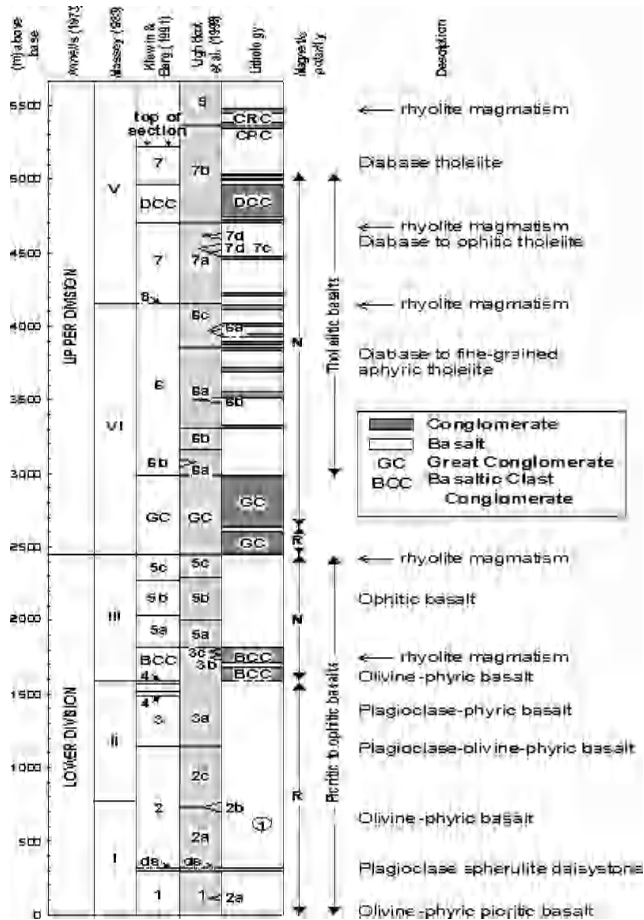


Figure 5. Petrographic and geochemical variations through the Mamainse Point Formation with the stratigraphic subdivisions of Annells (1973), Massey (1983) and Klewin and Berg (1991) modified by Lightfoot et al. (1999). Magnetic polarity is based on Halls and Pesonen (1982).

phenocrysts up to 8 mm in size and altered euhedral feldspar (Annells 1973). In one location Annells (1973) described a composite sheet of felsic and mafic material which was interpreted to indicate that the felsic and mafic lavas were erupted simultaneously.

Felsite dykes cut, and are cut by, structures hosting the copper mineralization at the Coppercorp and Mamainse mines, and are considered to have been emplaced contemporaneously with fault movement, brecciation and sulphide deposition (Heslop 1970). Keweenaw quartz-feldspar porphyries and breccia pipes hosting copper and molybdenum mineralization intrude the Archean rocks to the east of the MPF (e.g. Tribag Mine), and may be related to the felsite dykes.

Mafic Intrusive Rocks

Mafic intrusive rocks are relatively rare in the MPF and typically consist of narrow diabase and fine-grained dykes cutting the flows. Annells (1973) describes the dykes as typically less than 3 m, east or north striking with steep dips, and varying degrees of alteration. No connection was observed between the dykes and flows.

Clastic Sedimentary Rocks

Clastic sedimentary rocks occur at a number of levels within the stratigraphy of the MPF and consist of volcanic conglomerates in the Lower Division and polymictic conglomerates in the Upper Division (Fig. 5). The volcanic conglomerate was described by Annells (1973) as being composed of poorly sorted, angular to subangular clasts of fine- to coarse-grained Keweenaw basalt in a silty basaltic matrix. Some of the clasts are irregular, rounded, amoeboid shaped which was interpreted to be a result of deposition while still hot. Rare red siltstone, but no basement rocks or felsic volcanic, clasts were observed. It was noted that the horizons become finer grained and well laminated upwards.

There are a number of horizons of clastic sedimentary rocks intercalated with the mafic flows of the Upper Division, but the largest volume occurs in the Great Conglomerate which is located approximately in the middle of the Formation between the Lower and Upper Divisions. The Great Conglomerate is a sequence of predominantly polymictic boulder conglomerates containing thin lenses of red to grey sandstone, siltstone, shale and granite, and is interbedded with two basalt flows of the Upper Division. The base of the conglomerate is described by Annells (1973) as a thin layer of red sandstone, overlying a scoriaceous flow top. The conglomerates are poorly sorted, with indistinct bedding containing well rounded to sub-rounded, pebble to boulder sized clasts of granite and basalt, with minor amounts of diabase, felsite, and vein quartz. Conglomerates exposed along strike to the south of the highway occur as 10 to 20 cm thick, graded beds with some beds displaying weakly developed cross bedding suggesting that the trough in which the Great Conglomerate was deposited is deeper to the north-northwest. Some of the well laminated sandstone lenses in the

highway section are cross-bedded. Annells (1973) suggested that the conglomerates were deposited in an alluvial fan environment. The presence of granite clasts suggests a reduction in the rate of, or possible hiatus in, volcanism so that material could be transported from the adjacent Archean terrains or a more extended period of time than previously interpreted. Regionally, the Great Conglomerate resembles the conglomerate exposed on Puff Island, near the top of the exposed portion of the Osler Group which is located near the top of the ~3 km of exposed volcanic rocks.

Younger Clastic Sedimentary Rocks

The Mica Bay Formation is an approximately 61 m thick sequence of clastic sedimentary rocks unconformably overlying the volcanic rocks of the MPF along the north side of the formation (Giblin 1974). An up to 30 cm thick, polymictic, matrix supported conglomerate forms the basal member of the formation. Most of the formation is composed of grey-brown siltstones, arkoses, and minor immature quartz pebble conglomerates with siltstones forming approximately 70% of the section. Giblin (1974) interpreted these rocks to have been deposited in a shallow water environment based on the presence of ripple marks, graded bedding, cross-lamination, flame structures, and ball-and-pillow structures with flute casts and clastic dikes indicating current flow towards the north. The Mica Bay Formation is considered to be the equivalent of the Freda Formation (e.g. Annells 1973; Giblin and Armbrust 1969).

To the south, the Mamainse Point Formation is in fault contact with sandstones displaying the typical red and white mottling of the Jacobsville Formation. The Jacobsville Formation is interpreted to form the floor of much of the east part of Lake Superior (e.g. Giblin 1974). Paleomagnetic age estimates by Halls and Pesonen (1982) suggest that both of these younger sedimentary units are late Keweenawan.

ALTERATION

All of the mafic flows appear to have undergone low-grade hydrothermal metamorphism, and some alteration appears to be deuteric. Annells (1973) noted that olivine is replaced by saponite and hematite even in basalts

with fresh feldspar. Plagioclase is variably zeolitised and some have patches of albite and epidote. Augite is partially altered to clin amphibole and chlorite. Opaque minerals are commonly hematized, with titanium-rich phases altered to leucoxene and sphene. In the felsic rocks, the feldspar is kaolinized and quartz fills cavities. The felsic rocks at Cottrell Cove are mottled light reddish brown to beige, and also contain irregular patches or funnel-shaped features. The mottling resembles the variations observed in the oxidized Sibley Group sedimentary rocks of the Nipigon area, suggesting that this variation may be in part a result of possibly deuteric reduction of an originally oxidized rock. However, the funnel-shaped features may be a result of alteration during degassing of the flows.

All vesicles within the mafic flows are always filled, and the composition of the amygdules is variable. Annells (1973) describes some fillings as an outer zone of chlorite with a chalcedony rim, and a core of colourless quartz and zeolite but some have yellow epidote, colourless prehnite and calcite. Similar mineralogy may also occur as fracture fillings. Lightfoot et al. (1999) suggest that there was a stratigraphic variation with zeolites, including heulandite and stilbite, common in the Upper Division flows and prehnite and pumpellyite common in the Lower Division flows.

Epidote alteration is also more common in the Lower Division flows (e.g. Annells 1973) and, along with hematite and specular hematite, in major crosscutting veins and fissures associated with mineralization at the Coppercorp and Mamainse Mines (e.g. Richards and Spooner, 1989). Calcite is also present in fractures cutting the clastic sedimentary units interbedded with the Lower Division and in the Great Conglomerate.

STRUCTURAL GEOLOGY

The flows of the MPF vary in strike from south to north from northwest to north with dips decreasing from east to west from 55° to 15° west defining a broad antiform that gently plunges to the west (Annells 1973). In the area of Pancake Point and Cottrell Cove, the strike of the flows is highly variable and some flows appear to be overturned which has been interpreted to be a

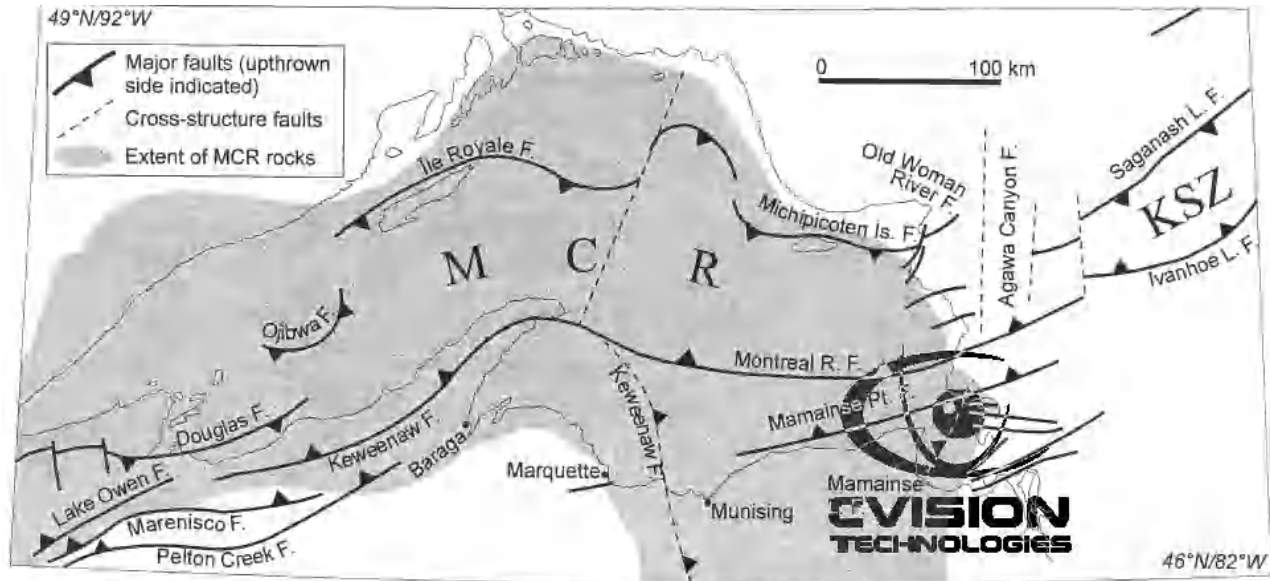


Figure 6. Major faults of the Lake Superior portion of the Midcontinent Rift. From Manson and Halls (1997)

result of the intrusion of a number of felsic bodies.

