GEOLOGICAL SURVEY OF CANADA

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IRON-FORMATION AND METALLIFEROUS SEDIMENTS IN CENTRAL CANADA

[FIELD TRIP 8]

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8TH IAGOD SYMPOSIUM

FIELD TRIP GUIDEBOOK

8th IAGOD SYMPOSIUM

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INTRODUCTION

This field excursion has been organized to show some of the common facies relationships and metallogenic features of Algoma type iron-formations in the Canadian Shield. Four areas have been chosen, Temagami, Kirkland Lake, Timmins, and Wawa, where data and good exposures of iron-formation are available in mine areas.

Iron-formation in the Temagami area is associated mainly with immature clastic sediments, tuff and mafic to felsic volcanic rocks, and appears to be one of the least metamorphosed Archean hydrolithic sediments in the Superior Province. Primary depositional and diagenetic features are well preserved and have been extensively studied in this area. Distinctive micro- and macro-banded oxide facies, composed of red jasper, green to grey or black chert, magnetite and hematite, are interbedded with various carbonate, iron-silicate, sulphide or carbonaceous facies, turbidites, and fine-grained clastic beds.

Two main facies groups of iron-formation and associated stratafer sediments are extensively developed in the Kirkland Lake area. Dark blue-black thin-banded magnetite oxide facies was mined at Adams mine in the Boston Township iron range. The dense well segregated magnetite laminae, facies of lean iron-formation and chert, and the subtle association of thin laminae of polymetallic sulphide facies interbedded in the main oxide facies, are of special interest in this iron-formation. The other main facies group exposed east of Kirkland Lake is composed mainly of thin laminated to massive beds of chert with variable amounts of carbonate consisting of siderite, ankerite or dolomite in association with metasediments, tuffs and volcanic rocks. Many facies units of this group contain gold and constitute important metallogenetic marker beds.

One of the principal domains of iron-formation metallogeny is well demostrated at Kidd Creek mine near Timmins where good examples of polymetallic sulphide facies of iron-formation are associated with rhyolitic volcanism. Other facies of iron-formation are widely distributed in this region and have important significance as marker beds in propsecting for gold, sulphide and iron deposits throughout the Abitibi belt.

The Wawa area in the Michipicoten District has been studied extensively as a typical geological setting for Algoma type iron-formation. Various lithological facies are developed and their stratigraphic relationships and depositional environments are well defined. Transitions from distinctive pyrite-pyrrhotie, siderite, and oxide facies, and their possible proximal to distal relationships to hydrothermal effusive centres, are displayed in this area.

Based on accepted practice, iron-formation is used as a lithological term for all stratigraphic units of layered, bedded, or laminated rocks that contain 15 per cent or more iron, in which the iron minerals are commonly interbanded with quartz, chert, oxide, carbonate or silicate minerals, and the banded structures of the ferruginous rocks conform in pattern and attitude with the banded structure of the associated sedimentary, volcanic and metasedimentary rocks. The important distinctions between iron-formation and ironstone lithologies are maintained. The term "stratafer" is used for the large group of metalliferous chemical sediments that includes a great variety of lithological facies of Algoma- and Lake Superior-types of banded cherty iron-formation, manganese-iron, polymetallic sulphide, and other associated hydrolithic facies, which may or may not contain 15 per cent iron, and which formed by chemical, biogenic, sedimentary, and hydrothermal effusive or exhalative processes. They are commonly composed of banded chert and quartz interbedded with oxide, sulphide, carbonate and silicate minerals and contain ferrous, nonferrous and/or precious metals (Gross, 1988).

Volcanogenic, hydrothermal effusive or exhalative concepts were proposed in some of the early work on the origin of iron-formations, especially in Scandinavia and Germany, but they were not considered seriously or applied in the study of iron-formations in Canada and in North America until the middle of this century. The significance of volcanogenic concepts in guiding exploration for polymetallic sulphide deposits was soon recognized in Canada and in many parts of the world. In many cases volcanogenic concepts for iron-formation and the associated sulphide facies have been considered independently and separately, and their genetic relationships to other lithological facies in the stratafer group of hydrolithic sediments have been ignored. As a result, the variety and significance of many important metallogenetic features in these volcanogenic hydrolithic sediments have not been fully appreciated or understood.

The cooperation and assistance of the staff at; Sherman Mine and Adams Mine, Dominion Foundries and Steel Limited, and Cliffs of Canada Limited; Kidd Creek Division, Falconbridge Limited; Algoma Ore Properties Limited; the Ontario Geological Survey; the Geological Survey of Canada; and the Geology Department of Carleton University; in the planning and preparation of this field excursion are especially acknowledged, and we thank them sincerely for their contributions. We thank Richard Lancaster, Geological Survey of Canada, Ottawa, for preparing some of the figures and illustrations in a format suitable for the guidebook. Special acknowledgments are also given to authors of published information referred to in the preparation of the guidebook.

Because both Sherman Mine and Adams Mine will be closed by the time this guidebook is published, access to the open pits may be substantially modified. For this reason specific stops within the pits have not been designated. Anyone planning to visit the mine areas described in the guidebook must obtain permission from the appropriate property owners.

Part 1

IRON-FORMATION IN TEMAGAMI AND SHERMAN MINE AREA

J.A. Donaldson and R.G. Garrett

Sherman Mine

Introduction

Much of the information summarized herein was derived from: Boyum and Hartviksen (1970), Pye, Lovell, Bright, Petruk, et al. (1972), and Donaldson and Munro (1982).

The Sherman Mine in Briggs, Strathcona and Strathy Townships, northeastern Ontario, consists of four open pits clustered around a concentrating and pelletizing plant that is approximately 1 km west of the town of Temagami, 380 km north of Toronto (Fig. 1-1). Named after Frank Sherman (1887-1967), a pioneer of the Canadian steel industry, the Sherman Mine is a joint venture between Dominion Foundries and Steel Company (Dofasco) (90%) and Tetapaga Mining Company (10%), a subsidiary of Cleveland-Cliffs Iron Company. The mine is operated by Cliffs of Canada, also a subsidiary of Cleveland-Cliffs Iron Company.

Barlow (1899) was the first to report iron-formation in the Temagami area; staking followed soon after. Concentration tests on samples collected in 1903 and 1907 led to drilling in 1913 and 1914 that was curtailed by the start of World War I. Additional claims were staked and evaluated by trenching and geophysical surveys in 1943; geological mapping was continued by Savage (1935), Moorhouse (1942), Simony (1964), Bennett (1969), Wilton (1969), Bright (1969, 1970), and Campbell (1978). Detailed geological mapping and geophysical assessment of the property was renewed in 1959 by Cliffs of Canada, which provided the basis for additional drilling in 1960-1961. Beneficiation tests by Cleveland-Cliffs on large bulk samples collected in 1961 and 1964 were encouraging, leading to a decision to begin construction in 1965 of the mining, concentrating and pelletizing complex. The concentrator was in operation by 1967, and the pelletizing plant by 1968. Crude ore blasted from the open pits was loaded by electric shovels into 65- and 85-ton trucks for haulage to the primary gyratory crusher, where it was reduced to -18 cm fragments that were gravity fed to autogenous grinding mills. After secondary grinding to -325 mesh in pebble mills and magnetic separation and dewatering in disc filters, the moist ore concentrate was combined with bentonite as a binder in balling drums to produce pellets containing 64 % iron. These pellets were dried and heat hardened at 1315°C (2400°F) in a rotary kiln, cooled and carried by conveyor belt to an automatic load-out silo above the ore-car railway tracks. All grinding, concentrating and pelletizing operations were automated and centrally controlled and monitored from a single control room.

The Sherman Mine, which has produced more than 22 million long tons of iron ore pellets, is notable as being the first iron-ore property in North America to produce self-fluxing pellets (crushed limestone and dolomite incorporated directly into the pellets) on a full-time basis beginning in 1985. Self-fluxing iron ore pellets are now becoming the accepted standard on world markets for use in blast furnaces making pig-iron and steel.

The entire annual production capacity of 1.1 million long tons was shipped daily in covered ore cars, of 91 long tons capacity each, via Ontario Northland Railway and Canadian National Railways, to be consumed in Dofasco's steel-making plants in Hamilton, Ontario. The mine started full production in 1968; production ceased in 1990. More than 300 full-time employees held jobs at the mine during peak production. Considerable attention was given throughout the operation to

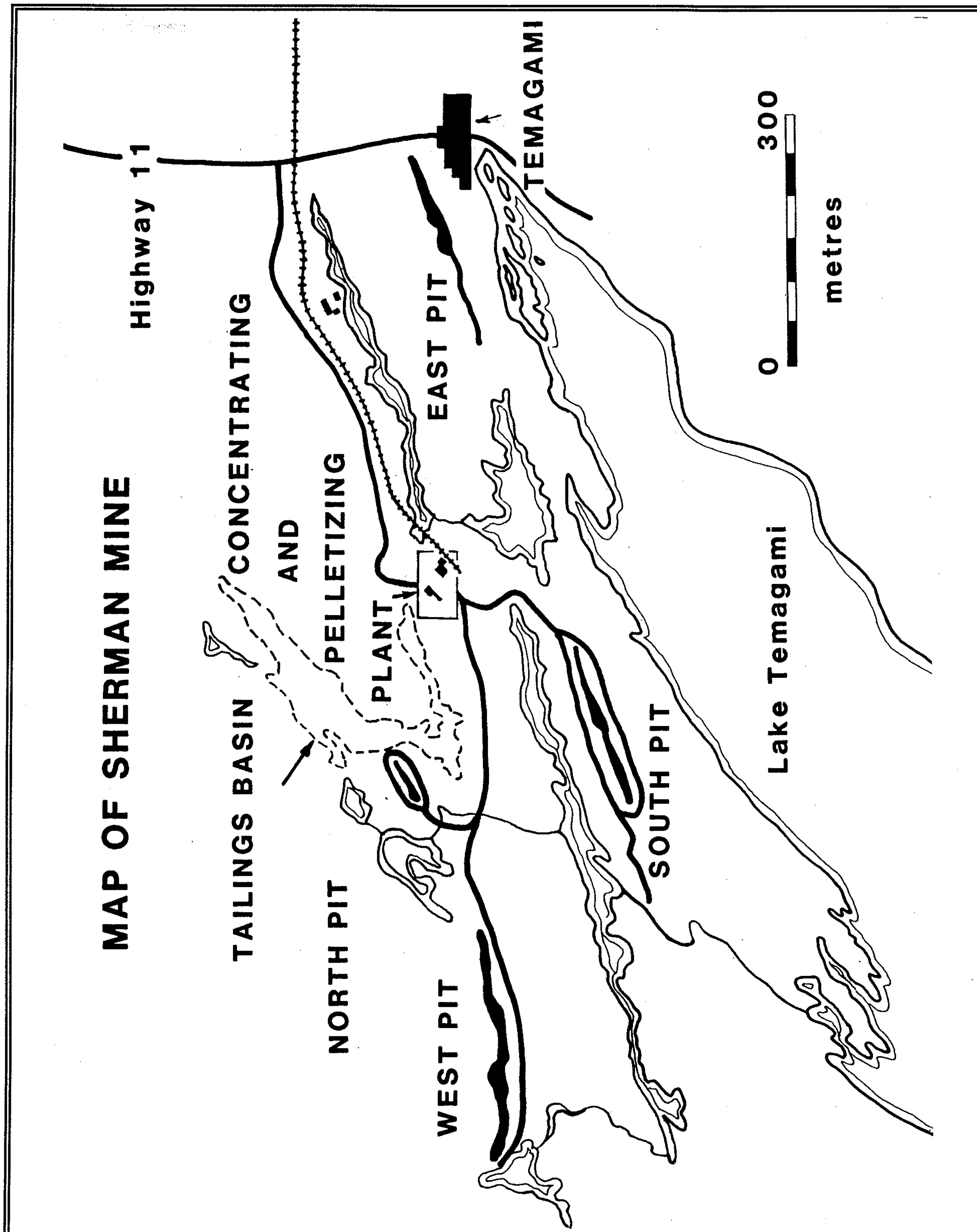


Figure 1-1. Location of open pits, Sherman Mine

environmental concerns. Of the 27,000 gallons of water per minute required for peak operation, 90% was recycled; the remaining 10% carried waste to the tailings pond, which is now being revegetated.

Geological Setting

The Sherman Mine ore occurs within two parallel northeast-trending members of iron-formation within the Temagami greenstone belt, on the southern margin of the Abitibi subprovince of the Superior structural province.

The Temagami greenstone belt comprises an older assemblage of predominantly felsic volcanic rocks in the north and a younger assemblage of mafic volcanic rocks intercalated with volcaniclastic sedimentary rocks in the south. The Sherman Mine ore-bearing strata consist of chert-magnetite and minor carbonate and sulphide facies iron-formation associated with volcaniclastic strata of the younger volcanic assemblage. The stratigraphic units have a regional trend near 070°; most dips range from 70° to vertical.

Geology of the Ore Deposits

Magnetite is the principal iron-bearing mineral: the ore contains 25% total iron, of which 20.5% is in magnetite. Hematite, iron carbonate, pyrite and iron silicates such as stilpnomelane are locally abundant. Although rocks in the region have been metamorphosed to greenschist facies, some textures in the iron-formation are suggestive of diagenetic growth.

The South Pit is characterized by well-banded white to drab grey magnetic cherty iron-formation which contains jaspilitic layers. The iron-formation averages about 60 m in stratigraphic thickness (90 m maximum) over a length of 1500 m. Interbedded tuffs, ranging in thickness from 0.15 to more than 5 cm, are composed mostly of chlorite and/or stilpnomelane. On the south side, a few thin beds of lean iron-formation are intercalated with the underlying metavolcanic rocks, forming a transition zone. A thin but persistent chert zone of variable thickness, with low iron content, occurs on the northern side. This is capped by graphitic argillite rich in pyrite.

The North and West Pits are in the northern belt of iron-formation, which extends from Lake Vermilion on the east to the west side of Iron Lake. In contrast to the southern belt, this belt of iron-formation is characterized by a greater thickness (averaging 90 m and ranging up to 185 m) and by a greater variety of internal facies and associated strata, including intraformational felsic tuffs in layers up to 25 m thick. Drab-coloured magnetite-rich cherty iron-formation predominates in the West Pit, whereas magnetite-rich cherty iron-formation in the North Pit is interlayered with both chert-carbonate and chert-silicate iron-formation and contains abundant red jaspilite. A pyrite-rich graphitic horizon, less well developed than in the South Pit, occurs along the northern edge of the northern belt of iron-formation.

Extensive interbedding with volcanic rocks along the southern margin is lacking, in contrast to the basal transitional zone in the South Pit. Sulphide minerals, almost exclusively pyrite, are widely disseminated throughout the iron-formation, tuffaceous beds, graphitic argillites and associated volcanic rocks. Much of the pyrite in the graphitic argillites occurs as bedding-parallel discoid nodules up to 3 cm in diameter.

Stratigraphy and Sedimentology

Although the two parallel units of iron-formation that contain the Sherman Mine ore have been interpreted as limbs of a steep-dipping isoclinal fold (Moorhouse, 1946), tops determinations in the surrounding volcanic and volcaniclastic strata and within both units of iron-formation indicate facings toward the north, suggesting two similar cycles of chemical sedimentation, or probable repetition of a single unit by faulting. The tops indicators include pillow structures, vesicular flow tops, graded bedding, flame structures, ball-and-pillow structures, crossbedding and channels (Atkinson, 1978). Structures in the iron-formation such as compositional grading, syneresis cracks and truncated synsedimentary faults and slumps (Donaldson and Gross, 1988) locally are consistent with tops indicators in the associated volcanic and clastic sedimentary strata (Fig. 1-2).

Chemical precipitation of silica gels with admixtures of iron hydroxides is suggested by the syneresis structures; local rip ups and channels indicate penecontemporaneous lithification and reworking. Asymmetry of both composition and silica-mosaic grain size in some of the chert-magnetite and jasper-magnetite beds is inferred to represent primary chemical grading (Donaldson et al., 1988). This interpretation is compatible with deposition in a starved basin in which iron was episodically introduced into the water column from hydrothermal vents.

Stop 1 South Pit, Sherman Mine

This stop provides access to spectacular examples of Algoma-type banded iron-formation in which delicate microbands are accented by jaspilitic laminations. Chemical grading in which individual beds show upward increases in iron oxides relative to silica is locally well-developed. In the transition zone along the south side of the pit, congruent clastic grading can be seen in the intercalated beds of tuff. On the north side of the pit, concretions and cubic crystals of pyrite are abundant in the graphitic schist.

Stop 2 North Pit, Sherman Mine

Carbonate facies and silicate facies iron-formation are interbedded with oxide facies iron-formation in the North Pit. Good examples of soft-sediment folds and truncated penecontemporaneous microfaults can be seen in rubble at the top of the pit. Felsic tuff beds are intercalated with the banded iron-formation, and jaspilite beds are abundant. Pyrite-bearing graphitic argillites flank the north side of the pit.

Stop 3 Highway Cut, Iron-formation

(west side of Highway 11, 0.2 km north of Temagami)

This exposure provides a good vertical cross-section through most of the southern belt of iron-formation, 1 km east of the South Pit, Sherman Mine. Chemical grading in the iron-formation is congruent with clastic graded bedding in tuff beds of the transition-zone along the southern part of the exposure. Several intricate folds probably were produced by soft-sediment deformation. (Fig.) 1-2

Stop 4 Felsic Volcanic Rocks

(west side of Highway 11, adjacent to transformer station, 6.0 km north of Temagami)

Textures and primary structures of flow-banded rhyolites and derived flow breccias are well displayed on glacially polished surfaces at this locality. Although pervasive cleavage indicates considerable deformation, intricate folding confined to angular blocks within the flow breccias demonstrates a primary origin for these folds, suggesting viscous flowage. Clots and stringers of pyrite and chalcopyrite in the flow breccias may be syngenetic.

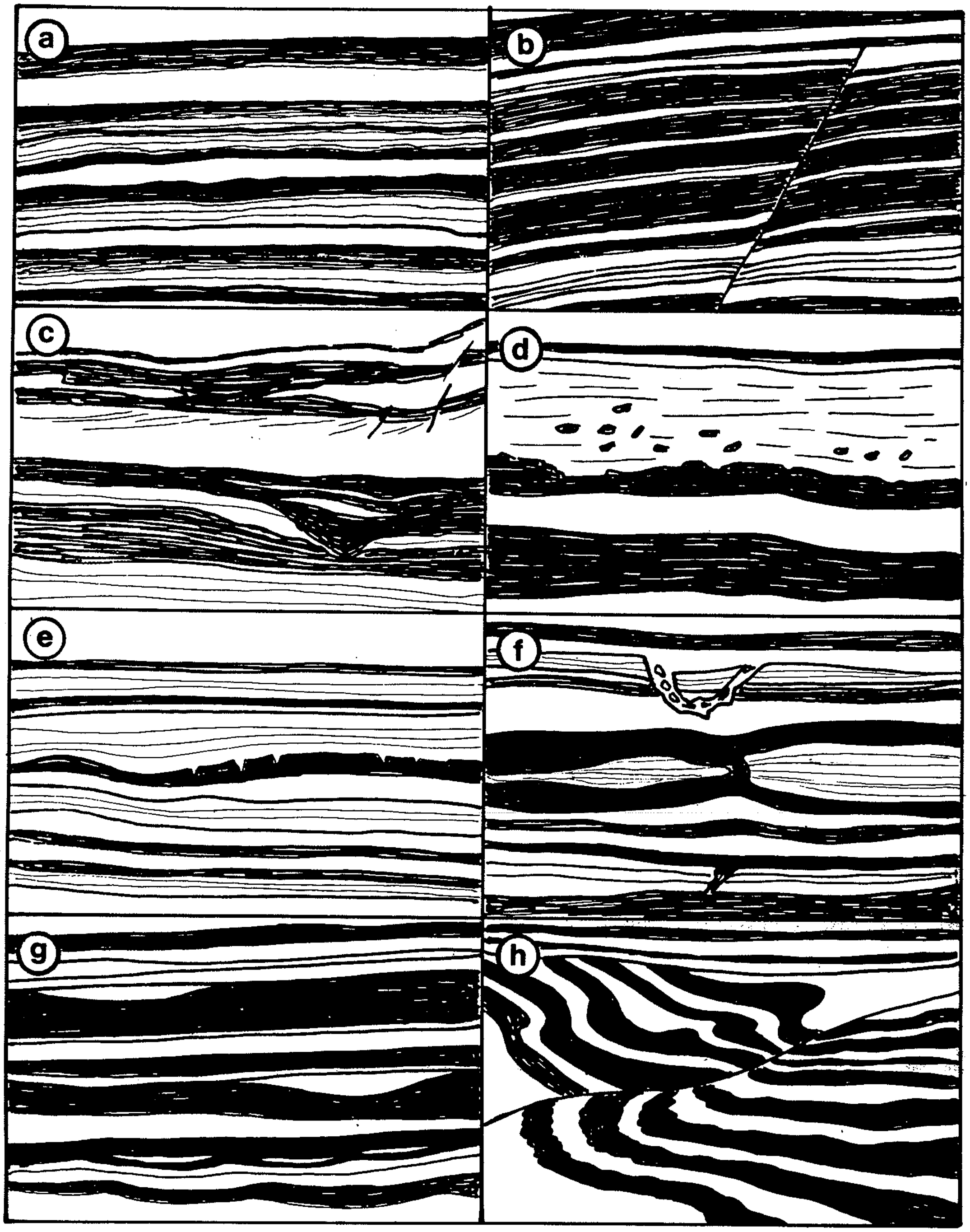


Figure 1-2. Primary structures in Algoman iron formation that provide tops criteria, sketched from samples (x 1/2) collected at Sherman Mine (Stop). a. Graded bedding, b. Truncated penecontemporaneous fault, c. Scour-and-fill; crossbedding, d. Erosional surface overlain by derived clasts, e. Shrinkage cracks (silica gel dehydration?), f. Pull-aparts and graben-like collapse structure, g. Asymmetric chert lenses (chemical precipitation in scours?), h. Truncated soft-sediment folds.

from Donaldson and Munro (1982)

Part 2

IRON-FORMATION AND STRATAFER SEDIMENTS IN KIRKLAND LAKE AND ADAMS MINE AREA

Gordon Gross and Howard Lovell

General Geology and Metallogeny

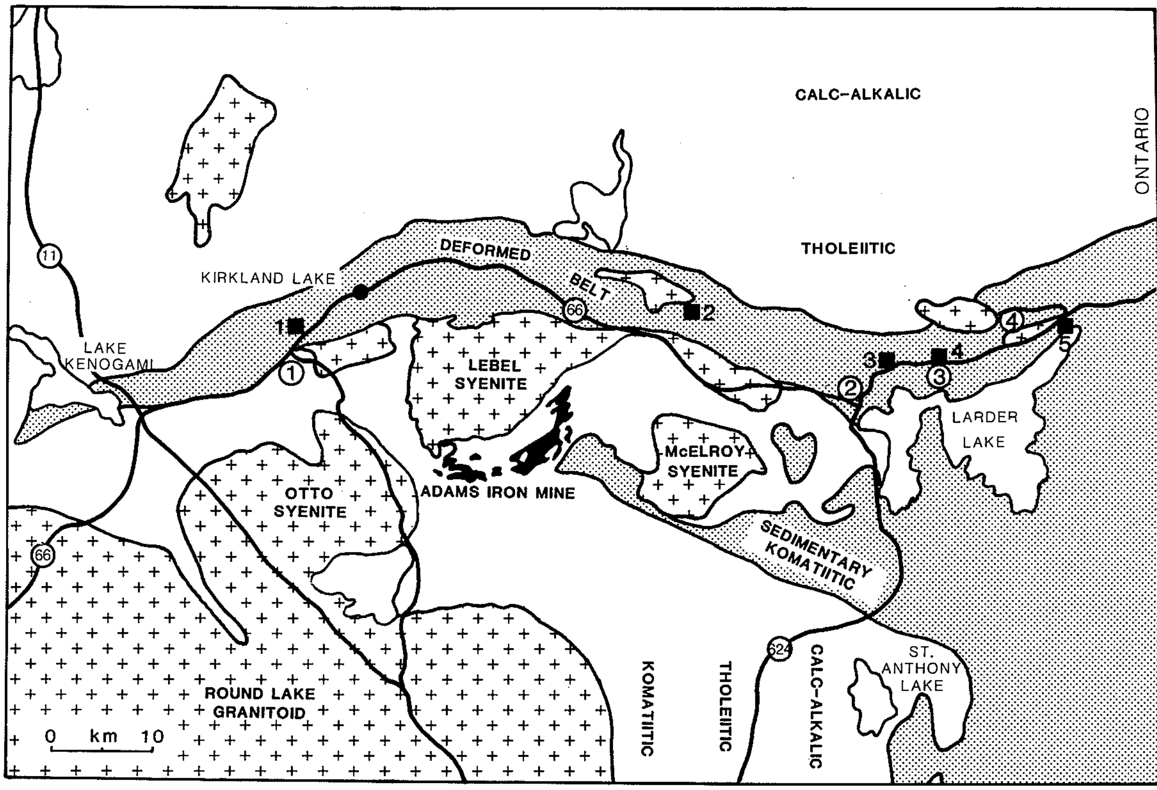
Two complete volcano-sedimentary cycles are the most prominent Archean feature in the Kirkland Lake-Larder Lake area. The first cycle began less than 2 750 million years ago and the second ended about 2 680 million years ago. Each cycle consists of a platform of komatiites and Mg-rich tholeiites differentiated stratigraphically upward through Fe-rich tholeiites to calc-alkalic rocks, ultimately to edifices composed partly of sodic rhyolite, and to alkalic extrusive rocks largely occupying east-west rifts. Upper strata, mainly rhyolitic flow breccias and pyroclastics of the older underlying complete volcano-sedimentary cycles, are intercalated with basalt members consisting largely of komatiitic fissure eruptives, of the younger complete volcano-sedimentary cycle.

