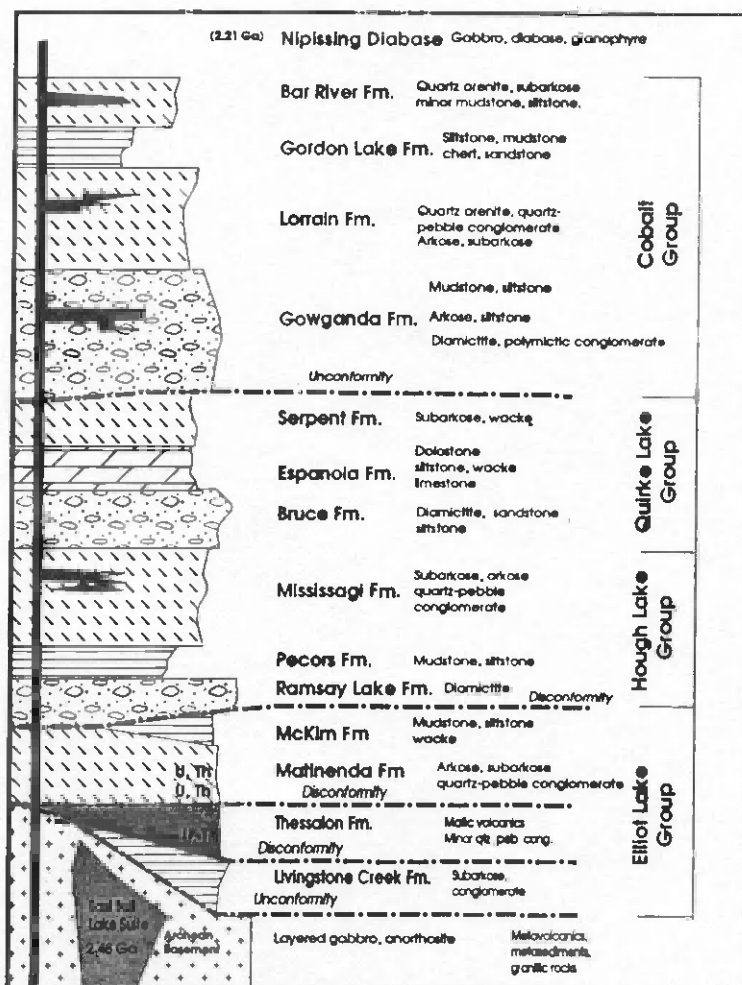


THE HURONIAN SUPERGROUP BETWEEN SAULT STE. MARIE AND ELLIOT LAKE

EVIDENCE FOR THE EARLY PROTEROZOIC ATMOSPHERE, CLIMATE AND TECTONICS

by

G. Bennett, K. D. Card and
K. Y. Tomlinson



INSTITUTE ON LAKE SUPERIOR GEOLOGY
43 rd ANNUAL MEETING, MAY 6, 11, 1997
SUDBURY, ONTARIO

Field Trip Guidebook, Volume 43, part 2

<u>EVENT</u>	<u>ROCK UNIT</u>	<u>AGE (MA)</u>
<u>MIDDLE PROTEROZOIC</u>		
Grenville Orogeny		1000-1200 Cu
Midcontinent Rift System	Keeweenawan volcanics, sediments	1100
Dyke emplacement	Sudbury swarm	1238
Anorogenic magmatism	Croker Island Complex, Manitoulin Island intrusions	1450-1500
<u>EARLY PROTEROZOIC</u>		
Felsic plutonism	Chief Lake, Cutler batholiths	1700-1750
Deformation and metamorphism (late Penokean)		
Sudbury Event	Sudbury Igneous Complex Whitewater Group	1850 Ni, Cu, PGE, Zn Pb
Deformation and metamorphism (early Penokean)		
Dyke emplacement, rifting (ocean opening?)	Kenora-Kabetogama, Marathon swarms	~2150
Mafic magmatism	Nipissing diabase	2219 Ni, Cu, PGE, Ag, Co, Cu, Au
Deformation (Bleazardian Orogeny)		
Oxyatmoverision	Upper Huronian Supergroup	Si
Sedimentation, mafic magmatism	Lower Huronian Supergroup Matchewan dykes, mafic-felsic volca gabbro-anorthosite intrusions Creighton, Murray granites	U 2450-2496 Ni, Cu, PGE
<u>ARCHEAN</u>		
Late deformation		Au
Late plutonism	Algoman granites	~2650 U
Early deformation and plutonism	Levack Complex tonalite gniess	~2680
Vocanism and sedimentation	Abitibi Subprovince greenstone belt	2735-2700 Cu, Zn, Fe

Table 1. Precambrian rock units and tectonic and metallogenic events in the

Lake Huron Region (After Card and Jackson, 1995)

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Table 1. Precambrian rock units and tectonic
and metallogenic events in the Lake Huron region..back cover

THE HURONIAN SUPERGROUP BETWEEN SAULT STE. MARIE AND ELLIOT LAKE

Introduction

The Huronian Supergroup is one of the Earth's most studied sequences of rocks. Since the turn of the century the results of hundreds of studies of Huronian rocks have been published in scientific journals and government publications. These studies have led geoscientists to present evidence for the Earth's earliest glacial periods, the development of free oxygen in the atmosphere of the early Earth, the deposition of paleoplacer deposits of uranium, and evidence for plate tectonic activity during the Proterozoic. Much of the evidence presented is based on rock exposures which will be visited during this field trip.

The Huronian Supergroup is a sequence of Paleoproterozoic sedimentary and minor volcanic rocks lying unconformably upon Archean rocks of the Superior Province of the Canadian Shield. The Huronian belt extends eastward from Lake Superior, along the north shore of Lake Huron to Sudbury and then northward to the Noranda area of Quebec, a distance of about 450 km (270 miles) (Figure 1). The Huronian Supergroup attains its greatest thickness of 12,000 metres (40,000 feet) southwest of Sudbury. The sequence thins northward due to the wedging out of basal units, thinning of clastic units, and erosion within the sequence (Roscoe, 1969; Frarey and Roscoe, 1970).

The 2219 Ma radiometric age of the Nipissing intrusions places an upper limit on the age of the Huronian Supergroup, while the Copper Cliff Ryolite (2450 Ma) is probably close to the date of initial Huronian deposition in the Sudbury area.

The Huronian Supergroup consists of four groups, which in ascending stratigraphic order are: The Elliot Lake Group, Hough Lake Group, Quirke Lake Group and Cobalt Group (Figures 2,3). Formations of the three upper groups, with the exception of the Serpent Formation, show stratigraphic continuity, and display a remarkable cyclicity of lithological units; beginning with matrix-supported conglomerate (diamictite), followed by mudstone, siltstone or limestone and capped by coarse, cross-bedded sandstone. Many paleocurrent studies have shown paleocurrents flowed south to southeast, with southeast being the predominant direction (Figure 5).

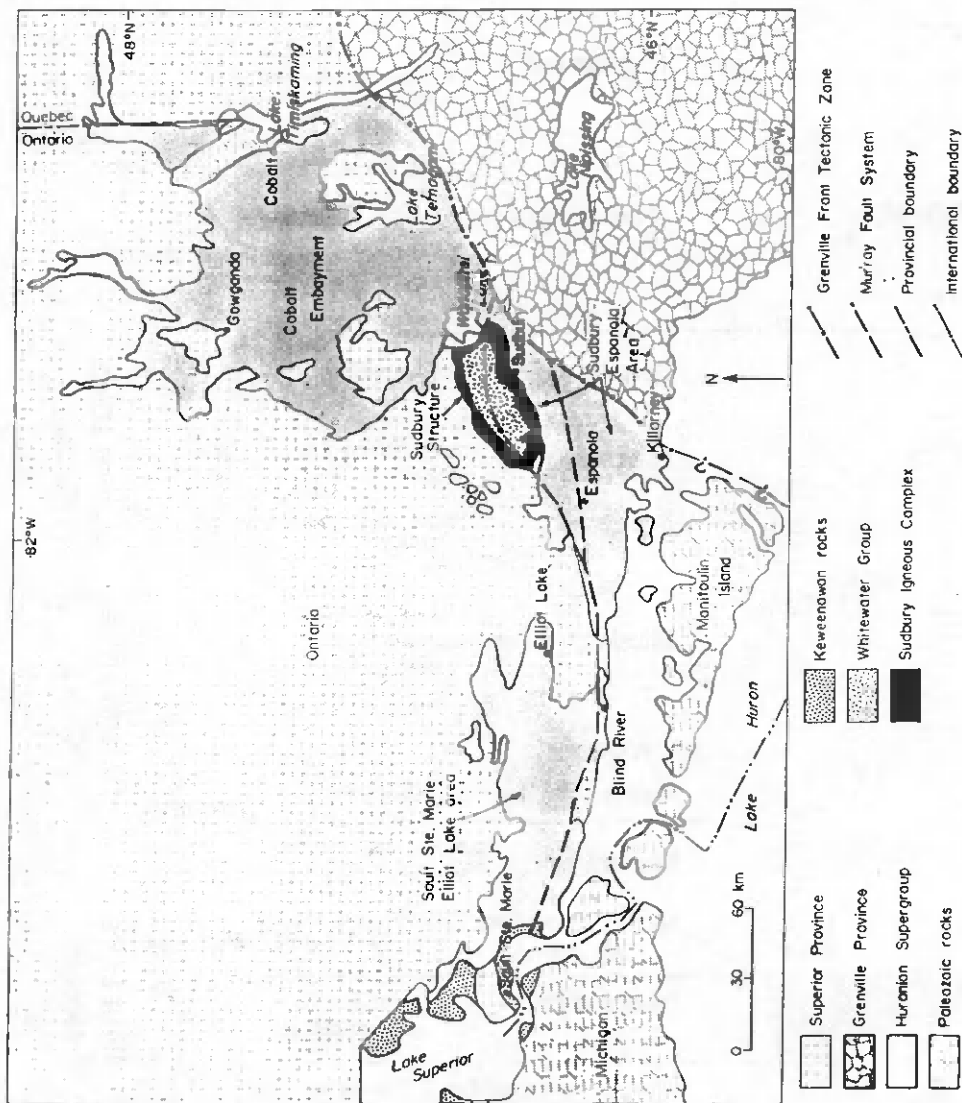


Figure 1. The distribution of rocks of the Huronian Supergroup

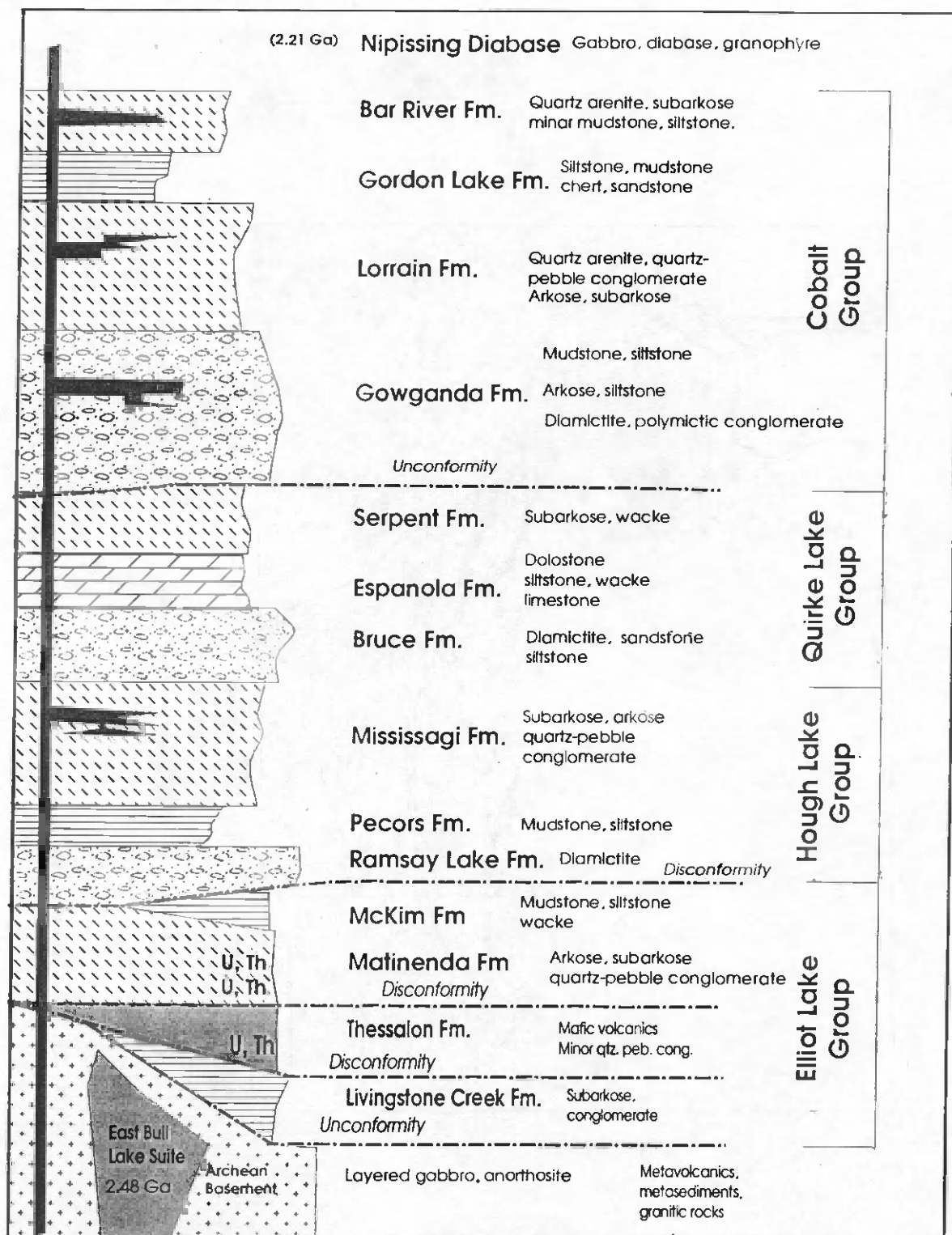


Figure 2. Huronian Stratigraphy - Sault Ste. Marie-Elliot Lake area

The Elliot Lake Group

The Elliot Lake Group differs from the overlying Huronian groups in that: (1) its internal stratigraphy is generally discontinuous and less extensive; (2) it does not show the diamictite-mudstone-sandstone sequence; (3) it contains the only important uranium deposits; (4) and the only volcanic rocks in the entire supergroup.

The Livingstone Creek Formation

The polymictic conglomerates and sandstones of the Livingstone Creek Formation (Frarey, 1967) form the lowermost Huronian formation. It is the only Huronian formation known to precede some of the Huronian igneous activity.

The Livingstone Creek Formation is at least 1200 feet (400 m) thick in the Sault Ste. Marie area and between 300 feet (100 m) and 1000 feet (300 m) thick in the Thessalon area.

The formation has been correlated with grey sandstone and conglomerate near Crazy Lake in Nicholas Township (Bennett, 1978; Bottrill, 1971). A remnant of the conglomerate member occurs as far east as Pecors Lake on the south limb of the Quirke Lake Syncline (Jensen, 1990) (Figures 4, 6,). The Livingstone Creek Formation has not been recognized east of the Quirke Lake Syncline.

The Livingstone Creek Formation consists of two distinctive rock types: an upper fine- to medium-grained arkose, subarkose and subwacke; and a lower clast-supported polymictic conglomerate with cobble to boulder-sized megaclasts.

The sandstone member of the Livingstone Creek Formation may be distinguished from other Huronian sandstones by the uniform grain size (fine- to medium-sand) of the former. Mudstone and pebbly units (even isolated pebbles) are lacking within the sandstone member of the Livingstone Creek Formation. Another characteristic feature of the sandstone units is the presence of carbonate along the foresets of the commonly well-developed trough cross-beds. Planar cross-beds are rare.

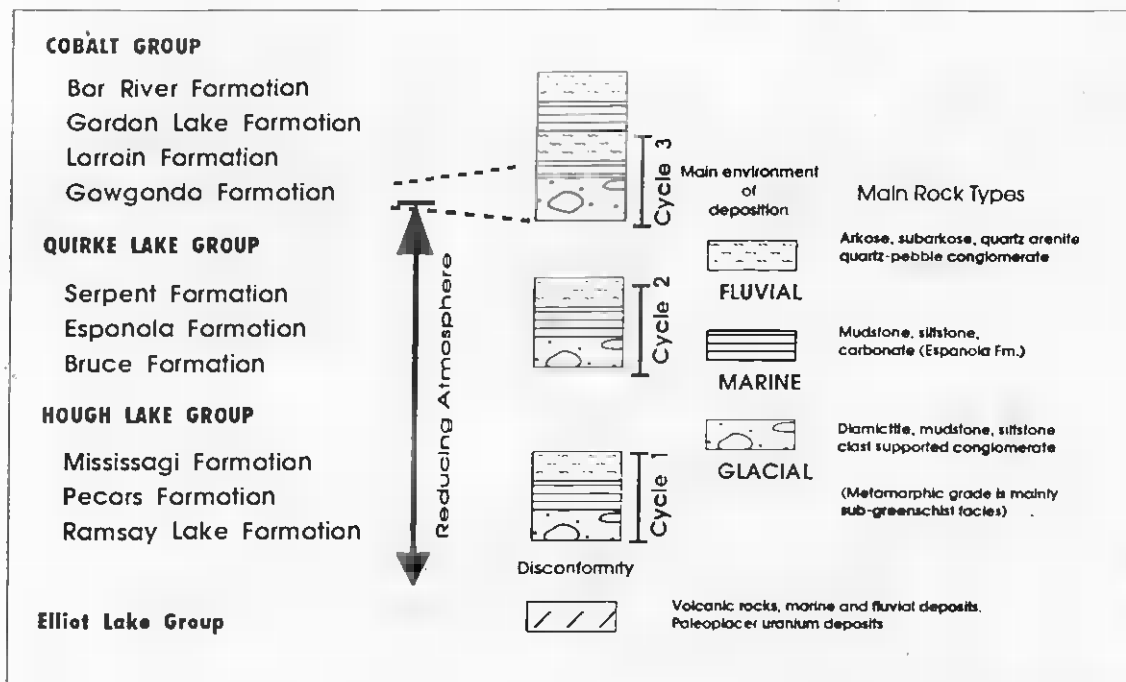


Figure 3 . The cyclicity of Huronian sedimentation

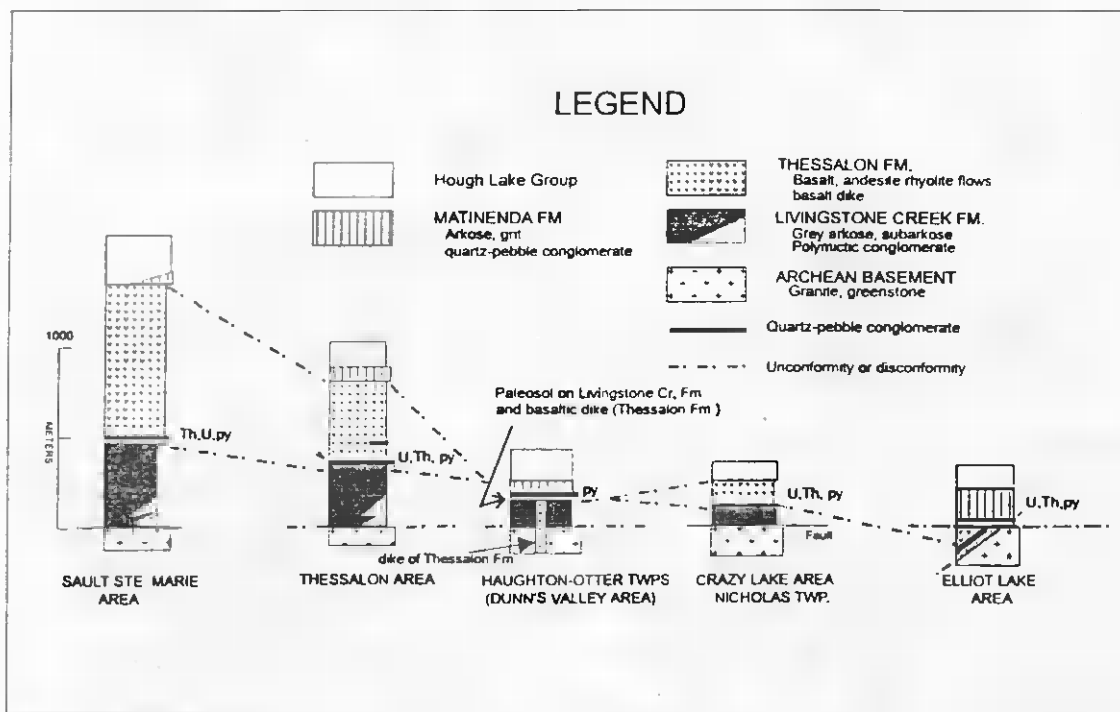


Figure 4. Stratigraphic relationships in the Elliot Lake Group - Sault Ste. Marie Elliot Lake area.