Rocks of the Mica Bay Formation, that overlie the flows of the MPF to the north, strike 065° , are gently folded, and dip 15° to 30° north or south (Giblin 1974). The Jacobsville sandstones, which overlie the flow to the south, strike 335° to 320° and dip 15° to 25° west.

The Alona Bay flows strike north and dip 45° to 49° west with the basal unit unconformably overlying Archean felsic plutonic rocks (Annells 1973). This section terminates against a northwest-trending fault filled by a diabase dyke. The orientation of these flows is comparable to the northern flows of the MPF.

A large number of northeast- and northwest-trending normal faults with limited vertical displacements cut the flows of the MPF (Annells 1973). However, Annells (1973) considered the ~6000 m of stratigraphy within the MPF to be in part a result of possible fault repetition. A series of apparently radially distributed faults, with a focal point roughly near the Coppercorp Mine, offset stratigraphy (Tortosa and Moss 2004). The focal point corresponds to a magnetic high and an adjacent large felsite body located about 4 km east of the Coppercorp Mine. A large number of fractures of variable orientation and no discernable displacement cut

the flows. These fractures are up to 30 cm wide and commonly filled with silt and other material similar to the matrix of the conglomerates. Annells (1973) speculated that these fracture fillings were clastic dykes formed as a result of minor adjustment of the flows during deposition.

There are 2 major regional faults, Mamainse Point and Montreal River faults, that bound the MPF to the north and south (Fig. 4 and 6) (Manson and Halls 1997). To the south, the northeast-trending Mamainse Point Fault juxtaposes the flows of the MPF against red sandstones of the Jacobsville Formation. This fault is a re-activated ductile shear zone that forms the southern margin of the Batchawana greenstone belt to the east and may correlate with faults in northern Michigan and Wisconsin. To the north, the Montreal River Fault forms the northern boundary of the MPF and is the western boundary of the Abitibi and Wawa subprovinces, and the southwest extension of the Ivanhoe Lake fault which is the eastern boundary of the Kapuskasing Structural Zone. This fault may correspond to the Keweenaw Fault to the west (Fig. 6). Both of these faults have been interpreted to be major reverse faults associated with late compression related to the Grenville Orogen in the late Keweenawan.

Two major faults, Mamainse Lake and Hibbard Bay faults, that transect the MPF and offset or truncate stratigraphy (Fig. 4 and 6). The Mamainse Lake Fault trends northeast, has a variable sinistral displacement, and appears to

converge with the Mamainse Point Fault under Pancake Bay. The Hibbard Bay Fault is northwest-trending, subparallel to the rift axis located to the west under Lake Superior, and truncates stratigraphy at an acute angle.

LITHOGEOCHEMISTRY

Geochemical studies by Massey (1980) and Klewin and Berg (1991) have characterised the flows of Mamainse Point Formation, and have identified geochemical variations correlating with stratigraphic position within in the MPF. Massey (1983) identified five major groups of flows with the break between the Lower and Upper Division occurring stratigraphically at the break between Groups III and IV, across the Great Conglomerate (Fig. 5). Klewin and Berg (1991) subdivided the MPF into seven groups, with Groups 1 to 5 corresponding to Groups I to III of Massey (1983) (Fig. 5). Lightfoot et al. (1999) proposed a subdivision of the groups of Klewin and Berg (1991) (Fig. 5).

The Lower Division contains olivine-rich flows (Annells 1973), and some of these flows were identified by Klewin and Berg (1991) to be picritic in composition. Based on the presence of skeletal olivine and the fact that the flow composition did not fall along an olivine control line, Berg and Klewin (1990) concluded that these flows were not olivine cumulates but rather formed as a result of melting at deeper levels in the mantle. Overall the Lower Division flows, Groups 1 to 5, consist of basal picrites to picritic basalts overlain by the “daisy stone”, and then a series of tholeiitic to high Mg-tholeiitic basalts. Some of the main characteristics of the different groups were summarized by Lightfoot et al. (1999) (Fig. 5, 7, and 8a, b):

- Group 1 and 2a - high Mg-numbers (0.64-0.70), TiO₂ (1.1-2.0 wt.%) and Gd/Yb, with low CaO and Al₂O₃.
- Groups 2b and 3 - lower MgO, TiO₂, and Gd/Yb compared with Groups 1 and 2a, but high La/Sm, Al₂O₃, and CaO.
- Group 4 – higher MgO (9.0-10.5 wt.%) but low P, Zr and Hf compared to other groups
- Group 5 - quite low TiO₂ (<1.5 wt.%), a wide range of MgO and La/Sm with low Gd/Yb, with very low Ni and moderate

Cu in some flows; other flows have high La/Sm and SiO₂ suggesting crustal contamination.

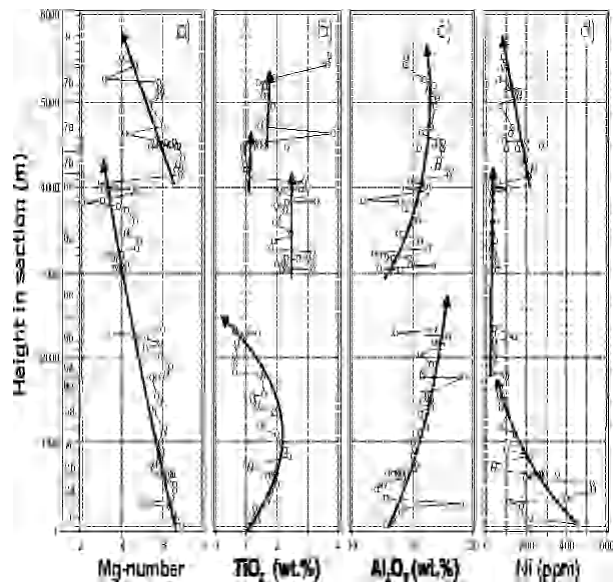


Figure 7. Variations in selected elements with stratigraphic position after Klewin and Berg (1991) and arrows indicating the general direction of geochemical evolution. GC - Great conglomerate; BCC - basalt clast conglomerate. Sample position in metres above the base (from Lightfoot et al. 1999).

Most of the variation in the Upper Division flows is a difference in the absolute trace element abundances rather than incompatible element ratios. Some of the main characteristics of the different groups were summarized by Lightfoot et al. (1999) (Fig. 5, 7, and 8a, b):

- Group 6 - high Yb (2.3-5.7 ppm), highest TiO₂ (1.8-3.4 wt.%) and Mg-number (0.30-0.48); subgroups 6a, 6b, and 6c defined by varying Ce, Yb, and Zr contents and may reflect interdigitate throughout the stratigraphy, possibly in part due to local fault repetition
- Group 7 – more primitive than Group 6 with elevated Ni (>75 ppm), low Cu (dominantly less than 100ppm), and TiO₂ (~0.9 wt.%); subgroup 7a has elevated Mg-number (0.62-0.70), low TiO₂ (0.9-1.2 wt.%), and low incompatible elements abundances (e.g. Ce=15-20 ppm); subgroup 7b has lower Mg-number (dominantly 0.52-0.60),

but higher TiO₂ (1.3-1.9 wt.%) and incompatible element abundances (Ce=20-25 ppm).

Group 8 – are interspersed with Groups 6 and 7; elevated incompatible elements and LREE (e.g. Ce: 120-130ppm) and high TiO₂ (3.6-3.7 wt.%)

Group 9 - elevated TiO₂, Ce, Yb, Zr, La/Sm, LILE, and low Mg-number, Al₂O₃, and Ni

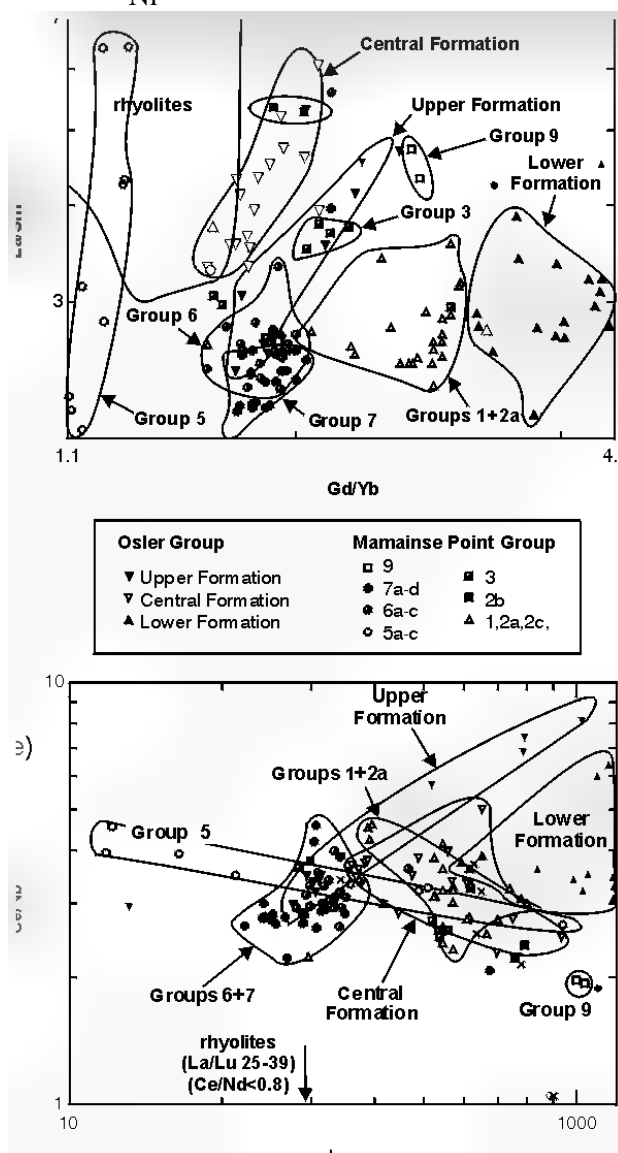


Figure 8a. Variation in La/Sm versus Gd/Yb with symbols representing samples from different groups in the MPF and Osler Group volcanic rocks; Figure 8b. Variation in Ce/Nb versus La/Lu in MPF and Osler Group flows. (from Lightfoot et al. 1999)

The felsic rocks have SiO₂ of 72-81 wt.% with moderate Al₂O₃ (11-15 wt.%) (e.g. Annells,

1973; Lightfoot et al. 1999). These rocks have Zr/Y ratios of 1.9 to 7.3, 10 to 53 ppm Y, (La/Yb)_{cn} ratios of 2.67 to 8.92 with (Yb)_{cn} values of 4.55 to 25. They also have moderately positive Nb+Ta, and negative P, Ti, and Eu on a chondrite normalized extended element diagram (Lightfoot et al. 1999). Lightfoot et al. (1999) compared these rocks to sialic volcanic rocks found in other CFB such as the Salsette Island suite north of Bombay, India, in the Deccan Trap, and based on this similarity suggested that these rocks formed by a similar mechanism of partial melting of basaltic crust. These rocks could also be classified as FII type felsic volcanic rocks which suggests that they may have the potential to host volcanogenic massive sulphides mineralization, and that they formed by partial melting of a basaltic source at depths >10 km (e.g. Hart et al. 2004).