Sedimentary rocks are mostly detrital derivatives of the rhyolitic and komatiitic rocks, and in addition, feldspathic chert and iron-formation. Most occurrences of gold, iron, copper, lead, zinc, nickel and asbestos are located where the two cycles are intercalated. Many occurrences, mines and potential producers of gold are in the same stratigraphic package as iron-formation, reminiscent of the position, a short distance below the gold ore strata, of iron-formation at the Johannesburg mines of South Africa.

Lenses of iron-formation are numerous. The largest accumulation of iron-formation is in the Adams Mine area where pelletized iron ore concentrate was produced from magnetite facies. This iron-formation was deposited on a marine shelf, distal from the St.Anthony Lake calc-alkalic volcanic centre that is situated 20 kilometres southeast of the iron mine. Iron-formation, in addition to being widespread along strike and down dip, is repeated several times in a few hundred metres of stratigraphic thickness, and it is doubled by folding in a tight syncline. This syncline arcs around and is roughly parallel to the southern contact of the Lebel syenitic stock. Within the contact metamorphic aureole the magnetite is more coarsely crystalline, and it is more easily beneficiated by crushing, grinding and magnetic separation.

The oxide facies iron-formation consists mainly of magnetite with minor hematite. It is interbanded with grey feldspathic chert, darker grey where magnetite is finely disseminated in the chert, and reddish brown where hematite colors the chert. The iron-formation is intruded by dykes of diabase and lamprophyre and interbedded with flows, tuffs and sedimentary rocks. The gangue minerals in the iron-formation ore are principally chlorite, epidote, garnet, tremolite, and actinolite. The major sulphides are pyrite and lesser amounts of pyrrhotite that are interbedded in sulphide facies iron-formation. Sulphide minerals occur as disseminated grains, relatively pure bands, and nodular pyrite concretions. Many interbands are chloritic, some are cherty, and others are graphitic and carbonaceous. Minor chalcopyrite is present in the following states: as blebs in pyrrhotite, interbanded with cherty or chloritic material, and in quartz-carbonate veins. Minor amounts of sphalerite are interbanded with pyrite, with graphitic schist or slate, and with galena in carbonate veins.

The following field tour stops are indicated on the accompanying index map (scale approximately 1:210 000). (Fig.) 2-1



■1 Macassa #3 shaft-7,225' single lift shaft at west end of Kirkland Lake (23 million ounces of gold produced)

■2 Upper Canada (1.2 million ounces of gold produced)

■3 Omega (215,000 ounces of gold produced)

■4 Cheminis Exploration shaft

■5 Kerr Mine (10 million ounces of gold producted)

SEDIMENTS

VOLCANICS

GRANITIC

1–4 FIELD STOP LOCATIONS

Figure 2-1. Field stops in the Kirkland Lake and Adams Mine area.

Stop 1 Kirkland Lake Core Library, Ontario Ministry of Northern Development and Mines

Boxes of core from Omega Mine, a past gold producer, now owned by Greater Lenora Resources Corporation, are on display in the core examination room. In this core you will recognize: carbonaceous ("graphitic") pyritic slate or schist; thinly laminated sheared sericite-silica-carbonate-pyrite gold ore; volcanic extrusives, etc. Omega mine produced 215 000 ounces of gold and 29 000 ounces of silver from 1 615 000 tons of ore milled.

Stop 2 Iron-formation in conglomerate at Larder Lake

An outcrop of unusual conglomerate at Laguerre gold mine, controlled by Sudbury Contact Mines Limited, can be seen south of the highway on the east side of the community of Larder Lake. A lens of banded magnetite-chert iron-formation that contains sulphide minerals, appears to have been broken and brecciated, and forms the majority of coarse epiclasts in a matrix of talc-chlorite material that is derived from komatiites.

Stop 3 Cheminis Gold Mine, controlled by Northfield Minerals Incorporated.

Stripped exposures display such features as : black carbonaceous chert cut by sedimentary dykes that result from de-watering; carbonate rock that displays the polysutured texture of a komatiite flow; calcareous siltstone retaining such primary textures grain gradation, load casts, pull-apart beds, climbing ripples and dunes, scour-and-fill channels; and also magnetic iron-formation that was folded both prior to and since consolidation.

Stop 4 Barber Larder Mine, past gold producer, controlled by Northfield Minerals Incorporated, Deak Resources Corporation, and GSR Acquisitions.

The lithological sequence exposed across the open pit includes from stratigraphic top at the south to the base at the north: Turbidite "caprock", Carbonaceous (graphitic) pyritic schist about 1 metre thick, Dark cherty rock containing disseminated pyrite and gold, Green carbonate rock.

ADAMS IRON ORE MINE, BOSTON TOWNSHIP IRON RANGE
by G.A. Gross, and from F. Dubuc, (1966)

Introduction

The Adams Mine is located in the Boston Township iron range about 11 km southeast of the town of Kirkland Lake. The mine, owned since 1971 by Dofasco Inc.,(Dominion Foundries and Steel Company), of Hamilton, Ontario, was managed and operated by Cliffs of Canada, Limited, a subsidiary of the Cleveland-Cliffs Iron Company.

The iron-formation was discovered in 1902, but no extensive exploration was carried out during the following 46 years. The Dominion Gulf Company conducted an airborne magnetometer survey over the Boston Township iron range in 1948. This survey, flown at an elevation of about 150 metres, revealed a 17,000 gamma anomaly. Mapping, ground magnetometer surveys, sampling and drilling, and preliminary beneficiation studies were carried out during the next six years.

In 1954, The Jones & Laughlin Steel Corporation of Pittsburg acquired a mining option and continued the exploration programme. Two years later, Jones & Laughlin acquired a 99-year mining lease on 69 patented claims. Extensive exploration was carried out from 1957 to 1962 by Jones & Laughlin's Canadian Exploration Company, Jalore Mining Company, Ltd. The eight orebodies defined for open pit mining contained 100 million long tons of crude ore with an average grade of 22 % magnetic recoverable iron, or the equivalent of 30 million long tons of ore concentrate.

Jones & Laughlin announced on February 1, 1962, that it would develop the mine and produce one million long tons of iron ore pellets that year. The first pelletized ore was produced on December 19, 1964 and transported by rail on December 23 to the Jones & Laughlin's blast furnaces in Pennsylvania.

Adams Mine was purchased by Dofasco Inc., on July 30, 1971, and became a wholly-owned Canadian company. All of the pelletized ore produced at Adams Mine was transported daily by unit trains to Dofasco's blast furnaces in Hamilton, Ontario.

Early in 1985, a decision was made, based on successful trials at the Sherman Mine, to convert from acid pellets to self-fluxing pellets. A flux plant was constructed during the fall and winter of 1985, with startup on February 13, 1986. Since then, all pellets produced have contained dolomite flux.

The decision to close the Adams Mine on March 31, 1990 was announced on March 6, 1989. Factors contributing to this decision were the deteriorating competitive position of the mine, and the disadvantages of its small size and the low grade of the ore. From the start-up of the mine in 1964 to its shut-down in 1990 more than 27 million long tons of pelletized ore containing 65 % iron were produced.

The Boston Township iron range extends through typical glaciated Precambrian terrain with extensive rock exposure on low rounded hills that rise above the gravel and clay overburden, muskeg swamps, small lakes and beaver ponds. The western part of the iron range has no distinctive topographic expression, but the eastern and most important part of the range rises to an elevation of nearly 400 m above sea level and about 75 m above the surrouding land. The iron-formation and volcanic rocks have evidently been more resistant to glacial erosion than other rocks in the area.

Geological Setting

The Boston iron range is 1000 to 1200 m wide and extends southwestward for 10 km across Boston Township (Fig. 2-2). The three main stratigraphic units of magnetite facies iron-formation are interbedded with basic to intermediate volcanic flows consisting mainly of basalt, andesite, pillow lava, tuff beds and sediments. Felsic rocks are present mainly as tuff, agglomerate, and tuffaceous sediments. The iron range forms an arcuate structure about a kilometre southeast of the Lebel syenite stock, and extends parallel to the southeast margin of this circular intrusion which is about 6.5 km in diameter. Several sill-like masses of diorite and metadiorite, up to 300 m thick, intrude the volcanic rocks and iron-formation, and are most abundant in the southwestern part of the range. Numerous syenite and lamprophyre dykes that range in thickness from a few centimetres to more than a metre, and thicker diabase dykes, occur locally throughout the area.

The stratigraphy and geological history of the area is summarized in Table I.

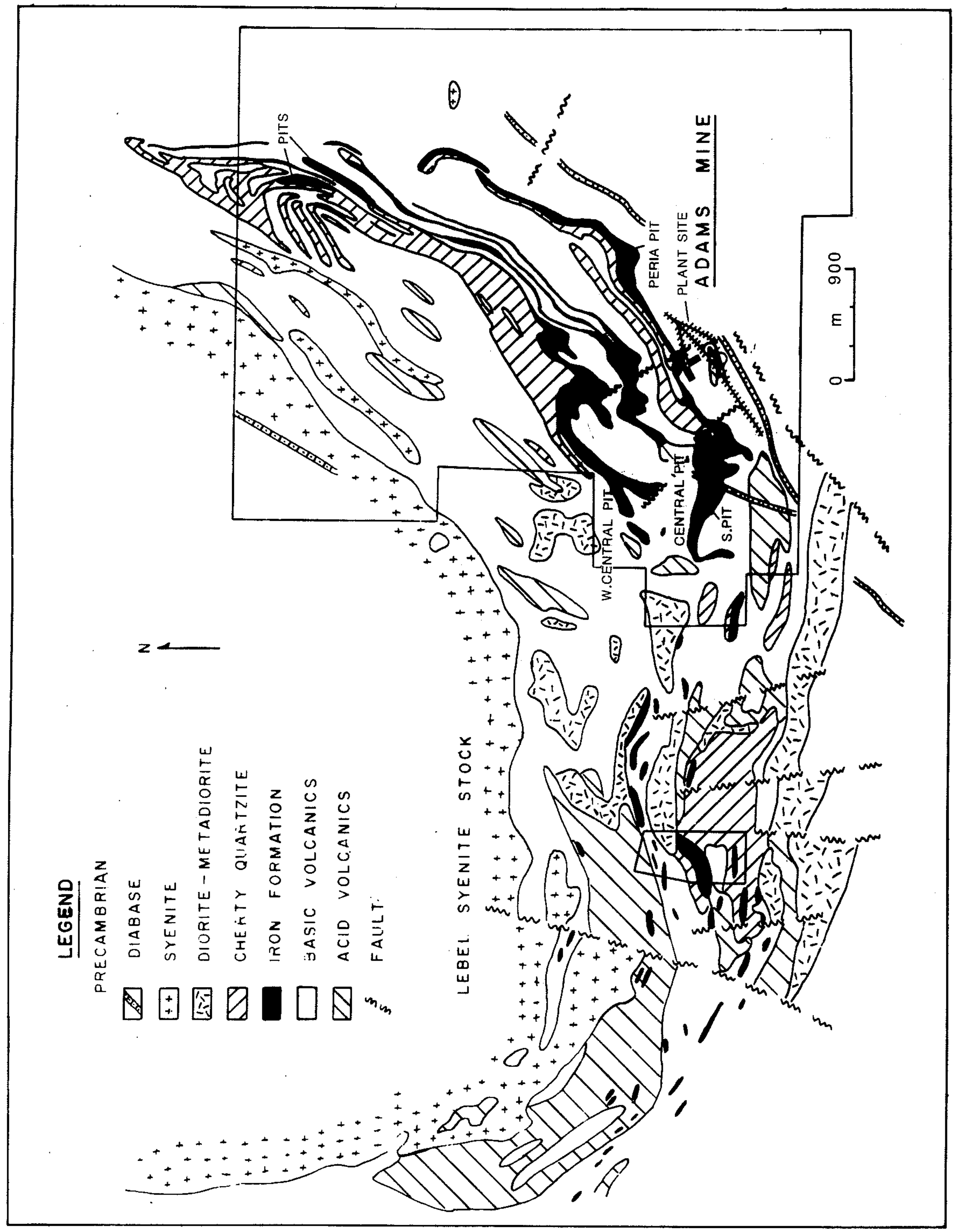


Figure 2-2. Geology of the Boston Township iron range, from Adams Mine.

Table I - Geological History -- Boston Township Iron Range
(after Dubuc, 1966)

Precambrian
Diabase
Syenite Intrusion -- Lebel syenite stock
a] Syenite and lamprophyre dykes -- probably introduced during several successive episodes of intrusion
b] Diorite and metadiorite
---------------------- Intrusive Contact ----------------------
*** [Cherty Quartzite [Iron-Formation [Lean Iron-Formation [Mafic Lava Flows - andesite, basalt, pillow lava and/or [tuff; minor felsic volcanics *
This stratigraphic succession is repeated several times; all members were not developed consistently in each cycle.

Stratigraphy --
Iron-Formation

Most of the iron-formation is thin banded oxide facies consisting of alternating layers of chert and magnetite that contain up to 26 % iron (mostly in magnetite) in stratigraphic units up to 100 m thick. The laminated chert beds are light to dark grey, black or reddish-grey and range in thickness from one mm to 5 cm. The quartz grains form equigranular to sugary textures and are generally less than 0.5 mm in diameter. Dark grey-black to -blue magnetite beds interlayered with the chert range in thickness from 2 cm to less than a millimetre, and average about one cm, and the grain size rarely exceeds 0.5 mm.

Minor amounts of hematite form separate laminae and thin irregular lenses within the magnetite beds. It is present consistently within the reddish to maroon coloured chert beds. Reddish garnet is commonly associated with the better grade iron-formation in isolated masses of euhedral grains. Epidote is associated with the garnet in some parts of the iron-formation. Needle-like crystals of tremolite and actinolite are disseminated within or adjacent to magnetite layers. Bluish amphibole instead of tremolite and actinolite is found in many parts of the iron-formation. Chlorite is abundant with or without disseminated magnetite in some thin beds. Small amounts of pyrite and pyrrhotite in thin layers or disseminated cubes are associated with the chloritic-magnetite beds throughout the iron-formation

The iron-formation is extensively recrystallized and metamorphosed, but many primary features are discernible which indicate the nature of the protofacies of this hydrolithic sediment. Differential compaction, contraction and syneresis cracks developed during dehydration of the banded and laminated siliceous ferruginous mud or ooze. Relict primary sedimentary features including bedding, microbanding and thin laminations mark numerous slump, glide and crenulation structures formed during penecontemporaneous deformation. Intraformational breccia beds are not prominent in the Boston Township iron-formation. Their paucity is compatible with deposition in a deep-water relatively quiescent tectonic environment. Dubuc (1966) noted that considerable dislocation of the beds took place during the period of sedimentation. Much contortion and some brecciation confined to single beds occurs locally and the beds and layers immediately above and below the deformed zones are relatively undisturbed. This type of deformation of the bedding is attributed to slumping and distortion that took place before induration of the proto sediment and developed before the regional tectonic folding. Apparently the soft iron-formation proto sediment was disturbed by volcanic and tectonic activity.

The general sequence of deposition within the three main stratigraphic members of the iron-formation are: first, lean oxide facies, followed by the main magnetite-chert facies iron-formation, and finally the thin banded cherty quartz facies. At least three major iron-formation units are recognized in the eastern part of the range that merge with one another along strike in a few places.

The intercalated volcanic flow rocks appear to have invaded only part of the depositional basin at any one time. Only relatively small detached lenses of iron-formation are present in the western part of the range and volcanic flows apparently covered the whole basin. The three members of iron-formation are not developed consistently throughout the area. There are indications of considerable variation in the deposition and source of material, even in this relatively small basin which, according to existing maps and data, may have been 10 km in length.

Lean iron-formation containing from 12 to 18 % magnetically recoverable iron is most abundant along the south side of the iron range. Stratigraphic units of lean iron-formation are usually 5 to 10 m thick but some are 30 m thick. The lean iron-formation near the contacts with volcanic rocks contains banded chert and pyrrhotite facies units up to 3 m thick. Chalcopyrite occurs in thin lenses, fractures, and irregular masses in the chert-sulphide facies, and more rarely as thin lenses and local isolated masses, up to 5 mm thick, in lean oxide facies of the iron-formation.

The chert-quartz member in the upper part of the iron-formation sequence which is also referred to as " cherty quartzite " is composed mainly of banded silica with less than 5 % magnetite. The cherty bands and laminations are similar to those in the iron-formation. This highly siliceous facies does not contain 15 % iron, as specified in definitions of iron-formation, but it is typical of many stratafer facies developed in or associated with iron-formations. Bedding in the chert-quartz facies is not as well developed as in the iron-formation facies, and bedding is less well developed where the silica content is highest. Most of the chert-quartz facies units are 5 to 10 m thick, but in the northwest part of the iron range, a unit of this facies is exposed over a width of 300 m and extends along strike for about 2 km.

Most of the magnetite in the chert-quartz facies is disseminated in the cherty layers and associated with silicate minerals, commonly buff-coloured grunerite-cummingtonite amphibole. Graphite is finely disseminated in and imparts a black colour to local chert beds. Pyrite and pyrrhotite are commonly present in beds up to 12 cm thick, and in nodules with concentric layering. Chalcopyrite occurs in the chert-quartz facies in fractures, in thin beds, and within pyrite nodules, or as complete nodules and irregular masses. In some places it is associated with pyrite and occasionally with pyrrhotite.

Volcanic Rocks

The mafic to intermediate volcanic rocks in the Boston Township iron range are fine- to coarse-grained massive flows. The extrusive or intrusive origin of many of the coarser grained volcanic units may be difficult to determine. Stratigraphic tops in the succession of flow rocks have been determined from well preserved pillow structures.

Tuff beds are most abundant in the eastern and western parts of the iron range. The tuffaceous rocks are fine grained, well bedded, and appear to be conformable with the iron-formation. Light green sedimentary beds, 3 to 5 m thick, and probably of tuffaceous origin, are commonly developed along the contacts between iron-formation and lava flows.

Dyke Rocks

Three types of dyke rock occur in the iron range: syenite, lamprophyre, and diabase. The syenite is pink, medium grained and composed mainly of feldspar and small amounts of fine-grained disseminated pyrite. The lamprophyre dykes are greyish green and are characterized by biotite phenocrysts in a fine-grained matrix. Some of the larger lamprophyre dykes, up to 4 m thick, contain granite or syenite inclusions, with rounded to regular outlines, as large as 30 cm in diameter. The smaller isolated chloritized zones in the dykes probably are altered volcanic inclusions.

The composition of the dykes appears to grade from that of syenite to lamprophyre. In some places separate intrusions of the two types occur side by side filling one fracture. Apparently one parent magma was differentiated to give rise to predominantly felsic or mafic intrusions, and to some intrusions of intermediate composition.

Detailed study of the South and Central ore zones after stripping of glacial overburden revealed a major northeast trend of the dykes, especially the lamprophyre dykes that are about one metre thick. Other lamprophyre dykes up to 3 or 4 m thick occupy well-defined east-trending fracture patterns. A few lamprophyre dykes trend northwesterly. At least two different ages of lamprophyre have been established; the east-trending intrusions are cut by the northeast-trending dykes. The attitudes of these dykes are difficult to determine, and although dips as low as 20 degrees have been observed, they generally appear to be much steeper. The syenite dykes trend mainly north or northwest.

The youngest dykes in the area are diabase. A steeply dipping diabase dyke, about 30 m wide, intruded the middle part of the South ore zone. A northern and narrower extension of this dyke intruded the West-Central ore zone. Most of the diabase characteristically has coarse ophitic texture in the central parts of the intrusions and is finer grained at the chilled margins.

