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# STRATIGRAPHY AND SEDIMENTOLOGY OF THE LORRAIN FORMATION, HURONIAN SUPERGROUP (APHEBIAN), BETWEEN SAULT STE. MARIE AND ELLIOT LAKE, ONTARIO, AND IMPLICATIONS FOR STRATIFORM GOLD MINERALIZATION

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ABSTRACT

The Lorrain Formation is a thick (maximum 2500m) deposit of meta-sedimentary rocks in which three regional subdivisions are recognized: 1) a Lower Unit (maximum thickness 638m), characterized by varicoloured feldspathic sandstones and minor amounts of shales, that contains poorly preserved sedimentary structures; 2) a Middle Unit (maximum thickness 1311m), consisting of cross stratified hematitic quartzose sandstones and interbedded quartz and jasper pebble conglomerates, that is locally red; and 3) an Upper Unit (maximum thickness 762m), distinguished by white quartzose sandstones that contains poorly preserved sedimentary structures. Locally, five to eight members or map units are distinguishable.

Eight recurrent lithofacies types are defined, including two conglomerate lithofacies (massive conglomerate and crudely cross stratified conglomerate), five sandstone lithofacies (massive sandstone, planar cross bedded sandstone, trough cross bedded sandstone, horizontally laminated sandstone and rippled sandstone), and one shale lithofacies (horizontally laminated shale). The eight lithofacies types are grouped into four lithofacies assemblages and interpreted environmentally as: 1) transitional marine deposits (massive sand-stone assemblage); 2) distal fluvial (wet) fan deposits (pebbly sandstone assemblage and cross bedded sandstone assemblage); and 3) proximal fluvial (wet) fan deposits (conglomerate assemblage).

The Lower Unit was deposited rapidly in a transitional environment following deglaciation and deposition of Gowganda sediments. Isostatic rebound, climatic change and/or tectonic uplift resulted in the progradation of a series

of coalescing fluvial fans (Middle Unit) transverse to the depositional basin. A decrease in uplift coupled with a rise in sea level resulted in the reworking of previous deposits, primarily by waves and wind, and deposition of the Upper Unit. Stratigraphically, the Lorrain Formation records a regressive event (transitional deposits of the Lower Unit and distal and proximal fluvial fan deposits of the Middle Unit), succeeded by a transgressive event (proximal and distal fluvial fan deposits of the Middle Unit and transitional deposits of the Upper Unit).

Stratiform gold mineralization (averaging 4.5 ppb) is interpreted as Witwatersrand-type sedimentary paleoplacer concentrations. Heavy mineral laminae (principally specularite) probably formed by selective sorting (i.e. lighter and larger quartz grains were entrained and transported at a higher rate than heavier and smaller specularite and gold grains). The Middle Unit of the Lorrain Formation (pebbly sandstone and cross bedded sandstone assemblages, representing distal fluvial fan deposits) has the greatest potential for hosting economic gold deposits.

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# 1. INTRODUCTION

## 1.1 Scope of Study

The Lorrain Formation is a thick (maximum 2500m) deposit of metasedimentary rocks, consisting predominantly of sandstones with minor amounts of interbedded conglomerates and shales. It forms part of the Huronian Supergroup of northern Ontario that was deposited during the Early Proterozoic (Aphebian), approximately 2.5 to 2.15 Ga (Frarey, 1977). The origin of the formation is enigmatic and environments of deposition suggested for all or part of the strata include marine (Collins, 1925, Pirie, 1961, Card, 1967, Hadley, 1968, Pettijohn, 1970, Young, 1973), transitional (Hadley, 1968, Casshyap, 1969, Siemiatkoska, 1977, 1978), and continental (Collins, 1925, Pettijohn, 1957, Frarey and Roscoe, 1970, Young, 1973, Wood, 1975, Frarey, 1977, Siemiatkowska, 1977, 1978, Bennett, 1982, Chandler, 1984). Recently, the strata have been identified as hosting Witwatersrand-type paleoplacer gold mineralization (Colvine, 1981, Mossman and Harron, 1983, 1984), and have become the focus of intensive sedimentologic and exploration activity (Colvine, 1981, 1982, Long, Leslie and Colvine, 1982, Long and Colvine, 1984, Tortosa, 1984, Lowey and Long, 1985).