The model proposed by Klewin and Berg (1991) to explain the upward geochemical variations in the MPF was partial melting of different sources at decreasing depths followed by fractional crystallization replaced by periodic replenishment, tapping, and fractionation in magma chambers combined with assimilation and fractional crystallization, and finally simple fractional crystallization at two broad levels in the crust. This model was modified by Shirey et al. (1994) based on isotopic data to reflect interaction with old subcontinental lithospheric mantle in the lower flows, crustal assimilation in the middle flows, and a mixture of plume and depleted mantle comparable to Phanerozoic mid-ocean ridge basalt (MORB). A study of the picritic basalts by Shirey (1997) suggested a mixed source of enriched mantle plume and unradiogenic continental lithosphere, and possible involvement of recycled slab from late Archean subduction.

Lightfoot et al. (1999) compared the MPF with the Osler Group volcanic rocks and observed that Groups 1 to 3c, except for the possible lithospheric interaction, resemble but are not identical to the Lower Formation of the Osler Group. Picritic basalts are also present in the Lower Formation but are not the lowermost flows and are underlain by tholeiites. The Osler Group lacks flows comparable to Group 5. Groups 6 and 7 broadly resemble the least contaminated basalts of the Central formation of the Osler Group.

There are only a couple of picritic basalt flows in the Osler Group, and although they are located near the base of the Group but are not the lowest flows (Hart 2002).

ECONOMIC GEOLOGY

Copper deposits of Keweenawan age are of economic importance in the area and consist of 3 types:

- (i) fissure filling carbonate vein breccias which carry chalcocite, bornite, chalcopyrite, specular hematite, and very minor amounts of native copper
- (ii) porphyry copper type deposits, in which chalcopyrite, chalcocite, molybdenite and pyrite are disseminated in quartz-feldspar porphyry
- (iii) breccia pipe deposits in which wallrock fragments are set in a matrix of quartz, carbonate and minor fluorite. Chalcopyrite and pyrite, with minor molybdenite, sphalerite, galena, tetrahedrite, stibnite and scheelite occur in the matrix of the breccia.

The Tribag Mine is the best example of the breccia pipe deposits but will not be visited during this field trip. The deposit is located 16.1 km north of Batchawana Bay, and past production included copper and minor gold and silver from a breccia pipe during the period 1967 to 1974. Milling rate at these mines averaged 400 to 500 tons per day of ore grading approximate 2% Cu with minor values in gold and silver.

Mamainse Mine

The existence of copper at Mamainse Point was known in very remote times and the so-called “Indian diggings” near Hibbard Bay attest to the mining activities of the natives in this region. The similarity of the geology at Mamainse Point to that of the Michigan copper district attracted the attention of mining interests when the Michigan camp was being developed. There are sketchy records of intermittent mining activity from 1842 until 1894 (Photo a and b).

During this period shafts were put down at several places in the area: the best known developments are those at the Mamainse mine and the Copper Creek and Silver Creek shafts. According to the report of the Royal Commission



Photo a: Mamainse copper mill (Coleman 1899)



Photo b: Shaft and engine house at Mamainse (Coleman 1899)

of 1890, the deepest workings were on the 300-foot horizon at the Copper Creek shaft. There is no record that any significant amount of copper was produced until recent years when two mines, the Coppercorp and the Tribag came into production in the Batchawana Bay area. There are three shafts at the Mamainse Mine with 4 levels established. Work began by the Lake Superior Native Copper Company in 1882. The shafts are about 300 m apart on the vein.

Amongst the companies engaged in early exploration were the Montreal Mining Company in 1856-57, the Ontario Mineral Lands Company in 1871, the Silver Islet Consolidated Mining and Lands Company in 1882-84, the Canada Lands Purchase Company in 1890, and the Nipigon Mining Company, probably about 1892. From 1906 to 1908, the property was optioned by the

Calumet and Hecla Mining Company of Michigan.

Mineralization at the Mamainse Mine is hosted by a quartz-carbonate vein / fracture fill, striking 334° dipping 50° east and varying from 0.46 to 4.0 m wide. Tracable for 457 m, the vein and an associated felsite intrusion pinch and swell along strike in the northwest-trending fracture which cross-cuts the north striking mafic volcanic flows at an oblique angle. Mineralization in these veins consists of hematite and chalcocite in veins with minor chalcopyrite and native copper along with malachite and azurite as weathering products. The structure associated with the mineralization at the Mamainse Mine is similar to the main NNW trending, east dipping structures seen at the Coppercorp (Tortosa and Moss 2004).

The main vein can be examined along the shoreline (see Stop 6), and it was along this vein where three shafts were sunk to 18.3, 85.3 and 97.6 m with four levels established. The vein cuts flows of the Upper Division and hosts minor native copper and finely disseminated chalcocite in cross fractures. The basalts are thin flows of diabasic and ophitic olivine tholeiite with amygdules containing quartz, agate, calcite, copper sulphides and native copper. Annells (1973) reported that specks of native copper are common in the vesicles and flow tops of the Upper Division flows and that a 67 kg piece of native copper was discovered during highway construction in the area south of the Mamainse Mine.

Coppercorp Mine

The Coppercorp Mine is a past producer located in the Mamainse Point area, about 80 km north of Sault Ste. Marie, Ontario. The mine produced 1.021 million tons grading 1.16% Cu, along with 237,603 oz Ag and 1,964 oz Au from a number of veins between 1965 and 1972 (Tortosa and Moss 2004). Nikos Explorations Ltd. currently has an agreement to acquire Amerigo Resources Ltd. interest in the property. The following information has been extracted from the technical report of Nikos Explorations Ltd. completed by Tortosa and Moss (2004).

The Coppercorp deposit is hosted by volcanic and intrusive rocks situated on the eastern edge of the Midproterozoic Midcontinental Rift system. Copper

mineralization consists of disseminated native copper in amygdules, and veins and vein hosted copper sulphides that occur in fault-related breccia zones that transect flood basalts, conglomerates, and felsic intrusive and volcanic rocks of the Keweenaw-age Mamainse Point Formation (Fig. 11). Mineralization consists of chalcocite with minor malachite and chalcopyrite associated with pyrite and hematite.

Regional westward folding of the Mamainse Point Formation combined with possible contemporaneous radial faulting may have provided the structural conduits for the mineralizing fluids in the Coppercorp Mine and elsewhere on the property (Fig. 12). The presence of a high area of magnetic intensity in the focal area of the radial fault system combined with associated felsic intrusive and extrusive activity in the lower volcanic sequence suggests the presence of a volcanic or intrusive centre in the area.

History

Exploration on the property probably began at the same time as the work on the nearby Mamainse Mine, and much of the early work appears to have concentrated on the native copper mineralization in amygdules and fractures (Table 1). Between 1948 and 1952, work by Macassa Mines, and C.C. Houston and Associates examined the old copper showings and drilled 10,180 m outlining several mineralized zones, including the C Zone, D Zone, SB Zone and Silver Creek Zone (Fig. 11 and 13).

Table 1: History of Ownership of Montreal Mining Sand Bay Location

| Years | Ownership |
|-----------|--|
| 1856-1857 | Montreal Mining Co. |
| 1871 | Ontario Mineral Lands Co. |
| 1882-1884 | Silver Islet Consolidated Mining and Lands Co. |
| 1890 | Canada Lands Purchase Synd. |
| 1892 | Nipigon Mining Co. |
| 1906-1908 | Calumet and Hecla Co. |
| 1948 | Macassa Mines Ltd. |
| 1951 | C.C. Huston and Associates |
| 1955 | Coppercorp Ltd. |
| 1964 | leased by Vauze Mines Ltd North Canadian Enterprises Ltd. |
| 2002 | Terry Nicholson & William Gibbs |

from Tortosa and Moss (2004)

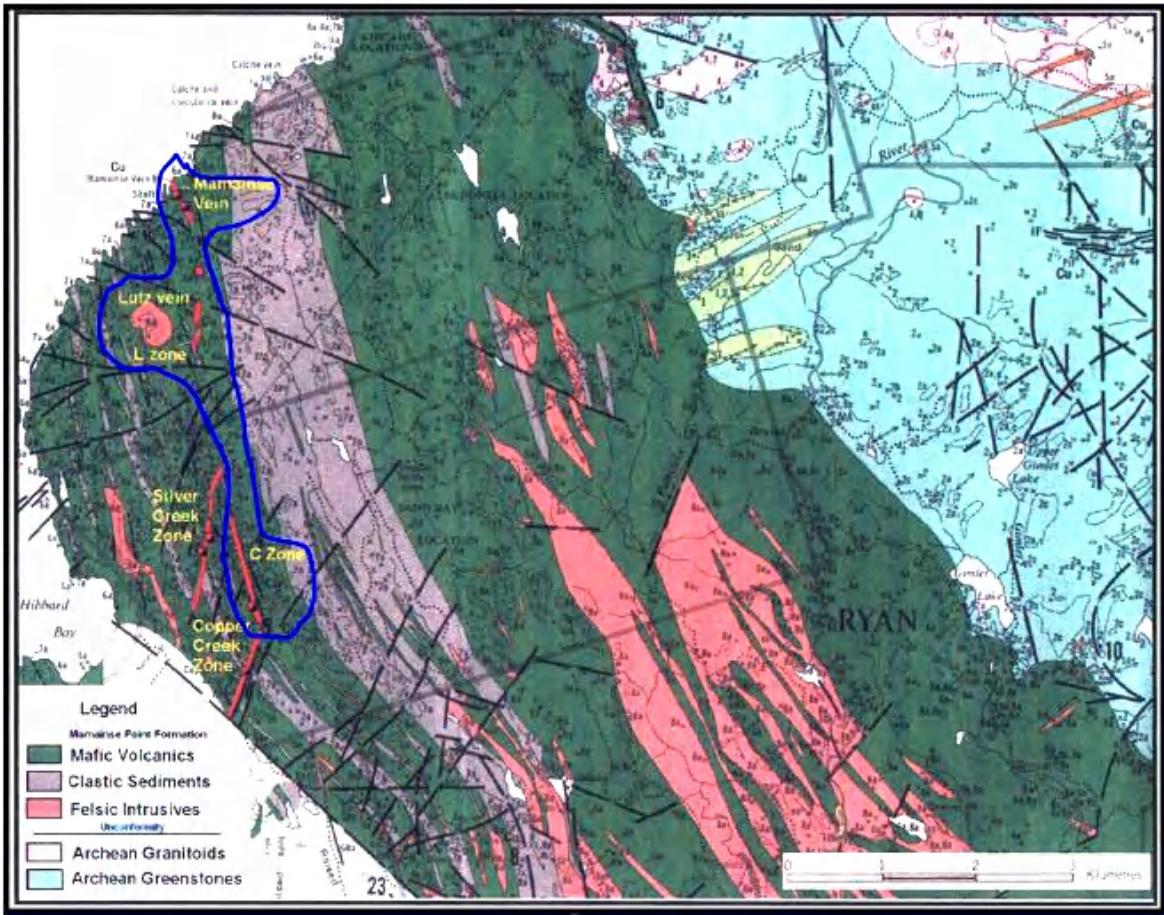


Figure 10: Detailed Geology around the Coppercorp Mine area showing the location of some of the surface and projected mineralized zones (Giblin, 1973). Blue outline shows the C Zone, L Zone, Lutz Vein and Mamainse Vein.