Clast-supported, polymictic conglomerate is a prominent rock type in the lower sections of the Livingstone Creek Formation. Cobble- to boulder-sized clasts of grey granitic rocks and minor mafic plutonic and metamorphic rock clasts are set in a sparse matrix of coarse, grey arkose or arkosic grit. No clasts of Huronian volcanic rocks were recognized. Thin units of cross-bedded, grey arkose are locally interbedded with the conglomerate (Frarey, 1977, Bennett et al., 1991). The grey granitic mega-clasts of the conglomerate member is in contrast with the predominantly reddish hues of the underlying Archean basement rocks. This colour difference appears to be due to the reduction of ferric iron in the feldspars of the red granitic clasts in the conglomerate, and not a result of differing provenance. This conclusion is supported by the observation that granitic rocks in a "paleosol zone" a few metres to a few tens of metres below the base of the Livingstone Creek Formation commonly display a grey colour as well.

The clast size, local source and low stratigraphic position of the Livingstone Creek conglomerates are consistent with deposition on an alluvial fan. The uniform, fine- to medium-grained sand of the trough cross-bedded sandstone member suggests a different, although probably related depositional environment than that of the conglomerate. The sandstone member may represent deposition by median streams flowing in a fault bounded valley with scarps covered by alluvial fans (Bennett et al., 1991). The well sorted nature of the sandstone suggests an aeolian component or even aeolian deposition (Meyer, W., 1983).

Early Huronian Intrusive Rocks

Several petrographically distinctive, mafic to ultramafic intrusive bodies have been recognised between the eastern end of the Sudbury Igneous Complex and the nose of the Quirke Lake Syncline. The intrusions are characterized by the presence of anorthositic phases and locally well developed, primary rhythmic layering of alternating anorthositic and gabbroic layers. Segregations, dikes and sheet-like bodies of granophyre are locally present (Card and Palonen, 1976; Peck et al., 1995).

Major intrusions of gabbro-anorthosite are found at Agnew Lake (Card and Palonen, 1976) and at East Bull Lake (Born and James, 1978; Kamineni et al., 1984). Bennett, et al. (1991) report two

additional bodies between Blind River and Thessalon. All gabbro-anorthosite bodies found to date have been emplaced in the Archean basement at, or just below the Archean-Huronian boundary.

Krogh et al. (1984) reported a U-Pb age 2491^{+5}_{-5} Ma for zircons from the gabbro-anorthosite intrusion at Agnew Lake and 2480^{+10}_{-5} Ma for the East Bull Lake gabbro-anorthosite body. The similarity of these ages to the 2450^{+25}_{-10} Ma (U-Pb zircon) age of rhyolite of the Huronian Copper Cliff Formation (Krogh et al., 1984) indicates that these gabbro-anorthosite intrusions form part of the early Huronian volcanic events (Card, 1978a).

The north to northwest trending Matachewan-Hearst dike swarm is the second largest dike swarm of the Canadian Shield. The 2.45 Ga age of the swarm (Heaman, 1988) is essentially the same as that of the East Bull Lake Suite and the Huronian volcanic rocks of the Copper Cliff Formation.

Krogh et al. (1996) report a U-Pb age of 2.48 Ga for the Murray Granite; one of several granitic intrusions cutting the lower part of the Huronian Supergroup near Sudbury. It is possible that these intrusions are magma chambers for Huronian felsic volcanic rocks in the Sudbury area.

Huronian Volcanic Rocks of the Sudbury Area

The Huronian bimodal volcanic sequence in the Sudbury area has been subdivided in the predominately mafic Elsie Mountain (1000 m thick) and Stobie Formations (1500 m thick), and the felsic Copper Cliff Formation (760 m thick) by (Card 1978a) (Figure 7). Krogh et al. (1984) obtained an age of 2450^{+25}_{-10} Ma (U-Pb zircon) age for rhyolite of the Huronian Copper Cliff Formation; the only Huronian supracrustal rock for which there is an absolute age. The volcanic rocks of the Sudbury area show evidence of submarine eruption from fault controlled vents along the edge of a depositional basin into which arkosic sandstones were being transported from the Archean granitic terrain to the north, while turbidites were deposited from sediment from both the volcanic and rejuvenated basement marginal to the basin (Card, 1978a). The volcanic rocks of the Sudbury area differ in terms of internal stratigraphy, overall thickness and depositional environment from the Huronian volcanic rocks in the Sault Ste. Marie-Elliot Lake area.

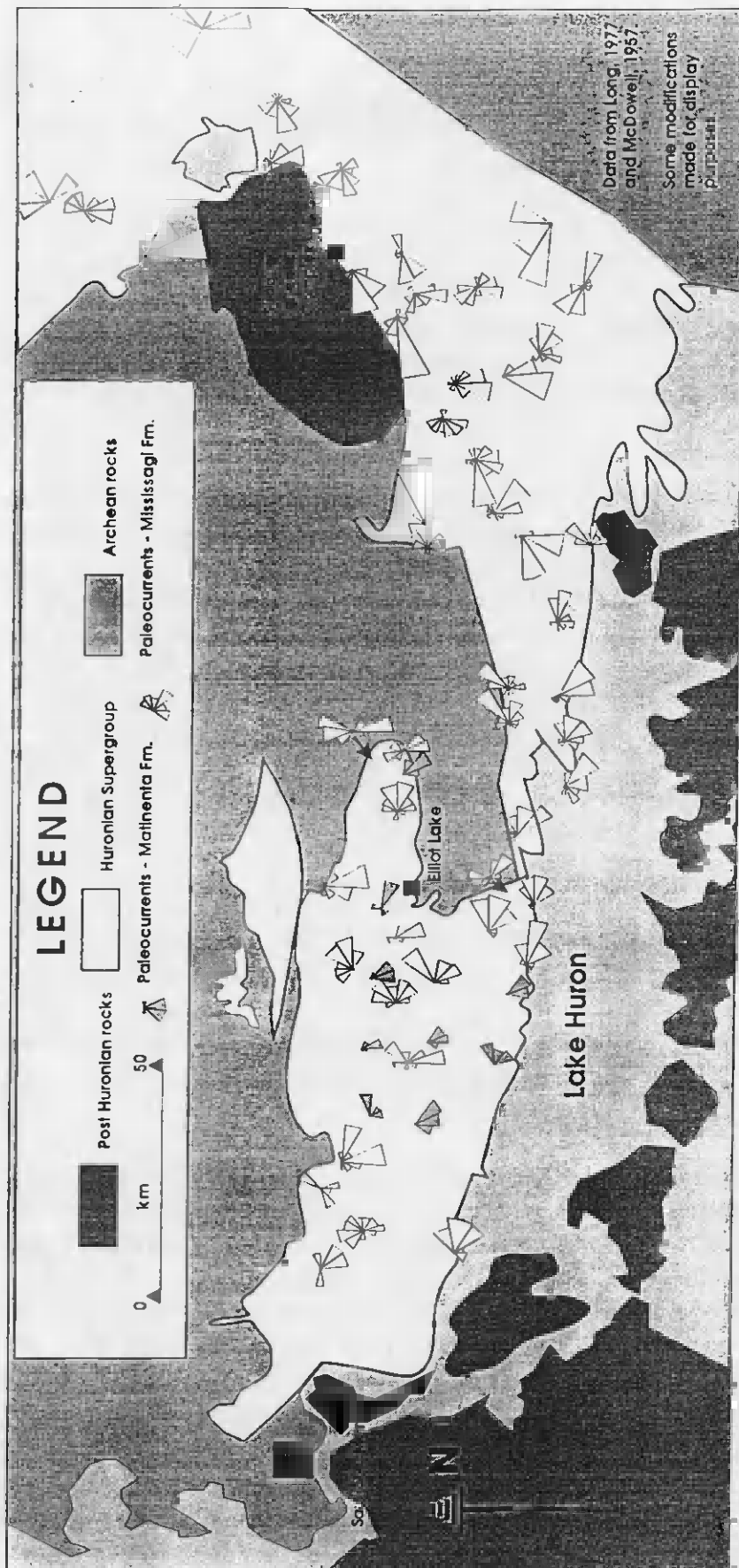


Figure 5. Paleocurrent roses for the Mississagi and Matinenda formations.

The Huronian Volcanic Rocks of the Sault Ste. Marie-Elliot Lake area

Volcanic rocks overlying the Livingstone Creek Formation were named the Thessalon Formation of the Elliot Lake Group by Frarey(1967). Jolly(1987) concluded the Thessalon Formation is a continental flood basalt sequence associated with continental rifting. Bennett et al.(1991) proposed that the Huronian volcanic rocks of the Quirke Lake Syncline should also be correlated with the Thessalon Formation.

Attempts to obtain an absolute age determination from rocks of the Thessalon Formation have so far been unsuccessful. However the spatial association of the East Bull Lake intrusions with the Huronian volcanic rocks of the Quirke Lake Syncline suggest Huronian volcanism in that area occurred about the same time as the emplacement of the East Bull Lake intrusions (2480 Ma). Given the potential error for the relevant age dates (Krogh et al., 1984), the age of the Thessalon Formation may not differ significantly from that of the Copper Cliff Formation of the Sudbury area (2450 Ma).

The maximum thickness of the Thessalon Formation in the Sault Ste. Marie area is approximately 650 m (2100 feet) and 820 m (2700 feet) (Frarey, 1977). Diamond drilling has indicated at least 670 m (2200 ft) of Thessalon volcanics under Lake Huron south of the town of Thessalon. The Thessalon Formation may be as much as 1080 m (3500 feet) thick at Bass Lake in Aberdeen Township.

Tomlinson(1996), who studied the geochemistry of the Huronian volcanic rocks between Sault Ste. Marie and Thessalon, concluded that the lavas of the Thessalon Formation are divisible into 7 distinct units based on mapping, petrography and major and trace element geochemistry (Figure 8). The 7 units were grouped into two "lava series". The upper lava series (units 6 and 7, of Tomlinson, 1996) is equivalent to the upper tholeiitic basalt sequence of Bennett et al. (1991). The lower lava series (units 1-5, of Tomlinson, 1996), consists mainly of basaltic andesite with subordinate, local rhyolite, mugearite, andesite and high magnesium basalt flows; and corresponds to the "diverse member" of Bennett et al.(1991).

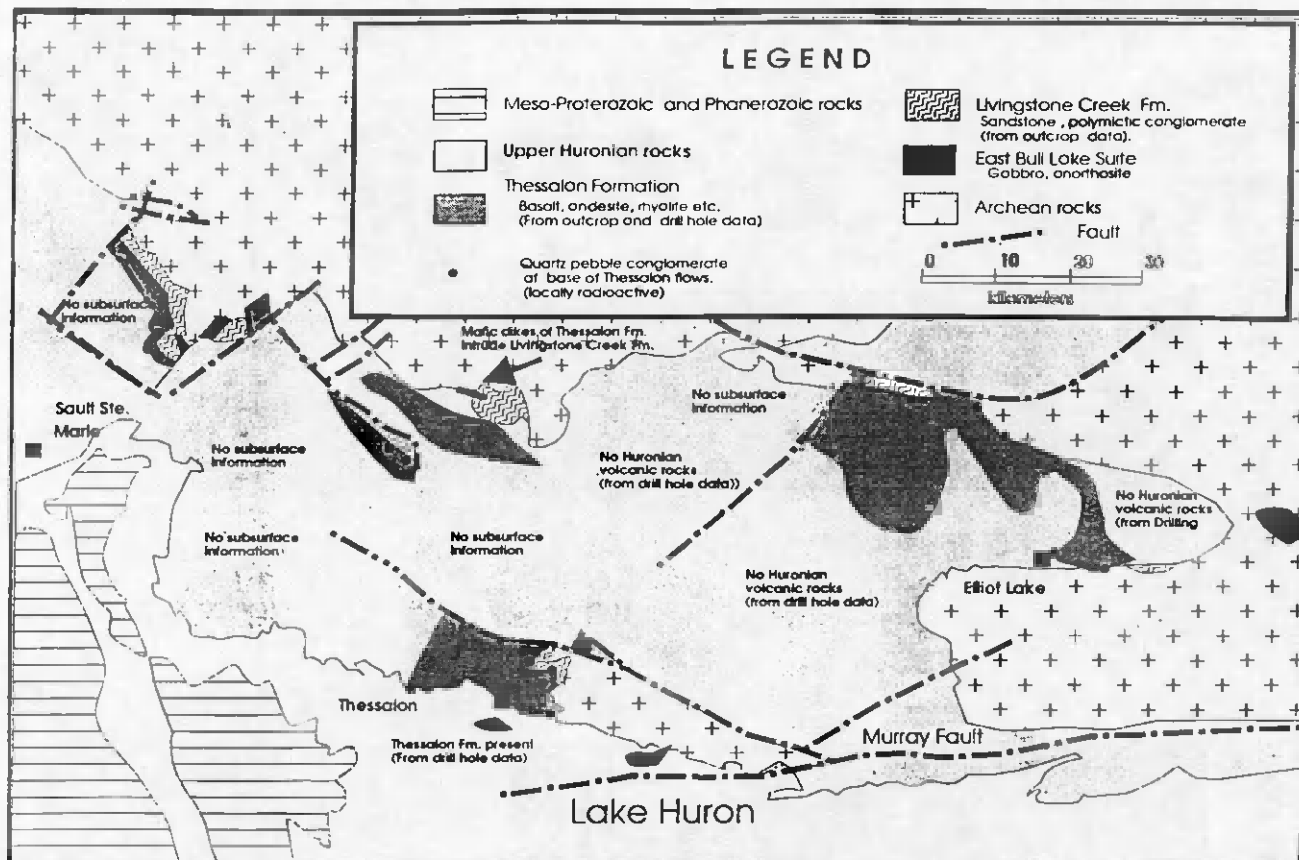


Figure 6 . The Distribution of Thessalon Formation and Livingstone Creek Formation.

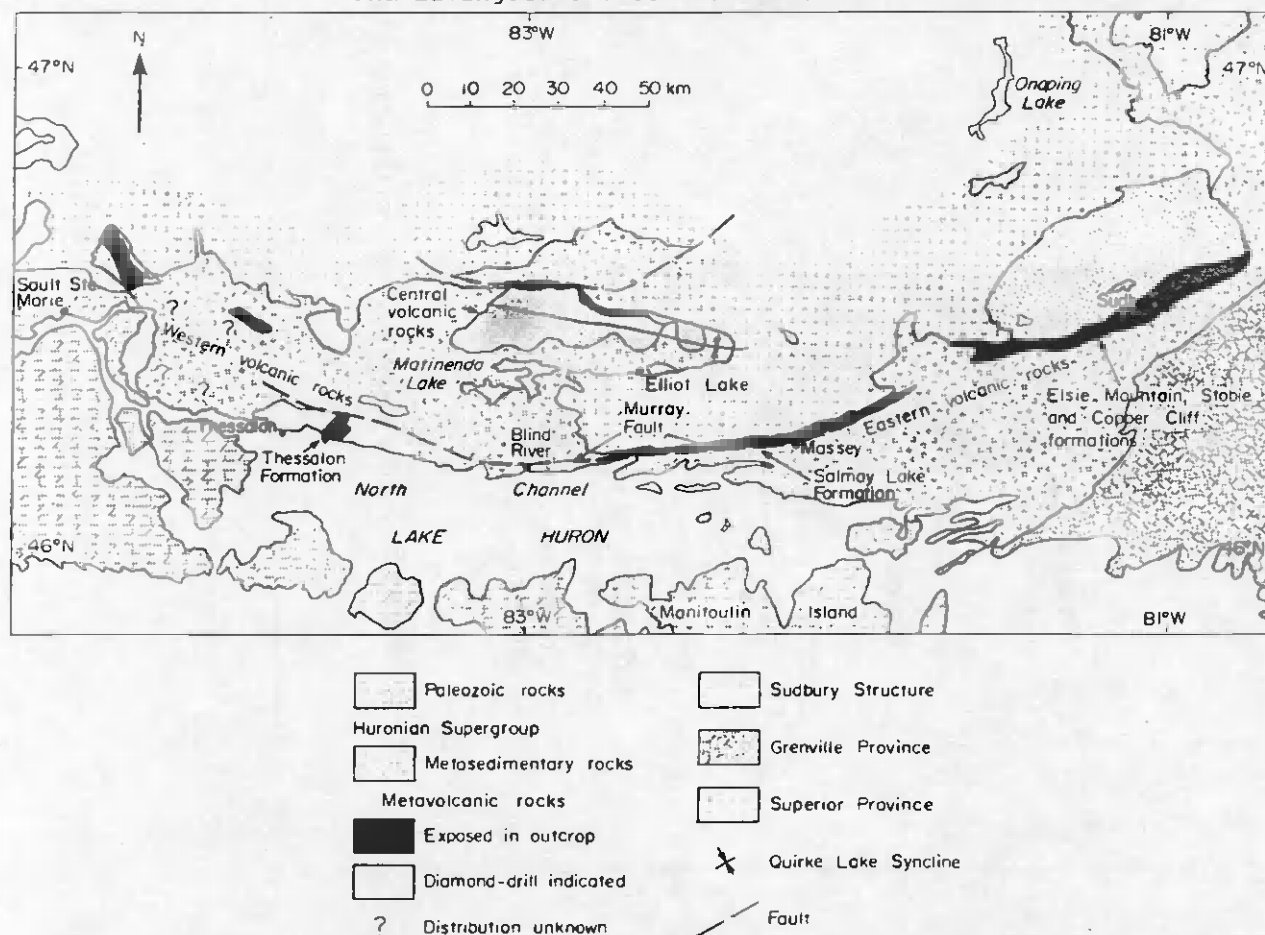


Figure 7. Distribution of Huronian volcanic rocks.