The present study is part of a long-term project to investigate the stratigraphy, sedimentology and stratiform gold potential of the Huronian Supergroup (Innes and Colvine, 1979, Colvine, 1981, 1982, 1983, Long, 1981, Long and Leslie, 1982, Long, Leslie and Colvine, 1982, Long and Lloyd, 1983, Meyer, 1983, Mossman and Harron, 1983, 1984, Long and Colvine, 1984, Tortosa, 1984, Lowey and Long, 1985, Long, in press). The purpose of this paper is to provide a better understanding of the depositional setting of the Lorrain

Formation and the distribution of gold mineralization. It discusses the Lorrain Formation exposed only in the area north of Lake Huron and between Sault Ste. Marie and Elliot Lake, Ontario (Fig. 1).

Field work was carried out during July and August, 1984. Approximately 800m of detailed stratigraphic sections were measured; 390 samples, including 121 samples for general lithology and 269 samples for geochemical analysis were collected; and approximately 300 paleoflow measurements were made. In all, 163 geologic control stations were established (Fig. 2). The textural and mineralogical classifications of Folk et al. (1970) and the shale classification of Potter et al. (1980) are utilized in this report.

## 1.2 Acknowledgements

This paper is based on research undertaken by the author while at Laurentian University as a Postdoctoral Fellow. Financial support was arranged by Dr. F.W. Chandler in the form of a personal service contract with the Geological Survey of Canada. Additional financial support was provided by an NSERC grant to Dr. D.G.F. Long. A.J. Fox performed admirably as field assistant. Discussions with Drs. Long and Chandler concerning Huronian stratigraphy and sedimentation was gratefully appreciated. An earlier version of this report was read by Dr. Long who made several helpful suggestions.

## 1.3 Previous Work

The majority of the project area was mapped by Frarey (1977) who provides a succinct description of previous geologic investigations. Additional summaries are provided by Hadley (1968) and Pearson (1980). Further mapping of exposures of the Lorrain Formation within the project area includes reports by Robertson (1970), Wood (1975), Siemiatkowska (1977, 1978) and Bennett (1982).

## 1.4 Regional Geologic Setting

A complete synthesis of the regional geologic setting of northern Ontario was made by Card et al. (1972). Additional summaries are reported by Roscoe (1969), Frarey and Roscoe (1970) and Frarey (1977).

The Lorrain Formation is the second formation of the Cobalt Group, which is the stratigraphically highest subdivision of the Huronian Supergroup (Table 1). The Huronian Supergroup is an extremely thick (maximum 15 km) sequence of metamorphosed sandstones, conglomerates and shales, and minor amounts of limestone and volcanic rocks, that generally thickens toward the south. It crops out in a belt 60 km wide between Sault Ste. Marie, Ontario, and Noranda, Quebec (Fig. 3).

The Huronian Supergroup is part of the Southern Province. This is characterized by Aphebian to Helikian in age sedimentary and volcanic rocks that rest unconformably on Archean granitic, sedimentary and volcanic rocks at the southern marin of the Superior Province. The Supergroup is also in fault and metamorphic contact along the Grenville Front with Helikian in age migmatitic rocks in the Grenville Province to the southeast (Card et al., 1972, Goodwin, 1972, Wynne-Edwards, 1972).

Strata of the Huronian Supergroup have been regionally metamorphosed and locally, alteration ranges up to amphibolite facies, although greenschist facies is prevalent (Card et al., 1972). The most important structural feature is the Murray Fault, an east-west trending fault zone that may have influenced Huronian deposition, since strata are reported to thicken appreciably across the fault (Roscoe, 1969, Card et al., 1972). Frarey (1977) disputes this interpretation and presents evidence that, at least in the western half of the Huronian belt, strata does not thicken appreciably across the fault.