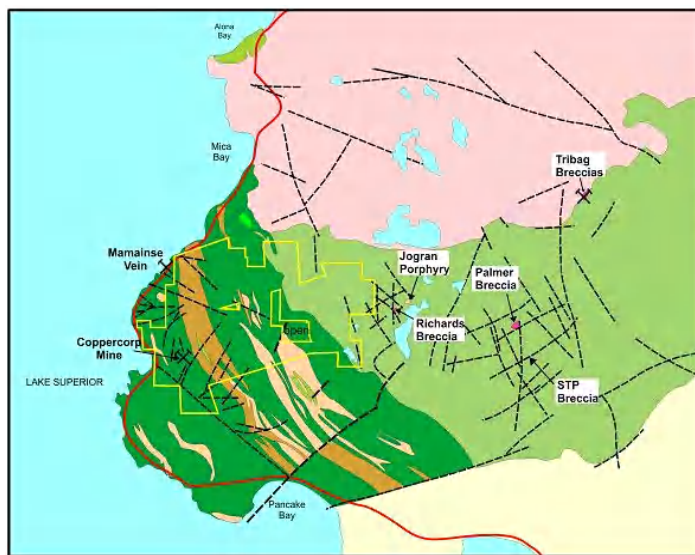


Figure 11: Distribution of faults and simplified regional geology of the Mamainse area with the outline of the Coppercorp Property shown in yellow (after Giblin, 1973; Richards, 1995) from Tortosa and Moss (2004).

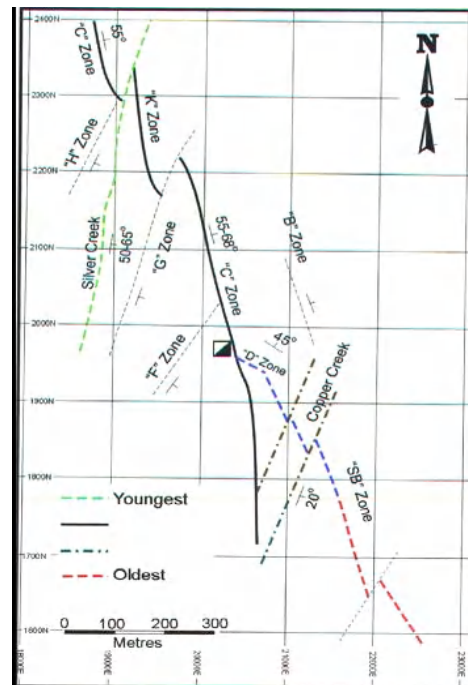


Figure 12: Mineralized structures in the Coppercorp deposit (Heslop, 1970) from Tortosa and Moss (2004)

Coppercorp Ltd. was a new company created in 1954 to sink a shaft, to 168 m with levels at 76, 114, and 152 m (Tortosa and Moss 2004). During the underground development, 4,267 m of lateral development were completed and 60,000 tons of ore were stockpiled. Operations ceased in 1957 due to falling copper prices. Vauze Mines Ltd. (controlled by Sheridan Geophysics Limited) leased the mine in 1963 and completed additional drilling along with a surface exploration program which included geophysical surveys and geological and geochemical examinations. In 1965, a decision was made to bring the Coppercorp deposit into production and the original shaft was de-watered and deepened to 192 m. The operation produced 500 tons per day processed into a 50% copper concentrate at a recovery rate of <90%. The Coppercorp Mine produced 1, 021,358 tons grading 1.16% Cu plus approximately 237,603 ounces of silver and 1,964 ounces of gold from such veins between 1965 and 1972. Some of the available historical statistics on underground development, drilling, pre-production ore reserve estimates and production figures are provided in Table 2.

Table 2: Historical statistics on underground development and drilling at the Coppercorp Mine (Tortosa and Moss 2004).

| Exploration Activity | Type of Activity | Information Source |
|-------------------------|--------------------------|--------------------|
| Underground Development | Drifts: 34,882 feet | SMDR 000852 |
| | Crosscuts: 3,628 feet | SMDR 000852 |
| Drilling | Surface: 16,900 feet | SMDR 000852 |
| | Underground: 20,000 feet | SMDR 000852 |

| Table 4: Historical Pre-Production Ore Reserve Estimates* at the Coppercorp Mine | | |
|--|--------------------------|--|
| Mineralized Zone | Ore Reserve Estimate | Information Source |
| G Zone and C Zone South** | 460,000 tons @ 2.3% Cu | SMDR 000852; Coppercorp Report for 1965 |
| Silver Creek South Zone | 490,000 tons @ 1.9% Cu | SMDR 000852; Coppercorp Report for 1965 |
| H and Silver Creek North Zones | 650,000 tons @ 2.1% Cu | SMDR 000852; Coppercorp Report for 1965 |
| Total Ore Reserve Estimate for the Coppercorp Deposit | 1,540,000 tons @ 2.1% Cu | SMDR 000852; Coppercorp Report for 1965; Northern Miner 1965 |

| Coppercorp production (Source: SMDR 000852) | | | | | |
|---|----------------|------------------|--------------|----------------|-------------------|
| Year | Tons Hoisted | Tons Mined | Au (Oz) | Ag (Oz) | Cu (lbs) |
| 1957* | 60,000 | | | | |
| 1965 | 14,882 | 38,919 | 386 | 20,069 | 832,928 |
| 1966 | 118,848 | 140,691 | 390 | 57,296 | 3,716,325 |
| 1967 | 146,601 | 146,441 | | 35,500 | 3,557,000 |
| 1968 | 142,986 | 142,986 | 268 | 33,622 | 3,175,730 |
| 1969 | 161,488 | 161,488 | 249 | 55,761 | 4,769,452 |
| 1970 | 141,055 | 140,830 | 231 | 4,785 | 2,447,500 |
| 1971 | 155,811 | 156,111 | 440 | 58,570 | 3,109,758 |
| 1972*** | 82,510 | 84,802 | ? | ? | 2,173,245 |
| Total*** | 965,190 | 1,021,358 | 1,964 | 237,603 | 23,782,028 |

Recent exploration on portions of the property was completed by J.F. Paquette and Cominco Ltd.. J.F. Paquette held a property covering the Lutz vein and L zone in 1991-92, and a self-potential survey along with prospecting and sampling programs were conducted (Fig. 11). Cominco Ltd. optioned this property in 1993 and completed geological mapping, surficial geochemistry, electromagnetic (UTEM) and magnetic surveys.

Mineralization

Copper mineralization occurs as disseminated native copper in amygdule and veins, and vein-hosted copper sulphide deposits. Production on the property has concentrated on the copper sulphides mineralization.

The copper sulphide veins occur in fault-related breccia zones that generally display gradual transitions from high grade sulphide veins to barren oxide cement. The copper sulphides are dominantly chalcocite, with lesser chalcopyrite and bornite, rarely native copper and are usually accompanied by specular hematite. Massive chalcocite veins, 20 to 25 cm wide, were found at numerous localities within the deposit. Richards (1985) recognized four stages of mineralization, which were: 1) pyrite-chalcopyrite, 2) chalcopyrite-bornite, 3). chalcocite-hematite, 4). native copper, native silver, copper arsenides, malachite and hematite. The third stage was the most important source of copper producing rich veins of chalcocite and replacing earlier sulphides. The veins and breccias consist of quartz and carbonate with subordinate laumontite and fluorite. Large vugs of varying size are lined with quartz, calcite, and sulphides and were commonly found throughout the deposit, suggesting a shallow 'open space filling' type of mineralizing process (Heslop, 1970). The wallrock is commonly chloritized and sericitized and may contain epidote.

The faults hosting mineralization cut Keweenawan basalt flows and conglomerates. The width of the fault zones varies along strike from shears less than 1 m to disrupted lenses up to 12 m across (Richards, 1985). The faults have two orientations, northeast and northwest. North-northeast trending faults dip 60° to 65° east and host the Copper Creek Zone, Silver Creek Zone and 'G', 'H', and 'F' Zones. North-northwest

trending faults that dip 50° to 70° east and almost parallel the volcanic and sedimentary rocks (Fig. 12 and 13). These faults are the most productive structures, hosting the C Zone, SB Zone, D Zone and B Zone. Where northwest faults intersect the Great Conglomerate, the fault narrows and the sulphide mineral content decreases possibly due to the lower competency of the conglomerate compared to the mafic volcanic rocks (Heslop 1970). Mineralized structures also cut, and are cut by, felsite and diabase dykes. Both the diabase and felsite intrusions are considered to have been emplaced contemporaneously with fault movement, brecciation and sulphide deposition. Heslop (1970) defined four major stages of fault development based on the crosscutting relationships of the faults (Table 3) with an apparent younging in the faults from south to north, but mineralogical changes in the ore or other characteristics associated with this relative structural timing have not been documented.

Some zones, including the C, SB, and L zones, Lutz and Mamainse veins, display an apparent stratigraphic control. Mineralization in these zones occurs primarily where the structure is hosted by basalts of the upper section of the Mamainse Point Formation, 75 to 150 m above the Great Conglomerate (Fig. 11).

Table 3: Relative age of fault zones based on cross-cutting relationships with 1= oldest and 4=youngest (Heslop, 1970) from Tortosa and Moss (2004).

| Mineralized (Fault) Zone | Strike | Dip | Relative Age |
|--------------------------|---------|-----------|--------------|
| SB Zone | 342-335 | East | 1 |
| Copper Creek Zone | 020 | 55-60 E | 2 |
| C Zone | 345 | 55-68 E | 3 |
| Silver Creek Zone | 010 | 50-65 E | 4 |
| D Zone | 300 | 45 NE | 4 |
| B Zone | 345 | East | 4 |
| F Zone | 030 | Southeast | 4 |
| G Zone | 020 | East | 4 |
| H Zone | 020 | East | 4 |

There are several other deposits in the Batchawana area and these are summarized in Table 4.