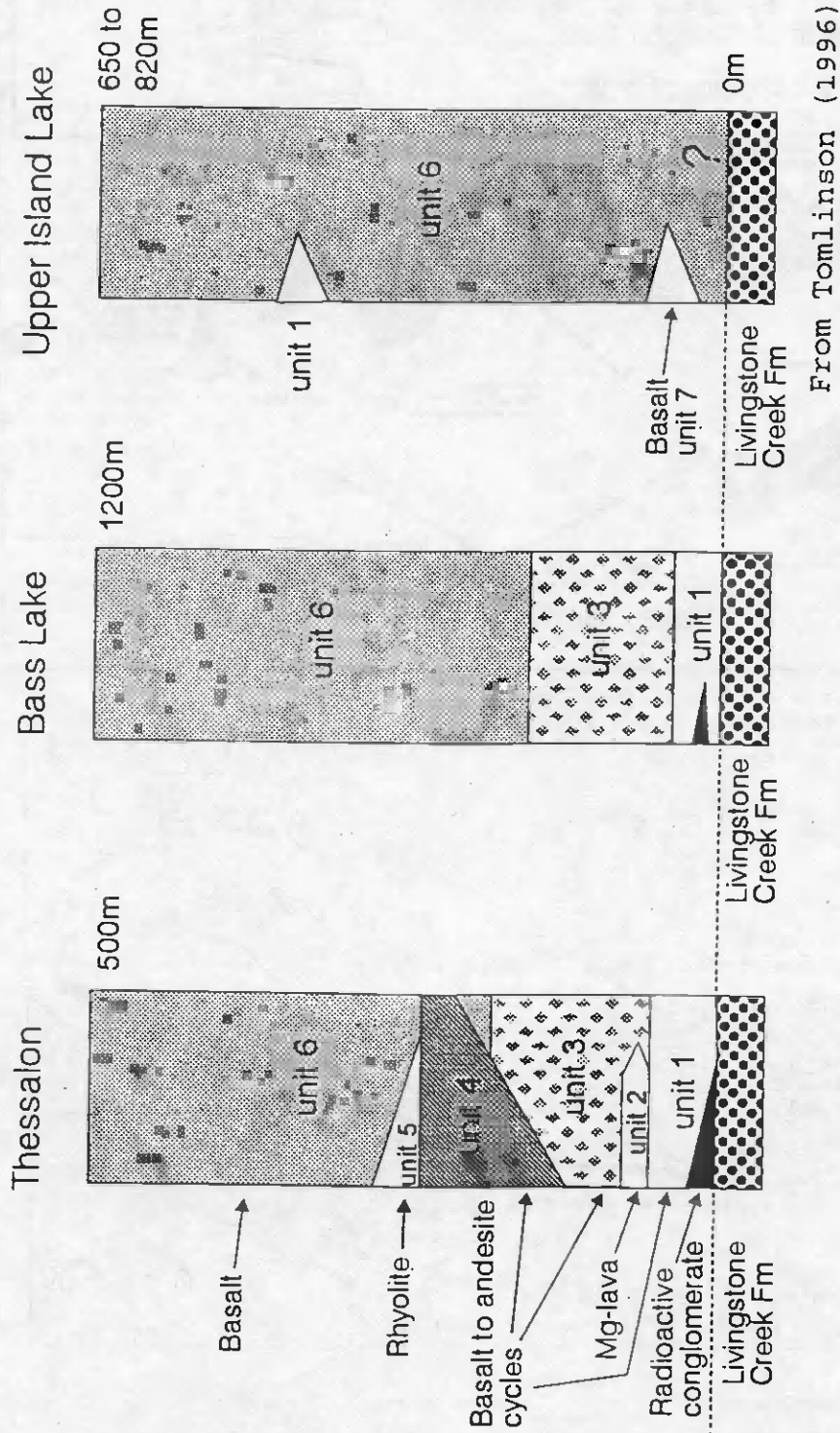
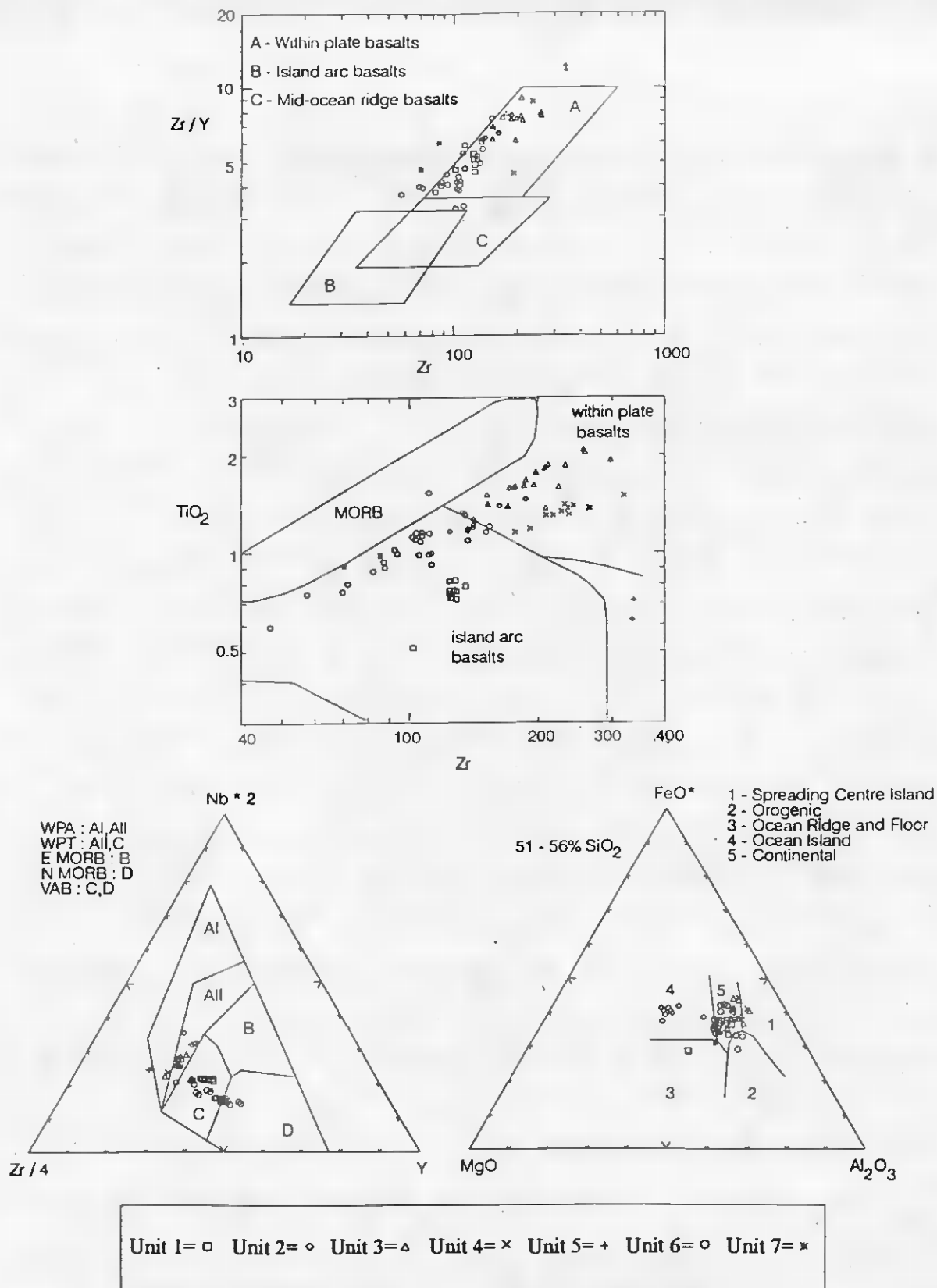


Figure 8. Schematic stratigraphy of the Thessalon Formation.



WPA = within plate alkali basalt, WPT=within plate tholeiite, E-MORB=enriched type mid-ocean ridge basalt, N-MORB=normal mid-ocean ridge basalt, VAB=volcanic arc basalt.

Figure 9. Discrimination diagrams for volcanic rocks of the Thessalon Formation
(from Tomlinson, 1996).

Bennett et al. (1991) proposed that the upper, basaltic flows of the Thessalon Formation (upper lava series) probably represent part of a continental flood basalt sequence, while the diverse member (lower lava series) appears to have erupted from central vents. The Huronian volcanic rocks of the Quirke Lake Syncline display lithological and geochemical similarities to the lower lava series of the Thessalon Formation west of the Quirke Lake Syncline (G. Bennett, unpublished data).

The upper, tholeiitic basalt flows of the Thessalon Formation (upper lava series of Tomlinson, 1996) are almost uniformly greenish-grey fine- to medium-grained tholeiitic metabasalt. The essential minerals are albite, actinolite, chlorite, clinozoisite, epidote and Fe-Ti oxides. Primary clinopyroxene is present in only a few samples of basalt from the Sault Ste. Marie area. The andesitic rocks of the lower lava series are generally darker coloured and commonly contain stilpnomelane and biotite with green pleochroism (Fe⁺³ rich?) in addition to albite and actinolite (Bennett et al. 1991). Tomlinson (1996) reports the presence of tremolite in some flows. Quartz is a minor component of basaltic and andesitic types. In most areas the metamorphic grade of the Thessalon Formation flows is lower greenschist facies.

Amygdules of epidote, chlorite, calcite, quartz and stilpnomelane, in complex zonal arrangements, are common. Flattened chlorite-filled amygdules a centimetre or less across are a distinctive feature of most mafic flows of the Thessalon Formation. Pillow structures are rare but were observed in most areas. Scoriaceous flow-tops and cross-cutting breccias are commonly filled with a fine-grained mixture of quartz and grey to red secondary albite.

Tomlinson (1996) states:

"The field and geochemical data indicate that the lavas are comparable to modern day continental basalt and andesites but that their source was similar to that of island arc basalt. Figure 9 shows the lavas plotted on a variety of discrimination diagrams where they are most comparable to modern within-plate basalt. Their arc-basalt geochemical characteristics result from their derivation from an upper mantle that had been metasomatically enriched during subduction in the Kenoran orogeny. Units within the sequence were generated from different pulses of magma, each of which stemmed from a different region of the relatively homogenous Huronian mantle. Only the unit 2 lavas require generation from part of

the mantle with slightly different characteristics to a source similar to that required to generate island arc basalt ID16 (a primitive basalt used by Tomlinson (1996) in making calculations). Different degrees of partial melting of this source that contains garnet in the residue (at less than 29.8% partial melting) are responsible for the REE characteristics of each unit. In the generation of the lower lava series, different batches of magma underwent crustal contamination to a greater or lesser extent within the lower or upper crust (or both) prior to eruption. The upper lavas series rocks are not contaminated. In all but the unit 2 lavas crystal fractionation occurred both early, as magma ascended to shallower depths, and later, in shallow level sills or magma chambers. Early fractional crystallisation was responsible for the low Mg, Ni and Cr values in most units, while later stage crystal fractionation was responsible for the major element and compatible element trends within single units, as shown on bi-element plots" (Tomlinson, 1996).

On the geochemistry and tectonic setting of the Thessalon volcanic rocks Tomlinson (1996) states:

"various lines of evidence from the Elliot Lake Group as a whole can be used to characterize the Huronian rifting event. Active rifting involves deep mantle upwelling or plume magmatism which splits the continental crust; whereas passive rifting involves mantle diapirism and adiabatic upwelling induced by differential stresses and stretching in the lithosphere (Wilson, 1989). The geochemical evidence from the Thessalon Volcanic Formation indicates that the source of the lavas was metasomatised upper mantle rather than a deep mantle or plume component. Structural subsidence patterns in the Archean basement (Zolnai et al., 1984) are thought to be responsible for lithospheric stretching, in-turn causing mantle upwelling, episodic partial melting and volcanism. This is supported by the presence of syn-depositional faults in up to 400 metres of Huronian sedimentary rocks below the volcanics. G. Bennett (personal communication, 1996) has also described syndepositional features (at 2 locations near Elliot Lake and Sault Ste. Marie) where sedimentary rocks of the Livingstone Creek Formation infill fractures in the underlying Archean basement. These features indicate that initially volcanism was a consequence of rifting. In active rifts just one uplift and melting event occurs as a plume impacts the lithosphere, but in passive rifts uplift and melting are episodic (Williamson and Keen., 1995). Multiple erosional surfaces within the Elliot Lake Group indicate that numerous episodes of uplift occurred. Based on these lines of evidence the Huronian rifting event can best be characterised as a typical passive rifting event" (Tomlinson, 1996).

Sedimentary Rocks Associated with the Thessalon Formation

In the Sault Ste. Marie area, thin units (<10 m) of radioactive and pyritic, quartz-pebble conglomerate, with directly overlying arkose and arkosic grit are found just above lowermost flows of

the Thessalon Formation. In the Thessalon area and in the Quirke Lake Syncline, similar units of quartz-pebble conglomerate and arkose are found directly below the mafic volcanic rocks where they lie upon the Livingstone Creek Formation, or upon the Archean basement, where the former is not present (Hay, 1963; Bennett et al., 1978; Meyer, 1983).

Bennett et al. (1991) proposed that the wide distribution of these units (Figures 4, 6) indicate the presence of a disconformity at the base of the Thessalon Formation throughout the Sault Ste. Marie-Elliot Lake area.

The Matinenda Formation

The Matinenda Formation of the Elliot Lake Group (Roscoe, 1957) is a sequence of arenites and intercalated quartz-pebble conglomerates which host the once important uranium deposits of the Elliot Lake area (Figure 2). The Matinenda Formation is up to 180 m (600 feet) in the Elliot Lake area (Robertson, 1981), where it lies on Huronian volcanic rocks and Archean basement. In the Thessalon and Sault Ste. Marie areas the Matinenda Formation consists predominantly of fine to medium grained subarkose and is probably less than 50 m (150 ft) thick (Bennett et al., 1978). In the Sudbury area clastic units correlated with the Matinenda Formation are as much as 600 m (200 ft) thick but they thin rapidly eastward where they are intercalated with the mainly metavolcanic rocks of the Stobie Formation and the mudstones of the McKim Formation (Card, 1978a).

The most abundant rock type of the Matinenda Formation in the Elliot Lake area is generally described as medium- to coarse-grained subarkoses, arkoses and grits consisting of poorly sorted quartz and feldspar grains set in a matrix of sericite and comminuted fragments. The ratio of K-spar to sodic feldspar is about 8:1. Minor constituents are pyrite, calcite, chlorite, zircon and rarely, leucoxene coated iron oxides and monazite (Robertson, 1968). Variable amounts of sericite produce what has variously been described as a green, apple green or greenish-yellow colour. Well sorted quartz-pebble conglomerate beds, containing well rounded pebbles and cobbles of quartz and chert, and pebbly subarkose units are scattered throughout the coarse subarkose units of the Matinenda Formation, but are more common near the base. (Robertson, 1968; Pienaar, 1963).

Trough cross-bedding, scour and fill structures are common in

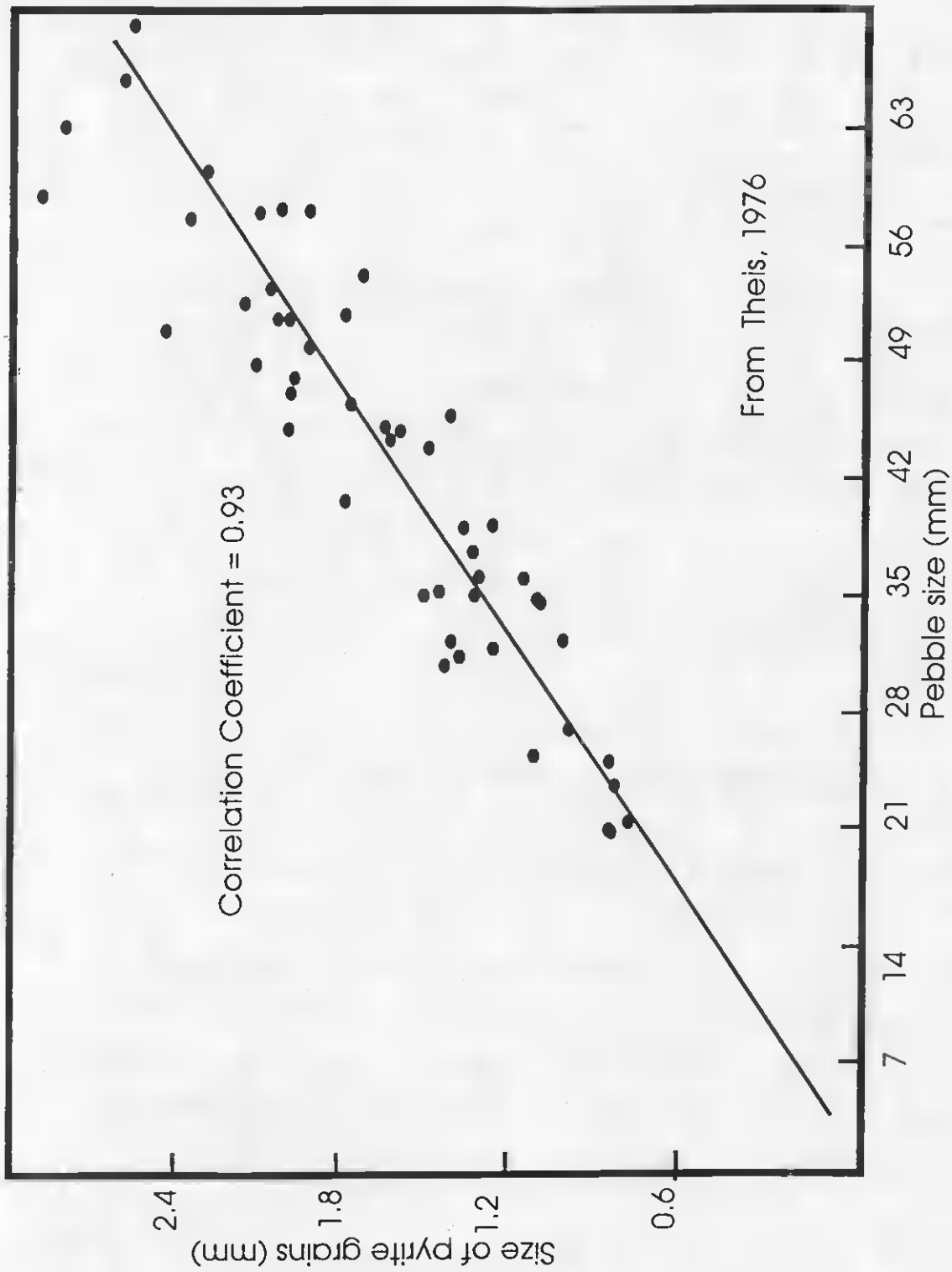


Figure 10. Pebble size vs. pyrite grains size. Mainenda Formation, Elliot Lake.

arkosic units (Robertson, 1968; Roscoe, 1969). Paleocurrent studies by McDowell(1957) and Long(1977) have established a northwest source area for the sediments of the Matinenda Formation (Figure 5). Fralick and Miall(1989) suggest the Matinenda Formation was deposited from shallow braided streams flowing down a south dipping paleoslope which underwent tilting to the southeast during deposition. Kimberly (1980) reported that the uraniferous conglomerates contained almost no magnetite-ilmenite and had very high potash/soda ratios. These are also features of Huronian paleosols, and suggest the sediment of the Matinenda Formation was formed by the intense weathering of a granitic source terrain as proposed by Roscoe(1969).

Two southeast trending ore zones were recognized since the early days of uranium mining in the Elliot Lake camp. The Nordic zone, east of the City of Elliot Lake is about 1 mile (1.6 km) wide and 3.6 miles (5.6 km) long. The Quirke Zone, in the Quirke Lake area, is about two miles (3.2 km) wide and six miles (9 km) long. Paleotopographic features of the basement are thought to have had a determining influence on the position and orientation of the zones. Ore grade (circa 0.1 % U_3O_8) conglomerate occurs as persistent lenses with individual units up to 15 feet (4.5 m) thick. The uraniferous quartz-pebble conglomerates are commonly well developed at the base of the Matinenda Formation but also occur within the arkose up to 150 feet (45 m) above the base (Roscoe, 1968).

The quartz-pebble conglomerate consists mainly of well-rounded pale-grey to dark-grey quartz and chert pebbles set in a matrix of pyrite with some quartz/feldspar grit and sericite. Pyrite usually forms about 15% of minable units. Radioactive minerals include uraninite, brannerite, uranothorite (Roscoe, 1968). Monazite and zircon are characteristic heavy minerals.

The sedimentological and mineralogical features of the uranium bearing zones of the Elliot Lake camp are now generally believed to support a modified paleoplacer origin of the ores as outlined by Roscoe(1969). Convincing evidence supporting the paleoplacer hypothesis was provided by Theis(1979) who demonstrated that a direct relationship exists between the size of quartz pebbles and pyrite grains (Figure 10), and the concentration of many other

components of the ore zones. Prior to the accumulation of significant free oxygen in the Earth's atmosphere, southeastward flowing streams carried quartz, pyrite and uraniferous minerals released by the extensive weathering of the Archean granitic terrain, and deposited them as southeast trending units determined by basement topography.

The McKim Formation

The McKim Formation is the uppermost formation of the Elliot Lake Group. It is mainly a turbidite sequence of generally dark grey, subarkosic wackes, mudstones, subarkoses, lithwacke and litharenite which extends from the Blind River area to the Grenville Front. Graded beds, parallel laminations, ripple marks, ripple-drift cross-laminations and Bouma cycles, indicative of deposition by submarine turbidity currents are reported (Parvianen, 1971; Card et al., 1977).

Robertson(1968) gives a thickness of 0-380 feet (0-100 m) for the McKim Formation on the south limb of the Quirke Lake syncline. It is missing on the north limb. The McKim Formation is thickest in the Sudbury area, where it is up to 2400 metres (8000 feet) thick.

The Murray Fault appears to have exerted an important influence on the deposition of the McKim sediments. North of the Murray Fault the McKim rarely exceeds a few hundred metres in thickness, whereas south of the fault the thickness of the McKim Formation is at least 2400 metres. Card(1978a) noted that the change from laminated siltstone in the west to more wacke in the east indicated a change from more distal to proximal facies, in turn suggesting more tectonic activity and possibly a source for the McKim sediments in the east. Fralick and Miall(1989)concluded that the McKim Formation of the Elliot Lake area represents a marine transgression which gradually drowned the Matinenda fluvial plain.

Stratigraphic Relationships within the Elliot Lake Group of the Sault Ste. Marie-Elliot Lake Area

The stratigraphic relationship between the Matinenda Formation and the Livingstone Creek Formation is revealed on a rock face near the southern Boundary of Otter Township about 30 km (18 miles) north of the town of Thessalon. At this location pyritic quartz-pebble conglomerate of the Matinenda Formation (Chandler, 1976) directly overlies an apple-green paleosol on grey, fine-grained sandstone of the Livingstone Creek Formation. About 600 metres (380 feet) northwest of the above occurrence arkose and quartz-pebble conglomerate of the Matinenda Formation disconformably overlies a steeply dipping, east-striking, mafic dike, the upper few metres of which are sericite-leucoxene paleosol (Figures 4, 6). The dike intrudes grey sandstone and apple-green paleosol of the Livingstone Creek Formation (Bennett et al, 1991; Sutton and Maynard, 1992). Less than 2 km south of the above location Chandler(1976) identified a fault-bounded block of Thessalon Formation volcanic rocks with a minimum thickness of approximately 500 m.