Structure of the Boston Township Iron Range.

The main structures in the iron range were outlined by Dubuc (1966). A synclinal fold about one kilometre in width is well defined at the northeast end of the iron range, figure 2-2. The axis of this fold strikes about 035^0 and plunges steeply southwest, probably about 60^0. About 1.6 km farther south, in the Peria ore zone, a similar attitude has been recognized in a large fold (referred to as a drag fold) that has an amplitude of more than 60 m.

Strata in the northeast and eastern parts of the range dip south to southeast, from 50^o to nearly vertical. As the main synclinal structure at the northeast end of the range is approached, the dip of the beds changes from vertical to northwest. Top determinations from pillow structures indicate that at least two main stratigraphic units of iron-formation in the eastern part of the range face north to northwest. It appears that the sequence of beds forming the iron range was not developed by close folding, but that the range represents an overturned limb of a major synclinal structure. Apparently most of the northwest limb of the syncline was truncated by the Lebel syenite stock.

Several of the faults that were mapped cross the full width of the iron range. The more important of these appear to be intensely fractured zones that are radial to the Lebel stock and apparently very little displacement has taken place where these faults cut the iron-formation.

Structurally the orebodies are complex, contacts are irregular and some reverse their position without the influence of faulting. An exception is the fault plane in the South ore zone that was intruded by a diabase dyke. Although no lateral displacement is indicated the iron-formation changes in attitude from vertical west of the dyke to 50^0 southerly immediately east of the diabase, suggesting that strong rotational movement took place along the fault plane.

At least four of the ore zones show exceptional local widening. Minor folds (drag folds) related to the regional folding may have contributed to this, but it is believed that considerable dislocation of the iron-formation beds took place during the period of sedimentation, and before their dehydration and consolidation.

Iron Ore Zones in Adams Mine

Eight zones of iron ore mineable by open pit methods were outlined in the Adams Mine property, seven in the eastern part of the iron range, figure 2-2, and one in the western part. Most of the iron-formation units are 30 to 50 m thick, which probably corresponds closely to the thickness of the primary siliceous ferruginous sediment. Ore zones have been delineated where the iron-formation has been thickened by tectonic folding, slump folding, brecciation, and deformation of the unconsolidated sediment, and the ore zones range in thicknesses from 60 to 180 m. The largest ore zone, mined in the South Pit, was about 1000 m long and up to 200 m wide, and the smallest in the western part of the range, was 600 m long and about 60 m wide. The average grade of the 100 million long tons of crude ore in the eight ore zones was estimated to be 22 % of magnetically recoverable iron, or the equivalent of 30 million long tons of iron ore concentrate.

The iron-formation in some ore zones contains up to 26 % magnetically recoverable iron over widths of 100 m on sections of the mine. In other places, especially along the southeastern part of the iron range, lean iron-formation grades from 12 to 18 % magnetically recoverable iron, and occurs in facies units generally 6 to 10 m thick, and up to a maximum of 30 m thick. The ore zones also contain numerous dykes of syenite and lamprophyre, and drill records indicate as much as 10 % dyke material in the South ore zone.

Dubuc (1966) noted that in order to produce iron ore concentrate containing 66 % iron at least 95 % of the crude ore had to be ground to -325 mesh size. The only exceptions were the more refractory parts of the lean iron-formation where the magnetite is finer grained and the chert beds generally contain fine disseminations of magnetite. In contrast, the bulk of the iron-formation is made up essentially of nearly pure magnetite layers interbedded with relatively pure chert beds. The lean iron-formation was utilized by blending and mixing it with the iron-formation of better grade.

Complex magnetic anomalies were measured over the wider parts of the ore zones where the iron-formation is intensely folded. The highest positive magnetic anomaly, 148,000 gammas above base level, was recorded in the South pit, and the strongest negative anomaly was 60,000 gammas below the same base level. The magnetic field over narrow straight-bedded iron-formation appears to be simple in pattern and shows a uniform rise. The magnetic relief over the iron-formation generally does not exceed 40,000 gammas (Fig. 2-3).

Copper and zinc minerals in microbands and lenses form facies of the iron-formation. Zinc and lead occur in local narrow carbonate veins as concentrations or pods of massive crystalline sphalerite and galena. A vein in the volcanic rocks of the southern hanging wall of the South pit, associated with a syenite dyke, is up to a metre thick and has been traced over a distance of 50 m.

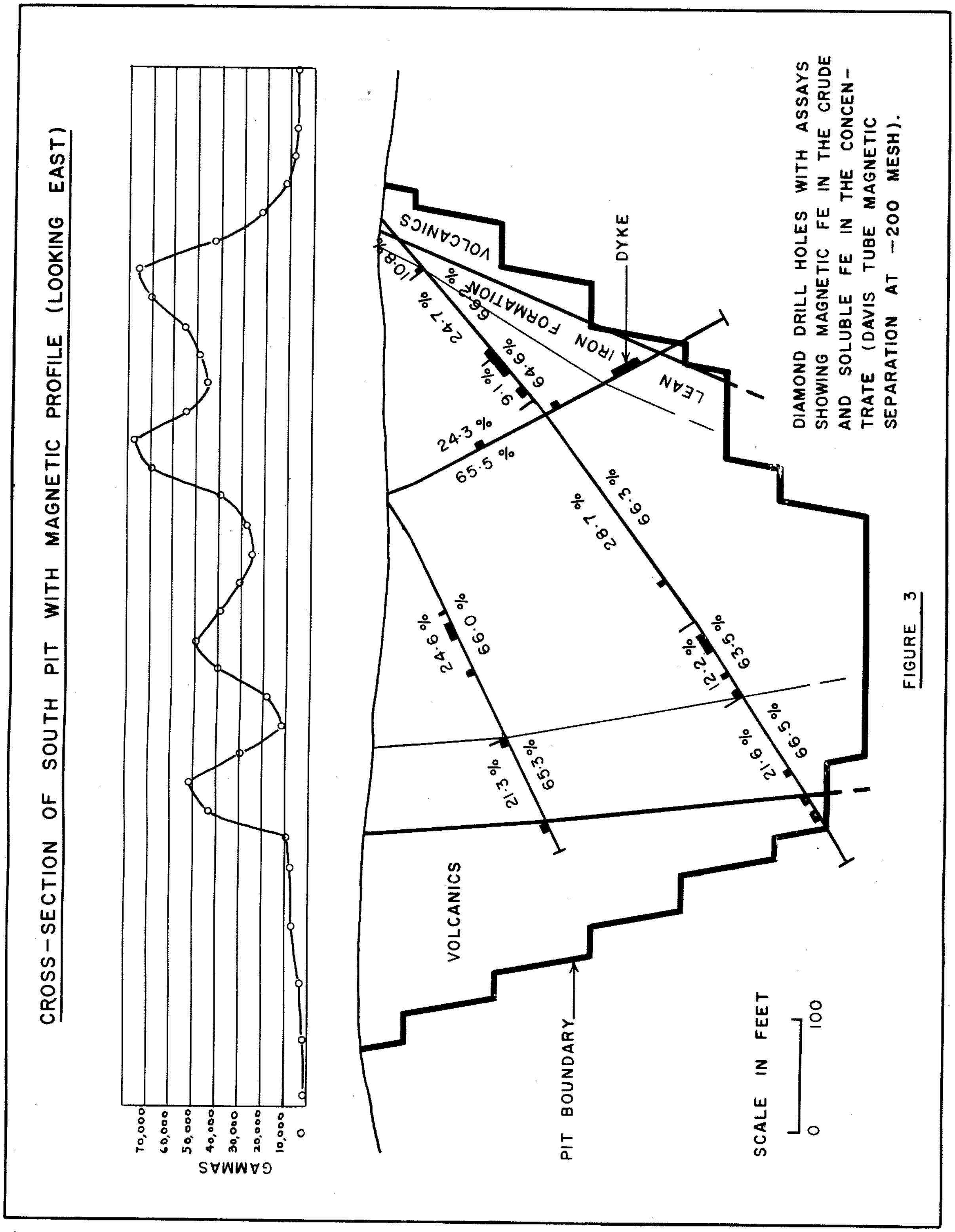


Figure 2-3. Cross-section of South Pit, Adams Mine, with magnetic profile (looking east), from Dubuc (1966)

Part 3

IRON-FORMATION AND SULPHIDE STRATAFER SEDIMENTS IN THE TIMMINS AND KIDD CREEK AREA

G.A.GROSS, D. BRISBIN, V. KELLEY, R. COOK, AND PAUL ROOS

Introduction
by - G.A. Gross

The Kidd Creek Mine is located 25.8 km north of Timmins in Kidd Township, Ontario, in a stratiform, massive, base metal sulphide deposit associated with felsic volcanic rocks. The discovery of a stratiform orebody of this size and grade obviously had a major impact on the national and international mining scene and has greatly influenced exploration strategy and methods.

Discovery of the Kidd Creek ore body has been attributed to the foresight, dedication, tenacity and hard work of the exploration team and not to some fantastic stroke of luck. Years of patient reconnaissance with the latest exploration equipment and technology, and advanced geological concepts were vital factors in the finding of this stratiform deposit. The area, situated only 25 km from the Timmins gold mining center where 17 major mines had operated for more than 50 years, had been thoroughly prospected by conventional methods. One prospector's cabin was located about 100 meters from the south end of the ore body on a rock exposure now occupied by a crushing plant. An electromagnetic survey flown from a helicopter and guided by valid geological concepts proved effective in detecting the ore deposit that was completely covered by layers of muskeg and clay. Some of the highlights in the history of exploration and development of the Kidd Creek mine of special interest here were summarized by Clarke of Ecstall Mining Limited (Clarke, 1974).

1958 Geological mapping of the Kidd Creek mine area.

1959 A three-year aerial exploration program was started that included nearly 25,000 km of flying and the recording of several thousand anomalies.

March 3, 1959 The Kidd electromagnetic anomaly was recorded.

Early 1963 The option was obtained to purchase the first of the four half lots overlying the orebody.

October 1963 Field crews carried out ground geophysical surveys of this land to locate a drill site.

November 1963 Core from the one hole drilled contained copper-zinc mineralization.

March 1964 All four tracts of land overlying the orebody were contracted and drilling started.

April 1964 Discovery of the deposit was announced, with eight drill holes confirming its existence, the drilling program was accelerated, metallurgical testing on the ore was started.

December 1964 Started to remove clay overburden at the open pit mine.

June 1965 Construction was started on the road from Timmins to the mine site.

July 1965 Construction of the mill was started.

October 1965 The pilot plant program for processing the ore was started at the Kam Kotia mill at the rate of 10,000 tons per month, for a year. The surface drilling program was terminated.

November 1966 Construction of the railroad was completed, and the first copper-zinc mill circuit was started.

March 1967 The mill operation reached full tonnage capacity, and 3 million tons of ore of good metallurgical quality was processed in 1967.

June 1968 Development was started on the tin recovery plant.

June 1969 Construction of the first shaft was started

March 1972 The shaft was completed to a depth of 3,050 ft. or 930 m.

December 1973 Operation of the tin recovery plant was started.

March 1975 A decision was made

to develop a second shaft to a depth of 1615 m, to enable mine production to increase to 5 million tons annually.
March 1966 to December 31, 1974, 28.6 million tons of ore was produced that assayed 1.56 % copper, 0.38 % lead, 9.66 % zinc and 4.3 oz. silver per ton.

Production from the mine in 1974 included 231,700 tons of copper concentrate containing 25 % copper; 9,500 tons of copper-silver concentrate; 36,200 tons of lead concentrate; 580,400 tons of zinc concentrate containing 52 % zinc; 107,900 tons of zinc metal; 188,300 tons of sulphuric acid; 782,200 pounds of cadium metal; 486,200 pounds of tin in concentrate; and 10,553,000 ounces of silver in concentrate (The Northern Miner, April 10, 1975, p.24).

Regional Geology

The Kidd Creek deposit is located near the western end of the Abitibi greenstone belt which is well known for its many gold and base metal sulphide deposits. The Abitibi belt is the largest early Precambrian greenstone belt in the Canadian shield and has been described in some detail by Goodwin and Ridler (1970). In the Porcupine mining area the older Archean rocks, previously referred to as Keewatin, consist of basic to intermediate volcanics with felsic volcanics developed locally. Greywacke sediments derived mainly from volcanic rocks are associated with and overlie the older mafic volcanic sequences. Younger Archean sediments, sometimes referred to as Timiskaming, are composed mainly of coarse clastics, and overlie the older volcanic sedimentary sequences unconformably (Matulich, Amos, Walker, and Watkins, 1974).

Bright (1972) outlined the regional geological setting as follows: " The "strata-bound" copper-zinc deposits in the Timmins Area (Texas Gulf, Kam-Kotia, Jameland, Canadian Jamieson and Genex) all lie within silicified, sericitized and in places chloritized zones of intercalated andesitic and subordinate rhyolitic tuffaceous-flow sequences. The close spatial relationship of these sequences within and adjacent to major accumulations of coarse-to-fine grained rhyolitic fragmental rocks and their equivalent epizonal intrusions lends strong support to the concept of a volcanic origin and of ore concentration near volcanic centers. The Kidd Creek orebody of Ecstall Mining Limited, the largest zinc-silver-cadmium producer in the world, contains an estimated reserve of more than 90 million tons grading 7.08% zinc, 1.33% copper, and 4.8 ounces silver per ton. This orebody occurs along the southern flank of the Carnegie-Prosser anticlinorium, a complexely folded domical structure containing at least two major vent areas, one in Prosser Township, the other in Reid Township. The pyroclastic-flow sequence in the area of the Kidd Creek mine probably was derived from a volcanic center to the northeast in Prosser Township, an area of coarse rhyolitic fragmentals intruded by an epizonal quartz-feldspar porphyry stock. The copper and zinc mineralization, however may have been related to a subsidiary system of fissure feeders along the flanks of the volcanic pile. South of the mine site the felsic pyroclastic-mafic flow sequence starts to merge laterally with a thick sequence of predominantly fine-grained tuffs and sedimentary rocks, a facies change that would be expected to occur at a considerable distance from the main vent. Although the pyroclastic-flow sequence near this facies boundary change contains pyrite-bearing graphitic tuff units, it also is characterized by an abundance of disseminated pyrite-pyrrhotite zones. The coarse fragmental rocks and associated flows near the main vent area often contain only disseminated pyrite, while numerous pyrite-bearing graphitic tuffs with little or no pyrrhotite characterize the fine-grained tuffs and sedimentary rocks much farther away. The Kidd Creek orebody, unlike those in the Kamiskotia area, contains little or no pyrrhotite; the nearby country rocks however, do contain zones of disseminated pyrite-pyrrhotite.

The smaller en echelon ore lenses in the Kamiskotia area mines west of Timmins occur within a mafic-felsic pyroclastic sequence along flanks of the Kamiskotia anticlinorium, a domical structure interpreted as surrounding a volcanic centre located approximately in the north part of Turnbull Township. "

The Kidd Creek deposit is an outstanding example of a volcanogenic stratiform to massive sulphide deposit. Most of the banded and layered ore if not all of the stringer ore, can also be properly classified as a polymetallic sulphide facies of iron-formation. Matulich et al. (1974) stated that "The Kidd creek ores are thought to represent syngenetic-sedimentary and near-surface, epigenetic mineralization which occurred in approximate contemporaneity with rhylitic volcanism in a submarine environment. This mode of genesis is evidenced by features and ore-wall rock relationships, as well as by analogy to other, similar deposits, many of which have been more exhaustively studied and which have undergone little post-ore modification (Gilmour, 1965; Hutchinson, 1965; Matsukuma and Horikoshi, 1970; Sangster, 1972; Mannard, 1973; Simmons, 1973). "

Kidd Creek Mine
by - D. Brisbin, V. Kelly, and R. Cook, Kidd Creek Division, Falconbridge Limited.

The deposit was discovered in 1963 using diamond drilling, based on an integrated regional geological and geophysical program. Ore was mined by open pit (Fig. 3-1) from 1965 to 1979 and is now mined from underground via the # 1 and #2 shafts, each 930 and 1560 metres deep respectively. Ore between the 4600 and 5300 levels will be mined by access provided by an internal ramp (Fig. 3-1). The #3 shaft, an winze, is currently under development to mine ore in the lower levels of the mine. This winze will begin at a depth of 1435 metres below surface, and will extend to a proposed depth of 2110 metres (Fig. 3-1).

From the commencement of mining in 1966 to the end of 1988, approximately 81 million tonnes of ore have been milled, with an average millhead grade of 106 g/tonne Ag, 2.06 percent Cu, 7.18 percent Zn, and 0.028 percent Pb. Cadmium is recovered as a by-product, and construction of a plant which will recover indium is underway. Tin has also been extracted. As of December 31, 1988, proven and probable reserves above the 5600 foot level, diluted at ten percent nil grade, are 48.9 million tonnes with an average grade of 63 g/tonne Ag, 3.45 percent Cu, 5.08 percent Zn, and 0.15 percent Pb.

<u>Regional Geological Setting</u>

The Kidd Creek deposit is one of the largest volcanogenic massive sulphide deposits in the world. It is located in the west end of the Abitibi greenstone belt, 27 kilometres north of Timmins, Ontario.

The deposit occurs within an east-west striking, steeply dipping, assemblage of intercalated Archean ultramafic, mafic, and felsic metavolcanic and intrusive rocks, interlayered with minor accumulations of metasedimentary rocks. These rocks are assigned to the Kidd-Munro assemblage. The orebody is located in an area, characterized by anomalous, north-striking lithological contacts, at the top of a felsic metavolcanic unit which averages less than 100 metres in thickness away from the deposit, but which attains a thickness of 300 metres in the immediate mine setting (Fig. 3-2). Stratigraphic units in the immediate mine area face to the west, and are overturned with dips of 70° to 80° to the east (Fig. 3-3). Both the orebody and the surrounding country rocks attained greenschist facies metamorphism, associated with the development of a penetrative cleavage and linear fabrics. Brittle and ductile faults disrupt the continuity of lithological units and mineralization in plan and section at both regional and mine scales (Fig. 3-4). Outcrop is sparse in the Kidd Creek area due to extensive Quaternary glacio-fluvial sediments and Recent swamp and stream deposits.

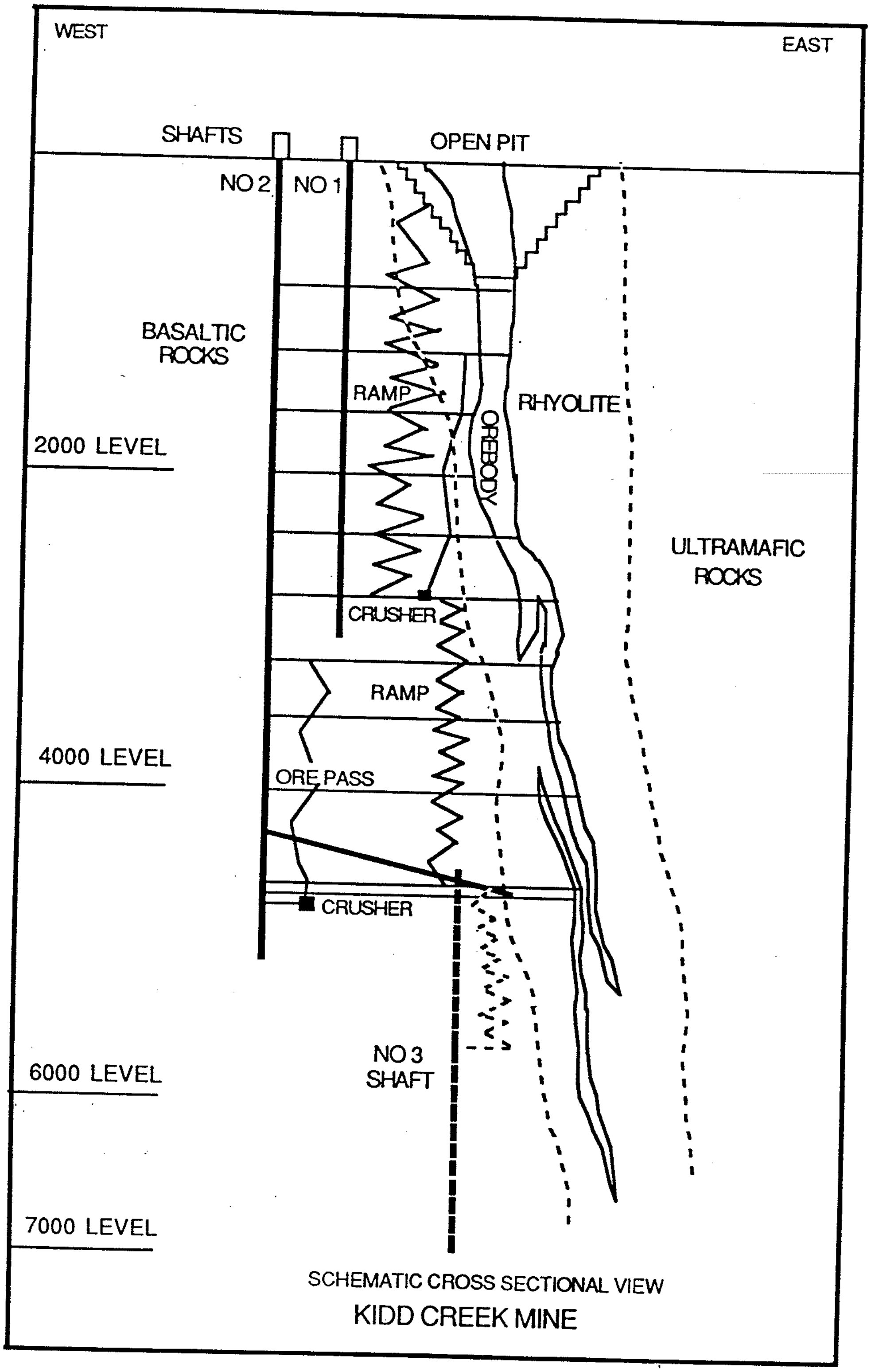


Figure 3-1. Schematic, east-west cross section, looking north, through the Kidd Mine, illustrating the simplified distribution of rock types, the massive sulphide orebody, and the location of the open pit and shafts.