Table 4: Copper deposits in the Mamainse Point-Batchawana Area (Tortosa and Moss 2004)

| Deposit | Deposit Type | Production Years | Production | Reserves | Source |
|----------------|--------------------|------------------|--------------------|---|--------|
| Coppercorp | Copper-quartz vein | 1955 to 1972 | 1.02 Mt @ 1.16% Cu | ? | 1 |
| Mamainse | Copper-quartz vein | 1882 to 1884 | ? | ? | 2 |
| Tribag | Breccia Pipes | 1967 to 1972 | 1.1 Mt @ 1.65 % Cu | ? | 1 |
| Breton Breccia | | | | 40Mt tons @ 0.2% Cu above 100m | 1 |
| East Breccia | | | | 125Mt tons @ 0.13% Cu and 0.04% MoS ₂ | 3 |
| West Breccia | | | | 0.1Mt tons @ 0.6 to 1.0% WO ₃ | 1 |
| Jogran | porphyry | N/A | | 48Mt tonnes @ 0.19% Cu and 0.03% MoS ₂ | 1 |

Sources: 1. Rupert, 1997; 2. Moore, 1926; 3. EM&R, 1989; 4. SMDR 000852

Deposit Model

Tortosa and Moss (2004) have proposed that the Coppercorp deposit is an iron-oxide copper-gold (IOCG) type deposit similar to Olympic Dam based on:

1. A continental rift-related tectonic setting on the eastern margin of the Midcontinent Rift system.
2. The Keweenawan basalts represent a significant volume of potential copper source rocks with an estimated thickness of 4,300 to 6,000 m.
3. The presence of a massive magnetite vein grading 3.9% Cu over 1.05 m at the Jogran porphyry and fluorite associated with the Breton Breccia at Tribag and with Coppercorp ore.
4. The presence of numerous faults some of which are splays off major crustal faults including the Mamainse Point Fault to the south of the property.
5. The apparent high level emplacement of the felsic intrusives
6. The presence of dilational sites along active structures.
7. The presence of a high temperature saline brine (350° to 450°C) 15-20 eq. wt.% CaCl₂ believed to be magmatic in origin, and a lower temperature fluid (<100° to 350°C, 0 to 15 eq. wt. %) believed to be a mixture of magmatic and meteoric fluid (Richards, 1985).
8. The occurrence of widespread Cu mineralization in the area as both low tonnage medium grade deposits (e.g. Coppercorp) and high tonnage low grade

deposits (e.g. East Breccia zone of Tribag mines).

9. The presence of a broad, regional aeromagnetic anomaly over the property and the presence of several gravity anomalies.
10. The production of limited amounts of gold and silver along with the copper at the Coppercorp Mine and the anomalous concentrations of gold and silver found in the outlying copper occurrences.

GEOCHRONOLOGY

There is a limited amount of geochronology completed in the Mamainse Point area and correlations with other areas in the Midcontinent Rift are often based on paleomagnetic data (e.g. Nicholson et al, 1997). A number of K/Ar ages have been determined but are regarded as minimum ages due to the probability of Ar loss (Wanless et al, 1966, 1967, 1968). These ages include the basalt exposed at Chippewa Falls (Stop 11), south of Pancake Bay and the main portion of the Mamainse Point Formation, which have an age of 915 +/-140 Ma, and samples of the Tribag Mine breccia pipe which returned ages of 785 +/- 103 Ma to 1055 +/- 35 Ma. A more accurate age of volcanism is the 1070 +/- 50 Ma Rb/Sr age for a felsites in the Mamainse Point area (Van Schmus, 1971). A U/Pb age of 1096.2 +/- 1.9 Ma for a felsic unit in the area of the volcanic conglomerate of the Lower Division is very similar to the Rb/Sr age but younger than the 1105 +/-4 Ma felsic volcanism in the Osler Group (Davis et al. 1995). A Re-Os age of 1128 +/- 54 Ma for the basal picrite volcanic rocks (Shirey 1997) probably represents a maximum age for the Mamainse Point Formation, and is comparable to the 1124 to 1114 Ma age for the ultramafic Seagull Intrusion of the Lake Nipigon area (Heaman and Easton 2005). However, if the picritic flows of Mamainse Point are equivalent to the Seagull Intrusion, the basal portion of the MPF is much older previous interpretations, and 1096 Ma felsic age of Davis et al. (1995) means that the sediments of the Great Conglomerate may represent a longer hiatus in volcanic activity.

PALEOMAGNETISM

Paleomagnetic studies of Keweenawan rocks of the Midcontinent Rift (e.g. Portage Lake volcanic rocks, Michigan; North Shore volcanic and intrusive rocks, Minnesota; various dykes south of Thunder Bay; Logan sills, Thunder Bay; Osler Group volcanic rocks, Nipigon; Cape Gargantua volcanic rocks, Wawa) indicate that the older rocks have reverse magnetic polarity and the younger rocks have normal polarity (e.g. Halls and Pesonen 1982; Nicholson et al. 1997). The volcanic rocks of the MPF have more complex pattern with 2 zones of reversed polarity overlain by zones of normal polarity with the polarity changes coinciding with the base of clastic sedimentary units (Fig. 5) (Palmer 1970). It was originally proposed that this repetition was the result of a strike fault located at the boundary between the lower normal and upper reverse zones, but the lithochemical stratigraphy indicates another explanation is required.

REFERENCES

- Annells, R. N. 1973. Proterozoic Flood Basalts of Eastern Lake Superior: the Keweenawan Volcanic Rocks of the Mamainse Point Area, Ontario; Geological Survey of Canada, Paper 72-10. 51 p.
- Cannon, W.F., Green, A.G., Hutchinson, D.R., 1989. The North American Midcontinent rift beneath Lake Superior from GLIMPCE seismic reflection profiling. *Tectonics*, v. 8, p. 305-322.
- Coleman, P.A., 1899. Copper Regions of the Upper Lakes, Report of the Bureau of Mines Vol. VIII Part 2, p.152
- Davis, D.W. and Green, J.C. 1997. Geochronology of the North American Midcontinent Rift in western Lake Superior and implications for its geodynamic evolution; *Canadian Journal of Earth Sciences*, v.33, p.476-488.
- Davis, D.W., Green, J.C., and Manson, M., 1995. Geochronology of the 1.1. Ga North American Mid-continent Rift; Institute of Lake Superior Geology, 41st Annual Meeting Proceedings Volume 41, Part 1: Abstracts, p. 9-10.
- Giblin, P. E. 1974. Middle Keweenawan Rocks of the Batachawana-Mamainse Point Area. Institute of Lake Superior Geology 20th Annual Meeting, Nipigon, Ontario, Program, Abstracts, and Field Guides, v. 20, p. 39-67.
- Giblin, P. E., and Leahy, E. J. 1967. Sault Ste. Marie - Elliot Lake Sheet, Districts of Algoma, Manitoulin, and Sudbury. Ontario Department of Mines, Geological Compilation Series, Map 2108. Scale 1 inch to 4 miles.
- Giblin, P.E. and Armsburst, G.A. 1969. Batchawana, Ontario Department of Mines. Map 2251, scale 1:63 360.

- Gmitro, T.T., 1990. Chemostratigraphy and petrogenesis of Keweenaw lavas at Alona Bay, Ontario. unpub. M.S. thesis, Northern Illinois University, DeKalb, Ill.
- Green, J.C., 1983. Geological and geochemical evidence for the nature and development of the Middle Proterozoic (Keweenaw) midcontinent rift of North America: Tectonophysics, v. 94, p.413-437.
- Halls, H.C. and Pesonen, L.J., 1982. Paleomagnetism of Keweenaw rocks; in Geology and Tectonics of the Lake Superior Basin; ed. R.J. Wold and W.J. Hinze; Geological Society of America, Memoir 156. p.173-201.
- Hart, T.R. 2002. Proterozoic Volcanic and Intrusive Whole Rock Geochemical Data Associated with the Keweenaw Midcontinent Rift, Lake Superior Area, Ontario; Ontario Geological Survey, Miscellaneous Release Data 114.
- Hart, T.R. and MacDonald, C.A., *submitted*, Proterozoic and Archean Geology of the Nipigon Embayment: Implications for Emplacement of the diabase sills and PGE-enriched mafic to ultramafic intrusions; Canadian Journal of Earth Sciences,
- Hart, T.R., Gibson, H.L., and Lesher, C.M., 2004. Trace Element Geochemistry and Petrogenesis of Felsic Volcanic Rocks Associated with Volcanogenic Massive Cu-Zn-Pb Sulfide Deposits; Economic Geology, v. 99, p. 1003-1013.
- Heaman, L.M., and Easton, R.M., 2005. Proterozoic history of the Lake Nipigon area, Ontario: Constraints from U-Pb zircon and baddeleyite dating. ; Institute of Lake Superior Geology, 51st Annual Meeting, Nipigon, Ontario, Part 1 – Proceeding and Abstracts, v. 51, part 1, 24-25.
- Heslop, J.B., 1970, Geology, Mineralogy and textural relationships of the Coppercorp Deposit, Mamainse Point area, Ontario. unpublished M.Sc. Thesis, Department of Geology, Carleton University, Ottawa, 95 p.
- Hutchinson, D.R., White, R.W., Cannon, W.F., and Schulz, K.J., 1990. Keweenaw hot spot: geophysical evidence for a 1.1 Ga mantle plume beneath the Midcontinent rift system in western Lake Superior; Journal of Geophysical Research, v. 95, p. 10 869-10 884.
- Jerram, D.A. and Widdowson, M. 2005. The anatomy of Continental Flood Basalt Provinces: geological constraints on the processes and products of flood volcanism; Lithos, v. 79, p. 385– 405
- Klewin, K.W. and Berg, J.H. 1990. Geochemistry of the Mamainse Point volcanics, Ontario, and implications for the Keweenaw paleomagnetic record; Canadian Journal of Earth Sciences, v. 27, p. 1194-1199.
- Klewin, K.W., and Berg, J.H. 1991. Petrology of the Keweenaw Mamainse Point Lavas, Ontario: Petrogenesis and continental rift evolution. Journal of Geophysical Research, v. 96, p. 457-474.
- Klewin, K.W. and Shirey, S.B. 1992. The igneous petrology and magmatic evolution of the Midcontinent rift system; Tectonophysics, v. 213, p.33-40.
- Lightfoot, P.C., Sage R.P., Doherty W., Naldrett A.J., and Sutcliffe, R.H. 1999. Mineral potential of Proterozoic Keweenaw intrusions: implications of major and trace element geochemical data from bimodal felsic and volcanic sequences of Mamainse Point and the Black Bay Peninsula, Ontario; Ontario Geological Survey OFR 5998, 91p.
- Manson, M.L. and Halls, H.C. 1997. Proterozoic reactivation of the southern Superior Province and its role in the evolution of the Midcontinent Rift. Canadian Journal of Earth Sciences, v. 34, p. 562-575.
- Massey, N.W.D. (1980). The geochemistry of some Keweenaw metabasites from Mamainse Point, Ontario. Ph.D. thesis. McMaster University, Hamilton, Ontario. 352p.
- Massey, N.W.D. 1983. Magma genesis in a late Proterozoic proto-oceanic rift: REE and other trace-element data from the Keweenaw Mamainse Point Formation, Ontario, Canada. Precambrian Research, v. 21, p. 81-100.
- Nicholson, S.W., and Shirey, S.B., 1990. Evidence for a Precambrian mantle plume: a Sr, Nd, and Pb isotopic study of the Midcontinent Rift System in the Lake Superior region; Journal of Geophysical Research, v. 95, p. 10 851-10 868.
- Nicholson, S.W., Shirey, S.B., Schulz, K. and Green, J.C., 1997. Rift-wide correlation of 1.1 Ga Midcontinent rift system basalts: implications for multiple mantle sources during rift development. Canadian Journal of Earth Sciences, v. 34, p. 504-520.
- Palmer, H. C.1970. Paleomagnetism and Correlation of some Middle Keweenaw Rocks, Lake Superior. Canadian Journal of Earth Sciences, v. 7, p. 1410-1436.
- Ojakangas, R.W., and Morey, G.B. 1982. Keweenaw sedimentary rocks of the Lake Superior region: a summary. In Geology and tectonics of the Lake Superior basin. Edited by R.J. Wold and W.J. Hinze. Geological Society of America, Memoir 156, pp. 157–164.
- Richards, J.P., 1985, A fluid inclusion and stable isotope study of Keweenaw fissure-vein hosted copper sulphide mineralization, Mamainse Point, Ontario. Unpublished M.Sc. thesis, Department of Geology, University of Toronto, 290p.
- Richards, J.P. and Spooner, E.T.C. 1989. Evidence for Cu-(Ag) Mineralization by Magmatic-Meteoritic Mixing in Keweenaw Fissure Veins, Mamainse Point, Ontario. Economic Geology, v. 84, pp. 360-385.
- Shirey, S.B., 1997. Re-Os isotopic compositions of Midcontinent rift system picrites: implications for plume – lithosphere interaction and enriched mantle sources. Canadian Journal of Earth Sciences, v. 34, p. 489-503.
- Shirey, S.B., Klewin, K.W., Berg, J.H. and Carlson, R.W., 1994. Temporal changes in the sources of flood basalts: Isotopic and trace element evidence from the 1100 Ma old Keweenaw Mamainse Point Formation, Ontario, Canada; Geochimica et Cosmochimica Acta, v. 58, pp. 4475-4490.