The above observations show clearly and unequivocally that there was a period of volcanic activity, as well as a significant period of erosion, separating the Matinenda Formation and the Livingstone Creek Formation. Since paleosols are well known upon Huronian flows in the Elliot Lake area, the sub-Matinenda unconformity extended to the Quirke Lake Syncline.

In addition, the above observations imply that:

1. The mafic dike referred to above was a feeder for Thessalon flows, since the Thessalon Formation is the only known igneous activity at this stratigraphic position.
2. The Thessalon Formation may once have extended beyond the limit suggested from its present outcrop distribution. This is to be exacted on consideration of Macdougall's(1988) statement "Since many CFB provinces have been uplifted and occur as elevated plateaus, dissection and removal is rapid". He notes as well that the general scarcity of pre-Cretaceous Continental flood basalt provinces is probably due to their erosion.

Hough Lake Group

The Hough Lake Group (Robertson, et al., 1969; Roscoe, 1969) is the lowest of the three Huronian groups which display the cyclic deposition of diamictite followed by a mudstone, siltstone, turbidite or carbonate sequence, and overlain by a cross-bedded arenite unit. Each cycle is generally thought to represent a sequence of glaciogenic - marine - fluvial and/or shallow marine deposition (Figure 3).

Ramsay Lake Formation

The Ramsay Lake Formation is the lowermost formation of the Hough Lake Group and is the oldest of three such conglomerate units

which define the base of Hough Lake, Quirke Lake and Cobalt Groups (Roscoe, 1969; Piennar, 1963) (Figures 2,3).

The Ramsay Lake Formation is a widespread, relatively thin unit which is up to 41 m thick in the Dunns Valley area (Chandler, 1973). In the Elliot Lake area the thickness of the Ramsay Lake Formation is from 0 to just over 30 m. (Diamond drill logs Assessment files, Sault Ste. Marie Resident Geologist's Office). The Ramsay Lake Formation is from 70 to 170 m thick in the Sudbury-Manitoulin area (Card 1978a).

Matrix supported polymictic conglomerate (diamictite) is the most abundant rock type in the Ramsay Lake Formation, especially near the base. The lowermost few metres of the formation usually reflects the underlying rock type (Robertson, 1968; Parviainen, 1973). Minor amounts of mudstone, wacke and arenite are locally present.

Subrounded to well rounded pebbles and cobbles of grey granitic rocks and angular to rounded clasts of very dark green to black volcanic rocks generally form less than 30 percent of the total volume of the diamictite. The dark matrix consists of quartz, feldspars, chlorite, muscovite-sericite-illite and pyrite (Parviainen, 1973).

Although some writers have argued for a debris flow origin, most

writers now accept the Ramsay Lake Formation as having a significant glaciogenic component (Roscoe, 1969; Robertson, 1976). Fralick and Maill(1989) identified an ice proximal association of pebbly sandstone and diamictite; subaqueous gravity flows and ice rain-out deposits; and ice-proximal, fluvial outwash deposits.

Pecors Formation

The Ramsay Lake Formation is conformably overlain by a sequence of generally dark, bedded and laminated wackes, mudstone, siltstones and sandstones of the Pecors Formation (Roscoe, 1969). The Pecors Formation is 30 m thick at Quirke Lake (Robertson, 1968) but is as much as 900 m thick south of the Murray Fault in the Sudbury area (Card, 1978a). It was not identified in the area between Thessalon and Sault Ste. Marie (Frarey, 1977). Ripple marks, graded bedding, cross-laminations parallel laminations, ball and pillow structures, clastic dikes and slumpage features have been reported in the formation. The basal part of the formation is commonly laminated resembling varves and, in places, has dropstones (Robertson, 1968; Parviainen, 1973). Partial Bouma sequences are common (Card, 1968; Robertson, 1976). The Pecors Formation is the result of transgressive units formed in deep water by turbidity currents (Card, 1978a). The presence of drop stones is evidence of a cold paleoclimate, and provides supporting evidence for the glaciogenic origin of the underlying Ramsay Lake Formation.

Mississagi Formation

The Mississagi Formation is a thick sequence of predominantly grey, arenitic rocks extending throughout most of the length of the Huronian outcrop belt. Within the Quirke Lake syncline the Mississagi Formation is from 344 to 704 m thick. South of the Murray Fault the formation is notably thicker, being more than 3000 m in the Sudbury area (Card, 1978a; Long, 1978). By far the dominant rock type in the Mississagi Formation is moderately well sorted, medium to coarse grained subarkose and arkose. Small to medium quartz/chert pebble conglomerate is a minor component of the formation, but is more common in the western and northeastern parts of the Huronian belt. Fine-grained pyrite along foresets

commonly results in rusty staining of outcrops. Greenish, thin, sericitic units form relatively thin planar bedded units between cross-bedded sandstones. Palonen (1971) provided evidence supporting a marine origin for the Mississagi Formation; however, Long (1978) argued that the abundance of mud-grade matrix in the immature arenites, and the predominance of unimodal paleocurrent directions (Figure 5), and the lack of quartz arenites argued against a marine environment for the Mississagi Formation. He concluded that the Mississagi Formation was deposited from braided streams with low to intermediate sinuosity and high width to depth ratios.

Bedding units are commonly about a metre thick but range from a few centimetres to over four metres. Trough cross-stratification and ripple cross-stratification are common sedimentary structures (Long, 1978). Individual cross-stratified beds may so show grain size gradation (McDowell, 1957).

Long (1978) measured over 2500 cross-stratified units in the Mississagi Formation (Figure 5). Two major stream systems were recognized: a stream system flowing southeast to easterly from the Sault Ste. Marie area joined a stream system flowing southwestward from the Cobalt Plain to form a southward flowing system southwest of the Sudbury area. These observations suggest that the area now occupied by the Sudbury Igneous Complex was elevated during the period of Mississagi deposition.

Quirke Lake Group

Bruce Formation

The Bruce Formation extends from the Bruce Mines area to about 70 km northeast of Sudbury. It consists mainly of matrix supported and minor clast supported conglomerate. Pebbly wacke, arkose, wacke and siltstone are locally present. Robertson (1968) reports the Bruce Formation is from 79 m (260 feet) to 12 m (40 feet) thick in the Elliot Lake area. It is 26 m (85 feet) to 37 m (120 feet) thick under the greater part of the Quirke Lake Syncline.

Pebble to boulder sized, angular to subrounded clasts generally

consist of pale-grey to whitish granitic rocks, Archean supracrustal rocks and fine grained mafic clasts. The upper parts of the formation may contain up to 5% carbonate (Robertson, 1968).

The Bruce Formation is generally interpreted as a tillite with minor beds and lenses of glacially derived sandstone. Dropstones have been observed in laminated units (Robertson, 1964, 1971). Casshyap (1969) concluded the formation was deposited from terrestrial wet-base glaciers. However Simms et al. (1981) proposed that the Bruce Formation is an accumulation of debris flows released as a result of normal faulting, a sudden increase in paleoslope and a sudden increase in water depth.

Espanola Formation

The Espanola Formation is the only widespread carbonate unit of the Huronian Supergroup. It is present from the Sault Ste. Marie area to the Maple Mountain area about 70 km northeast of Sudbury. Its widespread distribution and distinctive lithology make it the most useful stratigraphic marker unit of the Huronian Supergroup. In the Elliot Lake area the Espanola Formation can be subdivided into three parts: a lower limestone member (the Bruce Limestone), a middle siltstone, wacke, arenite member (the Espanola Greywacke) and an upper dolomitic limestone member (the Espanola Limestone) (Robertson, 1968). The latter generally contains 3 - 4% total iron which gives a distinctly brownish colour to weathered surfaces. All 3 members are generally thinly bedded to laminated. The threefold subdivision is not so well developed south of the Murray Fault (Young, 1982). Contacts between members tend to be gradational.

Intraformational breccias, mud cracks, ripple marks, flame structures and ball-and-pillow structures are common sedimentary features. Hofmann et al. (1980) described stromatolites in the Espanola Formation at Quirke Lake. These features suggest deposition in a quiet shallow water environment with carbonate deposition being interrupted by influx of fine-grained sediment. Young (1973) proposed that the relatively sharp change from the diamictites of the Bruce Formation suggests warm climatic conditions following a glacial advance. However, the recognition

of carbonate deposition at high latitudes (Williams, 1975) and the association of detrital uranium with intense chemical weathering (Maynard et al, 1991) adds uncertainty to attempts to model Huronian paleoclimate (Bennett et al, 1991).

Serpent Formation

The Serpent Formation is found throughout much of the Huronian belt; however, it is locally removed by erosion during a period of tectonic activity preceding deposition of the Gowganda Formation of the Cobalt Group. Reported thickness estimates of the Serpent Formation range from 150 up to 1500 m (Bennett et al., 1991). Robertson(1968) states that nowhere in the Blind River-Elliot Lake area is there any evidence that the total thickness of the Serpent Formation has been preserved.

The Serpent Formation is mainly fine to medium-grained, quartz arenite and arkose. Conglomeratic units have been noted, especially near the base of the Formation. Carbonate is a significant component near the base of the formation in the Elliot Lake area (Robertson, 1968). Planar cross-bedding, festoon cross-bedding, rip-up clasts, fine-laminations and mud cracks have been reported. Long(1976) proposed that the Serpent Formation was deposited in a distal braided stream environment with calcareous units representing a sabkha environment. Young(1982) noted that the presence of very large cross-beds and a bi-modal size distribution suggest eolian processes may have been active at least locally.

Cobalt Group

Gowganda Formation

The Gowganda Formation is a complex sequence of conglomerates, sandstones, siltstones and mudstones which comprise the lowermost formation of the Cobalt Group. Its thickness is about 1070 m in the Sault Ste. Marie area, from 970 to 1150 m around Whitefish Falls, on the North Shore of Lake Huron, and from 950 to 2700 m near Sudbury. Near Dunlop Lake, in the Elliot Lake area, the

Gowganda Formation is about 600 m thick.

Matrix-supported conglomerates are common, especially in the lower parts of the formation. However, these are commonly intercalated with clast-supported conglomerates, sandstone, and wacke units. Laminated mudstones and siltstone are especially prominent in the upper parts of the Gowganda Formation. Many occurrences of ice-rafted drop-stones have been reported in laminated mudstone/siltstone units. Individual units are generally relatively thin and discontinuous making subdivision of the Gowganda formation difficult except in well-exposed areas.

Most granitic clasts of Gowganda conglomerates have a distinctly pinkish or reddish hue, in comparison to the grey granitic clasts in the matrix supported conglomerates of the stratigraphically lower Ramsay Lake and Bruce Formations. Also, pink and red hued sandstones first make their appearance in the Gowganda Formation. Roscoe(1969) pointed out the appearance of red colouration (i.e. ferric iron) just above the basal units of the Gowganda Formation, and argued that it represents the appearance of free oxygen in the Earth's atmosphere, and a change from the previously reducing atmospheric conditions that allowed the accumulation of readily oxidized minerals such as pyrite and uraninite in a fluvial environment.

The depositional environment of the diamictites in the Gowganda Formation have been the subject of discussion since Coleman(1905) proposed a glacial origin for the matrix supported conglomerates. Many later writers including Ovenshine(1965), Cassyhap(1969), Lindsay(1971), Young and Nesbitt(1985), and others, have also supported a glacial, glacial-marine or glaciolacustrine origin for the Gowganda Formation.

Card(1968) concluded that, although glaciation may have supplied coarse detritus to the basin initially, debris flows and turbidity currents, released by vertical tectonic movement, may better explain the thickness variations, rock associations and distribution he observed in the Sudbury Manitoulin area. Roscoe(1969) also emphasized that glaciation is only one of several processes responsible for the deposition of Gowganda sediments.

Lorrain Formation

The Lorrain Formation is generally well exposed throughout most of the Huronian belt, where it commonly forms a background to some of the most scenic views in northern Ontario. It is overwhelmingly an arenitic sequence, with local siltstone units present in lower parts of the section. The formation is up to 2500 m thick near Sault Ste. Marie and in the LaCloche Syncline, southwest of Sudbury. It is up to 2300 m thick in the Cobalt Embayment.

In general, the lower part of the Lorrain Formation is dominated by pink, arkosic sandstones, the middle by hematite-rich subarkose and quartz-arenite, and the upper portion by pale grey to white mature, quartz-arenite. A distinctive jasper-pebble conglomerate found in the Sault Ste. Marie area is a popular decorative stone, known locally as "pudding stone".

The presence of aluminous minerals is a characteristic feature of the upper, quartz-arenites of the Lorrain Formation. Diaspore and kaolinite are common in the quartz-arenite of the Sault Ste. Marie area and north of Elliot Lake (Wood, 1973) while kyanite, andalusite and kaolinite are present as metamorphosed equivalents in the LaCloche Lake-Killarney area (Card, 1978a). Young (1973) and Wood (1973) interpret the presence of diaspore and kaolinite as the result of post-depositional in-situ alteration of feldspar under hot and humid climatic conditions.

The presence of abundant detrital hematite in the Lorrain Formation and the occurrence of thorium-rich, monazite-bearing, quartz-pebble conglomerate north of Elliot Lake has been interpreted by Frarey and Roscoe (1970) as indicating an oxidizing environment.

Planar and trough cross-bedding are common, as are ripple marks and other primary depositional structures. There is no consensus as to the depositional environment of the Lorrain Formation. Most of the sedimentary structures of the Lorrain Formation can be

found in either shallow marine or fluvial environments. Wood(1973), Young(1973) and Frarey(1977) favoured a fluviatile model while Pettijohn(1970) supported a marine environment for the Lorrain Formation. Card(1976b) proposed that the Lorrain Formation represents near-shore coastal shelf deposition during episodic marine transgression and regression.

Gordon Lake Formation

The Gordon Lake Formation displays a gradational contact with the underlying Lorrain Formation. It is made up predominantly of variegated mudstone, siltstone, chert and minor fine-grained sandstone. Robertson(1986) subdivided the Gordon Lake Formation of the Flack Lake area into a lower member of reddish arenite, siltstone, and chert with anhydrite and gypsum nodules, a middle member of green siltstone and mudstone, and an upper reddish mudstone, siltstone and chert. Abundant sedimentary features include small-scale cross-bedding, ripple marks and desiccation cracks.

Some of the features of the Gordon Lake Formation are unique for the Huronian Supergroup. Wood(1973) noted the abundance of feldspar in the formation, a marked contrast to rocks of the immediately underlying Lorrain Formation. He also described hematite oolites and the abundance of grains in the 0.02 to 0.05 mm range, a relatively uncommon grain size in sedimentary rocks. Since this size is found in loess deposits, Wood(1973) proposed that the quartz silt of the Gordon Lake Formation was formed by glacial action and carried by the wind and deposited in a tidal flat environment.

Jackson(1994) identified nodules and layers of dolostone in siltstone and chert of the Gordon Lake Formation in the Aberdeen area, east of Sault Ste. Marie. Bennett et al.(1989) reported a unit of dolostone in Fenwick Township, near Sault Ste. Marie and proposed a correlation with the Gordon Lake Formation in the Bruce Mines area and to the Kona Formation of the Marquette Range Supergroup.

Bar River Formation

The Bar River Formation is the uppermost formation of the Huronian Supergroup. It is characterized by quartz-arenite with minor ferruginous arenite and siltstone. It is approximately 300 m thick in the Flack Lake area, north of Elliot Lake. Wright and Rust (1985) concluded that the Bar River Formation was deposited in a tidal environment.

Nipissing Intrusions

Dikes, sills, and cone sheets of gabbro, diabase and granophyre, commonly referred to as "Nipissing diabase" are the most widespread igneous rocks within the Huronian Supergroup. Baddeleyite from Nipissing gabbro sills in the Gowganda area have been dated at 2219 Ma U-Pb; the minimum age for the Huronian Supergroup (Corfu and Andrews, 1986). Buchan and Card (1985) report that paleomagnetic data suggest at least two periods of Nipissing intrusive activity.

Olivine-bearing hypersthene gabbro, gabbro, feldspathic pyroxenite, two-pyroxene quartz gabbro, hornblende gabbro, granophyric gabbro and granophyre have been identified in Nipissing intrusions. Many of the Nipissing bodies are characterized by chilled margins 50 cm to 5 m wide, overlain by 10-20 m of quartz gabbro, then 100-500 m of hypersthene-poor gabbro-norite and vari-textured diabase (Lightfoot and Naldredt, 1996).

Nipissing intrusions are widely and evenly distributed throughout the Huronian belt but, with few exceptions, are not recognized within the Archean terrain. Individual intrusions may be up to several hundred metres thick and extend over an area of several hundred square kilometres. The form and orientation of Nipissing intrusions indicate that their emplacement may be controlled by older faults, folds and competency of the enclosing rocks (Card and Pattison, 1973).

Lightfoot, and Naldredt(1996) discuss the geochemical characteristics of the Nipissing magmas and the potential for platinum group metal deposits. They conclude that the Nipissing magmas were emplaced into the Huronian sedimentary sequence over a period of less than 10 million years. Parental magmas of remarkably uniform composition underwent in-situ contamination and differentiation within the intrusions (Lightfoot and Naldredt, 1996).

A spatial association between Nipissing intrusions and both magmatic and vein-type mineralization has long been recognized. Card and Pattison(1973) noted also that there is a variation in style and type of mineralization associated with Nipissing intrusions from the Cobalt area in the east to the Sault Ste. Marie area in the west.

Huronian Paleosols and Evidence for the Accumulation of Oxygen in the Huronian Atmosphere

It has long been recognized that the study of Huronian paleosols (ancient soil profiles) could provide information pertaining to the development the Earth's atmosphere and climate during the Proterozoic. Since iron is much less soluble in the ferric state

than when in the ferrous state, the behavior of iron in paleosols should provide some indication of the oxygen partial pressure of the environment.

Many of the best descriptions of Precambrian paleosols have been from those associated with Huronian unconformities (Gall, 1992).

Grandstaff et al.(1986) identified 8 features of paleosols, most of which can be observed in Huronian paleosols. These features are:

1. Stratiform
2. Relatively thin (<20 m)
3. Transitional lower boundary-sharp upper boundary
4. Colour variations
5. Destruction of primary rock textures accompanied by the development of soil textures
6. Destruction of primary minerals with formation of clay

minerals or metamorphic equivalents

7. Dikes of material from overlying sediment washed down into desiccation cracks in the soil
8. Rip-up clasts of overlying sediments

Well preserved paleosols below the Matinenda Formation in the Elliot Lake area have been described by many workers (Roscoe, 1957a, 1969, 1973, 1981; Pienaar, 1963; Robertson, 1964; Frarey and Roscoe, 1970; Freyer, 1977; Gay and Grandstaff, 1980; Kimberly et al, 1984; G-Farrow and Mossman, 1988; Prasad and Roscoe, 1991, Sutton and Maynard, 1991, 1993).

Bennett et al. (1991) have proposed that there are three disconformities or unconformities within the Elliot Lake Group which have potential for paleosol development (Figure 2). These are in descending stratigraphic order: 1) the sub-Matinenda disconformity; 2) the sub-Thessalon Formation disconformity, and sub-Livingstone Creek Formation unconformity.

The sub-Livingstone Creek Formation unconformity is the basal unconformity of the Huronian Supergroup and is the only entirely sub-Huronian unconformity (Figure 2). This unconformity is exposed in the Thessalon area, where the upper few metres of the Archean granitic rocks can be seen to progress from angular, slightly rotated blocks, separated by grey grit and fine-grained sandstone, upward, to more rounded boulders with a higher proportion of finer clastic material (Collins, 1925). This zone may be termed a "paleo-regolith", since there is little or no obvious development of the yellow, sericitic paleosol commonly found in the younger, sub-Matinenda paleosols.

Prasad and Roscoe (1996) described two paleosols in the same drill core from the Denison Mine at Elliot Lake. A paleosol was found above Huronian volcanic rocks and another, less well developed paleosol, was found upon Archean tonalite below a short section of quartz-pebble conglomerate and grit (Prasad, personal communication, 1997) below the 9 m thick volcanic unit (Figure 13).