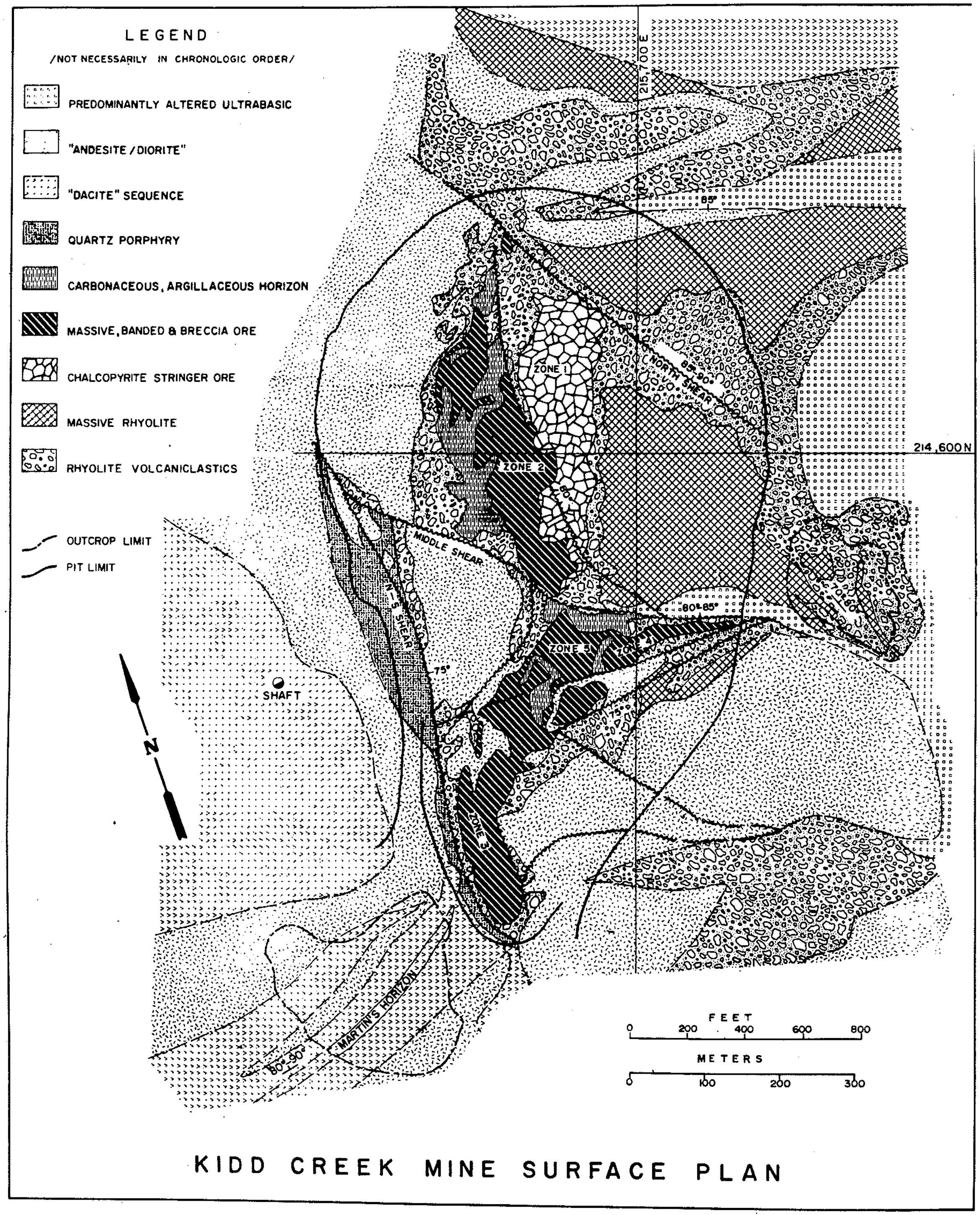


Figure 3-2. Simplified surface geology plan of the Kidd Creek Mine (after Walker and Mannard 1974).

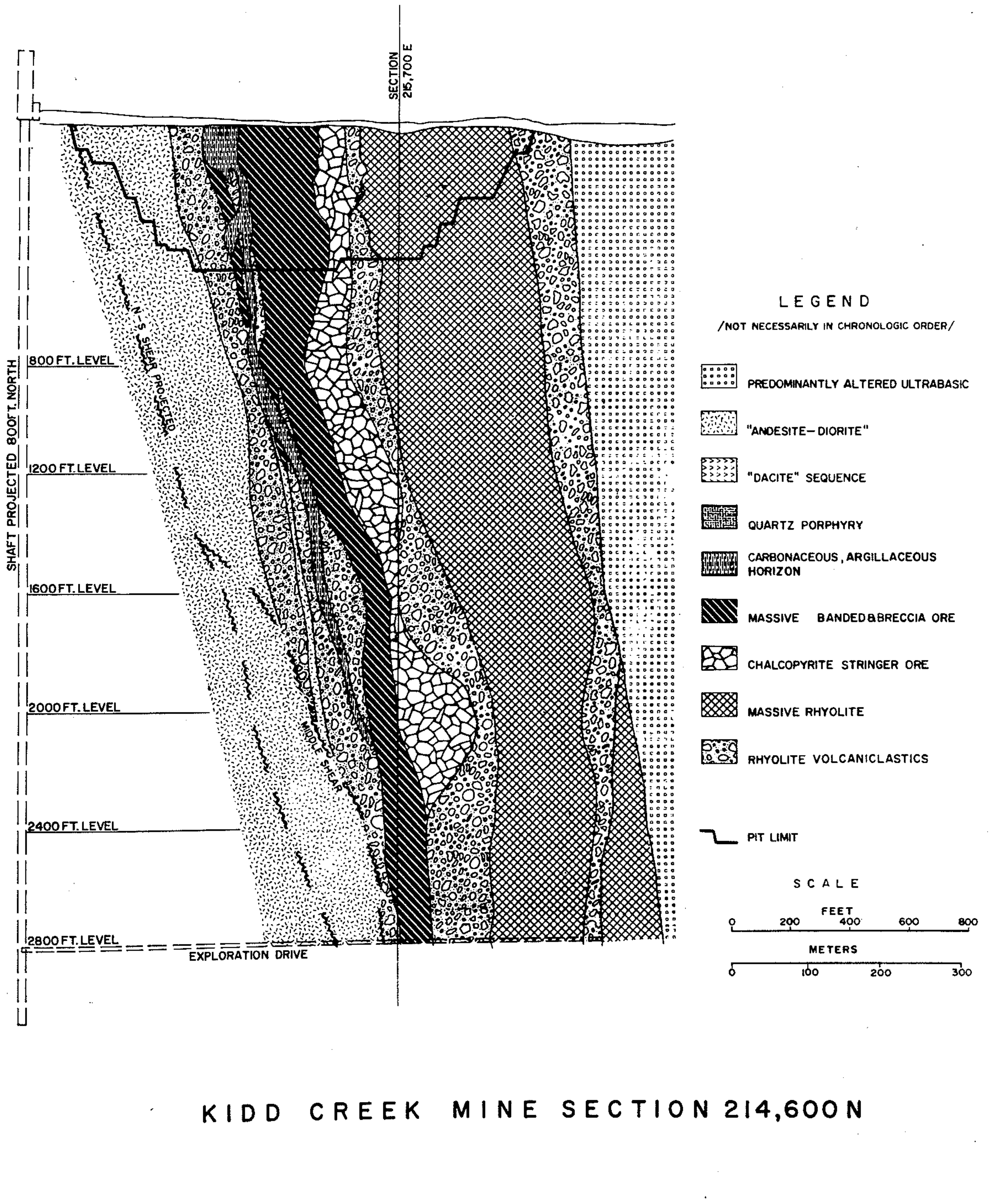


Figure 3-3. Simplified east-west cross-section, looking north, through the Kidd Creek Mine (Walker and Mannard 1974).

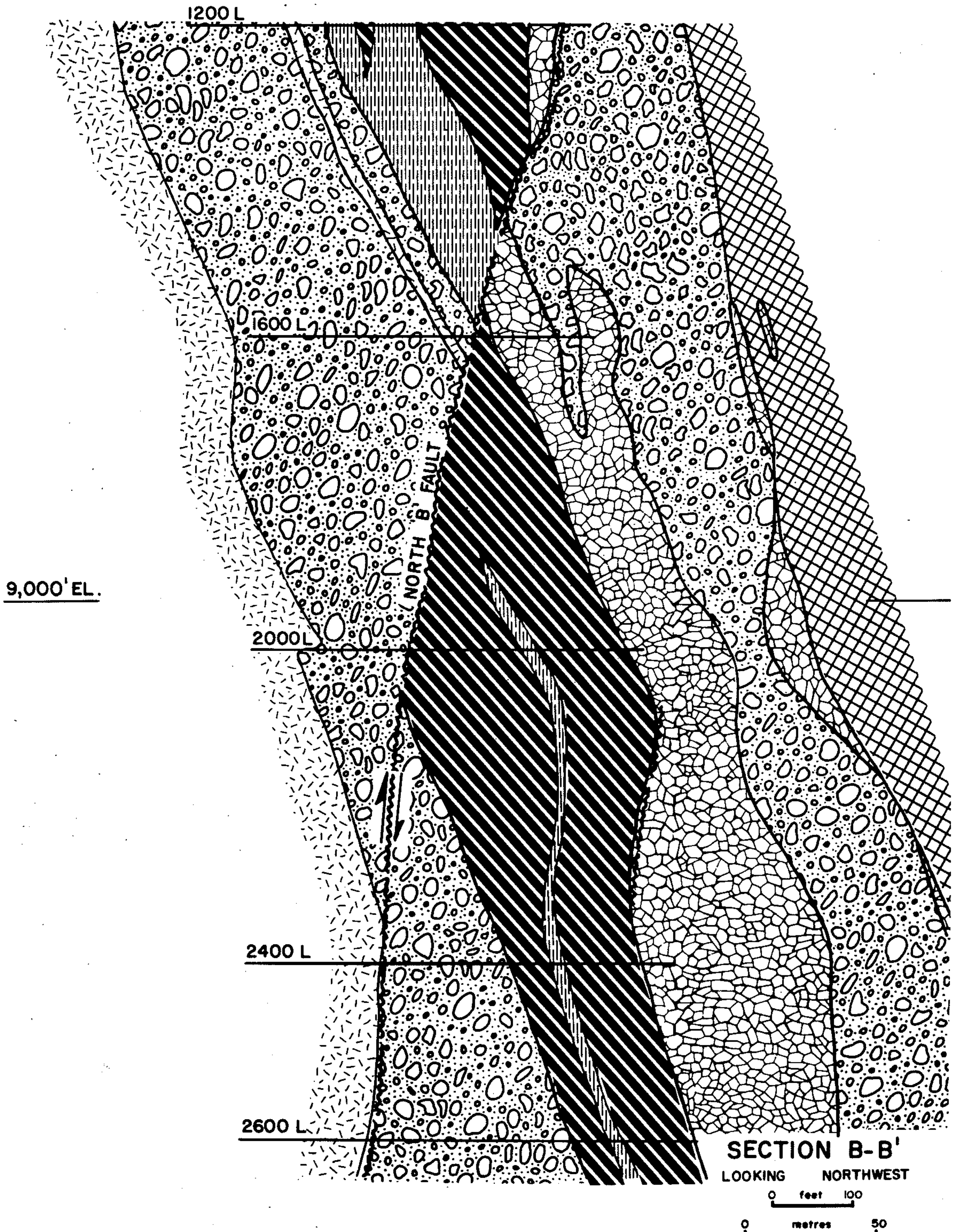


Figure 3-4. Simplified section throught the Kidd Creek Mine, illustrating the effects of late faulting.

Mine Geology

Our understanding of the geology of the Kidd Creek deposit (Fig. 3-2 and 3-3) is the result of work by the staff of the Geology Department at Kidd Creek Mine over the past 25 years. Published descriptions of the geology of the Kidd Creek deposit include those of Walker and Mannard (1974) and Walker et al. (1975). The geology and geochemistry of the footwall rhyolites was described by Coad (1985). The oxygen isotopic characteristics of "fresh" and altered rocks in the Kidd Creek area are described by Beaty et al. (1988). The geochemistry of hydrothermal tourmaline and chlorite in the Kidd Creek Mine stratigraphy are described by Slack and Coad (1989).

The Kidd Creek orebodies are located near the stratigraphic top of a locally thickened, felsic metavolcanic unit. The portion of the felsic metavolcanic unit which stratigraphically underlies the orebodies consists of several distinct rock types, known informally, in mine nomenclature, as the "rhyolite volcaniclastics", "cherty breccia", and "massive rhyolite". A fourth lithology, known in mine nomenclature as "mixed rhyolite fragmentals", occurs at a position which is stratigraphically equivalent to the massive sulphide mineralization. These rhyolites and the massive sulphide mineralization are intruded by gabbro sills, called andesite-diorite in mine terminology, and bodies of serpentinized ultramafic rock. To the west, the stratigraphic hanging wall rocks consist of a carbonaceous metasedimentary unit, a quartz-porphyritic felsic unit, and pillowed mafic metavolcanic flows.

"Rhyolite volcaniclastics"

The "rhyolite volcaniclastics" consist of lapilli and block sized rhyolite fragments in a tuffaceous, rhyolite matrix. Degree of fragment sorting and rounding is highly variable, as is the relative abundance of tuff, lapilli, and blocks. Rhyolite fragments range in colour from yellow, grey, or black, reflecting varying degrees of sericitic, siliceous, and chloritic alteration, respectively. When viewed on fresh surfaces, in core or in underground exposures, these fragments appear massive. Fragments in weathered metavolcaniclastic rhyolites, exposed on surface, on the east side of the open pit, exhibit a range of textures. These rocks may represent, in part, the autobrecciated margins of the flow-dome sequence and, in part, pyroclastic deposits that surround the flow-dome sequence.

"Mixed rhyolite fragmentals"

Volcaniclastic rocks locally include fragments of pyrite, sphalerite, banded pyrite-sphalerite, and less common chalcopyrite, mafic flows ("dacite"), and carbonaceous argillite. These polymictic, metavolcaniclastic rocks are known as "mixed rhyolite fragmentals" in the mine terminology. Volcaniclastic rhyolites which contain sulphide clasts, are restricted to portions of the rhyolite assemblage which are stratigraphically equivalent to, or lie above, the massive sulphide orebodies. These rocks possibly represent debris flows (Walker et al. 1975).

"Massive rhyolite"

"Massive rhyolite" occurs as sills and dikes in the lower portion of the rhyolite assemblage east and northeast of and stratigraphically below, the North Orebody stringer zone. "Massive rhyolite" is extremely siliceous and includes massive to flow banded subvolcanic intrusions, and intensely silicified metavolcaniclastic rhyolites, in which the primary metavolcaniclastic textures are no longer recognizable. Dykes of "massive rhyolite", cutting metavolcaniclastic rhyolite, are well exposed on the outcrop on the east side of the open pit. Bodies of "massive rhyolite" typically have dark grey to black, chloritic interiors and buff to yellowish-green, sericitic margins. Margins of "massive rhyolites" are commonly flow banded and brecciated. A light red colour, present locally, is attributed to the presence of disseminated sphalerite ("sphalerite dusting"). Conspicuous, white, subhedral albite and glassy, anhedral, quartz phenocrysts occur throughout the "massive rhyolites". This massive unit may represent the core of a flow-dome sequence.

"Cherty breccia"

"Cherty breccia" is the mine term for a light to medium grey, siliceous, aphanitic, intensely crackle-brecciated rhyolite. This unit occurs stratigraphically below the massive sulphide orebodies and it is commonly mineralized with stringers of chalcopyrite, pyrite, pyrrhotite, and sphalerite. The sulphide stringers, along with chlorite and iron-rich carbonate, fill fractures in the rhyolite. "Stringer ore" occurs where chalcopyrite stringers are abundant enough, over a large enough area in the "cherty breccia", to be mined as ore. The "cherty breccia" has been variably sericitized and chloritized. Fracture-controlled alteration has resulted in the presence of "speckle-textured cherty breccia". Flow-banding is locally present. This unit may represent the altered equivalent of the flow-dome sequence, although sharp intrusive contacts between massive rhyolite and "cherty-breccia" also exist.

"Carbonaceous horizon"

The "Carbonaceous horizon" is a lithologically variable metasedimentary unit which has a black, carbonaceous matrix. It occurs at or near the stratigraphic top of the North orebody massive sulphide lens, on the west side of Zone 2. Lithologies present in this unit include: 1) carbonaceous argillite; 2) finely laminated, carbonaceous argillite interbedded with pyrite and sphalerite; and 3) carbonaceous, polymictic, epiclastic breccias ("breccia ore").

"Andesite-diorite"

Three large masses of gabbro, termed "Andesite-Diorite" in the mine terminology, intrude the host rhyolites to the west, north, and southeast of the orebodies. "Andesite-Diorite-Type One" is massive, fine- to medium-grained, dark green to grey, and speckled with white to pink leucoxene grains up to two millimetres in size. A variety, known as "Andesite-Diorite-Type Two" is characterized by the presence of dark green, anhedral, femic phenocrysts up to one centimetre in size. These "Andesite-Diorite" bodies are roughly concordant to the rhyolites they intrude, and thus, appear as sills which have separated a once contiguous assemblage of rhyolite into a number of separate, lens-shaped, rhyolite units. Narrow dikes and sills of "Andesite-Diorite are also present within the orebodies and the host rhyolites. "Andesite-Diorite" masses located near the orebodies have been carbonatized to varying degrees (types three and four), indicating that, although post-ore, these gabbro intrusions were emplaced prior to cessation of hydrothermal activity.

"Quartz porphyry"

The westernmost, and stratigraphically youngest, rhyolite unit present in the mine workings is the called the "Quartz Porphyry". It is a sericitic to chloritic, massive to tuffaceous rhyolite with local lapilli tuff sections. The "Quartz Porphyry" is characterized by the conspicuous presence of one to twenty five percent combined, one to four millimeters quartz and plagioclase phenocrysts. This rock unit is typically schistose, particularly in the more sericite-rich portions.

"Dacite"

Mafic metavolcanic flows, termed "dacite" in the mine terminology, stratigraphically overlie the rhyolite unit to the west and north. The flows are light to medium green, aphanitic to fine-grained, and have been bleached, carbonatized and sericitized. Massive, pillowed, and pillow-breccia facies are present within the mafic flows. Pillows are generally less than one metre in diameter, sparsely amygdaloidal, and have selvages less than one centimetre thick. Hyaloclastite is commonly present along pillow selvages and in pillow interstices. Black, carbonaceous argillite units up to ten metres thick, with or without pyrite and pyrrhotite, are locally present along flow tops. Carbonaceous material and pyrrhotite also occur locally between pillows. Massive portions of the flows appear lithologically identical to the "Andesite-Diorite-Type One" described above. The name "dacite" is derived from the bleached, light green colour and hardness of the mafic flows, which immediately overlie the rhyolite, relative to darker green, softer, more chloritic mafic flows distant from the rhyolite.

Serpentinite

A large mass of variably carbonatized serpentinite is present, east of the mine, in the stratigraphic footwall to the mine rhyolite package. It is black to dark green, dominantly massive, but both spinifex and cumulate textures are also present locally. Talc and carbonate are present in fractures. It is uncertain whether this serpentinite mass is composed of a package of komatiitic flows, which underlie the mine rhyolites, or whether the serpentinite is entirely or partly an intrusive peridotite body. Units of felsic and mafic metavolcanic rock are present within the serpentinite, and may represent intercalated metavolcanic units, or large xenoliths.

Light grey, carbonatized varieties of the serpentinite are known as "Talc Carbonate Rock" in the mine mapping. A thin tongue of "Talc-Carbonate Rock" extends west from this serpentinite body into the east side of the open pit. A similar elongate body of "Talc-Carbonate Rock" occurs just north of the open pit. Both of these altered serpentinite bodies occupy prominent east-southeast-striking shear zones.

Geochemistry

Many massive, base-metal sulphide deposits in the Superior Province are spatially associated with subaqueous, felsic metavolcanic rocks (Sangster 1972); however, not all felsic metavolcanic packages are mineralized. Several geochemical studies have been undertaken to test the hypothesis that a specific type of felsic metavolcanic rock is preferentially mineralized (e.g., Thurston 1981; Lesher et al. 1984).

Felsic metavolcanic rocks in the Kidd Creek Mine area are characterized as rhyolites and high-silica rhyolites, having relatively flat REE patterns ($[La/Yb]_n = 1-4$), pronounced negative Eu anomalies ($Eu/Eu^* = 0.20-0.61$), low Zr/Y (2-6), high abundances of high field strength elements, and low abundances of Sc and Sr (Lesher et al. 1984).

Structure

The immediate mine area geology represents both a lithological and structural anomaly within the regional east- to northeast-striking metavolcanic-metasedimentary rock package. All lithologies in the mine, including the ore, have been subjected to complex folding and faulting. Overall strike of lithological contacts in the area of the open pit is north-northeast (Fig. 3-2). The orebodies and their host rocks dip 70° to 80° east and are overturned (Fig. 3-3).

The dominant cleavage present in the mine strikes southeast and dips 75° northeast. A second cleavage strikes east and dips 80° north. The intersection lineation of these two cleavage planes plunges 75° to 80° northeast, parallel to the plunge of the axis of greatest linear elongation of the orebodies. The intensity of cleavage is locally variable, and appears to be a function of both lithology and alteration intensity and type. Sericite-rich and talc-rich rocks in particular commonly exhibit moderately to strongly developed cleavage.

Brittle gouge-filled faults, and "shear zones" (zones of intense cleavage) are both present in the Kidd Creek Mine. Cleavage and brittle faults both deform mineralization, and thus, post-date ore. The "North-South Shear Zone" and the "Middle Shear" are the most prominent shear zones in the mine.

The "North-South Shear Zone" approximately follows the contact between the "Quartz Porphyry" and the "Wedge Andesite-Diorite" on the east side of the "Quartz Porphyry" (Fig. 3-2). It is a zone of strong cleavage, up to 18 metres wide, localized predominantly in sericitized "Quartz Porphyry". A parallel structure, known as the "North-South A Shear Zone", is localized along the eastern edge of the "Wedge Andesite-Diorite" where it is in contact with the "mixed rhyolite fragmentals" which overlie the orebody. Both these structures have a north strike and dip 75° east.

The "Middle Shear" is a zone of intense cleavage and faulting up to 30 metres wide that separates the "North" and "South" orebodies. It has a west to northwest strike and dips 80° to 85° north (Fig. 3-2).

South-dipping faults exhibit a reverse, left-hand sense of displacement. These faults strike east-southeast and dip 75° to 85° south. They are filled with gouge and/or quartz-calcite veins. Slickensides on the fault surface plunge 75° northwest. The south-dipping faults offset all rock types in the mine, including the orebodies (Fig. 3-4). They also crosscut and drag-fold the post-ore cleavage. Vertical offset is interpreted to be approximately 200 metres along each of these structures. The horizontal component of movement is minor.

The Gouge Fault strikes north-northwest, dips 55° to 65° northeast, and is localized in the "Andesite-Diorite" and rhyolite, situated west of the orebodies. The Gouge Fault has an apparent left-hand, normal sense of offset. It is filled with up to five centimetres of gouge and fault breccia. Subhorizontal joints, commonly filled with quartz-calcite veins, occur in the wall rock adjacent to this fault. The Gouge Fault commonly occurs as two or more closely spaced, anastomosing faults. This system of anastomosing faults, subhorizontal joints, and associated steeply dipping cleavage can create incompetent ground over widths of up to ten metres.