## 2. STRATIGRAPHY

### 2.1 Introduction

On a local scale five (Hadley, 1968) to eight (Robertson, 1970) members or map units have been recognized in the Lorrain Formation (Table 2). The contacts between these members or map units are gradational, rendering the subdivisions arbitrary. Only the uppermost unit (White Quartzite) can be traced throughout the entire project area with any certainty. The remaining subdivisions display a change in colour, texture or thickness between Sault Ste. Marie and Elliot Lake. These regional changes may be related to the overlapping of sediments derived from at least two major provenance terranes (Hadley, 1968) and are discussed further in the section on sedimentology.

Young (1973) suggested that on a regional scale the Lorrain Formation is amenable to a threefold subdivision (Table 2): 1) a lower unit, characterized by feldspathic sandstones and minor amounts of shales, that contains poorly preserved sedimentary structures and is locally red, green or yellow; 2) a middle unit, consisting of cross stratified hematitic quartzose sandstones and quartz and jasper pebble conglomerates, that is locally white or red; and 3) an upper unit, distinguished by white quartzose sandstones, that contain poorly preserved sedimentary structures. Young's threefold subdivision is followed in this report.

## 2.2 Descriptive Stratigraphy

### 2.2.1 Lower Unit

Throughout most of the project area the Lower Unit of the Lorrain Formation and the underlying Gowganda Formation are in intergradational contact. The base of the Lorrain Formation is generally placed at the top of an upper shale member in the Gowganda Formation (Frarey, 1977, Bennett, 1982, Wood, 1975), or where the sandstones display an increase in grain size, individual feldspar grains change colour from light red to fine-grained sandstones to dark red in coarse-grained sandstones, and the overall colour of the sandstones changes from light red to dark red or light green (Siemiatkowska, 1977, 1978). Where the Gowganda Formation is missing (i.e. northern part of the Rawhide Lake area), the Lorrain Formation rests non-conformably on Archean basement rocks (Wood, 1975).

The Lower Unit consists of varicoloured feldspathic sandstones and minor amounts of interbedded shales. The feldspathic sandstones are mostly light to dark red and grey, but locally are light yellow or light green in the Mount Lake area, and weather the same colour. Texturally they range from fine- to coarse-grained sandstone, to slightly gravelly coarse-grained sandstone. The modal grain size is medium-grained sand. Mineralogically they are classified as feldsarenites to subfeldsarenites with quartzarenites and sublitharenites locally present, particularly in the Mount Lake area. Hematite is locally abundant and in the Mount Lake area the sandstones are radioactive (Robertson, 1970). Beds are planar and range from 0.1 to 3m in thickness. They are mostly massive, although planar cross bedding, trough cross bedding and symmetric ripple marks are locally abundant. Syneresis marks are also present. Beds generally exhibit abrupt contacts.

The interbedded shales are most abundant in the Echo Lake area and Rock-Desbarats Lake area, where they form relatively thick (15 to 30 m) and distinctive members termed the Purple Siltstone (Frarey, 1977) and the Red and Purple Siltstone (Bennett, 1982). They are light to dark red or purple and weather the same colour. Texturally they range from claystone to very fine-grained sandstone, with coarse-grained silt the predominant grain size. The shales are classified mineralogically as feldslutites to subfelds-lutites and contain a hematite matrix. They form planar beds ranging from 0.1 to 1 m in thickness and are massive. Parting lineation, groove marks, flame structures and ball and pillow structures are present in the Echo Lake area (Bennett, 1982).

The Lower Unit attains a maximum thickness of 638m.

### 2.2.2 Middle Unit

The Middle Unit overlies the Lower Unit gradationally. It consists of cross stratified quartzose sandstones and interbedded quartz and jasper pebble conglomerates. Generally, either sandstone or conglomerate predominates and this provides the basis for a threefold subdivision into the Lower Red Quartzite, the Jasper Conglomerate and the Upper Red Quartzite members by Frarey (1977) and similar subdivisions by other authors, with the exception of the Rawhide Lake area (see Table 2).