- Sutcliffe, R.H. and Smith, A.R. 1988. Project Number 87-17. Geology of the St. Ignace Island Volcanic-Plutonic Complex; in Summary of Field Work and Other Activities, Ontario Geological Survey Miscellaneous Paper 141, p. 368-371.
- Tortosa, D. and Moss, R. 2004. Geology and Exploration of the Coppercorp Property, Sault Ste. Marie Mining Division, Ontario; March 23, 2004, prepared for: Nikos Explorations Ltd., 158p.; filed with SEDAR May 11, 2004; available from http://nikosexplorations.com/_resources/Coppercorp2004Report.PDF
- Van Schmus, W. R. 1971. Rb-Sr Age of Middle Keweenawan Rocks, Mamainse Point and Vicinity, Ontario, Canada. Geological Society of America, Bulletin 82, p. 3221-3226.
- Van Schmus, W.R. and Hinze, W.J. 1985. The mid-continent rift system. Annual Review of Earth and Planetary Sciences, v. 13, p.345-384.
- Walker, J.A., Gmitro T.T. and Berg J.H. 2002. Chemostratigraphy of the Neoproterozoic Alona Bay lavas, Ontario; Canadian Journal of Earth Sciences, v. 39, p.1127-1142
- Wanless, R. K. , Stevens, R.D., Lachance, G.R., and Rimsaite, J. Y. H. 1966. Age Determinations and Geological Studies, K-Ar Isotopic Ages, Report 6. Geological Survey of Canada, Paper 65-17, p. 58.
- Wanless, R. K., Stevens, R. D., Lachance, G. R. and Edmonds, C. M. 1967. Age Determinations and Geological Studies, K-Ar Isotopic Ages, Report 7. Geological Survey of Canada, Paper 66-17, p. 84-85.
- Wanless, R. K., Stevens, R. D., Lachance, G. R. and Edmonds, C. M. 1968. Age Determinations and Geological Studies, K-Ar Isotopic Ages, Report 8. Geological Survey of Canada, Paper 67-2, Part A, p. 95-96.

ITINERARY

| Stop | Locality | Km (south) | Km (north) |
|-------------|--|-----------------------|-----------------------|
| 1 | Alona Bay | 0 | 105.7 |
| 2 | Unconformity: Mica Bay Formation Mamainse Point Formation | 8.0 | 97.7 |
| 3 | Glomeroporphyritic Basalt "Daisy Stone" | 8.5 | 97.2 |
| 4 | Ropy Flow Top | 9.2 | 96.5 |
| 5 | Volcanic Conglomerate 10.7 or 11.3 | 10.7 | 95.0 |
| 6 | Mamainse Mine | 14.2 | 91.5 |
| | entrance to road | 15.0 | 90.7 |
| 7 | Ubetuwantit (Coppercorp Property) | 2.3 | |
| 8 | Coppercorp Mine | 4.6 | |
| 9 | Interbedded Conglomerate and Basalt | 21.8 | 83.9 |
| 10a | Domeykite Occurrence | 25.4 | 80.3 |
| 10b | Pseudotachylite | 25.9 | 79.8 |
| 10c | Cottrell Cove Felsic Intrusion | 26.1 | 79.6 |
| | Pancake Provincial Park | 32.9 | 72.8 |
| | Pancake River | 34.6 | 71.1 |
| | Mamainse Point Fault (approx.) | 35.5 | 70.2 |
| | Road to the Tribag Mine Site | 40.1 | 65.6 |
| | Batchawana River | 45.3 | 60.4 |
| 11 | Chippewa Falls | 54 | 51.7 |
| | Keweenawan basalt flows | 65.2 | 40.5 |
| | Jacobsville Formation sandstone | 69.0 | 36.7 |
| | Intersection at Highway 17 and 556 Water Tower Inn | 105.7 | 0 |

This field guide is an amalgamation of the field trip guides of Annells (1973) and Giblin (1974). All coordinates are in UTM (Universal Transverse Mercator), Zone 16, with a NAD83 Canada datum.

STOP 1 Alona Bay Scenic Lookout
UTM coordinates - 673636E 5219651N

The following historical description is from Giblin (1974).

An historical plaque commemorates the first discovery of uranium in Canada, made nearby in

the 1840's. A sample of pitchblende was described by Le Conte in the American Journal of Science in 1847 with the location given as a vein 5.1 cm wide located about 112.6 km north of Sault Ste. Marie, but subsequent papers gave the location as between 64.4 to 144.8 km. In 1948, Robert Campbell of Toronto found pitchblende at the northwest end of Theano Point, which can be seen north across the bay. Subsequently prospectors found several other pitchblende deposits inland, to the north and east.

Point Aux Mines on the south side of Alona Bay, was the site of the earliest organized mining venture in Ontario. In 1772-73, a mining company formed by Alexander Henry, the noted fur-trader, worked a copper deposit and shipped a small amount of ore to England.

Theano Point to the north and Point Aux Mines to the west southwest consists of Archean felsic plutonic rocks cut by diabase dikes. The Alona Bay volcanic rocks are an approximately 1200 m thick, southward younging sequence of Keweenawan basalt flows unconformably overlying the Archean rocks (Annells 1973; Gmitro 1990). These flows are unconformably overlain by siltstones and sandstones similar to the Mica Bay Formation, and possibly comparable to the post-magmatic Freda Sandstone (e.g. Annells 1973; Ojakangas and Morey 1982). The Alona Bay flows have been correlated with the Lower Division flows of the Mamainse Point Formation (MPF) (Walker et al. 2002; Annells 1973).

The Alona Bay flows are described by Annells (1973) and Gmitro (1990) as being composed of about 107 mafic flows averaging 6.8 m in thickness. Most of the flows have pahoehoe surfaces and vesicular-amygdular flow tops, and pipe vesicles are relatively common just above flow bases. Gmitro (1990) subdivided these flows into olivine phyric, plagioclase phyric, olivine-plagioclase phyric, and aphyric groups. Two basic dikes cut the section, one about 500 m from the base of the section and one at the top of the section in fault contact with Archean rocks. Clastic dikes are common throughout the Alona Bay section. All of the Alona Bay lava flows have undergone some low-grade burial metamorphism to prehnite-pumpellyite facies and deuteric alteration,

similar to that observed in the MPF (e.g. Massey 1980).

Walker et al. (2002) identified 4 geochemical groups based on decreasing TiO₂, Ni and MgO contents that reflect an upwards progression through the volcanic sequence. Although proposed to be equivalents to the flows of the Lower Division of the MPF, the majority of the Alona Bay flows have MgO concentrations between 6 and 10 wt.%, and none have MgO > 15.0 wt.%.

Proceed for ~8 km to the south

0 – 2 km: Alona Bay flows

2 – 6.6 km: Archean felsic plutonic rocks and diabase dykes unconformably underlying the Alona Bay and MPF

6.6 – 8 km: Mica Bay Formation

STOP 2 Unconformity: Mica Bay Formation and Mamainse Point Formation

UTM coordinates – 673691E 521891N

Park in the east side of the highway on a portion of the old highway roadbed.

BE CAUTIOUS AS THE HIGHWAY IS BUSY AND HEAVILY TRAVELLED BY TRACTOR TRAILERS

Cross the highway and proceed north to the culvert where the stream can be followed down to the beach.

BE CAUTIOUS AS THE MUDDY SILTSTONES CAN BE SLIPPERY, ESPECIALLY IF WET

Fine-grained siltstone and graphitic siltstone with trace sulphides are exposed in the section cut by the stream.

Proceed about 200 m to the south along the cobble beach, passing exposures of the Mica Bay Formation.

An angular unconformity between the clastic sedimentary rocks of the Mica Bay Formation and the underlying Keweenawan basalt of the Mamainse Point Volcanic Group is exposed in a

shallowly west dipping outcrop located along the edge of the water.

BE CAUTIOUS AS THE OUTCROP WILL BE SLIPPERY IF WET

The underlying Keweenawan basalts of the MPF strike N 30° W and dip 45° to 50° W. The basalts are thin olivine tholeiitic flows near the base of the MPF (Annells 1973), with upper vesicular zones exposed in this outcrop. Unconformably overlying the basalts is an up to 30 cm thick polyimictic, matrix supported conglomerate of the Mica Bay Formation (Photo 1a). Very little of the basal conglomerate remains, please do not collect samples or deface the exposure

The Mica Bay Formation has a total thickness of approximately 61 m, but only the lower 18.3 m are exposed along the beach. This section includes the basal conglomerate, which is overlain by grey-brown siltstones, arkoses, and minor immature quartz pebble conglomerates. Siltstones constitute approximately 70% of the section. Sedimentary structures include ripple marks, graded bedding, cross-lamination, flame structures, and ball-and-pillow structures indicative of a shallow water environment (Photo 1b and 1c). In other exposures, north of the section examined, flute casts and clastic dikes indicate a northerly direction of current flow.