Mineralization

There are three major types of ore within the Kidd Creek deposit: 1) stringer ore; 2) massive, banded, and bedded sulphides; and 3) sulphide breccia ore.

Stringer Ore

Stringer ore is characterized by irregular chalcopyrite-filled stringers hosted in a pale to dark grey, crackle - brecciated rhyolite. Chalcopyrite content of the stringer ore varies from three to thirty percent, but averages five or ten percent. Individual stringers are generally less than two centimetres wide, but are locally up to one metre wide. Pyrite and/or pyrrhotite occur with the chalcopyrite or occur alone in uneconomic stringer sulphide zones. Pyrrhotite content of the stringer ore increases below the 2300 foot level (1000 metres vertical depth). Sphalerite usually comprises between 0.1 and 1.0 percent of the stringer sulphide ore, and can be present as stringers and disseminated as a reddish-brown staining of the rhyolite host rocks. It is most abundant on the margins of the stringer chalcopyrite mineralization, particularly in the stratigraphic footwall of the stringer chalcopyrite orebodies.

Massive, Banded, and Bedded Ores

Massive, banded, and bedded ores stratigraphically overlie the stringer ore. This ore type varies in composition and texture from homogeneous, almost monomineralic pyrite, sphalerite, or chalcopyrite, to banded mixtures of pyrite, sphalerite, pyrrhotite, chalcopyrite, and galena. Rhyolite host rocks and gangue minerals comprise up to 50 percent of this ore type. Layers of massive or banded sulphides are locally intercalated with layers of metavolcaniclastic rhyolite, or with carbonaceous argillite.

Sulphide-breccia Ore

Sulphide-breccia ore consists of fragments of pyrite and/or sphalerite within carbonaceous argillites and metavolcaniclastic rhyolites situated at the stratigraphic top of the orebodies. Variable proportions of poorly sorted fragments of rhyolite, sulphide, basalt, and carbonaceous argillite are present in these chaotic, epiclastic breccias. Sulphide fragments are as large as a few metres across. Proportions of sulphide fragments present are highly variable over short distances, and the abundance of sphalerite fragments determines whether or not this lithology is mined. Chalcopyrite fragments are generally absent. These ores are interpreted to have been transported and deposited as debris flows.

Finely interbedded pyrite, sphalerite, and carbonaceous argillite occur at the same stratigraphic level as the sulphide-breccia ores, both interbedded with the breccia ore and as lateral facies equivalents to it. Individual beds are generally less than one centimetre thick, but range up to five centimetres in thickness. Locally, primary sedimentary textures such as load casting, flame structures, scours, and graded bedding are preserved. The sulphide beds may be composed of only pyrite or sphalerite, or composed of homogeneous to graded mixtures of pyrite and sphalerite.

Characteristics of Ore Types

The main Kidd Creek deposit is divided into the North and South orebodies. A small sulphide lense, known as the Southwest orebody, is also present. The ores are further subdivided for the purposes of computer modelling and ore reserve estimation into five zones. Each zone is defined by a particular combination of spatial, structural, host-rock, and ore-type parameters. The orebodies at Kidd Creek possess patterns of metal zoning characteristic of volcanogenic massive sulphide deposits.

Mineral Distribution

Copper is most abundant in the stringer ores and the basal portion of the massive ores. Zinc is most abundant in the massive, bedded, and banded sulphides which stratigraphically overlie the copper-rich ores. Silver, lead, tin, and cadmium are relatively enriched in pyrite-sphalerite ores. Indium and selenium are relatively enriched in copper-rich ores, and enriched in the bornite zone, which is described below. Silver occurs dominantly in the native form, lead occurs as galena, and tin occurs predominantly as cassiterite.

North Orebody

The North orebody strikes north-northwest to north-northeast, is overturned and dips 80° east. It has been defined by development and diamond drilling from surface to a vertical depth of 1700 metres (5600 level). Current deep diamond drilling is aimed at defining the extension of this orebody below 5600 level. The North orebody is divided into two zones based on ore type. Zone One, which constitutes the eastern portion of the North orebody, is the largest, most continuous area of chalcopyrite ore in the mine.

Zone Two is composed of massive to semi-massive pyrite and sphalerite with well developed banded and fragmental textures. It is the most pyritic of the ore zones, averaging 55 percent pyrite. The highest contents of lead, silver, and tin in the mine occur in sphalerite ore on the southwest side of Zone Two. Sulphide breccia ore is mined from the west side of Zone Two. The contact between zones one and two is sharp. Lenses of massive chalcopyrite commonly occur along this contact.

South Orebody

The South orebody extends from surface to a vertical depth of 1040 metres, with its bottom just below the 3400 level. It is subdivided into zones three, four, and five. Zone Three strikes north-northeast, is overturned and dips 70° east. It consists mainly of massive sphalerite, pyrite, and chalcopyrite. Sulphide banding is locally present at the margins of this zone. Metal zoning is poorly developed.

Zones four and five consist of banded pyrite, sphalerite, and chalcopyrite interlayered with metavolcaniclastic rhyolites. Zone Four has a strike of east-southeast, and a dip of 80° north. Zone Five is overturned, and has a strike and dip similar to Zone Three.

Bornite Zone

A discontinuous area of high-grade copper mineralization, known as the Bornite Zone, occurs on the stratigraphic footwall of the South orebody, between 1200 and 2800 levels (365 to 850 metres vertical depth). This mineralization consists of semi-massive to massive bornite, chalcopyrite, tennantite, and pyrite hosted in a fragmental-textured rhyolite. The Bornite Zone is enriched in Ag, As, Bi, Co, In, and Se, the most important of which is silver. Silver tenor up to 4450 g/t (130 ounces per ton), over 1.5 metres, have been obtained with minor associated gold values.

Southwest Orebody

The Southwest orebody is a massive sulphide lense which was discovered in 1977. It is located southwest of the South orebody. The orebody, which has subsequently been mined, extended from 2600 level (785 metres vertical depth) to the 3200 level (975 metres vertical depth). It consisted of pyrite, sphalerite, galena, and silver, but was devoid of copper mineralization. Subeconomic mineralization has been defined up to the 2400 level (725 metres vertical depth), and down to the 3600 level (1080 metres vertical depth). The width of the massive sulphide lense varied from two to 20 metres. The Southwest orebody is interpreted as the distal equivalent to the more proximal South and North orebodies.

Rock Alteration

Synvolcanic alteration minerals have been subsequently metamorphosed, so the mineralogy of altered host rocks described below does not necessarily represent the original alteration mineral assemblages.

Rhyolites within the stringer zone are intensely crackle-brecciated, and alteration is strongly fracture-controlled. These rhyolites are depleted in Na_2O, K_2O, CaO, and Al_2O_3, but are enriched in FeO, MgO, and SiO_2 relative to stratigraphically equivalent rhyolite outside the stringer zone. This alteration chemistry is expressed mineralogically by the destruction of feldspar, and by varying degrees of silicification, chloritization, and sericitization. Sericitic rhyolite has higher Al_2O_3 and K_2O abundances with respect to chloritic rhyolites. Iron-rich carbonate minerals are present both in the stringer zone, and within the massive sulphides.

Both iron-rich and magnesium-rich chlorites occur at Kidd Creek (Slack and Coad 1989). Iron-rich chlorites occur within the stringer sulphide zone, whereas, more magnesium-rich chlorites occur generally outside the zone of stringer mineralization. The formation of iron-rich chlorites is attributed to high temperature, iron-rich hydrothermal fluids, whereas the formation of the magnesium-rich chlorites is attributed to the influx of cooler, magnesium-rich seawater (Slack and Coad 1989).

Temporal Constraints

The Kidd Creek rhyolite, footwall to the mineralization, has a U-Pb zircon crystallization age of 2717 +/- 2 Ma (refined age reported by Barrie and Davis 1990, using an abraded fraction from Nunes and Pyke 1980). This represents the age of the rhyolitic rocks which are host to the massive sulphide mineralization at the Kidd Creek Mine. A tuffaceous rhyolite from Prosser Township, located to the east of the Kidd Creek Mine, has an age of 2716 +/- 4 Ma (Barrie and Davis 1990).

Tour Guide

A list of definite tour stops cannot be given at the time of writing, due to the necessity of altering underground tour routes to conform to mining activities at the time the tour is given. A proposed tour itinerary is given below.

Stop 1. Slide show

Proceed underground:

Stop 2. Chalcopyrite stringer ore.
Stop 3. Massive sulphide ore.
Stop 4. South-dipping post-ore fault.
Stop 5. Carbonaceous polymictic sulphide breccias.
Stop 6. "Andesite-Diorite"
Stop 7. "Quartz porphyry"
Stop 8. "Dacite"

Return to surface:

Stop 9. Diamond drill core and display specimens.
Stop 10. Massive and metavolcaniclastic rhyolites on the East Outcrop.

Carscallen Township Iron-formation, Morgan Claim G-3040

Paul Roos, Falconbridge Limited,
Exploration Division, Timmins, Ontario.

Geological relationships of iron-formation with mafic volcanic rock, crystal tuff and porphyry can be observed on an outcrop on the Morgan claim in Carscallen Township, southwest of Timmins. The geology and the locations of the samples analysed are shown in figure 3-5. Analytical data for the main types of rock are given in Table 1.

The pillowed mafic volcanic unit, sample A, at the base of the stratigraphic section and to the west, appears to be andesitic or basalt high in Al, depleted in Y, and has a higher than normal content of Ba and Rb relative to a similar lithology from the reference sample database. The iron-formation, sample B, stratigraphically overlying this pillowed unit contains 91.2 % SiO_2, 6.2 % Fe_2O_3 , and 1.54 % LOI, which comprises 98.9 % of the rock, as shown by a chip sample across the iron-formation unit. The iron-formation is well bedded and stratiform in contact with the pillowed mafic unit, however higher in the section it appears to have been disrupted by the feldspar porphyritic diabase, sample C, and its associated dyke, sample D. The porphyry may also have introduced the discordant quartz veining observed more commonly in the upper units. The crystal tuff, sample E, is dacitic in composition and has a high content of Ba. This unit exhibits fine bedding/laminations, and an assay, sample F, at the south end of the outcrop was taken from the well sulphidized contact between the pillowed mafic lava and the iron-formation.

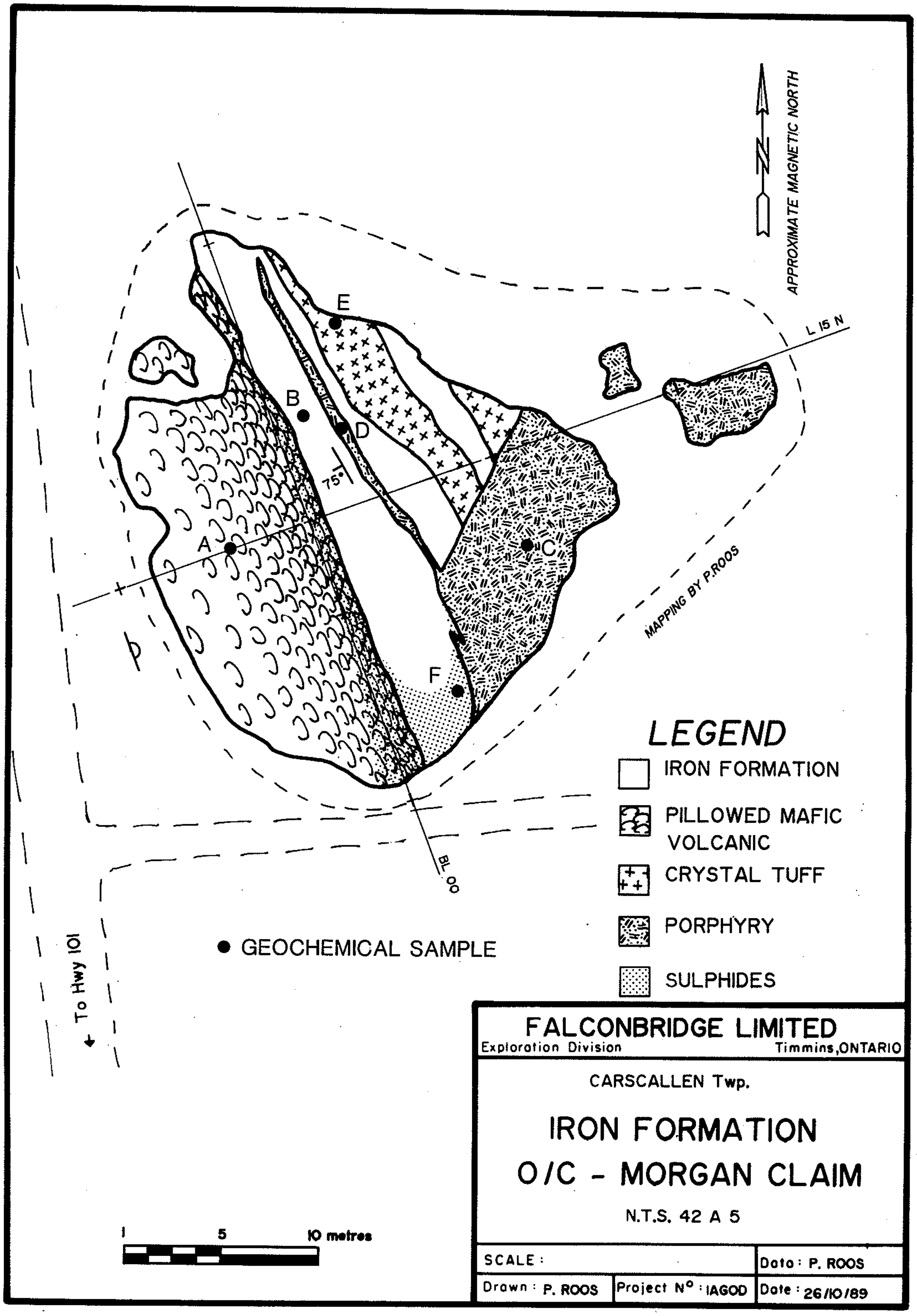


Figure 3-5. Iron-formation on Morgan Claim, Carscallen Township.

Table 1.
ANALYSES OF ROCKS FROM MORGAN CLAIM, CARSCALLEN TOWNSHIP

ROCK TYPES --- A-- Mafic pillow lava,
B-- Iron-formation (stratafer), C-- Feldspar porphyritic diabase, D-- Diabase dyke, E-- Crystal tuff, F-- Pyrrhotite contact rock

SAMPLE	A	B	C	D	E	F
ELEMENTS, in %, PPM, or PPB, and analytical methods						
SiO_2 %,XRF	57.7	91.2	51.0	47.2	61.7	
Al_2O_3 "	14.0	0.14	12.9	13.6	15.5	
CaO "	5.48	0.29	8.95	9.55	3.38	
MgO "	3.46	0.47	5.02	6.85	3.01	
NaO_2 "	0.34	<0.01	2.42	2.77	2.49	
K_2O "	4.07	0.03	0.78	1.80	4.97	
Fe_2O_3 "	8.55	6.18	15.8	12.2	6.08	
MnO "	0.43	0.33	0.28	0.43	0.13	
TiO_2 "	0.62	0.03	1.28	0.91	0.59	
P_2O_5 "	0.11	0.01	0.16	0.08	0.12	
LOI "	5.08	1.54	1.31	4.70	2.00	
SUM----	100.0	100.2	100.00	100.1	100.0	-------
Au-FADCP	2 ppb	6		<1	27 ppb	
Ag-AA PPM	<0.5	<0.5 PPM		<0.5	2.6 PPM	
As -NA	4	2		5		
S -XRF	<100	6090		883		
Se -NA	<3	<3		<3		
Li -ICP	18	<10		20		
B -DCP	50	20		20	1080	
Ba -XRF	629	141	282	237		
Be -DCP	<5	<5		<5		
V -DCP	130	10		240		
Cr -NA	240	200		290		
Co -ICP	18	2		49		
Ni -ICP	107	7	53	121	25	
Cu -ICP	1.9	19.4	191	15.5	17	90
Zn -ICP	122	78	133	172	17	50
Ge -DCP	10	<10		10		
Mo -ICP	<1	<1		<1		
Sc -NA	19.7	<0.5		38		
Cd -ICP	<1	<1		<1		
In -AA	<1	<1		<1		
Sb -NA	<0.2	<0.2		0.2		
Bi -ICP	<3	<3		<3		
Cs -NA	2	<1		1		
Sn -XRF	<10	15		<10		
W -NA	<3	<3		<3		
Ta -NA	<1	<1		<1		
Nb -XRF	12	<10	24	<10	19	
Hf -NA	3	<1		2		
Pb -ICP	<2	3		<2		36
Th -NA	2	<1		<1		
U -NA	0.6	<0.5		<0.5		
Rb -XRF	122	21	27	76	109	
Sr -XRF	138	<10	138	118	136	
Y -XRF	<10	<10	15	<10	20	
Zr -XRF	97	<10	133	64	147	
La -NA	12.7	1.1		4.6		
Ce -NA	25	<3		11		
Nd -NA	11	<5		7		

Sm	-NA	2.1	0.2			2
Eu	-NA	1.0	0.3			1.0
Tb	-NA	<0.5	<0.5			0.5
Yb	-NA	1.5	0.2			2.1
Lu	-NA	0.2	<0.1			0.3

Analyses by XRF, ICP, DCP, NA, AA, FADCP (Au), methods
by X-RAY ASSAY LABORATORIES, Don Mill, Ontario.
Provided by Falconbridge Limited.

Part 4

MICHIPICOTEN IRON-FORMATION IN THE WAWA AREA, ONTARIO

R.P. Sage , Ontario Geological Survey, Toronto

ACKNOWLEDGEMENTS

Illustrations for the field guide were prepared by Ms. K. Gil and Mr. D. Walker and modified by Ms. M. Sideris and Ms. S. Gray. The field trip is on the property of the Algoma Steel Corporation Limited which has given permission for the field tour to enter the property.

FRONTISPIECE

Iron sulphide replaced stromatolitic structures in fine grained massive siderite, Helen Iron Range, Wawa, Ontario. This material is currently under study by Dr. Hans Hofmann, University of Montreal.

Specimen collected in 1978 by Mr. Ed Berdusco, Chief Mine Geologist, McLeod Mine. The specimen was donated to the Royal Ontario Museum (ROM) by the Algoma Steel Corporation Limited in 1988. The sample is ROM catalogue number G35222, ROM petrology collection. Photography by Mr Brian Boyle, Royal Ontario Museum.

The sample was found on the M4 haulage drive east at mine plan coordinates 3750E and 1520N. It is located at an elevation of 9,580 feet where sea level is arbitrarily set at 10,000 feet. (Note: Lake Superior is 601 feet above sea level) The feature occurs within 15 feet of the mining footwall. The stratigraphic section is overturned thus the mining footwall is the stratigraphic hanging wall. The stromatolites are therefore found stratigraphicaly relatively high in the massive siderite facies of the Michipicoten iron-formation.

INTRODUCTION

The Michipicoten supracrustal rocks have been the subject of numerous published references since Sir William Logan first examined the Dore Conglomerate at Michipicoten Harbour (Logan, 1846-47). The Archean aged supracrustal rocks host several past and present gold mines and numerous gold showings. Iron ore has been extracted from the iron-formations since 1900 and has been a major influence in the economic stability of the town of Wawa for the past 50 years. It has been the iron and gold deposits that have attracted so much interest in the Wawa supracrustal rocks over the years, an interest that continues to this day.

The Wawa portion of the IAGOD field trip will concentrate on the major iron-formation unit that hosts economic iron deposits (Fig. 4-1). This focus will be on its volcanic environment and the various facies that make up the iron-formation. Mining operations close to the town of Wawa have exposed well developed sections through all facies of iron-formation. While not as well developed as one would like, sulphide facies iron-formation can be seen in the open pit on the Lucy Iron Range and for those that return to this area in the future, the sulphide facies is well exposed in open pits near Goudreau.

GENERAL GEOLOGY

The Wawa supracrustal rocks consist of at least three volcanic cycles (mafic to felsic volcanism), first recognized by Goodwin (1962) (Fig. 4-2). Uranium-lead zircon isotopic dating by Turek et al. (1982, 1984, 1988) have established these volcanic cycles at approximately 2700, 2750 and 2900 Ma.

OLDEST CYCLE

The oldest cycle is of limited distribution and occurs immediately east of the east end of Wawa lake and west of the small town of Hawk Junction. The lower mafic portion consists of basaltic and peridotitic komatiites and the upper portion of calc-alkalic dacites and rhyolites. The mafic portion consists of massive and pillowed flows and the felsic portion consists of feldspar crystal tuffs, quartz-feldspar crystal tuffs, lapilli tuffs, tuffs and oligomictic to polymictic breccias. These 2900 Ma volcanic rocks are intruded by equigranular to porphyritic rocks of the Hawk Lake granitic complex dated at 2888 ± 2Ma (Turek et al. 1984). This cycle of volcanism is capped by a relatively thin discontinuous unit of thinly banded iron-formation consisting of chert-magnetite-sulphide facies. The sulphide is concentrated toward the stratigraphic bottom of the unit which lies directly on intermediate to felsic metavolcanic rocks dated by U-Pb techniques at 2889 ± 9Ma (Turek et al. 1988).

MIDDLE CYCLE

Intermediate to mafic metavolcanic rocks of the 2750 Ma cycle lie on top of the iron-formation capping the 2900 Ma cycle. This 2750 Ma cycle of intermediate to mafic volcanism was followed by the development of a polymictic volcanic breccia and then the extensive development of calc-alkalic intermediate to felsic volcanism. The mafic portion of this middle cycle consists of massive and pillowed flows of high-magnesium tholeiite and high-iron tholeiite composition and the calc-alkalic portion consists of dacite to rhyolite on a Jensen (1976) cation plot. The intermediate to felsic metavolcanic rocks consist of quartz-feldspar crystal tuffs, feldspar crystal tuffs, lapilli tuffs, spherulitic flows, flow breccias and oligomictic to polymictic breccias. Some of the pyroclastic flow breccias contain well developed fiamme. The Jubilee stock dated at 2745 ± 3 Ma (Sullivan et al. 1985) is coeval with 2750 Ma cycle intermediate to felsic volcanism.