The best developed, and most studied, Huronian paleosols have been found directly below the Matinenda Formation. On mafic rocks, the sub-Matinenda paleosols can generally be recognized by the presence of an upper, distinctly apple-green to yellowish,

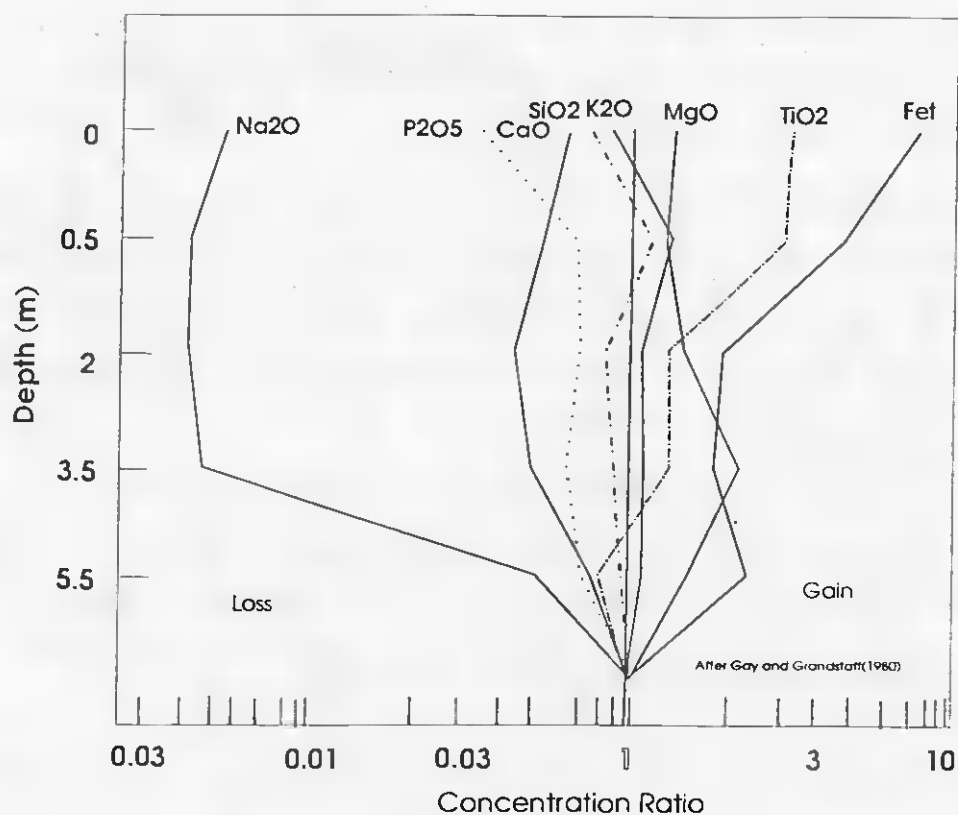


Figure 11. Concentration ratios relative to Al_2O_3 of components of the Pronto paleosol.

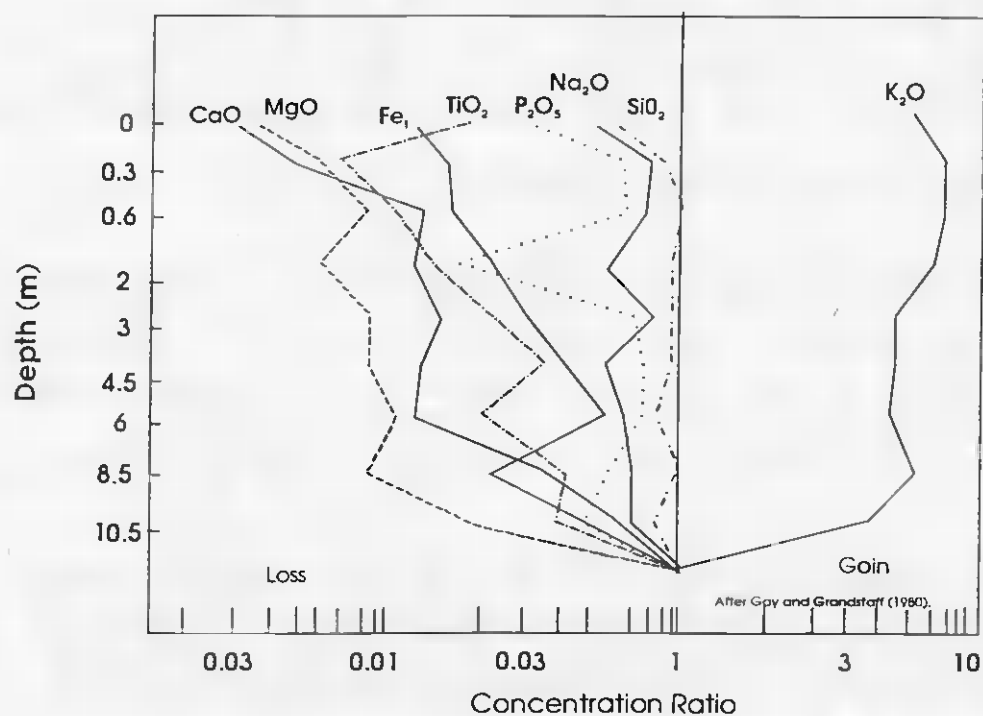
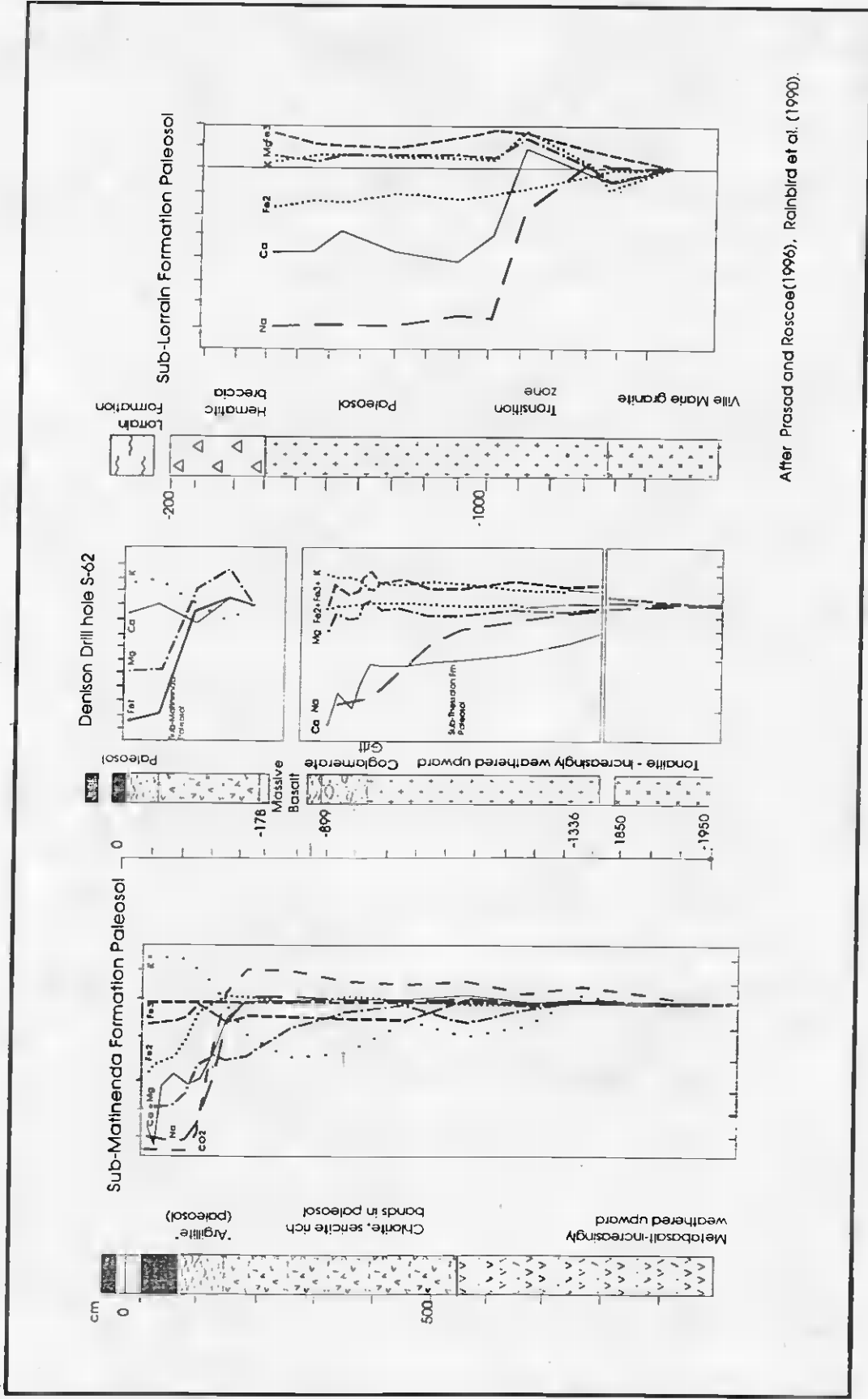


Figure 12 . Concentration ratios of components of Denison paleosol relative to Al_2O_3 .



After Prasad and Roscoe(1996), Rainbird et al. (1990).

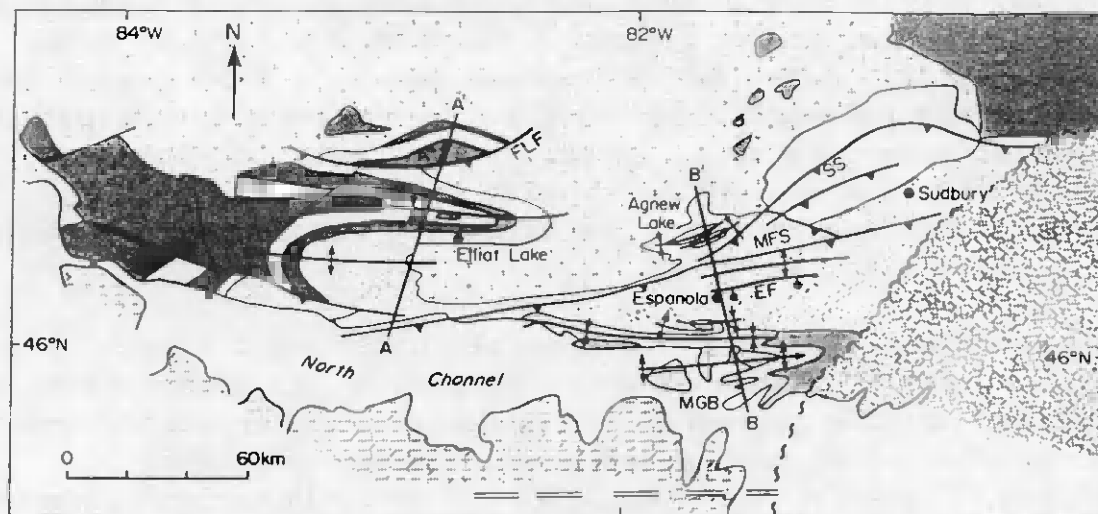
Figure 13. Concentration ratios in sub-Thessalon Fm., sub-Matinenda Fm. and sub-Lorrain Fm. Paleosols.

sericitic zone which grades downward, over a few centimetres to several metres, to an underlying, black, fine-grained, chlorite-rich eluvial zone up to several metres thick. Abundant pseudomorphs of titanium oxides after ilmenite are a feature of paleosols on mafic igneous rocks. Rip-up clast of sericitic paleosol (the "argillite scraps" of mine geologists) are commonly found in the lower few metres of the overlying Matinenda Formation. Prasad and Roscoe(1996) report significant amounts of carbonate and pyrite in sub-Matinenda paleosols in the Elliot Lake area.

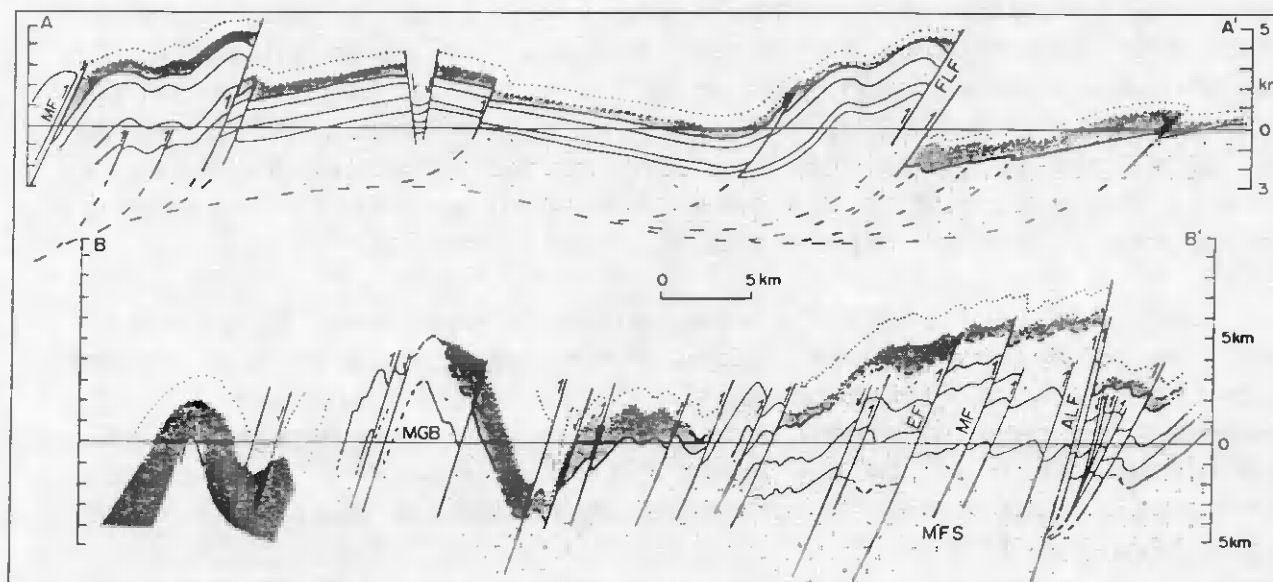
The uppermost sections of sub-Matinenda Formation paleosols on Archean granitic rocks and arkosic sedimentary rocks, are generally apple-green to yellowish rock composed mainly of quartz and sericite(Robertson, 1963; Gay and Grandstaff(1980); Sutton and Maynard(1992). Where the texture of the protolith is well preserved, but the original mineralogy is replaced, the paleosol may be termed a saprolith (Rainbird et al, 1990). The chlorite-rich eluvial zone of paleosols on granitic rocks is generally lacking or relatively thin.

Sub-Matinenda paleosols commonly show the pronounced loss of soda found in most paleosols (Figure 11). Lime, and magnesia are also depleted, but there is generally a large increase in potash content (Figure 12) (Gay and Grandstaff, 1990). In most cases, iron and manganese are depleted in upper parts of the paleosol. This is held to provide good evidence of weathering in a reducing environment. However, Gay and Grandstaff(1980) noted an upward increase in total iron in paleosol from the Pronto Mine area (Figure 11). They concluded this upward increase in iron content indicated the presence of free oxygen in the early Huronian atmosphere although at approximately 1% of the present level (Gay and Grandstaff, 1980). They suggested that the loss of iron shown in most Huronian paleosols could be due to local reducing environments. Some writers have concluded that the increase in potash (as sericite) in Huronian paleosols is largely due to diagenetic and metamorphic processes which may mask the environmental and hydrologic conditions operative during paleosol development (Gay and Grandstaff(1980); G-Farrow and Mossman(1988).

The mineralogy and geochemistry of Sub-Lorrain Formation paleosols have been described by Rainbird et al.(1990) and



After Zolnai et al. (1984)



Legend

- | | | |
|--|---|---|
| Paleozoic rocks | Thrust fault, teeth indicate hanging wall | FLF Flack Lake Fault |
| Mesoproterozoic rocks (Grenville Province) | Normal fault, spot indicates downthrown side | ALF Agnew Lake Fault |
| Cobalt Group rocks | Fault (observed, assumed) | MF Murray Fault |
| Pre-Cobalt Group rocks | Anticline, syncline | MFS Murray Fault System |
| Pre-Cobalt Group rocks derived from Archean basement rocks | Manitoulin Island Discontinuity | SS Sudbury Structure |
| Archean basement rocks (Superior Province) | Grenville Front Tectonic Zone (traceable on surface, traceable in subsurface) | MGB McGregor Bay |
| | A A' Location of cross sections | EF Unnamed fault 2 km north of Espanola Fault |
| | B B' | |

Figure 14. Geological cross-section of the Blind River and Sudbury-Maintoulin areas.

Sutton and Maynard(1991). In contrast to the older, sub-Matinenda paleosols, Sub-Lorrain paleosols commonly show an enrichment of Fe^{+3} at the expense of Fe^{+2} without a significant loss of total iron (Figure 13). Hematite is a common mineral in the upper parts of sub-Lorrain paleosols, in contrast to the presence of pyrite in sub-Matinenda paleosols. In this respect the sub-Lorrain paleosols resemble many post-Huronian paleosols and are consistent with weathering in an oxidizing atmosphere (Prasad and Roscoe, 1996; Rainbird et al., 1990).

Since pyrite and uraninite are unstable under oxidizing conditions, the abundance of detrital pyrite and uraninite in the paleoplacer uranium ore zones in the Matinenda Formation provide good evidence for an oxygen deficient atmosphere during weathering, transport and deposition of early Huronian sediments.

In marked contrast to the common red beds of younger clastic sequences, sandstones (and most granitic clasts in conglomerates) below the Cobalt Group are almost all drab coloured in spite of the abundance of red and pink granitic rocks in the continental source area (Roscoe 1969, 1973). Frarey and Roscoe (1970) noted the above and proposed that the drab colour of lower Huronian clastic rocks is due to the lack of free oxygen in the atmosphere during the period of deposition of lower Huronian rocks.

Red hued, hematite bearing rocks, which Roscoe(1969) proposed mark the presence of an oxidizing atmosphere, make an appearance with the Gowganda Formation of the Cobalt Group, and are important in parts of the Lorrain and Gordon Lake Formations of that group. What may be the first true red-beds are found in the purple siltstone member of the Lorrain Formation near Sault Ste. Marie (Frarey, 1977).

Regional Tectonic Patterns and Metamorphism

Major structures of the Huronian belt follow two main trends: 1)west-northwest trending folds and faults of the Sault Ste. Marie-Elliot Lake area; and 2)east to northeast striking folds and faults of the Sudbury-Manitoulin area (Figure 14). These two structural orientations are associated with differing fold styles, metamorphic grade and metamorphic fabric. Changes are

most notable across the east-west faults of the Murray fault system. This fault zone (Figure 14) is the most significant structural feature of the Huronian belt. Since many formations show a significant increase in thickness south of the fault, it is generally interpreted as an inverted growth fault. (i.e. an early listric normal fault, active during sedimentation, which, during a later compressive regime, was converted to a thrust or reverse fault (Card, 1978a; Jackson (1997)).

The rocks of the Huronian Supergroup have been subjected to several deformational events. This is particularly evident south of the Murray Fault zone. In the Whitefish Falls area (south of the Murray Fault) Young and Nesbitt(1985) conclude that some large-scale folding is related to syn-depositional and/or post-depositional deformation of unconsolidated sediment. Early syndepositional deformation is also indicated by an important unconformity below the Gowganda Formation of the Cobalt Group; and the presence of ragged, slumped contacts and large slump blocks along major faults (Card, 1978a; Young, 1983).

Convincing evidence of at least one important pre-Nipissing (2.2 Ga) deformational event, assigned to the Blezardian Orogeny (Stockwell, 1982), is provided by the observation that Nipissing bodies in the Sudbury-Whitefish Falls area transect axial surfaces of major folds (Card, 1978a). Jackson (1997) did not observe such relationships in the areas north of the Murray Fault. However, Jackson (1997) points out, as earlier noted by Robertson (1964), that the tendency of Nipissing dikes to occupy structures parallel to the axial plane of the Chiblow Anticline, suggests pre-Nipissing folding. Jackson (1997) also noted evidence of pre-Nipissing faults north of the Murray Fault zone.

Following emplacement of the Nipissing intrusions but prior to the emplacement of the Sudbury Igneous Complex (SIC) there was further deformation and regional metamorphism. Rb-Sr isotope studies on Huronian metasediments indicate that prograde metamorphism occurred at about 1.90-1.85 Ga (Fairbairn et al., 1969). Card and Jackson(1995) state that this event is probably correlative with the Penokean Orogeny of Michigan-Minnesota (Simms et al., 1989).