The quartzose sandstones are light red and white or rarely light green, and weather light red and white. Texturally they range from very fine-grained sandstones, to slightly gravelly coarse-grained sandstones, with clasts up to 8.5 cm long. Medium- and coarse-grained sand is the most abundant grain-size. Mineralogically the sandstones are classified as quartzarenites to sublitharenites. Clasts composition is the same as in the conglomerate beds and is described below. Hematite is abundant, especially as concentrations of specularite or cross stratification surfaces. Bedding is lenticular and ranges up to 1.8 m in thickness. Trough cross bedding and planar cross bedding are ubiquitous. Symmetrical ripple marks, graded planar cross bedded foresets, load structures and convolute lamination are also present. Contacts between beds are abrupt or gradational.

The pebble conglomerates are white or white and light red and weather the same colour. They are composed of sandy conglomerate with clasts ranging from 2mm to a maximum length of 30 cm, although pebbles 2 to 3 cm long are most common. Clast composition includes white vein quartz, quartzite, red jasper, red and grey banded jaspilite and grey and black chert. In the west half of the project area (approximately west of the Wakomata-Endikai Lake area) the conglomerates consist of 10 to 40% red jasper and chert (Plate 1) and are classified as lithrudites. Whereas in the east half of the project area the conglomerates contain less than 5% (and commonly less than 1%) jasper and chert and instead consist almost entirely of vein quartz (Plate 2), and are classified as quartzrudites. Beds are lenticular and range up to 8m thick. They are massive and rarely crudely planar cross bedded. Bedding contacts are erosional, abrupt or gradational.

The maximum thickness of the Middle Unit is approximately 1311m.

### 2.2.3 Upper Unit

The Middle Unit is overlain gradationally by the Upper Unit which consists of white quartzose sandstones and very minor amounts of interbedded conglomerates and shales. The quartzose sandstones are white or grey and rarely light red or light green, and weather white, light red, light green or light yellow. Texturally they range from fine- to very coarse-grained sandstone to slightly gravelly sandstone, with pebbles up to 7 cm long. The modal grain size is medium- to coarse-grained sand. Mineralogically the sandstones are classified as quartzarenites although sublitharenites and subfeldsarenites are present. Hematite is locally abundant. Beds are planar and range from 0.3 to 3m in thickness. They appear massive with rare planar and trough cross bedding, ripple marks and stromatoforms (stromatolite forms of uncertain organic origin) locally present (Plate 3). Bedding contacts are mostly abrupt but can also be erosional.

The interbedded conglomerates are white and weather the same colour. Clasts average 1.5 cm in length and consist of vein quartz and quartzite with rare jasper and chert pebbles. Beds are lenticular, ranging up to 0.3m thick and are massive with abrupt contacts.

The interbedded shales are light green and weather the same colour. They consist of silt and form beds ranging from 1 to 20 cm in thickness. The shales are horizontally laminated and rarely massive or rippled and beds display abrupt contacts.

The Upper Unit has a maximum thickness of approximately 762m. This unit is stratigraphically the highest subdivision of the Lorrain Formation and is intergradational with the overlying Gordon Lake Formation. The upper contact of the Lorrain Formation is generally placed at the appearance of abundant varicoloured shales (Frarey, 1977, Siemiatkowska, 1977, 1978), or where the thickness of sandstone beds decreases rapidly and where the first shale bed is greater than 2.5 cm in thickness (Wood, 1975).

## 2.3 Regional Stratigraphic Trends

As previously mentioned, the Huronian Supergroup thickens to the south, resulting in the progressive onlap of successively stratigraphically higher Huronian sediments onto Archean basement rocks in the north. In addition, the three regional units of the Lorrain Formation display a similar, though less apparent trend: that is, each unit generally thins in a north to northeasterly direction (Fig. 4). Within the Middle Unit there is a progressive decrease in both the maximum grain size and in the thickness of conglomerate beds from north to south.

Strata representing the proximal and distal basin facies equivalent of the Lorrain Formation are not exposed throughout the entire Huronian belt. It remains to be demonstrated whether the three regional units of the Lorrain Formation progressively onlap and pinch-out to the north and whether these units thicken and then thin to the south until they gradually pinch-out or if they terminate abruptly against rocks representing the basin floor.