The sedimentary rocks strike N 65° E, and in the section examined, dip 15° N. Steeply-dipping faults cut the sedimentary rocks with offsets of up to 1.8 m. These rocks lie on the south limb of a regional syncline, with the north limb exposed between the creek and the small granite headland at the north end of the beach. The north limb is in fault contact with the underlying Archean granite, and a thin basal breccia occurs on the granite north of the fault. Similar basal breccias are found overlying the granite, at several points along the shore of Mica Bay.

The age and correlation of these rocks are uncertain. The unconformity observed at this stop indicates that they are post-Middle Keweenawan, but they are lithologically and structurally different than the rocks of the Jacobsville Formation. The Mica Bay Formation appears to underlie the Jacobsville, which forms nearby islands in Lake Superior and much of the floor of

the eastern part of the lake. The age of the Jacobsville Formation is uncertain and has been variously assigned to the Lower and Middle Cambrian, and to the Upper Keweenaw. Thus, the Mica Bay Formation may be either Upper Keweenaw or Lower Cambrian. A thinner section of similar clastic sedimentary rocks occurs in Alona Bay, 6.4 km north, and may also be part of the Mica Bay Formation.

**STOP 3 Glomeroporphyritic Basalt
"Daisy Stone"**

UTM coordinates – 673437E 5218459N

Proceed south along the highway for about 400 m from the same parking site as used for Stop 2.

BE CAUTIOUS AS THE HIGHWAY IS BUSY AND HEAVILY TRAVELLED BY TRACTOR TRAILERS

The distinctive glomeroporphyritic “daisy stone flows” are located interbedded with olivine tholeiite flows of the Lower Division of Annells (1973), towards the north side of the MPF. The flow is exposed in the rock cut located on the east side of the highway, and can also be observed along the shoreline to the northwest. This flow strikes north to northwest and dips about 50° W which is steeper than the dips present in subsequent stops higher in the sequence. Giblin (1974) reported that the flow can be traced intermittently along strike for 11.3 km, and a new exposure located about 4.3 km south of this location provides an excellent exposure of these flows.

This flow varies from massive, fine-grained basalt to glomeroporphyritic, with radiating calcic plagioclase laths, up to 5 cm across (Photo 2). Annells (1973) reported that the massive portions of the flows are non-porphyrific containing abundant pseudomorphs after small olivine crystals. The plagioclase is variably epidotized or hematitized in different portions of the flow.

A plagioclase-rich ponded flow in the Osler Volcanic Group volcanic rocks is exposed on the southeast corner of St. Ignace Island, in the Thunder Bay area (Sutcliffe and Smith 1988). The top of that flow has a texture resembling the glomeroporphyritic “daisy stone” texture.

Proceed south for ~1.0 km

flows of the Lower Division of the MPF

STOP 4 Ropy Flow Top

UTM coordinates – 673127E 5217816N

Park in the drive about 200 m south of the rock cut

BE CAUTIOUS AS THE HIGHWAY IS BUSY AND HEAVILY TRAVELLED BY TRACTOR TRAILERS

Cross the highway and walk north along the shoulder of the highway to the south side of the rockcut at the top of the hill.

A ropy flow top is exposed on the south face of the outcrop located on the east side of the highway (Photo 3). The pahoehoe marks the top of a 6.5 m thick olivine tholeiite flow (Annells, 1973).

Proceeding to the north through the rock cut, there are several flows with thin basal pipe vesicle zones, thicker amygdaloidal zones in the upper parts of the flows, and ropy flow tops. The vesicles and amygdules are filled with calcite, celadonite, and a green mica.

About 150 m further north, on the east side of the highway, a northwest trending, 26° E dipping diabase dyke crosscuts the flows located near the top of the olivine phyric group (Annells, 1973). Scoriaceous flowtops probably on olivine-rich flows, are reported to occur in the west side of the rock cut in the area of the dyke.

Proceed south for 1.5 km

0 – 1.0 km flows of the Lower Division of the MPF

1.0 – 1.5 km clastic sediments (volcanic conglomerate horizon)

STOP 5 Volcanic Conglomerate

UTM coordinates – 670790E 5214845N

Parking is along the shoulder of the road.



Photo 1a: Polymictic conglomerate of the Mica Bay Formation unconformably overlying a MPF flow.



Photo 2: Glomeroporphyritic Basalt (daisy stone) with a distinctive radiating calcic-plagioclase in a fine grained to aphanitic basaltic matrix (new location to the south of the highway).



Photo 1b: Ball and Pillow Structures within the siltstone of the Mica Bay Formation.



Photo 3: Ropy flow top on the south face of the outcrop, east of the highway.

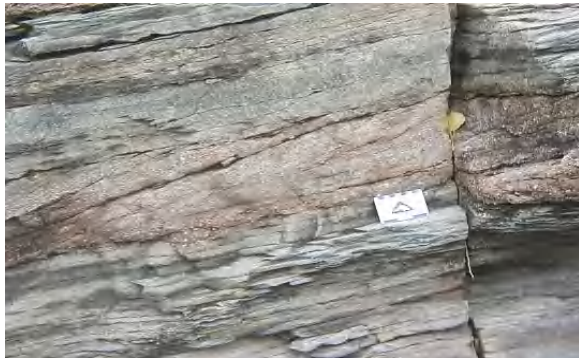


Photo 1c: Cross-laminations in the siltstones and arkoses of the Mica Bay Formation.

Photo 4: Mamine Vein looking east. Fracture fill carbonate-quartz vein hosted by the basaltic flows of the Upper Division.



BE CAUTIOUS AS THE HIGHWAY IS BUSY AND HEAVILY TRAVELLED BY TRACTOR TRAILERS

Interbedded with the basalt flows in the Mamainse Point Group are volcanic conglomerates composed entirely of basalt clasts. The conglomerate was described by Annells (1973) as poorly sorted, angular to subrounded clasts in a matrix of fine basaltic debris with some silty material. The clasts are massive to vesicular, up to 0.30 m in diameter, and some clasts are irregular shaped which Annells (1973) interpreted to be a result of emplacement while still semi-solidified. Annells (1973) also reported that this unit has a fine-grained, well laminated upper zone resembling a hyaloclastite or peperite. Although there are clasts and lenses of occasional cross-bedded red-brown silt there are no clasts of Archean basement rocks.

The conglomerate is cut by carbonate veins which carry minor amounts of quartz and laumontite.

Proceed south for 3.7 km

0 – 1.8 km: Flows of the upper portion of the Lower Division

600 m: distinctive hematite alteration along fractures in the flows - east side of the highway

1.8 – 2.6 km: clastic sediment, mainly polymictic conglomerates, of the “Great Conglomerate”

2.6 – 3.5 km: mafic flows and intercalated conglomerates of the Upper Division of the MPF

STOP 6 Mamainse Mine

UTM coordinates – 669939E 5214040N

Exit to the west onto the bush road, proceed about 100 m to the second opening and park.

The Mamainse Mine consists of 3 shafts that were put into production between 1842 and 1894, along with a stamp mill, service facilities and a village were constructed by the Lake Superior Native Copper Company. The area to the south of the parking site consists of rubble from the

mining operation, containing abundant specular hematite with lesser chalcocite.

The area is underlain by thin, dark green, amygduloidal olivine tholeiite flows (Annells 1973), that strike north and dip 30° to 40° west. Amygdules filled with quartz, agate, calcite, chlorite and / or epidote, and carbonate and quartz-carbonate fracture fillings are common in the flows.

The Mamainse Vein is described as striking 335° and dipping 50° east, similar to the C Zone on the Coppercorp property (Tortosa and Moss 2004). The vein was traced for 457 m, pinching and swelling along strike varying in width from 0.46 to 4.0 m. This vein appears to be exposed along the shore to the south, and there are a number of smaller fractures containing mineralization including one north of the parking site.

BE CAUTIOUS AS THE OUTCROP WILL BE SLIPPERY IF WET

Approximately 60 m south of the parking area on the lake shore, a west northwest trending fracture hosts an about 10 cm wide felsite dyke and the quartz-carbonate Mamainse vein fracture filling (Photo 4). Very fine fractures, filled with native copper and calcite, are oriented at right angles to the main northwest-trending fracture. The carbonate-quartz fracture filling and veining contains disseminated chalcocite, chalcopyrite, lesser native copper, with malachite and azurite weathering products, and associated specular hematite.

North of the parking area, a subparallel 5 to 10 cm wide fracture filled with carbonate and quartz also hosts chalcocite and chalcopyrite, with malachite and azurite.

Along the shore to the north, and in the rock cut on the east side of the highway, a polymictic conglomerate is interbedded with the flows. This conglomerate is located stratigraphically above the “Great Conglomerate” (Giblin and Armburst 1969).

Proceed south for ~875 m

*Turn east on the bush road
Proceed south for 2.3 km*

STOP 7 Ubetuwantit Vein (Coppercorp Property)*UTM coordinates – 670432E 5211228N*

Park the vehicles along the bush road and proceed about 300 m to the east along the trail to the pits.

This vein is exposed in two shallow pits on the west side of the powerline. Sampling by Nikos Explorations (Tortosa and Moss 2004) indicates that the 5 to 10 centimetre wide vein is composed of quartz and carbonate hosted by fracturing and minor brecciation within a basalt flow. The veins contain chalcocite and chalcopyrite with abundant specular hematite. The flow is amygduloidal with calcite veinlets and trace malachite staining. Some portions of the flow are pervasively hematitized with up to 1% specular hematite.

*Continue south for ~ 2.3 km**Passing through the area of the main shaft and waste pile for the Coppercorp Mine.***STOP 8 Coppercorp Mine***UTM coordinates – 671103E 5209365N*

In the open cut, the C Zone can be observed in a north-northwest trending fault. This is one of a set of north-trending, generally 50°-70° east dipping, faults that are almost parallel to the strike of the flows. The veins and breccia fillings consist of quartz and carbonate with subordinate laumontite and fluorite. The width of the fault zones varies along strike from shears less than 1 metre to disrupted lenses up to 12 metres across (Richards, 1985). The wallrock is commonly chloritized and sericitized and may contain epidote. Mineralization consists of predominantly copper sulphides, chalcocite with lesser chalcopyrite and bornite, usually accompanied by specular hematite. Large vugs of varying size are lined with quartz, calcite and sulphides and were commonly found throughout the deposit.

Samples may be obtained from the blocks piled to the south of the open cut.