After the emplacement of the SIC and the deposition of the Whitewater Group, there is evidence of further deformation and

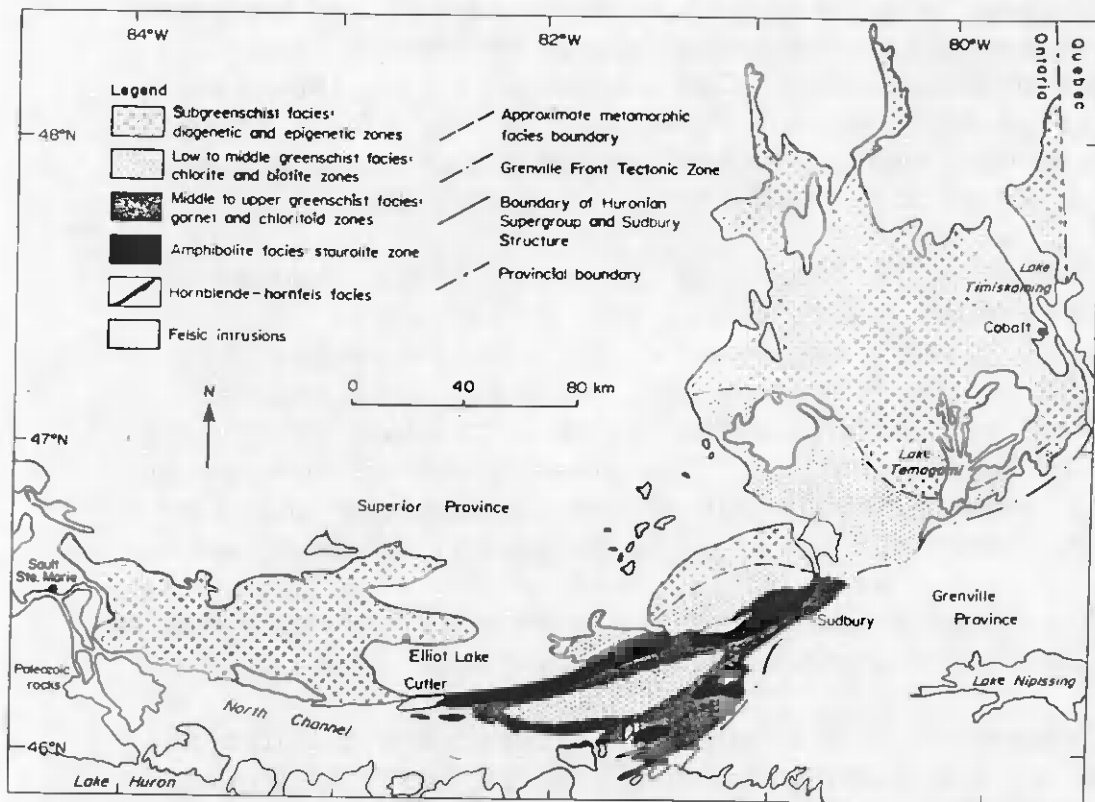


Figure 15. Metamorphism of the Huronian Supergroup (From Card, 1978b)

low-grade metamorphism, followed by intrusion of granite plutons at about 1.75 and 1.5 Ga. The post-SIC deformation and retrograde metamorphism was found mainly south of the Murray Fault, especially in the area between the SIC and the Grenville Front. Shanks and Schwerdtner(1991) report that this deformation is characterized by south-dipping thrust faults or deformation zones with northeast-trending foliation and southeast-plunging lineation. The last recognized deformational feature affecting Huronian rocks is the movement along faults which post-date the diabase dikes of the 1.25 Ga Sudbury swarm (Card and Jackson, 1995).

Recent work on magnetic fabrics, strain patterns, and microstructures in granitoid rocks of the Creighton and Murray plutons and their Huronian host rocks by Riller(1996) have provided a wealth of new information on the pre-2.2 Ga "Bleazardian Orogeny" (Stockwell, 1982). Riller concluded that major folding and amphibolite facies regional metamorphism in the Sudbury area was coeval with the emplacement of the Creighton and Murray Plutons, which were dated at 2.3 Ga by Frarey et al(1982) and Krogh et al. (1984) and more recently at 2477 ± 9 Ma by Krogh et al. (1996). Large-scale dome-and-basin structures in Archean basement and Huronian cover rocks represent major north-vergent nappes. The Sudbury Structure, a deformed relic of an astrobleme, is superimposed on a major antiformal dome cored by Archean granulite and granitoid rocks and flanked by overturned Huronian strata on the south and several remnant rim synclines of Huronian rocks on the north (Riller, 1996).

In the Sault Ste. Marie-Elliot Lake area fault and fold structures trend in general west-northwest to northwest. Folds are generally upright, open concentric structures with gentle, variably plunging hinges (Figure 14). There is only a weak development of minor tectonic structures. The metamorphic grade is subgreenschist (Card, 1978b). The major structural features of the Elliot Lake area include a gently south-dipping homocline south of the Flack Lake Fault, the open fold of the Quirke Lake Syncline and the Chiblow Anticline between the Quirke Lake Syncline and the Murray Fault. Jackson (1997) found no evidence of detachment at or near the basement-cover interface in the Elliot Lake area. He also proposed that the "inverted growth-fault" model as applied by Zolnai et al.(1984) to structural-stratigraphic relationships in the Huronian may, in some cases at

least, be interpreted as thrust faults with flats following depositional boundaries, and ramps that cut up through the stratigraphic section. Given the data available, neither model could be rejected for major northwest trending faults in the Sault Ste. Marie area. (Jackson, in press). Jackson (1997) points out that the curvature of the Flack Lake Fault is in the opposite direction to that expected if it is a thrust fault as proposed by Zolnai et al. (1984). In the Sault Ste. Marie area the presence of trust faults, as suggested by out-of-sequence units, has been confirmed, in at least one location, by diamond drilling (Assessment files, Sault Ste. Marie Resident Geologist's Office). South-southwest dipping foliation, and south-southwest plunging foliation may reflect north-northwest thrusting (Jackson, 1994).

The Murray fault zone separates the moderately deformed, low metamorphic grade rocks to the north from the multiply-deformed, higher grade rocks of the Sudbury-Manitoulin area to the south. The Sudbury-Manitoulin area is characterized by open to subisoclinal, flattened buckle folds with upright to northward overturned axial surfaces. Elongate domes and basins are formed by reversals in plunge. Penetrative axial plane cleavage and steeply plunging rodding or mineral lineation are well developed. More than one age of major and minor structures can be discerned south of the Murray Fault (Card and Jackson, 1995).

Metamorphism south of the Murray fault ranges from low greenschist to low amphibolite facies (Card, 1978b). Rocks of higher metamorphic grade occur in two zones or nodes, one along the Murray Fault zone and another northwest of the Grenville Front. Both zones coincide with major anticlinoria, although in detail, metamorphic isograds transect fold axes (Card and Jackson, 1995). Higher grade metamorphic nodes do not coincide with the few granitic intrusions which intrude the Huronian rocks south of the Murray fault. The 1.850-1.900 Ga age of metamorphism is much younger than the Creighton-Murray granite (2.45 Ga) and older than the 1.700-1.750 Ga of the Chief Lake and Cutler granites.

Jackson (1997) considers the origin of the high-grade staurolite-biotite assemblages of the McKim Formation in the hanging wall of the Murray Fault as one of the most enigmatic aspects of the tectonic history of the Southern Province. He concludes that

geobarometry indicates a relatively low pressure metamorphism (2-3 kbar) at high temperature. These conditions differ significantly from the 6-7 kbar pressures estimated for the Penokean metamorphism in Minnesota as determined by Holm and Silverstone(1990). He concluded that the high-temperature metamorphism was at or below pressure corresponding to the thickness of the Huronian rock column, thereby precluding crustal thickening as the origin of the metamorphism. Jackson (1997) concluded that a high heat flow regime developed in areas of crustal extension and related mantle upwelling. Such a model is compatible with Card's(1964) view that the high-grade metamorphism may be the result of rapid, focused heat flow.

Tectonic Models for the Development of the Huronian Basin

There have been various tectonic models proposed for the early development and later deformation of the Huronian basin. Many reconstructions are essentially modifications of the model put forth by Dietz and Holden(1966) which stated that the Huronian Supergroup represents a rift and passive margin sequence that was compressed, partly tectonically buried and metamorphosed during a collision with the Superior craton and another mass which overrode its southern edge. Zolnai et al. (1984), Bennett et al. (1991) accept the essential aspects of the Dietz and Holden (1966) model. They propose that rifting and continental breakup was coeval with Huronian volcanism (2.45 Ga) and that the much later deformation was equivalent to the Penokean Orogeny (1.860-1.835 Ga). This model does not attempt to account for the multiple deformation events affecting Huronian rocks and the origin of the Nipissing magmatic event.

Young (1982) proposed that the Huronian Supergroup was deposited in an aulocogen, an easterly trending fault bounded trough which opened towards an ocean in the area now occupied by the Grenville Province. Sims et al. (1980, 1981) concluded that the Huronian Supergroup, the Marquette Range Supergroup and Animikie rocks were deposited as intracontinental, fault controlled basins developed along a major, late Archean structure, the Great Lakes Tectonic Zone.

More recently, Roscoe and Card (1992), noting the close stratigraphic correlation between the Early Proterozoic sequences

of the Wyoming craton and the Huronian Supergroup, proposed that the Superior and Wyoming cratons are rifted portions of what was once a single continental land mass. They suggest the direction of the Matachewan-Hearst dike swarm (2.45 Ga) indicates an east-west tensional regime which resulted in a Huronian basin elongated in a north-south direction. On this larger craton the Huronian sediment was deposited in a southward deepening intracratonic basin. Roscoe and Card (1992) propose that it was during the Nipissing igneous event (2.2 Ga) that successful rifting of the Superior Province took place with the eventual drifting of part of the missing portion to its present location as the Wyoming craton. They attribute pre-Nipissing folding to the Blezardian Orogeny of Stockwell (1982) and the later more important deformation to be coeval with the Penokean Orogeny of Michigan, Wisconsin and Minnesota (Roscoe and Card, 1992).

Jackson (1997) supports the model of Roscoe and Card (1992) since the high heat flow, which he considers necessary to give the observed features of the high-grade metamorphic rocks, would be a necessary effect of mantle upwelling during continental break-up. He also interprets some of the early high-strain deformation as being consistent with a Nipissing age break-up of the Superior craton.

ROAD LOG - HURONIAN SUPERGROUP BETWEEN SAULT STE. MARIE AND
ELLIOT LAKE

INTRODUCTION

Some of the outcrops briefly described below will not form a part of the present ILSG field trip. They are included to allow those interested to visit them if travelling in the area at some future date. UTM coordinates have been provided for some locations for those who may wish to plot the locations on a map, or who may have a GPS device. The accuracy is about 50 m.

ROAD LOG ... DAY 1

=====

Proceed east along Highway 17 from Sault Ste. Marie.

The road log starts at the intersection of Highway 638 and Highway 17 East in the Town of Echo Bay

0.0 km - 0.0 miles - Highway 638 at Echo Bay - continue east on Highway 17.

4 km - 2.5 miles - Start of divided highway

7.9 km - 4.9 miles - At sign for Calabogie Road (UTM 16- 5 144 004 N, 725 322 E). Sub-Jacobsville unconformity

Outcrop on west side of Highway 17. The most southerly outcrop is white and grey quartzite (quartz arenite) of the white orthoquartzite member (Frarey, 1977) of the Lorrain Formation is overlain by a basal sharpstone conglomerate of the Keweenawan Jacobsville Formation. The conglomerate is comprised of angular clasts of Lorrain quartzite up to 60 cm across in a red siltstone matrix. The contact is irregular. No stratification was observed.

20.0 km - 12.7 miles. Highway to St. Joseph Island. Continue east on Highway 17.

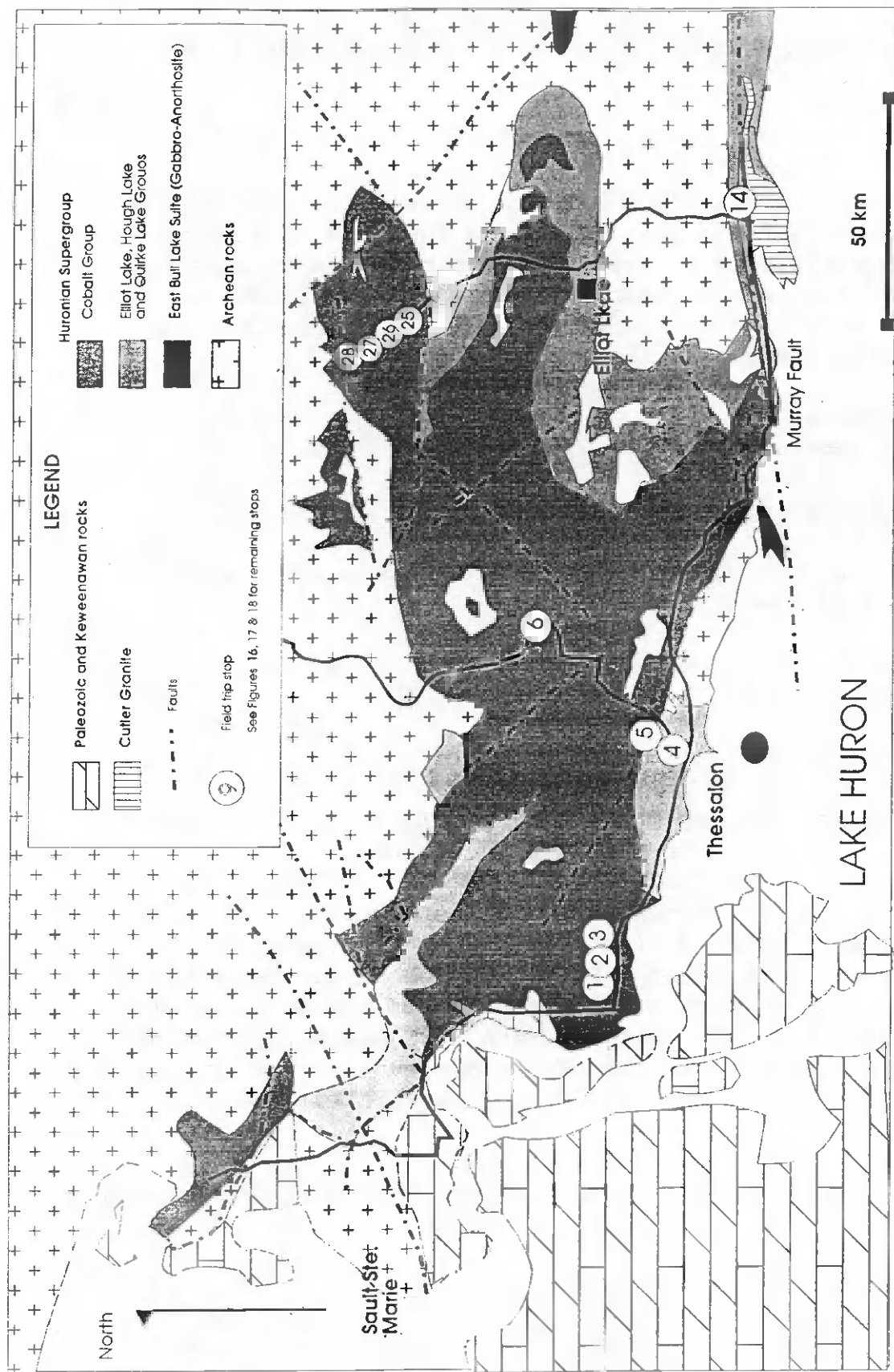


Figure 16. The distribution of rocks of the Huronian Supergroup. Sault Ste. Marie-Elliot Lake area.

25.0 km - 15.5 miles

STOP 1: Lower red quartzite member of the Lorrain Formation (Frarey, 1977). (Refer to Figure 16).

On the north side of Highway 17 steeply dipping beds of the lower red member of the Lorrain Formation reveal well preserved oscillation ripples on a large south facing surface.

Note: the differing ripple directions and local interference ripples. This impressive outcrop is known locally as the "Ripple Rock".

Main Street in the town of Desbarats (pronounced "Debarah")

26.8 km - 16.6 miles

STOP 2: Purple siltstone member of the Lorrain Formation.

Dark red to purple siltstone and sandstone constitute true red-beds (Frarey, 1977) in the Huronian. These hematite-rich rocks display the reduction along fractures typical of red beds, and a good indicator of deposition in an oxidizing environment. The bedding is faint, but locally distinct, striking 140° and dipping 10° south.

27.7 km - 17.2 miles Lake Huron Drive in the town of Desbarats

28.0 km - 17.4 miles.

STOP 3: Basal Arkose Member of Lorrain Formation. UTM Zone 17.
275461N, 5136234E.

Large outcrops of pink, medium-grained, rather massive arkose beds with hematite-rich spots about one centimetre across. Pale laminations in outcrop on south side of the road indicate shallow dips of about 10° west. The unit is about 1700 feet thick in this area (Frarey, 1977).

40.5 km - 25.0 miles copper bearing quartz vein in town of Bruce Mines.

In a rock-cut on the north side of Highway 17, in the town of

Bruce Mines, is a 3 metre wide quartz vein in Nipissing diabase. The vein contains small amounts of chalcopyrite, chalcocite, bornite and malachite. It is one of the few remaining remnants of the copper mineralization that once made this town known throughout the mining world. Mining began here in 1846 and continued to 1875, making Bruce Mines the first mining town in Canada. Please do not take samples from this outcrop.

About 75 metres north of this outcrop there is a reconstruction of a copper mining operation of that period built on one of the original mine workings, known as the "Simpson Shaft". During the summer months the Simpson Shaft site is open as a tourism operation.

42.6 km - 26.5 miles

Entrance to the quarry of Ontario Trap Rock (R.W. Tomlinson Limited). The quarrying of trap rock (Nipissing diabase) at Bruce Mines resumed in 1990. A predecessor near the lake operated during the First World War.

45.1 28.0 Highway 17 17-5 129 846N, 289 512E,
Low outcrops of Mississagi Formation. Waltonen Road at 45.4 km
or 28.2 miles at east end of outcrop.

Medium-sand to grit-sized, grey, subarkose with thin quartz-pebble beds and prominent planar cross-bedding are well exposed along the north side of the highway. Rusty staining on the outcrop reflects minor detrital(?) pyrite along the foreset beds. Black chert pebbles in pebbly beds, minor pyrite and metre scale bedding are common features of the Mississagi Formation. Roscoe, (1969) concluded that the drab colour and presence of detrital pyrite in Huronian sandstones and conglomerates is evidence of the reducing nature of the early Huronian atmosphere.

60.6 km - 37.6 miles Intersection of Highway 17 and Highway 129.
UTM Zone 17 - 303590E, 17-5126450N

STOP 4: Thessalon Formation tholeiitic basalt.
Refer to Figure 17.