# 3. SEDIMENTOLOGY

## 3.1 Lithofacies Types

Eight stratigraphically repeated lithofacies types were recognized in the Lorrain Formation (Table 3). The lithofacies types were defined on the basis of texture and sedimentary structures of individual beds (whose minimum thickness was 1 cm). They were assigned a mnemonic code adapted from the system of Miall (1977, 1978) that allowed the rapid measurement and description of the approximately 800m of detailed stratigraphic section. In this code system the first letter refers to the predominant texture (i.e. gravel, sand or mud) and the second letters refers to the dominant sedimentary structure (i.e. 'm' for massive, 'p' for planar cross bedded, etc.).

### 3.1.1 Lithofacies Gm: Clast supported, massive conglomerate

Lithofacies Gm is common throughout the project area and consists of clast supported, sandy conglomerate (Plates 4, 5 and 6). Clast size ranges up to 30 cm in length, with clasts 2 to 3 cm long the most common grain size. They form lenticular beds up to 8m in thickness that are internally massive. Both the lower and upper bedding contacts can be abrupt or gradational. Lithofacies Gm is overlain by lithofacies Sm or Sp.

### 3.1.2 Lithofacies Gp: Matrix Supported, crudely planar cross bedded conglomerate

This lithofacies is rare. It is composed of coarse-grained sandy conglomerate in which the conglomerate clasts are generally supported by the sandy matrix (Plate 7). Clast size averages 1 to 2 cm in length. Lithofacies Gp occurs as lenticular beds less than 0.3m thick. They are crudely planar cross bedded and the lower and upper bed contacts are abrupt. It is overlain by lithofacies Sm.

### 3.1.3 Lithofacies Sm: Massive sandstone

Lithofacies Sm is the most abundant lithofacies throughout the project area. It includes very fine- to coarse-grained sandstone and slightly gravelly coarse-grained sandstone (Plates 8 and 9). Graded bedding (from a thin conglomerate base into sandstone) is rarely present. Medium-grained sand is the most common grain size and conglomerate clasts range up to 2 cm in length. Lithofacies Sm forms planar beds ranging from 0.1 to 3m in thickness that are internally massive. The lower and upper bedding contacts can be erosional, abrupt or gradational surfaces. This lithofacies is overlain by lithofacies Sp, Gm or Ml.

### 3.1.4 Lithofacies Sp: Planar cross bedded sandstone

This lithofacies is common. It ranges from very fine- to coarse-grained sandstone to slightly gravelly coarse-grained sandstone, with a modal grain size of medium-grained sand (Plates 10 and 11). Lenticular beds up to 1.8m in thickness are common. Internally, the beds are planar cross bedded and rarely occurs as coesets. Graded foresets are locally present. The lower and upper bedding contacts are erosional or abrupt. Lithofacies Sp is overlain by lithofacies Sm, St or Gp.

### 3.1.5 Lithofacies St: Trough cross bedded sandstone

Trough cross bedded sandstones are also common and consist of fine-to coarse-grained sandstone and slightly gravelly medium-grained sandstone (Plate 12 and 13). The most abundant grain size is medium-grained sand, and conglomerate clasts range up to 2 cm in length. This lithofacies forms lenticular beds up to 1.8m in thickness that are trough cross bedded. Trough cross bedding almost always occurs as coesets. Bedding contacts for the lower and upper surfaces are erosional, abrupt or gradational. Lithofacies St is commonly overlain by lithofacies Sp.

### 3.1.6 Lithofacies Sl: Horizontally laminated sandstone

This lithofacies is rare and is composed of fine-grained sandstone (Plate 14). It forms planar beds ranging from 0.2 to 0.5m in thickness that are horizontally laminated. Bedding contacts are abrupt. Lithofacies Sl is overlain by lithofacies Sm or Sp.