*The mine may be exited either by returning north for ~4.6 km along the bush road to the highway, or if the roads are passable proceed south and west for ~2.3 km to the highway**Proceed south for ~5.8 km**0 – 5.8 km: flows and intercalated clastic sediments and felsic rocks of the lower portion of the Upper Division, MPF**4.3 km: south entrance to the Coppercorp Mine.***STOP 9 Interbedded Conglomerate and basalt***UTM coordinates – 66836E7 5207904N*

Park in the area near the top of the rise on the west side of the highway

BE CAUTIOUS AS THE HIGHWAY IS BUSY AND HEAVILY TRAVELLED BY TRACTOR TRAILERS

Walk north along the highway to the rock cut and cross with caution.

At this location, two polymictic conglomerates are separated by a basalt flow. There are a number of conglomerate horizons interbedded with the flows the MPF, with thicker concentration occurring in the “Great Conglomerate” located to the north and stratigraphically below this stop, and this conglomerate is typical of the polymictic conglomerates of the MPF (e.g. Annells 1973; Giblin 1974).

The conglomerates generally contain sub-rounded, up to 0.61 m clasts of predominantly Archean granitic rocks, with minor amounts of Archean mafic metavolcanic rocks, iron formation, and Keweenawan basalt (Fig. 5). In some locations, well laminated to cross-bedded sandstone is interbedded with the conglomerates (Annells 1973).

The basalt flow separating the conglomerate beds was described by Giblin (1974) as having a narrow amygdaloidal zone, with a few pipe vesicles, at the base, rapidly coarsening upwards through the flow, and a thicker amygdaloidal zone near the flow top. Minor faulting, ranging from a few to 30 cm, occurred at the base of the flow, and has been filled by carbonate.

Carbonate occurs in fractures cutting the conglomerate and also in the matrix.

Proceed south for ~3.6 km.

0 – 3.6 km: flows and intercalated clastic sediments and felsic rocks of the Upper Division

~2.6 km: hyaloclastite intercalated with the massive flows – west side of highway

STOP 10a Domeykite Occurrence

UTM coordinates – 669783E 5204844N

Park in the lane on the west side of the highway, south of the outcrop

BE CAUTIOUS AS THE HIGHWAY IS BUSY AND HEAVILY TRAVELLED BY TRACTOR TRAILERS

Walk north to the large sloping outcrop located on the east side of the highway and cross the highway with caution.

Domeykite (Cu₃As) is isometric, hextetrahedral, gray to yellow-brown to white, with a brittle fracture and habits that include botryoidal, reniform, and massive uniformly indistinguishable crystals. It has a hardness of 3 to 3.5, metallic luster, and a black gray streak (<http://webmineral.com/data/Domeykite.shtml>).

Domeykite mineralization is restricted to a pink to red, fine-grained felsic rock of rhyolitic composition that dips from 30° to 40° northwest with an overall thickness from 10 to 15m. The lowermost 3 to 4 m of the unit is strongly flow banded with tight asymmetric isoclinal folds. The lower contact with the basalt is sharp and has an aphanitic, 2 to 10 cm chilled zone that contains subangular to subrounded fragments of basalt. Spherical calcite-filled amygdules occur within the felsic unit for up to a few centimetres from the basalt. The basalt is a medium-grained, diabasic, dark green amygduloidal olivine tholeiite. This felsic unit is interpreted to be an intrusion into the older basaltic flows (e.g. Annells 1973).

Domeykite is a copper arsenide concentrated in green to grey patches best developed in the flow banded portions of the lower and central parts of the unit. The domeykite has not been observed in the basalts stratigraphically above or below. The restriction of the copper arsenide mineralization to the felsic unit suggests that the mineralization may be genetically related to the

felsic magma, perhaps concentrated in late stage magmatic fluids migrating along zones of shearing and deformation during the last stages of crystallization of the magma.

Return to the vehicles

Proceed south for ~800 m

STOP 10b Cottrell Cove Felsic Intrusion

UTM coordinates – 670390E 5204502N

Park in the bush road on the east side of the highway and proceed about 60 m north to the outcrop on the west side.

BE CAUTIOUS AS THE HIGHWAY IS BUSY AND HEAVILY TRAVELLED BY TRACTOR TRAILERS

The rock cut consists of a rock of rhyolitic composition (Annells 1973; Lightfoot et al. 1999), and is part of an approximately 250 m wide body that includes the pseudotachylite stop to the north (Stop 10c). The domeykite outcrop has been interpreted to be the northwest branch of this unit (Giblin and Armburst, 1969). This unit is also exposed along the shore of Cottrell Cove to the west.

The felsic unit is fine-grained, reddish brown, and varies from massive in the core to quartz porphyritic and flow banded towards the margins. The flow bands forms tight asymmetric isoclinal folds that are generally parallel to the contacts (Photo 6a). The contact consists of a breccia ranging from centimetres to tens of centimetres, and containing subangular to subrounded, pebble to cobble sized fragments of this unit, basalt, and granite in a felsic matrix (Fig. 6b). Dykes of felsite breccia reportedly intrude the adjacent basalts (Giblin 1974).

The massive core contains light brown to beige lenses and irregular patches or funnels



Photo 5: Polymictic conglomerate containing clasts of Archean felsic plutonic rocks intercalated with basaltic flows.



Photo 6c: Alteration along vertical fractures in rhyolite possibly related to magmatic degassing.



Photo 6a: Flow-banded rhyolite near the contact, with pink, grey to white alteration.



Photo 7: Pseudotachylite consisting of an aphanitic, matrix containing fragments of quartz, felsite, and basalt



Photo 6b: Autobrecciated felsite in contact with diabasic basalt.



Photo 8: Keweenaw basalt unconformity overlying Archean felsic plutonic rocks. ([http:// www.start.ca /users/ mharris/ waterfalls/ chippewa-falls.html](http://www.start.ca/users/mharris/waterfalls/chippewa-falls.html))

(Photo 6c). Giblin (1974) reported that this change was a result of alteration and extensive development of kaolin. The orientation of the funnel suggests that this alteration may be a result of post-depositional degassing and possibly related to the pseudotachylite of the previous stop. This irregular colour variation also resembles variations observed in the oxidized Sibley Group sedimentary rocks of the Nipigon area, suggesting that some of this variation may be in part a result of reduction of an originally oxidized rock.

These felsic units or felsites have been interpreted to be intrusive in nature (e.g. Annells 1973; Giblin 1974) based primarily on the brecciated nature of the exposed contacts. The depth of intrusion is not known, or whether some of these units may have formed high level cryptodomes that may have breached surface. The only known geochronology for the Mamainse Point area is a U/Pb zircon age of 1096 \pm 2.1 Ma (D. Davis, personal communication, 2005) for a unit with similar characteristics located north of the Mamainse Mine. However, the contact relationships at that location are ambiguous.

Proceed for ~200 m north

outcrop located on the west side

STOP 10c Pseudotachylite

UTM coordinates-670190 5204595

Please do not collect samples from the outcrop, as there are abundant fragments in the rubble used as fill for the road bed.

The pseudotachylite was originally described by Giblin (1974) and occurs as narrow branching veins, ranging in thickness from a few centimetres to thin films on fracture surfaces, cutting both the massive fine-grained felsic rock and the wallrock basalts (Photo 7). Veins are composed of a dark grey, black, to dark brown, aphanitic, matrix, that often breaks with a sub-conchoidal fracture, containing fragments of quartz, felsite, and basalt.

Thin-sections material show the veins to be a microbreccia consisting of angular fragments of quartz (free of strain shadows), feldspar, devitrified glass, quartz-feldspar porphyry with a matrix of devitrified glass, opaque minerals, felsite, and basalt (Giblin 1974). These fragments

are set in a matrix of finely comminuted fragments of the above-noted materials and larger, irregular grains of carbonate and chlorite. An overall pinkish colour was interpreted to be a result of finely disseminated hematite.

Giblin (1974) tentatively interpreted the pseudotachylite to be a result of gas escaping from the underlying felsic magma streamed upwards, under high pressure, through fractures in the overlying rocks. Fragments of the wallrocks, detached by erosive power of the gas and structural dislocation, were transported in a fluidized gas-solid system, which further eroded the wallrocks and the entrained particles. The fluidized material filled the fractures, and upon the eventual decrease in gas pressure, remained as veins of very fine-grained rock powder.

Proceed south for ~27.7 km

6.6 km: Pancake Bay Provincial Park

UTM coordinates – 675727E 5204458N

8.3 km: Pancake River

UTM coordinates – 678422E 5203459N

~8.8 km: Mamainse Point Fault separates the MPF to the north from the Jacobsville Formation sediments to the south.

8.8 – 21.8 km: Jacobsville Formation

~13.8 km: the road to the Tribag Mine exits on the east side of the highway

~19.0 km: Batchawana River

UTM coordinates – 688231E 5200663N

~21.8 – 27.7 km: Archean felsic plutonic rocks

The highway crosses over the Harmony River

The entrance to the parking lot is to the south side of the river on the east side of the highway.

STOP 11 Chippewa Falls

UTM coordinates – 695982E 5200414N

A monument in the small roadside park marks the approximate mid-point of the Trans-Canada Highway. Follow the trails for approximately 90 m to the top of the lower falls, where there is an excellent exposure of Mamainse Point flows unconformably overlying Archean trondhjemite and diabase dykes.

The best exposure is on the small island which is accessible only during periods of low water (Fig. 8). The contact on the island and the east side of the river can be viewed from the trail.

Giblin (1974) described the unconformity as generally 10° - 30° southwest dipping, but is nearly vertical on the east bank of the river. The basalt flow has a chilled lower contact with rare pipe vesicles, and near the east side of the island, a few pillows ranging in length from 0.3 to 1.2 m occur in the lower 3 m of the flow. These are the only pillows found to date in the Keweenawan lavas of the east shore of Lake Superior.

Proceed 51.7 km south to Sault Ste. Marie

0 – 9.8 km: Archean felsic plutonic rocks

9.8 - 13.1km: Keweenawan mafic flows

11.2 km: Optional Stop, Keweenawan Basalt

Optional Stop – Keweenawan Basalt

UTM coordinates –700261E 5192354N

Good cross-sections of the basaltic flows are exposed in the rock cut on the east and southeast side of the highway, and include thin basal amygdaloidal zones, thicker upper amygdaloidal zones, and common reddish, ropy flow tops.

13.1 – 15.2 km: Jacobsville Formation

15.2 – 17.4 km: Archean felsic plutonic rocks

17.4 – 19.9 km Archean felsic to intermediate metavolcanic rocks with the hill top to the west being a Nipissing sill.

19.9 – 25.0 km: sedimentary rocks of the Gowganda Formation of the Southern Province, intruded by gabbro sills of the Nipissing diabase to the northeast.

25.0 – 32..1 km: Jacobsville Formation in the Goulais River valley.

32.1 – 45.9 km: Archean granitic gneisses and migmatites cut by diabase dikes with Huronian sediments to the east along Highway 550.

45.9 - 51.7 km: Jacobsville Formation to the Water Tower Inn