Capping the 2750 Ma cycle of volcanism is a major unit of iron-formation which in the Wawa area exceeds 100 metres in thickness and which is believed to be correlatable with iron-formations occurring in the

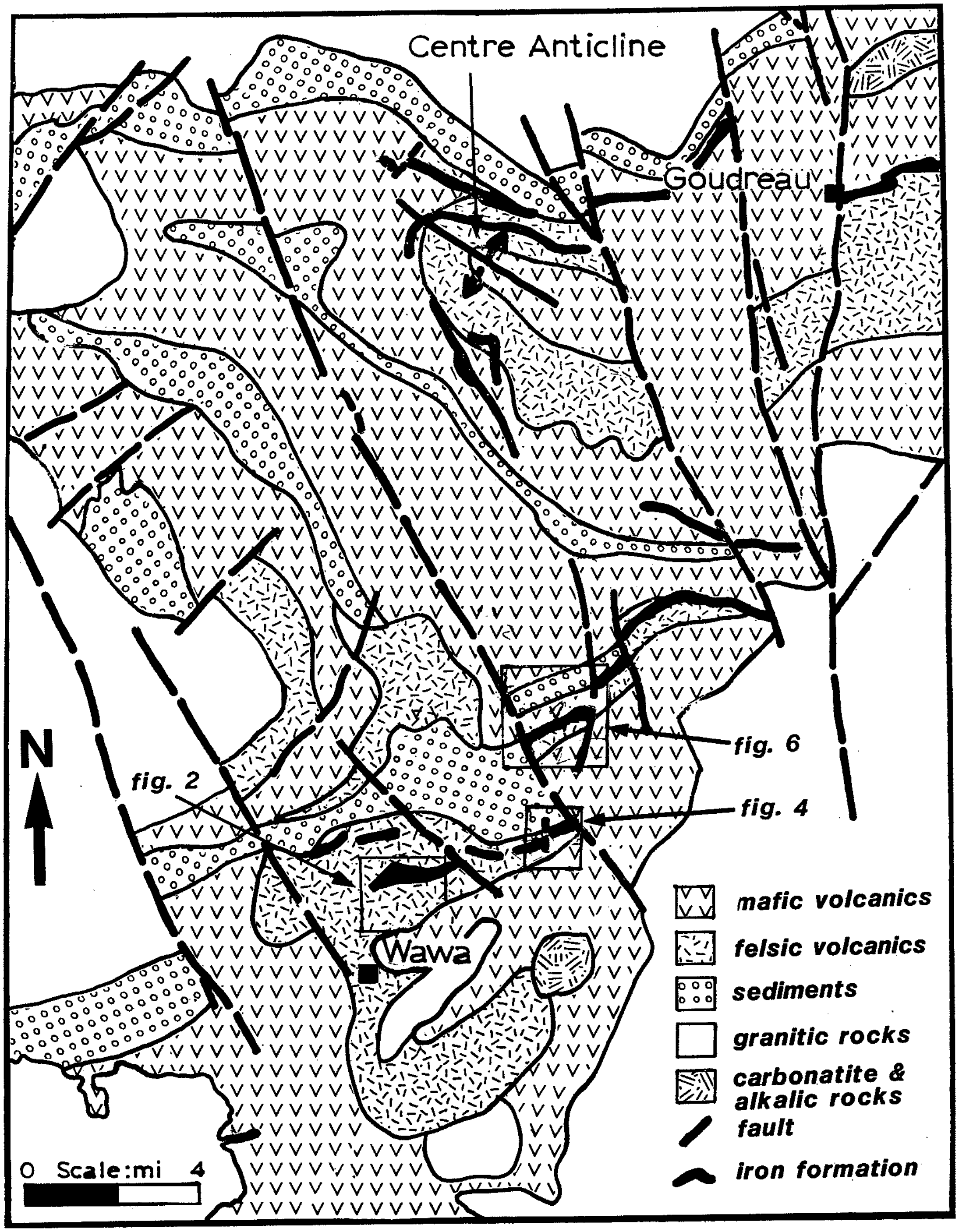


Figure 4-1. Geology map with tour sites indicated.

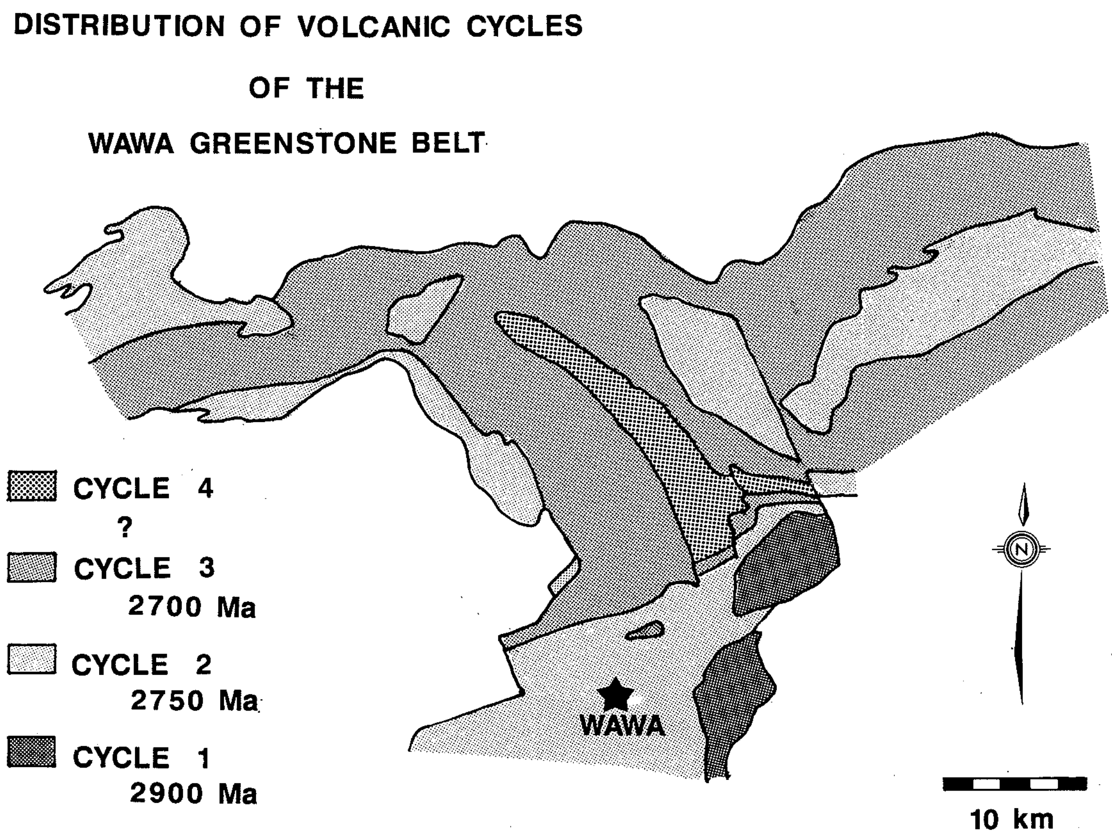


Figure 4-2. Simplified sketch map of the distribution of volcanic cycles within the Michipicoten supracrustal sequence.

Goudreau area when the effects of faulting and folding are removed. Assuming that the correlations are correct one is dealing with a strata that has a strike length of 80-100 km which serves as an excellent geological and geophysical marker horizon. It is this unit of iron-formation that has hosted all iron ore production from the region.

Intermediate to felsic tuffs immediately below the iron-formation at the Helen Iron Range in Wawa gave a U-Pb isotopic age of 2749 ± 2 and intermediate to felsic tuffs below the Morrison No. 1 Iron Range in Goudreau gave a U-Pb isotopic age of 2729 ± 3Ma. On the basis of isotopic age dating and similarity in lithologic distribution these iron ranges are believed to be the same and that the iron-formation was deposited on a regional unconformity. At the Helen Iron Range reworking of the tuffs immediately below the iron-formation, as evidenced by graded and cross bedding, suggests erosion of the intermediate to felsic stratigraphy has occurred exposing older rocks lower in the section. This zone of reworking is approximately 60 metres in width and has been interpreted as metasediment by Nebel(1982). Evidence for this reworking is absent at the Morrison No. 1 Iron Range suggesting little if any erosion occurred between the cessation of felsic volcanism and iron-formation deposition.

The Morrison No. 1 Iron Range is located some distance east of the Helen Iron Range and closer to the Kapuskasing Structural Zone which is a major upthrust block of Superior Province crust (Percival and Card, 1983). It is thus very likely that the numerous northwest transverse faults that cut the Wawa supracrustal rocks have their east side up exposing ever deeper sections within the Archean basin. If this is the case, the section representing the Morrison No.1 Iron Range represents a section deeper within the basin than that represented by the Helen Iron Range and perhaps was not subjected to erosion in Archean time before the start of iron-formation deposition.

YOUNGEST CYCLE

Lying stratigraphicaly on top of this major unit of iron-formation are the intermediate to mafic metavolcanics of the 2700 Ma cycle of volcanism. The lower portion of the youngest recognized volcanic cycle consists of massive and pillowed flows of high-magnesium tholeiite and high-iron tholeiite composition on a Jensen(1976) cation plot. The mafic portion of this cycle is overlain by intermediate to felsic metavolcanic rocks of calc-alkalic composition consisting of feldspar crystal tuff, quartz-feldspar crystal tuff, lapilli tuff, tuff and polymictic to oligomictic breccia. Coarse oligomictic volcanic breccias of this cycle north of the Magpie River have angular blocks exceeding 4 metres in long dimension. Samples collected from these coarse breccias gave a U-Pb age of 2698 ± 11 Ma (Turek et al.,1984) and quartz-feldspar crystal tuffs within the same cycle of volcanism exposed along highway 17 north of Wawa gave a U-Pb isotopic age of 2696 ± 2 Ma (Turek et al. , 1982).

The intermediate to felsic metavolcanic rocks of the 2700 Ma cycle interdigitate with Dore sediments indicating that volcanism and sedimentation were coeval. The metasediments consist of Dore-type (with granitic clasts) and non Dore-type conglomerates (without granitic clasts), wacke, siltstone, argillite, and subarkose to arkose. From the stratigraphic bottom to the top of the sedimentary section the primary structures and rock compositions suggest a resedimented (submarine fan) facies association followed by a non-marine (alluvial fan-fluvial) facies association with minor basinal and lacustrine facies (Neale, 1981; Thomas, 1984). Locally excellent graded bedding, mud chip breccias and flame structures occur in the lower section and trough cross bedding, ripple marks and rare desiccation cracks occur in the upper section. Current directions based on cross bedding and ripple marks indicate a west to east transport direction for the sediments and the presence of desiccation cracks indicate shallow water to subaerial conditions inferring that the associated volcanic rocks, from which the sediments were derived, were subaerial. Based on the relative increase in quartz content between porphyritc felsic flows, quartz-felspar crystal tuffs and derived sediments, a large volume of felsic volcanic material had to be eroded to produce the observed volume of sediment and the model proposed by Ayres (1983) for similar rocks in nearby Lake Superior Provincial Park would apply. Corfu and Sage (1987) report a U-Pb zircon isotopic age of 2696 ± 2 Ma for a trondjemite boulder collected from the fluvial Dore conglomerate exposed in the road cut along highway 17 north of Wawa. This granitic boulder may represent the eroded plutonic equivalent to the volcanics.

Iron-formation does not cap the intermediate to felsic metavolcanic rocks of the 2700 Ma cycle but does occur at the top of the intermediate to mafic metavolcanic rocks of this cycle or at the base of the Dore metasediments which are laterally equivalent to the 2700 Ma intermediate to felsic metavolcanics. This iron formation consists of at least two closely spaced parallel bands of chert-magnetite with subordinate sulphide. At some locations this iron-formation occurs within metavolcanic rocks and at other sites within wacke metasediments and perhaps occurs along an unconformity. This iron-formation is an excellent geological and geophysical marker horizon which extends along most of the strike length at the northern margin of the belt of Michipicoten supracrustal rocks.

CHARACTERISTICS OF THE VOLCANIC REGIME

The felsic and mafic components of the three volcanic cycles demonstrated occur in relatively sharp contact, indicating bimodal volcanism which, in conjunction with the very large volume of exposed felsic metavolcanic deposits, suggests that the mafic and felsic components of each cycle may have had different origins not related by simple crystal fractionation processes. Amygdules are rare within the older volcanic cycle, whereas within the 2750 Ma cycle they increase in abundance and size toward the upper part of the section; in the youngest section, amygdules are abundant and commonly of large size throughout. If amygdule size is a function of water depth at the time of extrusions (Moore, 1965), an ever-shallowing basin of deposition is indicated for the 300 Ma of geologic time represented by the three volcanic cycles.

The mafic components of each cycle are capped by intermediate to felsic metavolcanic rocks which, for the most part, display similar compositional and textural features. The 2750 Ma cycle contains numerous breccia flow units with well-developed fiamme representing large fragments of collapsed pumice. Somewhat quiescent outpouring of intermediate to mafic lava appears to have been followed by plinian style (Fisher and Schmincke, 1984) intermediate to felsic volcanism for each of the volcanic cycles. The intermediate to felsic metavolcanic rocks may represent coalescing deposits from several vent areas.

Work on the structural geology of the belt is in progress (McGill and Shrady, 1986; Arias and Heather, 1987; Heather and Buck, 1988) and any conclusions expressed at present are tentative. The original stratigraphic sequence, probably monoclinal and younging northward, has been subjected to thrusting. Nappe structures related to this thrusting have not yet been clearly established, but some preliminary unpublished evidence (Arias, Heather, Sage) suggests that they may be present. This deformed sequence of rocks was then folded into an east-trending series of anticlines and synclines. The dominant regional fold is an anticline represented by the synformal Centre anticline, figure 4-1, the cross folded, upright Alden Lake anticline and the upright Goudreau anticline. All were probably once parts of the same anticlinal structure, now segmented as a result of faulting and folding.

The folded supracrustal rocks are cut by numerous left-lateral northwest-striking transverse faults which display much greater offset along the southern margin of the belt than along the northern margin. These differences in degree of offset along strike, first noted by Goodwin (1962), probably are due to varying amounts of vertical uplift along strike of the fault. Quartz diabase and sparse olivine diabase dykes occupy faults and shear zones of this northwest trend.

The supracrustal rocks have been metamorphosed to the greenschist facies of regional metamorphism. Rocks of the amphibolite facies occur along the belt margins, in contact with the external granitoids. The zone of higher metamorphic grade approaches a width of 1 km and is likely the result of contact metamorphism of the supracrustal rocks against the younger external granites (Turek et al., 1982, 1984; Ayres, 1979).

IRON-FORMATION

Study of the iron-formation at Wawa has concentrated on one unit of iron-formation which contains the iron deposits and mines developed over the past 50 years. This is the regionally extensive, thick unit that caps the Middle, 2750 Ma, volcanic cycle. This iron-formation unit consists of five facies showing consistent stratigraphic distribution no matter where in the supracrustal belt this iron-formation unit is encountered. From bottom to top, the facies are carbonate which is siderite at Wawa and calcite near Goudreau, sulphide consisting of pyrite plus subordinate pyrrhotite, chert-magnetite, chert-wacke and argillite-pyrite-graphite (Sage 1987a, b, c) (Fig. 4-3). The relative amounts of each facies developed varies from iron range to iron range and from site to site within each range.

Coleman and Wilmott (1902) proposed that the Michipicoten iron-formation was a sediment representing the chemical precipitation of Ca, Si and Fe during a hiatus in volcanism, and they recognized the probable contribution of biological activity. However, their work was largely ignored and for the next 50 years, the carbonate and sulphide facies iron-formations were interpreted as replacement deposits. Collins, Quirke and Thomson (1926) provided the most complete description of the replacement model. They also suggested that the Michipicoten iron-formations may have been formed by the deposition of iron and silica that was extracted from volcanic rocks and transported to the surface by hydrothermal solutions, and precipitated by evaporation processes. In proposing these concepts they anticipated many of the volcanogenic processes for iron-formation that are now widely accepted.

Unpublished work by Young (1951, 1953) marks the beginning of modern work on the Michipicoten iron-formation and a return to a sedimentary model. Goodwin (1962, 1964) provided the first modern summary for the Michipicoten iron-formation, describing the geological setting of the iron-formation and the chemistry of rocks associated with the iron deposits of the Helen Iron Range at Wawa. One of Goodwin's (1964) major points was that the Fe and Si which compose the iron-formation was released as a result of the alteration of volcanic rocks by deeply circulating waters within the volcanic pile. This model, relating the iron-formations to fumarolic activity, has been advanced for Algoma type iron-formations by many investigators including recent work by Morton and Nebel (1984) in the Wawa area.

Karkhanis et al. (1980) identified "n" alkanes and the isoprenoid hydrocarbons pristane, phytane and fatty acids in the Michipicoten iron-formation which were attributed to the presence of autotrophic organisms. Goodwin et al. (1976), Thode and Goodwin (1983) and Goodwin et al. (1985) reported on a series of carbon and sulphur isotope studies which have been interpreted to indicate that bacterial reduction of sulphate occurred during iron-formation deposition, and that both marine and organic carbon is present. Thode and Goodwin (1983) proposed that deep circulating seawater acting on mafic

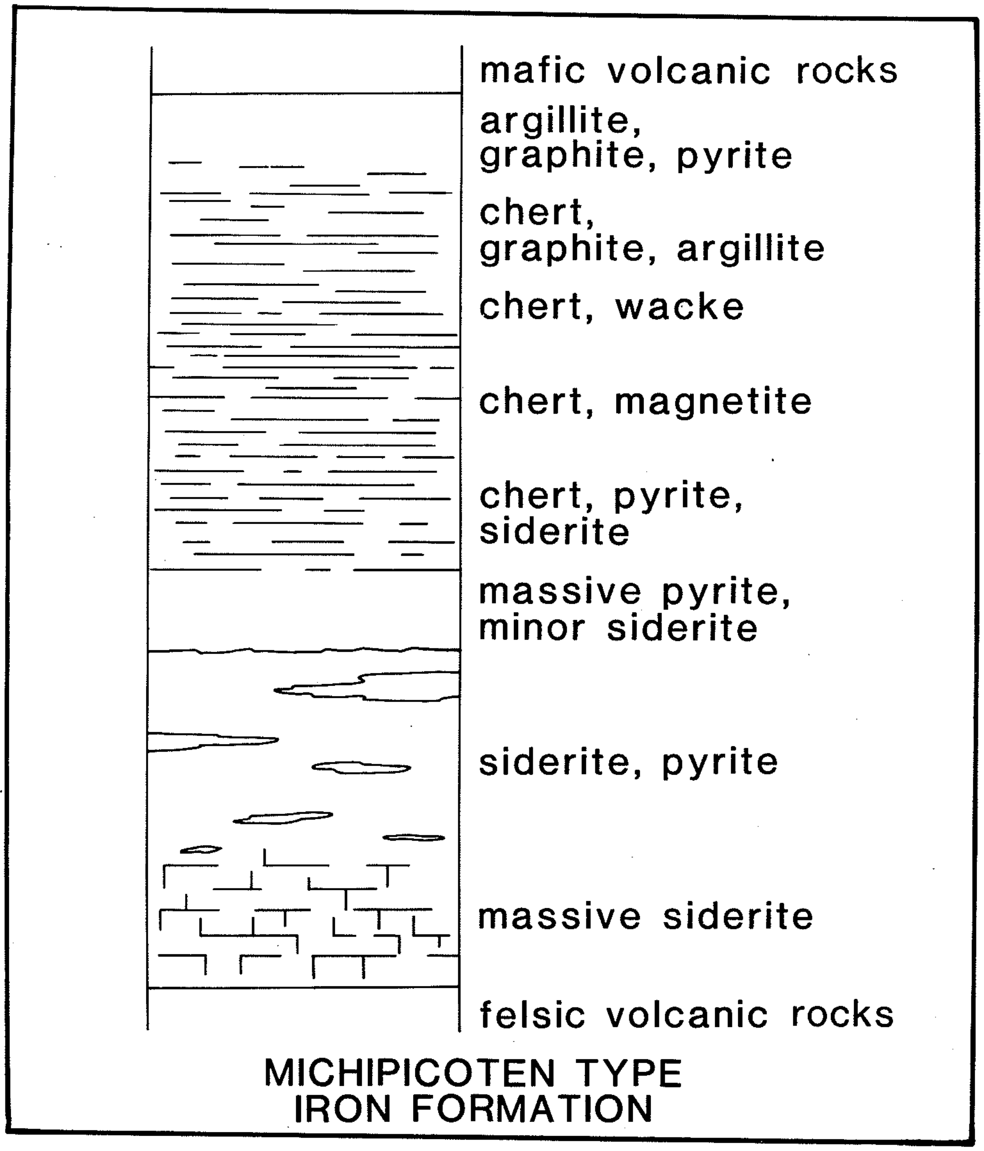


Figure 4-3. Sketch of idealized distribution of various facies within the Michipicoten iron-formation.

rocks produced the fluids in which this biological activity occurred.

Using oxygen isotope data from chert samples collected from the Lucy Iron Range, Leseelleur (1980) indicated that iron-formation deposition occurred at temperatures of 200°C or less and that the depositing fluids represented defocused flow and low water-to-rock ratios. Lockwood (1986) reached similar conclusions.

Structures possibly representative of stromatolites (Frontispiece) have been recovered recently from the siderite orebody, McLeod Mine, Helen Iron Range (Hans Hofmann, University of Montreal, personal communication 1990).

The Michipicoten iron-formation thus appears to have been formed by hydrothermal processes that were an integral part of and directly related to volcanism in the area and to subsequent alteration of the volcanic pile. Biological activity may have played a prominent role in the deposition of the iron-formation proto facies.

Numerous fault-bounded segments of the Michipicoten iron-formation are separated by northwest- to north-trending cross faults. These fault-bounded blocks have been referred to as "ranges" and the terminology followed here is consistent with historical precedent.

STOP 1 Helen Iron Range and McLeod Mine (Fig. 4-4).

Most of the iron ore mined in the district has been produced from the Helen Iron Range, situated immediately north of the town of Wawa. The iron-formation in this range has a strike length of approximately 2,500 metres and a width of 90 metres in the east and 330 metres in the west. Tectonic thickening of the iron-formation in the western part of the range has undoubtedly been an important factor in creating siderite deposits that could be mined economically. The range is truncated to the west by the Talbot Lake Fault and to the east by the Wallbank Lake Fault. It lies within a north-facing stratigraphic sequence of rocks that are steeply overturned and dip south.

The Helen Iron Range was the site of the first discovery of commercial iron ore in the Michipicoten supracrustal belt in 1897-1898. Upon arrival of the railroad from Michipicoten Harbour in 1900, production of hematite-goethite began and continued to 1918 with a cumulative production of 2,780,236 tons. The hematite-geothite ore was developed by oxidation and secondary enrichment processes and formed a cap rock over the siderite-sulphide deposits that extended to a depth of 213 metres below the original outcrop surface. In 1937, the Helen mine was opened in siderite facies of the iron-formation, using technology developed at the long-abandoned Magpie mine in the centre of the Michipicoten greenstone belt. Production has been continuous since 1938, and up to 1984 amounted to approximately 79,491,926 tons, with reserves of 58,246,000 tons (E. Berdusco, Mine Geologist, McLeod mine, Algoma Steel Corporation Limited, personal communication 1985). The siderite deposit has been developed on seven levels by the No. 5 shaft to a depth of 850 metres from the surface (Fig. 4-5).