Dark green, fine to medium grained basalt is exposed on the east

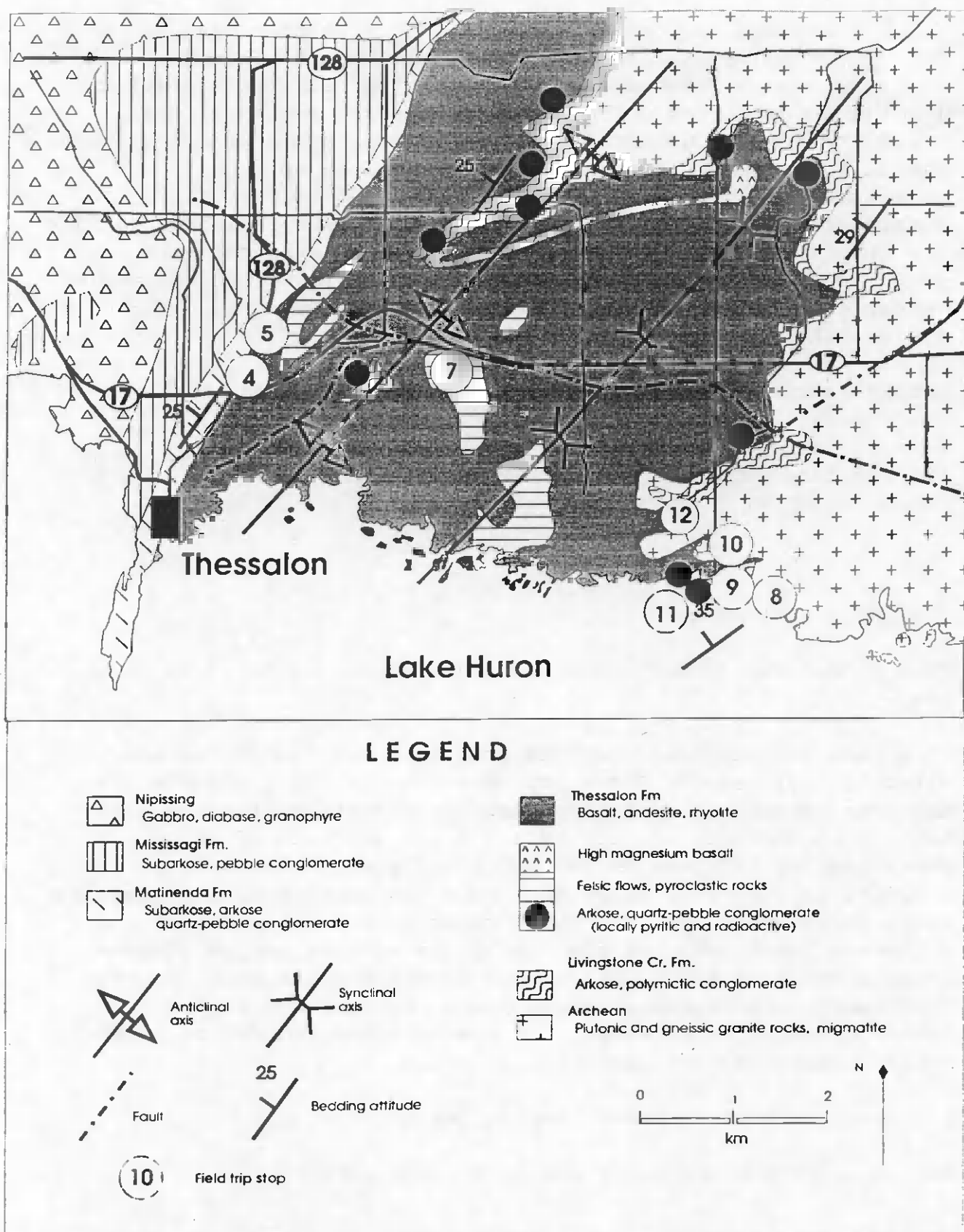


Figure 17. Geology of the Thessalon Area

side of Highway 129 just north of the intersection with Highway 17. This tholeiitic basalt forms the top of the Thessalon Formation in the Thessalon area and is typical of the thicker tholeiitic sequences which make up the upper parts of the Thessalon Formation in the Sault Ste. Marie and Aberdeen Township areas. The rocks consist of albite, chlorite, epidote, clinozoisite, leucoxene and minor quartz and oxides. The metabasalt contains amygdules of albite, quartz, epidote, calcite and chlorite. The relatively small, monomineralic chlorite amygdules ("chlorite buttons") are characteristic of the mafic volcanics of the Thessalon Formation between Sault Ste. Marie and Elliot Lake.

Glacial striae and chatter marks are well developed on the outcrop surface.

Proceed north on Highway 129. Reset odometre to 00 at Intersection of Highway 17 and Highway 129.

1.0 km - 0.62 miles

STOP 5: Outcrop of Matinenda Formation on east side of Highway 129.

This fine-grained, pale pink to greenish grey, subarkose which directly overlies the Thessalon Formation in the Thessalon area has been correlated with the Matinenda Formation of the Elliot Lake Group (Bennett et al., 1991). Faint outlines of trough cross-bedding, visible on the upper surface of the outcrop, indicate paleocurrent directions from the northwest. The greenish (sericitic) units and the trough cross-beds are typical of the Matinenda Formation, but the fine grain size is not. At Thessalon Point about 4 km southwest of this location these rocks contain thin quartz pebble conglomerate units, but the pyrite and radioactivity, characteristic of the Matinenda Formation of the Elliot Lake area, are lacking.

23.0 km - 14.9 miles The village of Warncliffe

29.1 km - 18.4 miles north end of Appleby Lake.

30.3 km - 19.4 miles UTM 17, 5 144 748N, 320 904E

STOP 6: Laminated siltstone of the Gowganda Formation on scarp west of Highway 129. (Refer to Figure 16.)

Proceed up steep slope to scarp located a few tens of metres into the bush.

Vertical joint faces in laminated siltstones-mudstone of the Gowganda Formation form an impressive cliff just west of Highway 129. The bedding comprises regular and remarkably continuous mudstone-siltstone couplets from 0.5 to 2 cm thick. The grey siltstone unit at the base of each couplet grades up to a darker mudstone which is in sharp contact with the siltstone base of the overlying couplet. The sequence closely resembles varves of Pleistocene glacial lakes. A few pink, discontinuous, fine, sandstone beds are also present.

Widely scattered through the sequence are pebble to boulder-sized "drop stones", predominantly of Archean granitic rocks. In the absence of volcanic activity within the Gowganda Formation, the only plausible source of the drop stones is the presence of floating ice which released its rock load during melting. This outcrop, and many others of a less spectacular nature, provide some of the best evidence for a cool climate during Gowganda time.

Church and Young, (1972) interpret the laminated unit as a varved sequence. They also note the presence of small sedimentary clasts, lithologically similar to the enclosing rocks. They interpret the clasts of sedimentary rocks as having been derived from the ablation of sediment on the upper surface of the glacier.

Jackson, (1971) reported pyritic, carbonaceous inclusions and "fossil gas bubbles", which he considered to be biogenic origin, associated with drop-stones at this location.

30.9 km - 19.5 miles. Intersection with Highway 554. Return to Thessalon along Highway 129.

30.9 km - 19.5 miles. Intersection of Highway 17 and Highway 129 at Thessalon. Reset odometer to 0.0.

2.6 km - 1.6 miles. UTM 306085E, 17- 126567N. Green Lane. Cross railway tracks (with care) and immediately turn left then south to short section of unpaved road between private properties. Outcrops of Thessalon Formation felsic metavolcanics lie at the end of the road.

STOP 7: Rhyolite of the Thessalon Formation. (Refer to Figure 17).

Volcanics are fine grained, grey to pink and maroon rhyolite (Table 2) consisting of a fine grained mosaic of albite, K-feldspar, and quartz with minor green pleochroic biotite. Amygdules are filled with quartz, biotite and stilpnomelane. Collapsed vesicles are also present. Local iron staining and darker chloritic areas indicate the presence of iron sulfides.

5.9 km - 3.6 miles. At Pine Ridge Road

Reset odometre to 000

Intersection of Highway 17 and Pine Ridge Road. Turn right (south) onto Pine Ridge Road.

2.9 km - 1.8 miles. At Lake Huron. Causeway to private property.

NOTE: In consideration of the privacy of residents there will be no road log for the next four stops.

STOP 8: Sub-Livingstone Creek Formation regolith. NOTE: High water levels on Lake Huron may prevent access to part of this area.

The granitic basement to the Huronian Supergroup is exposed near the shore of Lake Huron. The granitic rocks are predominantly red to grey coloured with zones of mafic xenoliths.

This will be a brief stop to examine sub-Livingstone Creek Formation regolith on the lowermost Archean granitic rocks. This sub-Livingstone Creek Formation unconformity is the lowermost unconformity in the Huronian Supergroup. A saprolitic paleosol is not as well developed as at the well studied sub-Matinenda

paleosol of the Elliot Lake area.

On a 2 by 5 m outcrop at the waters edge, grey, fine-grained arkosic sandstone surrounds sub-rounded blocks of grey to reddish granitic basement. The granitic blocks appear to be in place or only slightly dislocated.

On shoreline outcrops a few tens of metres further east, very fine-grained steeply dipping, silicious veins may also be related to the pre-Livingstone Creek weathering. Locally, sandstone filled seams (fissure or crack filling) appear to dip steeply to the east, i.e. about perpendicular to the paleosurface.

Return to the driveway.

STOP 9: Base of the Livingstone Creek Formation.

About 3 m of fine-sand to grit-sized, grey sandstone of the Livingstone Creek Formation is exposed in outcrops along the short ascent to the driveway. Although neither the contact, nor a complete transition zone between the Archean basement granite and Huronian Supergroup are exposed, these sandstones are only a few metres (stratigraphically) above the Livingstone Creek Formation-Archean unconformity.

At the base of the short exposed section, the Livingstone Creek sandstone is massive and has a few scattered (matrix supported), well-rounded to sub-rounded granitic cobbles and boulders. The diffuse edges and embayments of some clasts suggests that they have undergone little transportation and may be core stones of weathered granitic blocks. Widely distributed rusty areas up to 4 cm across indicate the presence of sulfide concentrations (nodules?). The basal portion of this section may be paleosol or material derived from adjacent paleosol. The upper part of the

exposed sandstone section shows trough cross-bedding. The recessive weathering pattern indicates that carbonate is prominent along the foreset beds.

STOP 10: Conglomerate member of the Livingstone Creek Formation

A low outcrop adjacent to the driveway on private property. The

rocks are clast-supported polymictic conglomerate which commonly forms the lowermost member of the Livingstone Creek Formation. The conglomerate is made up of cobble and boulder-sized clasts of pale-grey to white-weathering massive, porphyritic and gneissic granitic rocks with some foliated amphibolite and mafic plutonic rocks. There are a few thin beds of intercalated coarse arkose. No clasts of Huronian volcanic rocks have been identified in the Livingstone Creek Formation.

The polymictic clast population, sorting and size indicate deposition in a high energy environment such as an alluvial fan. Although the grey colour is dominant in these conglomerates, the pink to red colour, common in the Archean basement rocks, is scarce or lacking in the conglomerate clasts. This colour difference between the clasts and the source granites may be due to reduction of ferric iron in the feldspar lattice during pre-Huronian weathering or diagenesis.

STOP 11: Base of the Thessalon Formation - Sedimentary rocks of the Thessalon Formation.

Fine to medium sand-sized, cross-bedded dark-grey sandstone marks the top of the Livingstone Creek Formation in this area. The grey colour, recessive weathering along the foreset beds, and the restricted range of clast size, is characteristic of the sandstone member of the Livingstone Creek Formation.

Near the water line on the west side of the outcrop, a thin unit (a few cm thick) of radioactive, quartz-pebble and cobble conglomerate, striking 040° and dipping 45° west, lies on the upper surface of the grey sandstone of the Livingstone Creek Formation. The conglomerate consists predominantly of pale-grey and dark-grey to black, well-rounded quartz pebbles and cobbles up to 10 cm across. The conglomerate bed is, in turn, overlain by a unit of massive to cross-bedded, grey grit and arkose which forms the basal unit of the Thessalon Formation in the area.

Note: the 5 m displacement of the quartz pebble conglomerate along a steeply dipping dextral, northwest striking fault.

Diamond drilling done from the ice of Lake Huron in the 1970's indicates that the volcanic rocks which form the bulk of the Thessalon Formation directly overlie the grit unit but are at

this location covered by the lake waters.

Measurement of gamma radiation made with a McPhar TV1A gamma ray spectrometer are given below:

Livingstone Creek sandstone: $T_1=2,000$; $T_2=60$; $T_3=30$

Quartz Pebble Conglomerate (Thessalon Formation) : $T_1=20,000$;
 $T_2=700$; $T_3=60$

where $T_1=K+U+Th$; $T_2=U+Th$; $T_3 = Th$. measurements in counts/min

Earlier writers have (reasonably) concluded that the radioactive conglomerate is a unit of the underlying Livingstone Creek Formation. However, Bennett et al. (1991) concluded that the radioactive conglomerate at this locality is stratigraphically equivalent to the Thessalon volcanic rocks and significantly younger than the Livingstone Creek Formation. Some of the evidence for this conclusion is as follows:

1. Radioactive conglomerates occur within the volcanic flows near the base of the Thessalon Formation in the Sault Ste. Marie area (Hay, 1963) and the Aberdeen Lake area (Bennett, 1982).
2. At a few localities in the Quirke Lake Syncline radioactive conglomerate and arkose are found directly below the Thessalon Formation flows upon the Archean basement where the Livingstone Creek Formation is not present.
3. No quartz-pebble conglomerate has been identified anywhere within the Livingstone Creek Formation.
4. The resistate nature of the minerals in the conglomerate suggests extensive weathering of the source area and the presence of a disconformable relationship with the underlying unit.

Proceed from west end of causeway northward along Pine Ridge Road.

STOP 12: Saprolith on Archean Granitic Basement Rocks

Blocks of pale-weathering granitic gneiss, up to 1 m across, are separated by brownish-weathering arkosic sandstone filled cracks,

which appear to be products of the paleoweathering of the gneiss. The grain size of quartz in the inter-block sandstone is consistent with derivation from weathering of the surrounding granite. In places the prominent gneissosity in the granitic rocks shows that no rotation of the blocks has taken place during the development of the sandstone units. The sandstone units are up to 2 m wide, and in places include numerous sub-angular to sub-rounded blocks of granitic gneiss. The very thin arkosic units appear to be no more than altered seams in the granitic basement. At the west end of the outcrop the sandstone units are fined grained, grey and resemble the sandstones of the overlying Livingstone Creek Formation.

Proceed north on Pine Ridge Road to Highway 17. Reset odometer then proceed east on Highway 17.

Reset odometre.

13.5 km Melwell Road

14.1 km Chalcopryite bearing quartz carbonate vein cut pebbly siltstone of the Gowganda Formation on the south side of Highway 17. The vein and mineral assemblage (quartz-carbonate-pyrite-chalcopryite-hematite) is typical of many in such occurrences between Sault Ste. Marie and Sudbury.

47.6 km Downtown Blind River (at Tim Horton's).

66.7 km Pronto Road

Turn north onto the Pronto road and continue until prevented by a gravel barrier from proceeding further. Continue on foot past the barrier to the west end of a beaver pond just north of the road. Proceed along a trail across the west outlet of the pond, then around the north end of the pond and up a steep hill. Turn left (to the north) on a gravel road at the top of the hill. Continue to an area of outcrop and gravel fill which marks the former open stope of the Pronto mine. If not accompanied by a guide, please do not attempt to access this site without a compass as well as suitable footwear and clothing.

NOTE: During the field trip we hope to arrange for access from the normally restricted mine property.

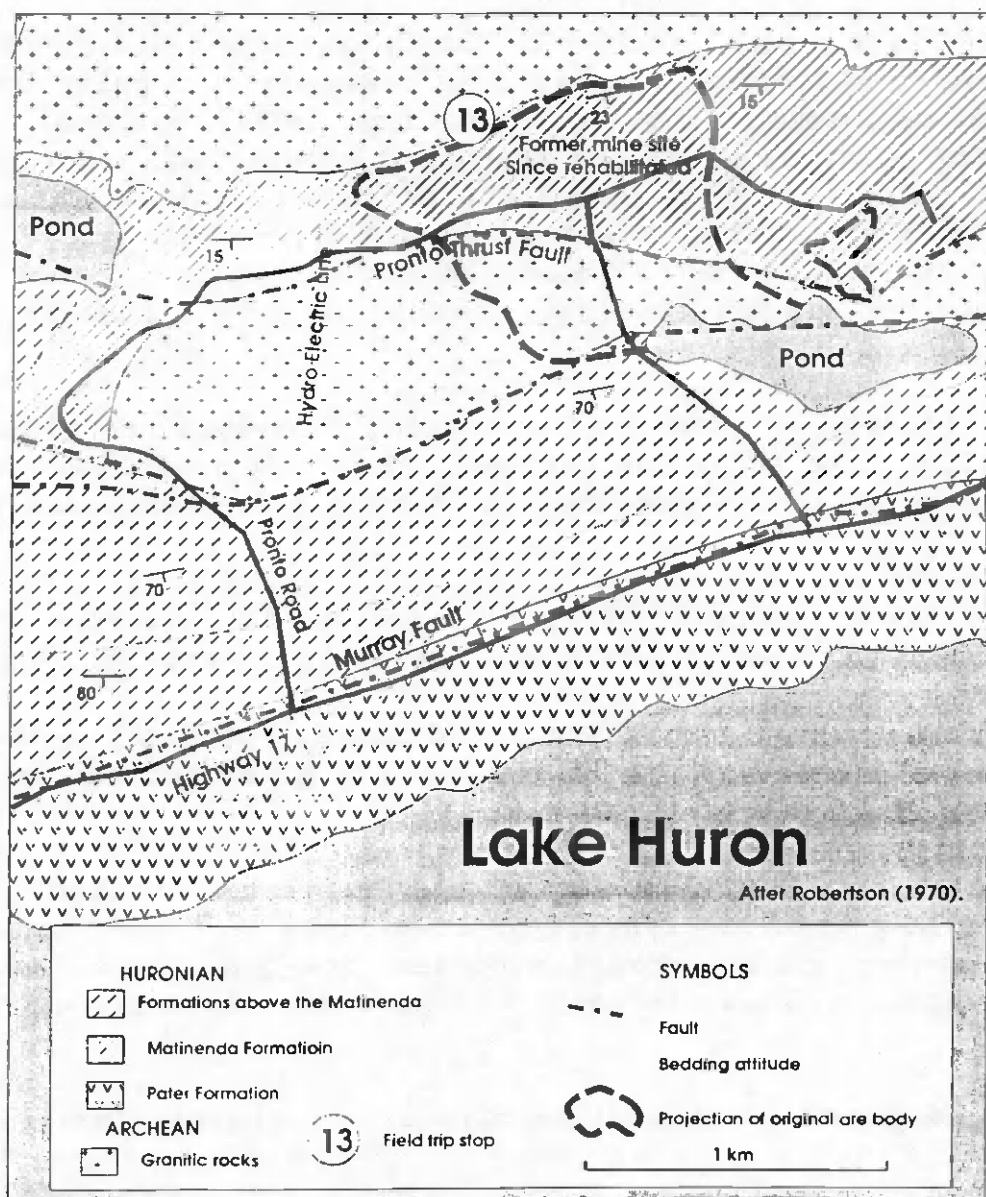
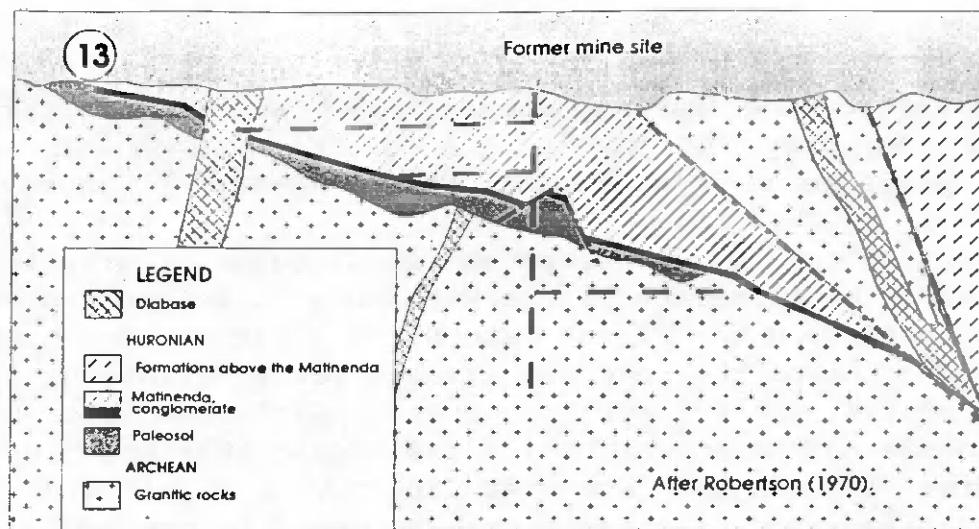


Figure 18. Plan and section of the Geology of the Pronto Mine area.

STOP 13: Pronto Mine (past producer) - This property is currently undergoing restoration to a condition as closely as possible to it's original state. (Refer to Figure 18).

This is one of the few locations where exposures of uraniferous quartz pebble conglomerate of the Matinenda Formation can be found on surface in the Elliot Lake-Blind River area. In the depression south of the road are exposed rusty-weathering outcrops of radioactive, pyritic, quartz-pebble conglomerate of the Matinenda Formation which mark the base of the ore bed of the Pronto Mine. The conglomerate lies directly upon yellowish, sericitic paleosol developed on Archean granitic basement.

Proceeding in a general northerly direction some features of the original granitic rocks, displayed as dikes and irregular bodies of aplite and pegmatite, can be recognized in the paleosol (saprolith). Continuing up the southward sloping outcrop the yellowish colour of the paleosol can be seen to take on a pinkish and reddish hue normal to the Archean granitic rocks of the area. Continuing north and west to near the highest point on the outcrop one can discern the faint outline of core-stones in the granitic rocks.

Return to Highway 17. Continue east along Highway 17 to Highway 108 to Elliot Lake. Continue eastward for a few hundred metres past Highway 108 to low outcrops in an open area just south of Highway 17.

STOP 14: McKim Formation - Staurolite schist. Low outcrops a few tens of metres south of Highway 17. (Refer to Figure 16).

This outcrop, which lies a few hundred metres south of the Murray Fault Zone, displays the higher metamorphic grade and deformation common to rocks south of the fault.