STOP 1a

The main purpose here is to examine the oxide facies of the Helen Iron Range. The climb to this outcrop is physically taxing, and those who have a medical condition dictating avoidance of excessive exertion (as well as those physically out of shape) should exercise caution at this stop.

The group should move northeast down and across the open pit and up to the banded cherts of the upper part of the iron range. Samples of the original gossan can be collected as we walk across the pit. We will cross the iron-formation and the intermediate to mafic metavolcanic rocks of the 2700 Ma cycle, and walk east parallel to the strike of the iron-formation. As we move east, parallel to the iron-formation, a quick stop will be made at an outcrop

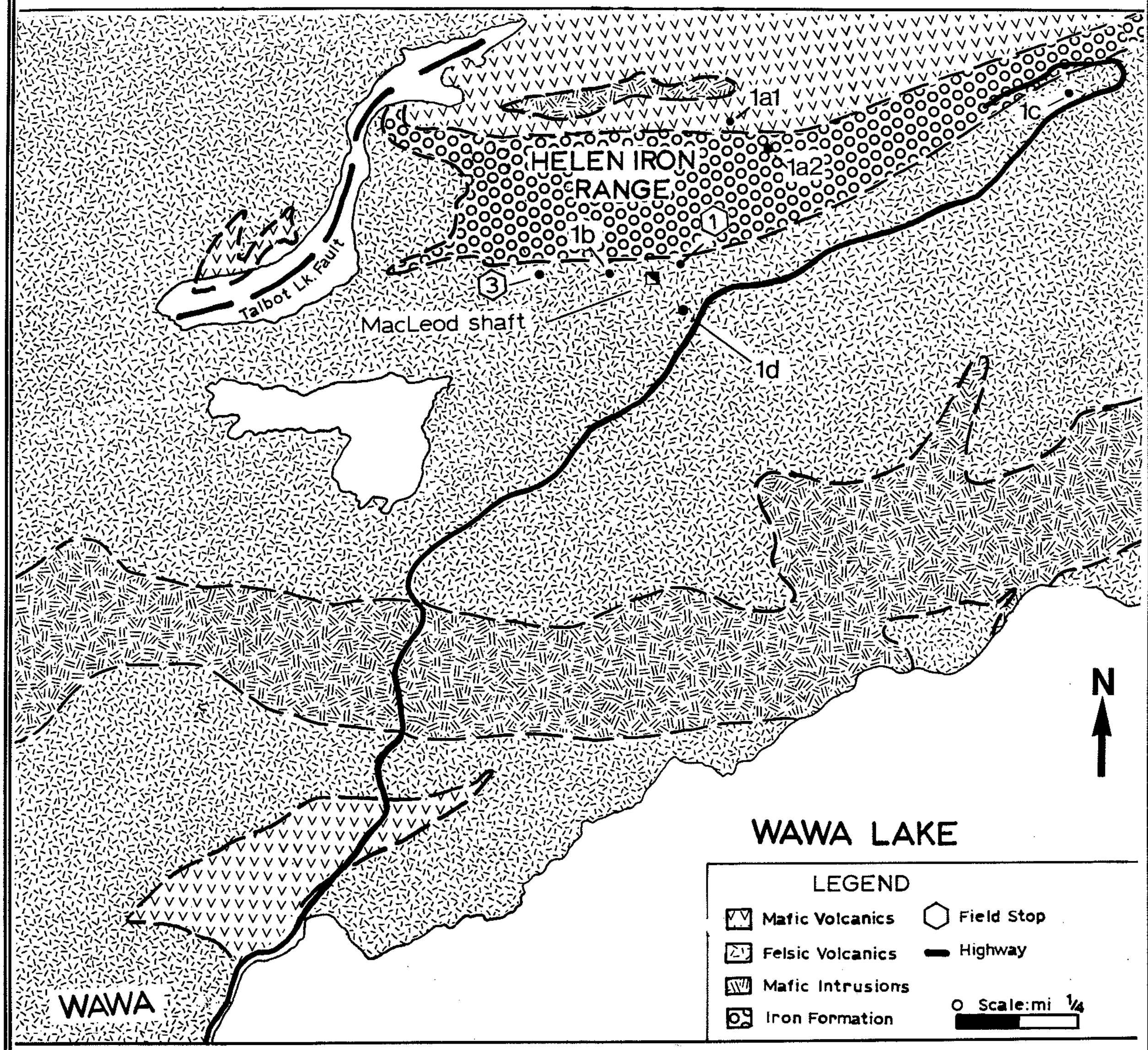


Figure 4-4. Geologic sketch map of the Helen Iron Range with stops indicated.

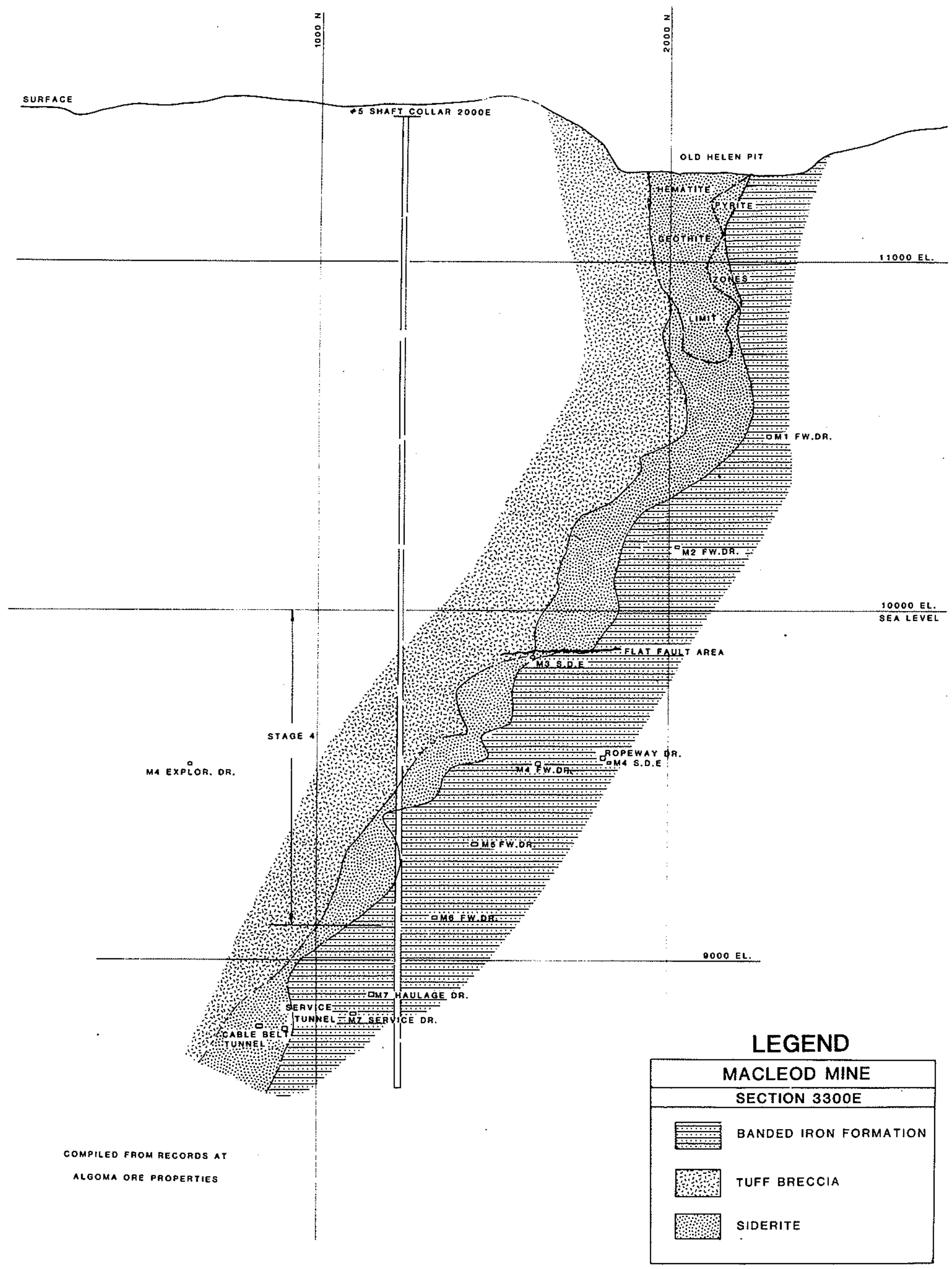


Figure 4-5. North-south cross section through McLeod Mine, Helen Iron Range illustrating the steeply south dipping siderite ore body. The stratigraphy faces north and the stratigraphic footwall is the mining hanging wall in this overturned section. Compiled from the records of the Algoma Steel Corporation Limited.

of massive to locally pillowed mafic flow containing chloritoid porphyroblasts up to 2 mm across (Stop 1a - 1). Chloritoid porphyroblasts are abundant in the underlying felsic metavolcanic rocks, but they are less apparent in the overlying mafic metavolcanic rocks. The chloritoid in this mafic rock has been discussed in detail by Latour et al. (1980).

From the chloritoid outcrop we will continue east for a short distance to an abandoned adit and then climb the steep hill to examine thinly bedded chert-magnetite-wacke iron-formation at the top (Stop 1a - 2). This is one of the best exposures of oxide facies in the Michipicoten iron-formation and this facies continues for the entire strike length of the iron range. At the east end of the iron range, thin wacke beds commonly display grain-size gradation, indicating tops to the north (consistent with determinations based on pillow shapes in the overlying metavolcanic rocks). Upon completion of the examination we will return along the same path as we came and, if time permits, we will make two quick stops during the return trip.

Upon reaching the contact between the intermediate to mafic metavolcanic rocks and the iron-formation, walk a short distance west to observe several good exposures of stretched pillows in direct contact with the iron-formation. The contact between the iron-formation and the metavolcanic rocks of the overlying cycle is sharp. Some of the pillows are not too highly deformed, and can be used to establish the north-facing attitude of the stratigraphic succession.

Continuing a short distance further, several folds can be seen in the iron-formation. These folds occur only at the west end of the Helen Iron Range, where the iron-formation is cut off by the Talbot Lake fault and the strike changes from northeast to north. The fold axis, as well as elongated clasts in the underlying tuff, plunge 50-60 degrees to the east. From this point we will return to the parking lot.

STOP 1b (Fig. 4-4).

The main purpose of this stop is to examine tuffs and breccias that form the footwall to the Helen Iron Range.

Walk northwest to the outcrop north of the mine office building. At this site, schistose felsic tuffs are crosscut by numerous reddish-brown-weathering breccia dykes. These dykes, emplaced before regional folding, consist of fragments of the adjacent tuff in siliceous siderite cement. All of these crosscutting breccia dykes are within 100 metres of the base of the iron-formation, and perhaps served as feeders for fluids associated with iron-formation deposition. Similar breccia dykes have been observed in all of the iron ranges from the Helen Iron Range to the Josephine Iron Range northwest of Hawk Junction.

Return to the base of the outcrop and walk west across the outcrop behind the core racks. The schistose lapilli tuffs at this site provide one of the best examples of preferred chloritoid development in clasts in comparison to matrix. At the Helen Iron Range, chloritoid displays preferential growth in felsic precursor rocks; however, throughout the Wawa supracrustal belt, chloritoid is roughly equally distributed between the mafic and felsic rocks, and it is absent in the metasedimentary rocks. Lockwood (1986) completed an extensive study of chloritoid in the Michipicoten rocks, and has tabulated considerable chemical and mineralogical data. Carbonate alteration invariably accompanies chloritoid, and Lockwood (1986) concluded that carbonate was essential for the formation of chloritoid by serving as a sink for excess Ca, Mg and Fe during regional metamorphism. Most porphyroblasts are randomly oriented, implying development after regional metamorphism, but in thin section some porphyroblasts can be seen to be cut by the schistosity. Development of chloritoid thus appears to have overlapped the terminal phase of regional deformation, which peaked before the major episode of regional metamorphism.

From the chloritoid-bearing outcrop, continue west across a small ravine to a large outcrop of felsic metavolcanic rock that contains blocks up to 1 metre and, in contrast to the last outcrop, displays little deformation. Although the clast compositions are chemically similar, the clast textures indicate that the coarse breccia was likely derived from a number of flow units. Aphanitic, flow-banded and spherulitic clasts are abundant and there are a few small accidental mafic clasts. One exposure contains possible glass shards. Before mining operations made walking to the north dangerous, one could walk up section and observe the decreasing clast size and the presence of fine-grained well-bedded tuff at the contact with the iron-formation. This breccia unit may have been produced by a phreatic eruption that disrupted a number of flow units, or by collapse of a volcanic edifice which was subsequently subjected to erosion and reworking of its upper surface. Upon completion of the outcrop examination, return to the parking area.

STOP 1c

From the parking area we will drive to the east end of the large open cut that is readily visible from the parking area.

This site displays excellent clast-size gradation within siliceous, and siderite-cemented lapilli tuff. This exposure is within a few metres of the lower contact with the iron-formation, and is taken as evidence for reworking and resedimentation of the felsic tuffs. This feature has not been observed at the base of other iron ranges.

STOP 1d (optional)

Time permitting, on our return to Wawa, a brief stop will be made to observe fracture-controlled chloritoid development within the footwall tuffs exposed southeast of the mine office. At this stop one can also walk along the mine access road and examine the outcrops below the "Eagle's Nest" and see abundant chloritoid. Chloritoid up to 5 mm in diameter occurs in this section.

Below the Helen Iron Range, chloritoid porphyroblasts have been encountered over an area of 600 x 2000 metres, with its long dimension parallel to stratigraphy. Throughout the Wawa supracrustal belt the chloritoid displays strong stratigraphic control, and is not related to an alteration pipe below the iron-formation, as suggested by Morton and Nebel (1984). Several chloritoid-bearing zones conformable with stratigraphy, exceeding 10 km strike length, have been outlined within the Wawa area. Some of these zones are not associated with iron-formation. Where chloritoid occurs as part of the stratigraphy with iron-formation, it is best developed in the stratigraphic footwall. Locally, it is well-developed in the stratigraphic hanging wall with the best examples being the Helen and Rand No. 2 Iron Ranges.

STOP 2

Upon completion of examination of the Helen Iron Range, drive to the Eleanor Iron-Range and park on the north rim of the Sir James open pit (Fig. 4-6).

The Eleanor Iron Range is the eastern extension of the Helen Iron Range, separated from it by several intervening north- to northwest-trending faults. The iron-formation is 790 metres long and 76 metres thick, within a vertically dipping north-facing succession bound to the west and east by branches of the Mildred Lake Fault. Mining operations ceased in 1967 after removal of 5,553,297 tons of waste rock and 7,790,632 tons of siderite. Development was initiated for underground production, but never completed before operations ceased. Open pit ore has been exhausted, but additional ore remains underground.

This provides the best-exposed example of the upper facies of the iron-formation. This exposure consists of argillite-sulphide -graphite facies cut by a quartz porphyry dyke overlain in sharp contact by the

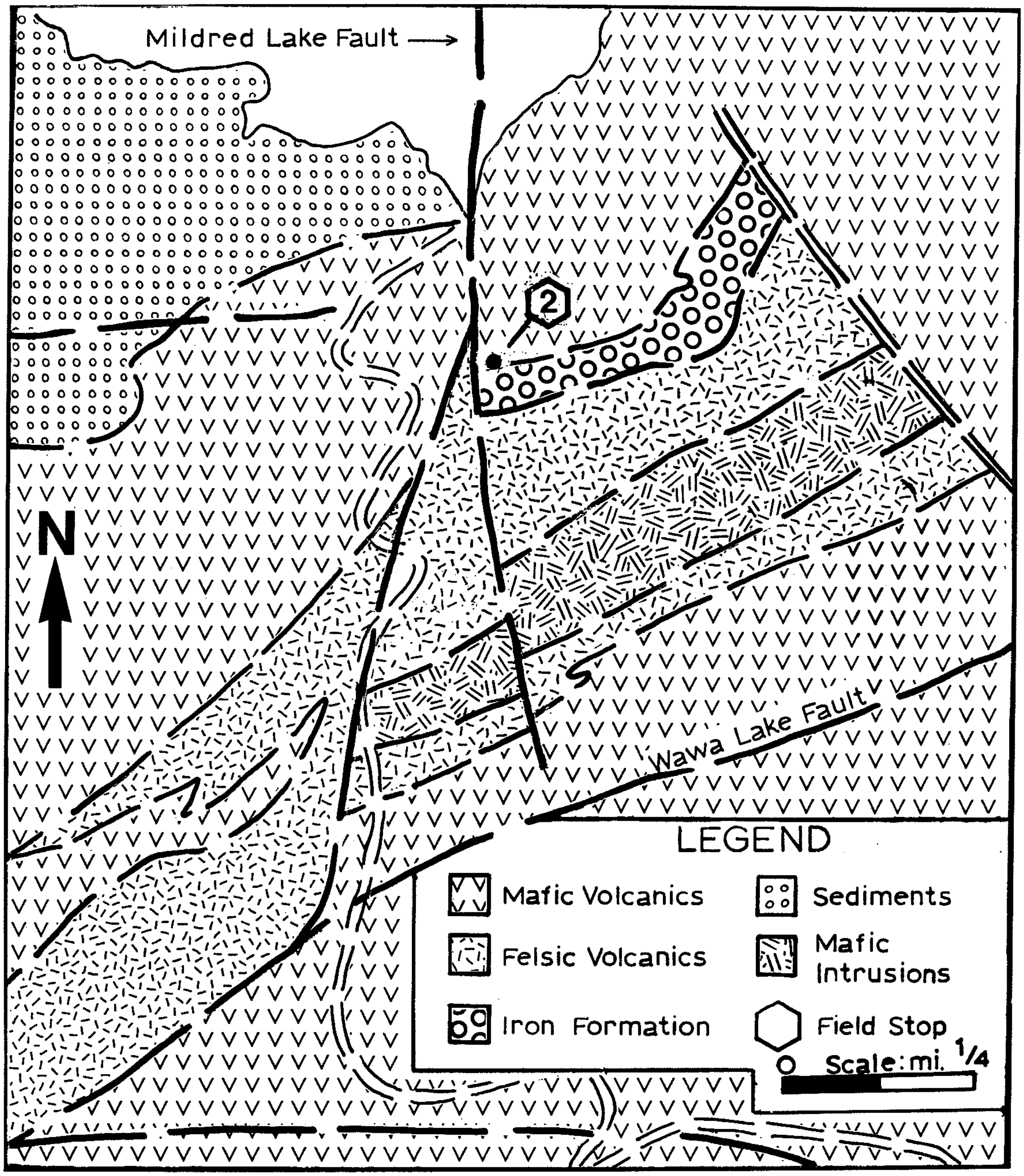


Figure 4-6. Geologic sketch map of the Eleanor Iron Range with stops indicated.

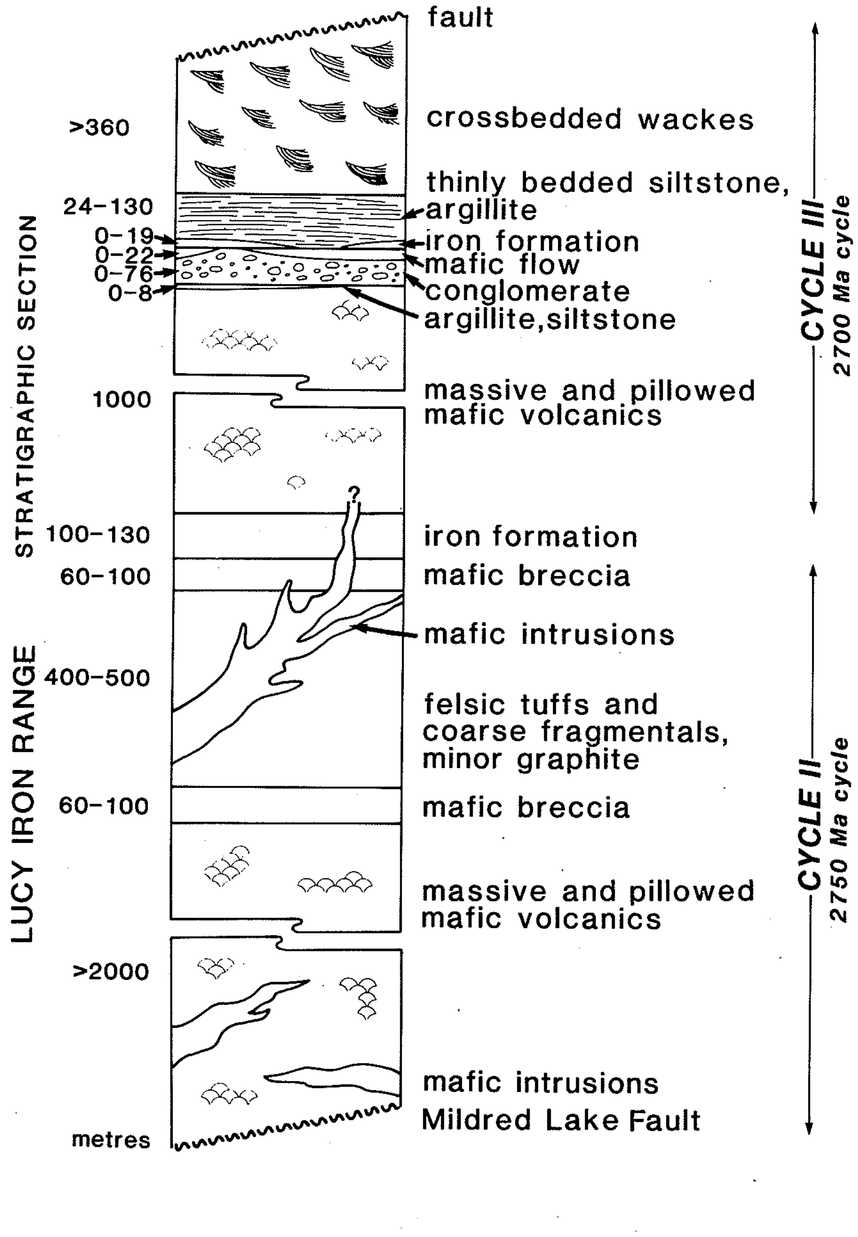


Figure 4-7. Schematic stratigraphic section for the Lucy Iron Range.

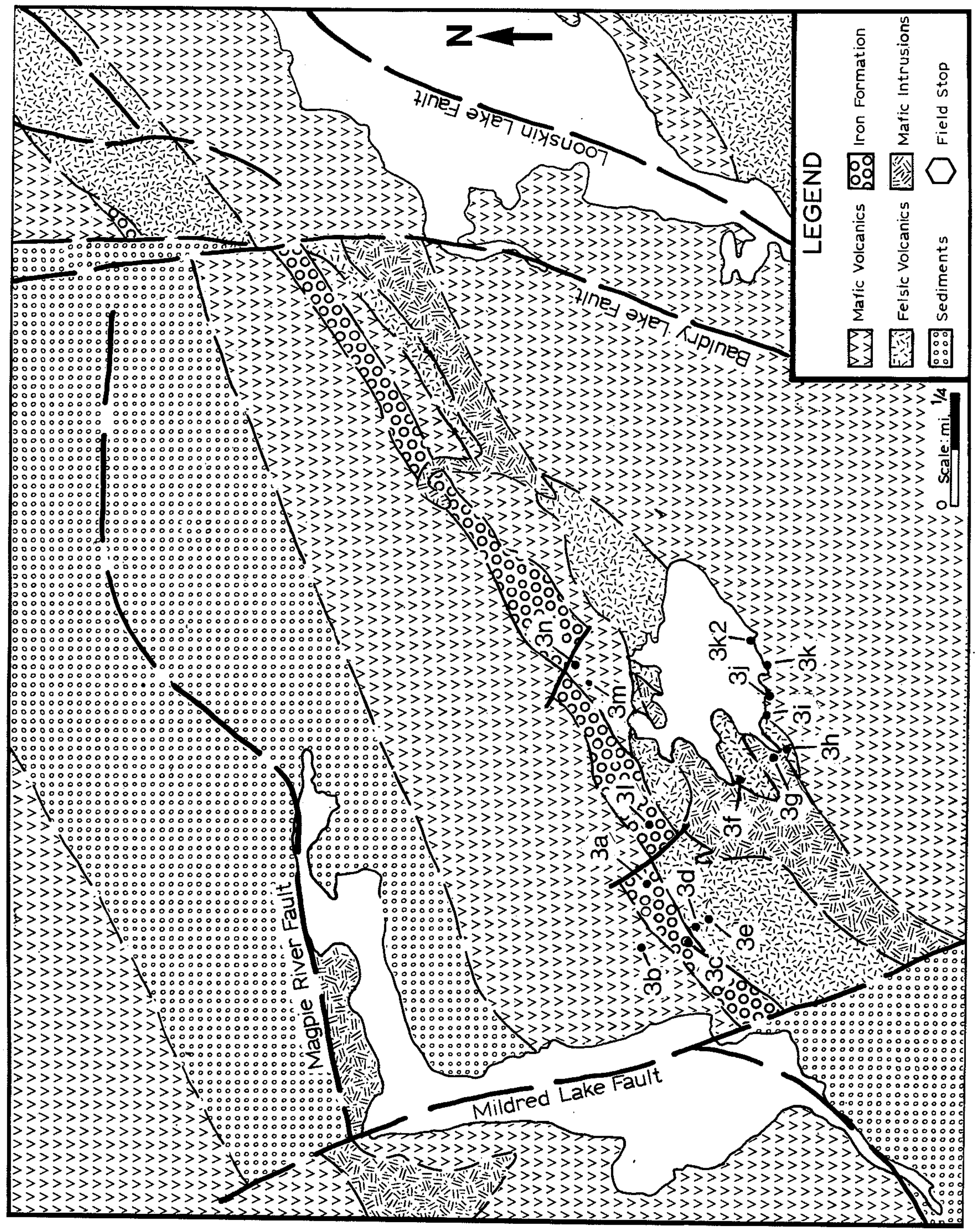


Figure 4-8. Geologic sketch map of the Lucy Iron Range with stops indicated.

massive base of an intermediate to mafic flow of the 2700 Ma volcanic cycle. The top of this flow is pillowed, and can be observed in outcrop along the road just west of the exposure. During examination of this upper facies, walk east along the ledge of the pit and examine the blocks of chert-siderite breccia on the pit floor. Note the relatively undeformed nature of the intermediate to mafic flow and look across the pit to the very schistose intermediate to felsic tuffs that form the stratigraphic footwall. In all of the iron ranges, the rocks forming the stratigraphic footwall appear more deformed than the stratigraphic hanging wall.

STOP 3

The Lucy Iron Range is the faulted eastern extension of the Eleanor Iron Range, and offers one of the more accessible stratigraphic sections through the volcanic sequence (Fig. 4-7). This stop will traverse from the base of the 2700 Ma cycle to the top of the intermediate to mafic component of the 2750 Ma cycle (Fig. 4-8). Upon completion of this traverse, we will enter the open pit and examine the iron-formation.

The Lucy iron-formation is approximately 3050 metres long and 91 metres wide. The west end of the range is cut off by the Mildred Lake Fault which has a left-lateral displacement of 3533 metres, and thus the west end of the Lucy Iron Range is correlated with the east end of the Eleanor Iron Range. The east end of the Lucy Iron Range is cut off by the left-lateral Bauldry Lake Fault, which has an apparent offset of 600 metres. The east end of the Lucy Iron Range correlates with the west end of the Ruth Iron Range, which will not be examined during this visit.

Open pit mining operations have recovered 1,107,773 tons of siderite from the Lucy Iron Range. Mining at the Lucy Pit ceased in 1970; siderite, recoverable by both open pit and underground mining methods, remains.

Stop 3a

The start of the stratigraphic section tour begins in the upper part of the iron-formation northwest of the open pit. At this site, thin-bedded chert and wacke are well exposed and the outcrop is an excellent example of intrastratal brecciation, which is common in the Michipicoten iron-formation. This feature consists of alternating zones of brecciated and unbrecciated iron-formation, suggesting penecontemporaneous slump at the time of deposition in a tectonically unstable volcanic environment. The preservation of delicate primary sedimentary structures within the undeformed thin beds implies that the breccias were not storm induced, and therefore must have originated below wave base, presumably as a result of downslope movement. The chert beds would have had to be lithified, and the wacke beds unlithified and probably water saturated.

The thick chert beds at this stop have faint laminations reminiscent of cross bedding, and one of the wacke beds displays excellent grain-size gradation, indicating stratigraphic tops to the north. The topping data from the wacke bed is consistent with top determinations based on pillow shapes within volcanic strata above and below the iron-formation.

Stop 3b

Walking northwest down the slope towards the west end of a small lake, massive and pillowed intermediate to mafic metavolcanic rocks at the base of the 2700 Ma cycle of volcanism are encountered. The pillows are up to 1 metre in size, and excellent indications of north facing tops can be obtained from pillow shapes. Amygdules in the pillow rims are up to 1 cm in maximum dimension. Approximately 1000 metres of amygdaloidal pillowed volcanics of the 2700 Ma cycle are present from the iron-formation towards the north, where volcanic rocks lie in sharp contact with Dore metasediments.

Stop 3c

Walk south up the steep hill and across the weathered gossan of the Lucy Iron Range. The first outcrop south of the weathered iron-formation is a mafic breccia containing amygdaloidal mafic clasts, up to 30 cm. The breccia contains abundant carbonate, and occurs along the base of the Lucy Iron Range for most of its length. This is the only iron range in which the Michipicoten iron-formation directly overlies mafic volcanic rocks. A sparkle to the rock in bright sunlight is due to small chloritoid porphyroblasts.

Stop 3d

Southeast of the mafic breccia is an exposure of thinly bedded mafic and felsic tuff. The folds may have been formed by tectonism or penecontemporaneous slumping. The interpretation of this folding has been the subject of much debate on previous tours.

Stop 3e

Walk south a short distance to a large outcrop that overlooks a swampy area. At this site a large outcrop of lapilli tuff containing clasts is particularly notable due to large wispy apple-green areas of sericite alteration. This is the only outcrop in the Wawa area that displays this colourful green sericite alteration.

Walk due east along the ridge of outcrop to the road at the west end of the Lucy pit. Along this ridge, excellent examples of tuff and lapilli tuff display poor to excellent bedding. The walk from the outcrop with the apple-green alteration to the road provides a view of a typical suite of rocks that form the stratigraphic footwall to the Michipicoten iron-formation.

Stop 3f

Walk along the road and across the large pile of waste rock to the northwest corner of Brooks Lake. The first outcrop encountered south of the waste rock is a carbonatized unit of poorly bedded breccia and lapilli tuff. The highly carbonatized and fissile character of this outcrop is typical of some footwall rocks to the iron-formation.

Stop 3g

Follow a skid road along the west side of Brooks Lake, passing on the right a large outcrop of lapilli tuff with possible fiamme cut by a fine-grained mafic intrusion. Mafic intrusions within the intermediate to felsic part of the 2750 Ma cycle are commonly fine grained and can easily be mistaken for massive flows in areas of poor exposure and thick bush.

Stop 3h

Continue along the trail and cross a small shallow stream that flows out of Brooks Lake. Immediately south of this stream is a relatively massive unit of feldspar crystal tuff in which some breccia-size clasts can be seen near its stratigraphic base on water-washed outcrops at the edge of Brooks Lake. These rounded to subangular clasts consist of feldspar porphyry.

Stop 3i

South along the shore of Brooks Lake, a thin unit of intermediate to felsic tuff is in contact with the feldspar crystal tuff. This unit is fissile and highly carbonatized.

Stop 3j

The intermediate to felsic tuff is in sharp contact with a mafic breccia unit approximately 100 metres thick. This mafic breccia is well exposed along the west shore of Brooks Lake, and has been traced eastward to Hawk Junction, a distance of at least 7 to 8 km. The Brooks Lake exposure is the best of the breccia outcrops observed, and serves as a local geological marker. Features in this outcrop can easily be destroyed:

NO HAMMERING OR SAMPLING OF THE OUTCROP ---- PLEASE.

At least three flow units can be differentiated on the basis of clast size distribution in the 100-metre section. Clast types show a wide range of compositions and textures; accretionary rinds are common to a large number of them. A few clasts display narrow bleached reaction rims up to 2 mm thick.

Rounded to angular clasts range up to 20 cm, and some are amygdaloidal. Midway through the section, a narrow breccia dyke cuts across the mafic breccia in a very irregular fashion. The jagged, clinkery weathered surface is due in part to the high carbonate content of the matrix relative to the clasts.

The breccia unit(s) have been interpreted as lahar(s) that mark the change from intermediate-mafic to intermediate-felsic volcanism within the 2750 Ma cycle. The unit most likely has significant petrological importance by marking the hiatus between two compositionally diverse magmas in strongly bimodal cyclic volcanism. The presence of laminated chert clasts within the breccia suggests that chemical sedimentation took place before brecciation, and thus this mafic breccia may mark the onset of intermediate-felsic volcanism rather than a terminal event of intermediate-mafic volcanism.

STOP 3k

Walk south along the west shore of Brooks Lake through the section of mafic breccia to the southeast corner of the lake. The first outcrop at the southeast corner of the lake is a carbonatized, amygdaloidal, intermediate to mafic metavolcanic rock.

(Stop 3k - 2)

Eastward along the trail that flanks the south shore of Brooks Lake, pillowed amygdaloidal intermediate to mafic metavolcanic rocks are exposed on the first point projecting into Brooks Lake. On the basis of pillow shapes, tops here are to the north.

A mafic dyke with chilled contacts cuts the pillowed intermediate to mafic metavolcanic rocks, which represent the stratigraphic top of the mafic portion of the 2750 Ma volcanic cycle. Large, abundant, mineral-filled vesicles characterize these volcanic rocks.

THIS COMPLETES THE TOUR OF THE STRATIGRAPHIC SECTION. RETURN TO THE LUCY PIT AND ENTER THE WEST END OF THE PIT.

STOP 31

While walking down the ramp to the pit floor, note the fissile and highly carbonatized stratigraphic footwall rocks on either side of the ramp. On the pit floor at the base of the ramp, a large block of carbonatized footwall rock contains large amygdaloidal angular to subangular fragments. Most of the vesicles are quartz filled, and some exceed one centimeter in their longest dimension.

From the large block of footwall rock, one can look at the pit face and observe the sharp contact between the massive siderite of the iron-formation and the footwall tuffs. Numerous references in the literature erroneously refer to this contact as gradational. This interpretation of a gradational lower contact provided support for nearly 50 years for genesis of the iron-formation and associated carbonate and sulphide rocks by replacement processes.

At the face of the pit, doubly terminated prisms and needle-like crystals of arsenopyrite can be seen in the massive siderite. These crystals do not appear to have grown into open space cavities, perhaps they grew in a siderite mud before lithification.

DO NOT HAMMER ON THE PIT FACE: MUCH OF THE ROCK ABOVE IS LOOSE AND MAY PRESENT A HAZARD..

North across the pit floor, large blocks composed of siderite and sulphide display delicate branching structures. They contain about equal amounts of sulphide and siderite, and provide the best representative samples of sulphide facies iron-formation in the immediate Wawa area. Massive beds of sulphide iron-formation in the Goudreau area northeast of Wawa commonly contain up to 90 percent granular, massive-textured sulphide.

the transition from massive siderite, at the base of the iron-formation, to bedded siderite with a gradual increase in the content of sulphide minerals can be seen readily. Banded chert first appears beyond the centre of the pit; the north wall of the pit consists mainly of grey to black thinly bedded graphitic chert.

Upon completing the traverse across the pit floor, one can walk east along the pit floor to the rib in the centre of the pit that projects approximately half way across the pit floor. Fine-grained circular, pisolitic-like and microbial-mat-like sulphide structures can be observed in the siderite. Over the years, weathering has tarnished these features, rendering them less obvious than they once were.

STOP 3m

On the way back to the vehicles we will stop at a very good exposure of cross-cutting phreatic explosion breccia in the footwall tuffs. Angular blocks of the tuff are cemented with silica and siderite at this outcrop, which is thought to be identical in origin to breccia dykes observed in the footwall of the Helen Iron Range, Stop 1. At this site, the position of the open pit at the base of the iron-formation is apparent. Looking eastward to a weathered exposure in the upper part of the iron-formation, offset of the iron-formation due to minor faulting can be observed.

STOP 3n

From the outcrop of phreatic breccia, walk up the slope a short distance to examine an outcrop of mafic breccia exposed in a drill road. The fragments are rounded to angular, highly vesicular, pervasively impregnated with carbonate and display both oval-shaped and elongated pipe-like vesicles. In bright sunlight the outcrop may sparkle due to the presence of randomly oriented porphyroblasts of chloritoid less than 1 mm in diameter. This unit likely is the same one examined at stop 3c.

Part 5

GEOCHEMICAL DATA ON IRON-FORMATIONS

G.A.GROSS

Analytical data for 18 to 25 elements in five Algoma type iron-formations are summarized in Table 1 for general reference. The iron-formations at the Adams Mine, Sherman Mine, and Helen Mine - Wawa areas have been described in previous sections of this guidebook. The Kukatush iron-formation, situated a few kilometres south of Highway 101 about 80 km southwest of Timmins consists of oxide facies associated mainly with mafic, ultramafic and felsic volcanic rocks. The Moose Mountain iron-formation is situated north of Capreol and is associated with mafic volcanic rocks and greywacke sediments. The samples analyzed were collected from the various oxide facies mined at the Moose Mountain property.

The average content of most elements in the five iron-formations of Table I are of the same magnitude as the average for all Algoma type oxide facies recorded in the IFCHEM file of the Geological Survey of Canada. The standard deviation data indicate that individual elements vary greatly in content within a given facies unit or single iron-formation member. The average gold content shown for the Temagami iron-formation is the same as the average obtained from 63 samples taken from 27 Algoma type iron-formations.

TABLE 1: MEAN CONTENT OF ELEMENTS IN ALGOMA TYPE IRON-FORMATION
ADAMS MINE, SHERMAN MINE-TEMAGAMI, KUKATUSH, MOOSE MOUNTAIN, HELEN-IF-WAWA AREA
PART 1 Content of elements in per cent, Au in ppm

	SiO2	Al2O3	CaO	MgO	Na2O	K2O	H2Otot	CO2	S	As	Ba	P	Au ppm
(M.L.)	0.4	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.04	0.5	0.001	0.02	0.001
ADAMS MINE:	OXIDE FACIES												
MEAN	53.64	0.44	2.13	1.62	0.10	0.15	0.22	0.48	0.17	0.0004	0.006	0.07	0.07
S.D.	10.8	0.3	2.2	0.8	0.2	0.2	0.2	0.7	0.2	0.002	0.006	0.03	-
N	59	59	59	59	59	59	59	59	59	56	59	59	2
TEMAGAMI:	OXIDE FACIES												
MEAN	55.22	1.20	0.77	1.56	0.04	0.10	1.27	0.76	0.30	-	0.003	0.05	0.04
S.D.	16.6	1.8	1.3	2.3	0.1	0.4	1.5	1.7	1.5	-	0.004	0.05	0.04
N	121	119	111	121	121	121	121	121	121	0	95	121	7
TEMAGAMI:	SULPHIDE FACIES												
MEAN	31.38	1.99	1.02	1.69	0.01	0.12	3.47	1.68	16.68	-	0.002	0.12	0.05
S.D.	24.2	2.3	1.7	1.1	.0	0.1	1.7	3.1	10.1	-	0.003	0.2	0.006
N	9	9	9	9	9	9	9	9	9	0	8	9	3
KUKATUSH:	OXIDE FACIES												
MEAN	62.05	0.51	0.69	1.55	0.11	0.15	1.20	2.88	0.23	0.003	0.003	0.06	-
S.D.	16.4	0.4	1.0	0.7	0.2	0.08	0.6	2.3	0.2	0.006	0.001	0.04	-
N	30	30	30	30	30	30	30	30	30	12	30	30	0
MOOSE MOUNTAIN:	OXIDE FACIES												
MEAN	42.15	0.59	1.58	1.89	0.10	0.11	0.57	0.27	0.2128	0.0008	0.007	0.05	0.05
S.D.	16.0	0.4	0.6	0.6	0.2	0.1	0.2	0.3	0.4	0.003	0.01	0.03	0.01
N	39	39	39	39	39	39	39	39	39	38	39	39	4
*HELEN-B4:	MAGNETITE CHERT FACIES												
MEAN	78.0	0.10	0.70	1.95	-	0.008	-	-	0.42	0.02	-	0.026	0.002
S.D.	6.1	0.06	0.32	0.47	-	0.01	-	-	0.33	0.01	-	-	0.006
N	23	23	23	23	-	11	-	-	23	23	-	11	9
*HELEN-A3:	SIDERITE PYRITE FACIES												
MEAN	7.1	0.84	0.92	3.97	-	0.08	-	-	6.7	0.02	-	0.026	0.002
S.D.	5.5	1.37	0.20	0.30	-	0.08	-	-	2.65	0.01	-	-	0.0002
N	5	5	5	5	-	3	-	-	5	5	-	5	3

Note: Statistical calculations are based on element content reported
ML = Measurement limit SD = Standard deviation N = Number of samples
* (GOODWIN ET AL. 1985) HELEN IRON-FORMATION
GROSS, 1990, In, ANCIENT BANDED IRON-FORMATIONS, Theophrastus Publications, Athens

Table 1: Part 1
Mean content of elements in Algoma type iron-formation.

TABLE 1: MEAN CONTENT OF ELEMENTS IN ALGOMA TYPE IRON-FORMATION
ADAMS MINE, SHERMAN MINE-TEMAGAMI, KUKATUSH, MOOSE MOUNTAIN, HELEN-IF-WAWA AREA

PART 2

	FeO	Fe2O3	Fe	Mn	Ti	V	Cr	Co	Ni	Cu	Zn	Sr	Zr	Y
(M.L.)	0.1	0.1	0.1	0.002	0.003	0.002	0.001	0.001	0.001	0.0007	0.002	0.001	0.003	0.002
ADAMS MINE:	OXIDE FACIES													
MEAN	12.81	28.17	29.68	0.04	0.01	0.002	0.001	0.0003	0.0008	0.002	0.004	0.004	0.0005	0.001
S.D.	3.6	8.2	8.5	0.05	0.005	0.0009	0.0009	0.0001	0.0006	0.004	0.001	0.004	0.0003	0.0004
N	58	58	58	59	59	58	54	38	45	59	59	59	59	59
TEMAGAMI:	OXIDE FACIES													
MEAN	13.52	24.84	27.90	0.09	0.05	0.009	0.007	0.004	0.01	0.02	0.003	0.003	0.005	0.005
S.D.	5.8	12.3	13.04	0.1	0.15	0.013	0.03	0.006	0.03	0.08	-	0.004	0.002	0.001
N	120	120	120	121	97	33	71	59	73	70	2	57	54	53
TEMAGAMI:	SULPHIDE FACIES													
MEAN	12.34	28.70	29.68	0.33	0.05	0.006	0.004	0.007	0.019	0.03	0.006	0.009	0.007	0.005
S.D.	5.3	14.0	13.7	0.3	0.06	0.002	0.001	0.004	0.017	0.04	-	0.004	0.005	0.003
N	5	5	5	8	9	4	5	8	9	9	1	3	4	5
KUKATUSH:	OXIDE FACIES													
MEAN	13.68	16.97	22.52	0.06	0.008	0.002	0.003	0.0002	-	0.002	0.006	0.002	0.0006	0.0006
S.D.	4.7	11.1	11.2	0.04	0.004	0.0007	0.003	0.0001	-	0.002	0.003	0.003	0.0004	0.0005
N	29	29	29	30	30	15	23	10	0	29	30	29	28	29
MOOSE MOUNTAIN:	OXIDE FACIES													
MEAN	16.26	37.42	38.83	0.05	0.01	0.003	0.0008	0.0004	0.0003	0.001	0.006	0.002	0.0006	0.001
S.D.	4.6	11.6	11.6	0.03	0.01	0.002	0.0004	0.0003	0.0002	0.001	0.002	0.002	0.0005	0.0004
N	37	37	37	39	39	38	34	17	29	36	39	39	39	39
*HELEN-B4:	MAGNETITE CHERT FACIES													
MEAN	-	-	15.2	0.51	0.018	-	-	-	-	0.0005	0.003	0.0008	0.0006	0.0005
S.D.	-	-	2.9	0.10	-	-	-	-	-	0.0007	0.002	0.0009	0.0003	0.0003
N	-	-	23	23	11	-	-	-	-	9	9	6	6	6
*HELEN-A3:	SIDERITE PYRITE FACIES													
MEAN	-	-	37.8	2.12	0.07	-	-	-	-	0.0009	0.004	0.0006	0.003	0.002
S.D.	-	-	2.1	0.27	-	-	-	-	-	0.0014	0.0005	0.0009	0.004	0.0003
N	-	-	4	4	4	-	-	-	-	3	3	3	3	3

Table 1: Part 2
Mean content of elements in Algoma type iron-formation.

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