At this location argillaceous units of the McKim Formation contain pale prismatic crystals of staurolite which have undergone retrograde metamorphism to sericite-quartz aggregates. A few pseudomorphs show the characteristic cruciform twinning of staurolite.

The enhanced growth of staurolite crystals in the originally more

argillaceous upper portions of the beds has resulted in "reverse graded bedding" in a few places.

Return to the intersection of Highway 17 and Highway 108. Proceed north along Highway 108 to the Town of Elliot Lake.

ROAD LOG ... DAY 2
=====

Day 2 of the field trip begins in the City of Elliot Lake at the intersection of Highway 108 and Hillside Drive North. (Refer to Figure 18).

Turn west onto Hillside Drive North.

Continue west on Hillside Drive North for about 1 km to Spine Road. Turn west onto Spine Road

1.9 km Spine Road at Lawrence Ave (End of Spine Road). UTM
370525E, 17-5137802N

STOP 15: Radioactive quartz-pebble conglomerate of the Matinenda Formation.

The low outcrops on the north side of Spine Road are grey, buff and dark-grey arkose and radioactive, pyritic, quartz-pebble conglomerate of the Matinenda Formation. Pebble units are about 20-30 cm thick and dip about 10 degrees to the north. Pebbles in this outcrop are about 1-2 cm across and are generally much smaller than the pebbles in the ore zones of the Elliot Lake mines. Ruzicka and LeCheminant, (1984) report the radioactive conglomerate contains :

"rare-earth-elements-bearing uranothorite(?), large zircons, a Ti-U-Si-Fe phase (brannerite ?), chalcopryrite and chromite. The distribution of radioactive minerals in the conglomerate displays layering thus indicating a detrital origin of these grains"

The dark-grey areas in the radioactive beds are due to the presence of minor amounts radioactive carbon generally known in

LEGEND

For figure 18

POST-HURONIAN MAFIC INTRUSIVE ROCKS NIPISSING DIABASE



Dabase, gabbro, metagabbro,
granophyre

INTRUSIVE CONTACT

HURONIAN SUPERGROUP COBALT GROUP Bar River Formation

Not Present in the
Quirke Lake Syncline

Quartz arenite

Not Present in the
Quirke Lake Syncline

Gordon Lake Formation

Siltstone, argillite, subarkose



Lorrain Formation

Quartz arenite, subarkose, arkose, conglomerate,
thorium-bearing conglomerate

Gowganda Formation



Conglomerate, argillite,
wacke, subarkose, siltstone

HIATUS

QUIRK LAKE GROUP Serpent Formation



Subarkose, conglomerate

Espanola Formation (3)



Limestone, dolomite, calcareous
siltstone

Bruce Formation (3)
Conglomerate

HOUGH LAKE GROUP Mississagi Formation



Subarkose, arkose, conglomerate

Pecora Formation (4)



Argillite siltstone

Ramsay Lake Formation



Conglomerate

ELLIOT LAKE GROUP McKim Formation



Siltstone, argillite, wacke

Matinenda Formation



Subarkose, arkose, conglomerate,
uranium-bearing conglomerate

DISCONFORMITY

Thessalon Formation (5)



Basalt, andesite, minor mugearite-hawaiite,
rhyolite, metabasalt, and intercalated
sedimentary rocks

DISCONFORMITY?

Livingstone Creek Formation



Arkose, polymictic conglomerate

UNCONFORMITY

ARCHEAN



Plutonic granitic rocks, gneisses,



Felsic to mafic metavolcanic rocks,
metasedimentary rocks



Shaft - former uranium mine



Fault

(21) Field trip stop

Source of information

Oslen and Leach (1978)

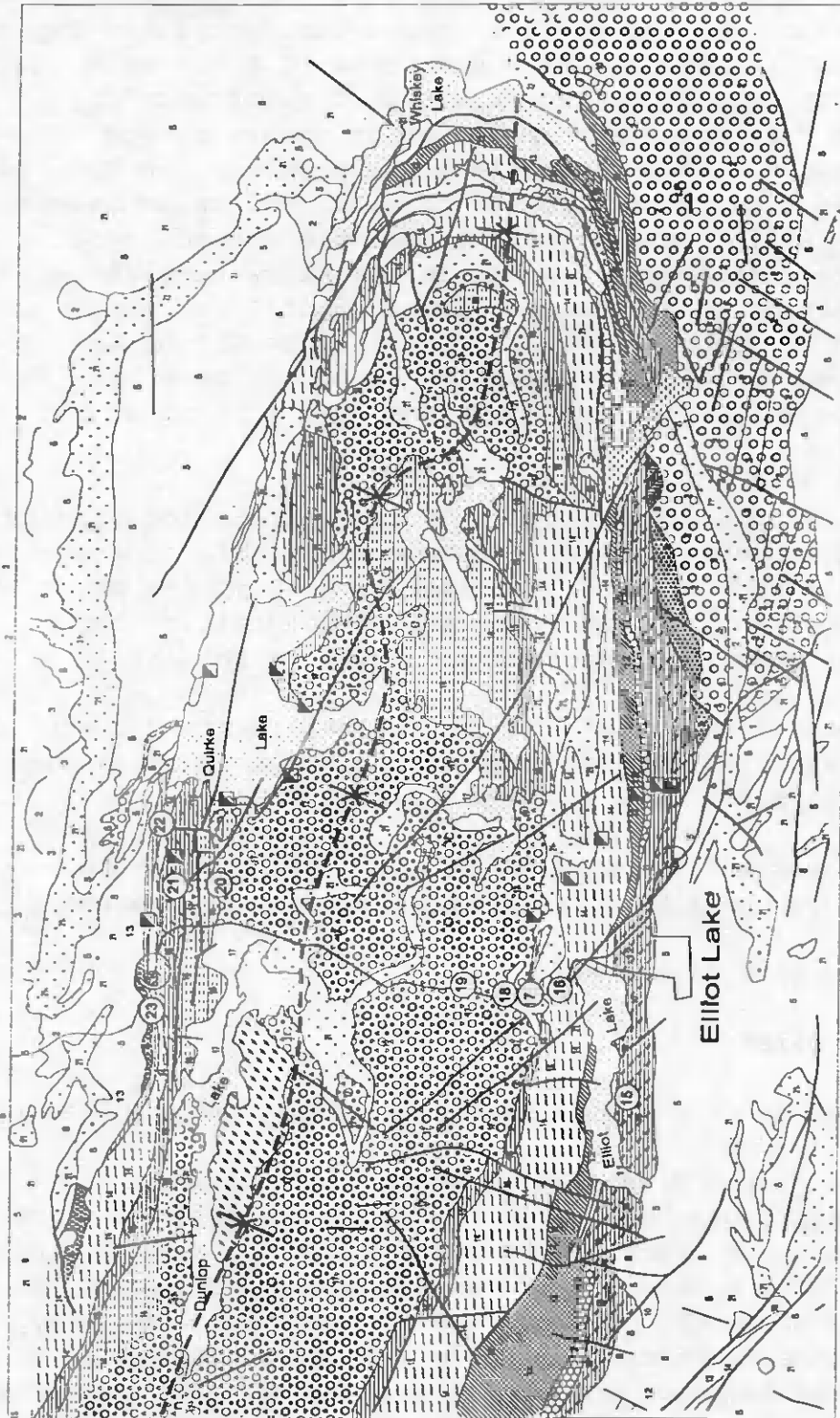


Figure 19. Geology of the Elliot Lake area.

the Elliot Lake area as "thucolite" but also referred to as a hydrocarbon kerogen. Ruzicka and LeCheminant, (1983) note that several generations of carbon occur in the conglomerates of the Matinenda Formation. The earliest generation occurs as layers concordant with the bedding or a component of the matrix and appears to have been deposited in areas of quiescent sedimentation during the last phase of an upward fining sedimentary cycle. Later generations are probably remobilized phases of the first generation of carbon. The carbonaceous matter in the Elliot Lake ores is comparable in occurrence and composition to similar hydrocarbon in the Witswatersrand gold reefs; interestingly Ruzicka and LeCheminant(1984) report elevated gold content (1000 - 2000 ppb) in the Elliot Lake carbonaceous matter. The radioactive carbon at this site is reported to be auriferous, although the gold content is not available.

A drill hole was drilled about 30 m south of this location by Rio Algom Mines Limited in 1955. The logs of this hole indicate that the radioactive beds exposed here are about 35 metres above the basement of Archean granitic rocks. Diamond drilling has indicated that there are no ore-grade units in this area.

Grab samples collected by G. Bennett in 1982 returned up to .80 lbs/ton U3O8 and 0.78 lbs/Ton ThO2. A continuous chip sample returned 0.31 lbs/ton U3O8 and 0.53 lbs/ton ThO2.

Return to Highway 108 and proceed north on Highway 108 to Milliken Road (about 1.5 km north of Hillside Drive North).

Reset odometer at Milliken Road.

1.0 km - 0.63 miles

STOP 16: Subarkose of the Mississagi Formation, Hough Lake Group.

Grey subarkose of the Mississagi Formation displays well-developed trough cross-bedding in bedding units about a metre thick. Paleocurrents are from the west. The rusty iron-staining on the face of the outcrops reflects the minor pyrite content which commonly is deposited along the foreset beds. The grey colour of these sandstones, and the presence of apparently detrital pyrite, is held to indicate very low partial pressure of

free oxygen of the atmosphere in this time.

1.4 km - 0.9 miles

STOP 17: Nipissing Diabase/Gabbro, altered Mississagi Formation, Bruce Formation.

A sill-like body of Nipissing gabbro/diabase is exposed on the east side of Highway 108. Rhythmic, compositional layering is visible on the vertical face of the exposure. Near the north end of the Nipissing sheet the present erosion surface displays evidence of water erosion presumably as a result of melting of adjacent Pleistocene glacial ice. North of gabbro sill, the upper portion of the Mississagi Formation is exposed along the east side of the highway. The sandstones here have been subjected to metasomatism, presumably related to the adjacent Nipissing intrusion. The metasomatic effect is visible as the distinctly pinkish hue of the sandstone, which is probably due to the development of albite. The dark-green to black chlorite deposited along thin fractures may also reflect metasomatic alteration by fluids circulated by the hot diabase.

Continue northward on foot for a few tens of metres. Here the Mississagi Formation is overlain by diamictite of the Bruce Formation at the base of the Quirke Lake Group. The dispersed megaclasts of the Bruce Formation are predominantly grey granitic rocks with smaller mafic clasts of what appear to be, at least in part, Huronian volcanic rocks. The abundant matrix of the conglomerate is dark-grey to black. Sand-sized quartz grains have a glassy, black appearance, a reflection of the chlorite content of the matrix. There is no evidence of significant disconformity at the base of the Bruce Formation.

Proceed by vehicle to near the top of the hill.

1.8 km - 1.4 miles.

STOP 18: Espanola Formation and Nipissing diabase sills.

The base of the Espanola Formation is a green laminated unit about a metre or so thick. This is overlain by laminated silty limestones of the Bruce Limestone member, Espanola Formation. At this location the proximity of Nipissing intrusions has led to

the development of a skarn with grossularite garnet, idocrase (vesuvianite), diopside, and wollastonite. The latter can be found, just below the north-dipping diabase sill near the north end of the exposure. Wollastonite occurs as sub-parallel groups of pale-grey to white prismatic crystals about one mm wide. The pink coating on joint surface is apophyllite ($\text{KFCa}_4[\text{Si}_8\text{O}_{20}]8\text{H}_2\text{O}$) an uncommon mineral, sometimes found in amygdules in basalts, but is also associated with calc-silicates. Young(1991) states that the small scale thrust faults and folds displayed in the limestone on the west side of the highway are probably the result of slumping during early tectonic activity.

The upper, ferruginous dolostone-bearing member of the Espanola Formation and the overlying Serpent Formation are not present at this location. They have probably been removed during a period of pre-Gowganda erosion. The basal units of the Gowganda Formation are visible on the west side of the highway.

2.0-2.5 km - 1.3-1.6 miles Gowganda Formation diamictite.

Massive diamictite of the Gowganda Formation. Megaclasts of pink granite, grey granite and granitic gneiss and mafic rocks are widely distributed in a dark green matrix. Most geologists now consider at least some of the diamictites in the Gowganda Formation to be tillites, although a debris-flow origin, either glaciogenic or as sub-marine debris flows is also reasonable. Roscoe, (1969) places the appearance of free oxygen in the atmosphere ("oxyatmoverion") as coinciding with the appearance of the reddish hue of hematite just above the base of the Gowganda Formation.

3.8 km. - 2.4 miles.

STOP 19: Stratified Gowganda Formation.

Park just south of the rock-cut on east side of the highway.

This is an impressive exposure through a stratified sequence of diamictites and sandstones of the Gowganda Formation. The base of the sequence at the extreme southern end of the exposure on the west side of Highway 108 consists of massive diamictite overlain

by a thin unit of laminated mudstone siltstone with drop stones. About 1 m of stratified Gowganda overlies the siltstone. Diamictite, sandstone, pebbly sandstone and clast supported polymictic conglomerate are present. Some conglomerate units display normal and reverse grading suggestive of debris flows. The rocks displayed here may be interpreted to represent a depositional environment proximal to a retreating glacial margin.

Note: the predominance of red and pink granitic clasts, is in marked contrast to the pale grey clasts of the Bruce and Livingstone Creek Formations seen earlier.

4.7 km. - 2.9 miles. Pink sandstones and diamictite of the Gowganda Formation.

6.7 km - 4.2 miles. Diamictite with large boulder, Gowganda Formation.

Pink and red arkose with pebbly and bouldery mudstone (diamictite). Relatively massive bed of pink arkose with scattered pebbles and a boulder of red granite on the west side of the highway. The continuity of strata is broken by faulting, channelling and deformed arkose bodies in grey pebble siltstone (near south end of rock-cut).

8.2 km. - 5.1 miles Stanrock Road

11.4 Denison Mine Road - Turn east. Reset odometre to 000 km

3.6 km.

STOP 20: Gowganda Formation - Serpent Formation disconformity
376102E, 17- 5150299N

The Serpent Formation has been partially removed during a period of pre-Gowganda erosion in the southwestern part of the Quirke Lake Syncline and the Blind River Sault Ste. Marie area. At this

location, on the south side of the road, well-sorted sandstone of the Serpent Formation is overlain by polymictic conglomerate of the Gowganda Formation. The contact is sharp but irregular. Evidence of a sub-Gowganda disconformity at this location is given by the presence of pebble and cobbles of the Serpent

Formation near the base of the Gowganda Formation.

Return to Highway 108 Reset Odometre, turn north
000

0.5 km - 0.5 miles. Disseminated carbonate in sandstone of the Serpent Formation on east side of Highway 108.

1.4 km - 0.8 miles. Outcrop of Espanola Limestone Member of the Espanola Formation with ripple marks is exposed on the east side of Highway 108. The carbonate units of the Espanola Limestone are actually ferruginous dolomite containing approximately 3% total iron.

1.6 km - 1.0 miles. Road to Quirke Lake and former Panel Mine. Turn onto Panel Mine road.

Reset odometre to 000

1.3 km - 0.8 miles

STOP 21: Espanola Member of the Espanola Formation.

Rock-cut in ferruginous dolomite and siltstone of the Espanola Limestone Member of the Espanola Formation. The Espanola Limestone Member is the uppermost member of the three members of the Espanola Formation recognized in the Elliot Lake area. It is characterized by intercalated siltstone and reddish-weathering, ferruginous dolostone beds containing 3-4% FeO. Intraformational breccia, ripple marks, small scale cross-bedding, and various soft sediment features are present. Near the east end of the outcrop a grey, complex clastic dike crosses the stratification at a high angle.

4.1 km - 2.5 miles.

STOP 22: Ramsay Lake Formation overlain by Pecors Formation.

Diamictites of the Ramsay Lake Formation contain cobbles of grey granitic rocks, mafic clasts of Huronian volcanic rocks and Archean felsic volcanic clasts in an abundant dark-grey to black sandy matrix. The Ramsay Lake Formation is overlain by dark laminated siltstone and mudstone of the Pecors Formation. The

latter contains a few drop-stones. Note: the Matinenda Formation of the Elliot Lake Group, expected between the basement and the Ramsay Lake Formation, is truncated by the Ramsay Lake Formation in this area. The Matinenda Formation does occur in the mine workings down-dip from this location.

Continue east to the end of the Panel Mine road. This is the rehabilitated area of the former Panel Mine. There is little evidence of the uranium mine and mill complex that was on this site until 1993.

Return to Highway 108. Continue north on Highway 108.

Tailings dam of the Quirke Mine is visible west of the Highway.

Highway 108 ends and Highway 639 begins. Reset odometre.

0.8 km - 0.5 miles. Diamictite of the Bruce Formation is exposed west of the Highway.

1.5 km - 0.9 miles. Outcrops of Mississagi Formation are exposed along Highway 639. Note the yellowish colour characteristic of the Mississagi Formation where it lies directly on the Archean granitic basement (Robertson, 1968).

2.2 km - 1.4 miles

STOP 23: Huronian volcanic rocks of the Thessalon Formation (Dollyberry Volcanics).

Road leading west from Highway 639 leads to the Quirke Mine tailings dams. Park near the gate and walk a short distance along the road to a snowmobile bridge over the stream from the tailings dam. Follow the trail from the bridge to outcrops of mafic volcanics of the Thessalon Formation (Dollyberry Volcanics) near the crest of a low hill. Chemical analyses of the Huronian volcanics in this area indicate the volcanic rocks include transitional alkalic types, hawaiite and mugearite.

The unconformity between the Archean granitic basement rocks and Huronian volcanic is visible in this area. There is no visible paleosol at this location. Near the trail a thin, quartz-pebble

conglomerate unit of angular to subrounded, quartz-clasts, overlies the granitic rocks at the base of the volcanic unit. Walking eastward from this point scattered, isolated, pebble- and cobble-sized clasts of quartz can be found along the unconformity. A similar quartz-pebble conglomerate occurs at the base of the Huronian volcanic rocks where they overlie Archean mafic volcanic rocks in the haulage drift of the Stanleigh Mine on the south limb of the Quirke Lake Syncline. A few kilometres west of this location, occurrences of this conglomerate unit contain more rounded quartz clasts, and are commonly overlain by a thin arkosic unit. Quartz-pebble conglomerate, which locally contains significant pyrite as well as uranium, occurs sporadically at the base of the Huronian volcanic sequence of the Quirke Lake Syncline and westward to the Sault Ste. Marie area. The conglomerate at this location is correlated with the radioactive, quartz-pebble conglomerate of Stop 11.

Return to Vehicle and continue north on Highway 639.

Archean granitic rocks cut by diabase outcrops along the highway.

8.8 km 5.5 miles

STOP 24: Archean pillowed metavolcanics. (Refer to Figure 16).

Archean mafic metavolcanics displaying well-developed pillow structures are exposed on a north sloping outcrop on the east side of highway. Pillows are deformed, but facing directions can easily be determined. Small amygdules are concentrated near the upper surface of many pillows.

9.4 km - 5.8 miles. Flack Lake fault occupies a valley near this point.

9.9 km - 6.1 miles. Outcrops of hematite-stained sandstone of the Bar River Formation.

10.5 km - 6.5 miles. Entrance to Mississagi Provincial Park.

10.8 km - 6.7 miles. Pale grey sandstone of the Bar River Formation with herringbone cross bedding.

11.4 km - 7.2 miles. Christman Lake

STOP 25: Bar River Formation

Sandstones of the Bar River Formation display ripple marks, mud cracks and sinuous structures which have been described as possible worm casts. Comparison with desiccation structures in the Gordon Lake Formation led Young, (1969) to suggest that these features are the result of the transportation of consolidated desiccation fracture fillings.

15.3 km - 9.5 miles.

STOP 26: Gordon Lake Formation

Laminated, maroon buff siltstone and chert with reduction spots in the upper part of the Gordon Lake Formation. This is another red-bed occurrence within the Cobalt Group.

16.6 km - 10.3 miles

Stop 27: Gordon Lake Formation.

Siltstones and sandstones of the Gordon Lake Formation display ripple marks, desiccation cracks, cross bedding and a late cleavage. Note: the presence of pyrite in contrast to the generally hematitic nature of the Gordon Lake Formation near the top of the formation.

19.7 km - 12.2 miles. View of the Boland River valley.

21.0 km - 13.0 miles

STOP 28: Lorrain Formation

White to pale pink quartz arenite of the upper portion of the Lorrain Formation is exposed on the east side of the highway.

22.8 17.8 miles. Junction with Little White River road (Highway 546.)

End of field trip.

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