### 3.1.7 Lithofacies Sr: Rippled sandstones

Lithofacies Sr is also rare. It consists of fine-grained sandstone that forms planar beds ranging from 2 cm to 1m in thickness that contain symmetric ripples (Plates 15 and 16). Bedding contacts are abrupt and this lithofacies is commonly overlain by lithofacies Sm.

### 3.1.8 Lithofacies Ml: Laminated shale

Laminated shale beds are rare and range from 1 cm to 20 cm in thickness (Plates 17 and 18). Silt is the predominant grain size. Contacts are abrupt. Lithofacies Ml is overlain by lithofacies Sm.

### 3.2 Lithofacies Assemblages

The eight lithofacies types can be grouped into four lithofacies assemblages (Table 4). These are naturally occurring vertical associations of lithofacies types and provide the basis for interpreting the environments of deposition of the Lorrain Formation.

#### 3.2.1 Conglomerate Assemblage

Description

The conglomerate assemblage (Fig. 5 and 6) is characterized by 10 to 90% conglomerate (based on the percentage of cumulative thickness of lithofacies Gm and Gp in measured stratigraphic sections). Massive sandstones (Sm) are also important. Planar cross bedded conglomerates (Gp) and sandstones (Sp) are present locally. This assemblage is restricted to the Middle Unit of the Lorrain Formation and corresponds approximately to the Jasper Conglomerate Member (d) of Frarey (1977) and similar units of other authors (see Table 2).

Interpretation

Thicker (greater than 0.3m) beds of massive, clast supported conglomerate are interpreted as amalgamated, multistorey longitudinal gravel bars, whereas thinner (less than 0.3m) beds probably formed as channel lag gravels. Conglomerate beds displaying planar cross bedding are interpreted as transverse bars. Together, the conglomerate beds represent deposition in relatively deep (greater than 1m) channels. The planar and massive sandstones were probably deposited as transverse or linguoid sand bars or sand waves in relatively shallower channels and in overbank areas during floods.

The conglomerate assemblage is similar to the Donjek-type and $G_{111}$-type distal gravelly braided river models of Miall (1978) and Rust (1978), respectively. It is interpreted as gravelly braided river deposits.

### 3.2.2 Pebbly Sandstone Assemblage

Description

The pebbly sandstone assemblage (Fig. 7) is distinguished by massive and planar cross bedded, slightly gravelly sandstones (Sm and Sp) that display graded bedding from a pebbly base and by less than 10% conglomerate (Gm). Trough cross bedded sandstones (St) are locally present. This assemblage occurs in the Middle Unit and corresponds approximately with the Lower Red Quartzite Member (c) and the Upper Red Quartzite Member (e) of Frarey (1977) and similar units of other authors (see Table 2). It is occasionally present in the Jasper Conglomerate Member (d) of Frarey (1977, and see Table 2).

Interpretation

The planar cross bedded pebbly sandstones are interpreted as sandy transverse or linguoid bars or sand waves that accumulated over very thin channel lag gravels in relatively deep channels. The massive pebbly sandstones may simply contain cryptic sedimentary structures and formed as similar bedforms to the planar cross bedded sandstones. Alternatively, they may be interpreted as planar bed flow deposits that accumulated during flash flood conditions. The rare conglomerate beds are interpreted as transverse bars. Slightly pebbly trough cross bedded sandstones were probably deposited as migrating sand dunes in relatively shallow channels.

The pebbly sandstone assemblage is similar to the Platte-type sandy braided river model of Miall (1978) and the $S_{11}$-type sandy distal braided river and alluvial plain model of Rust (1978). It is also similar to Miall's (1978) Bijou Creek-type model and Rust's (1978) $S_1$-type model, representing proximal sandy braided rivers subject to violent flash floods. The pebbly sandstone assemblage is interpreted as sandy braided river deposits.

### 3.2.3 Cross Bedded Sandstone Assemblage

Description

This assemblage (Fig. 8) consists of trough cross bedded sandstones (St) and planar cross bedded sandstones (Sp) and less than 10% conglomerate (Gm). Minor amounts of massive sandstone (Sm) and horizontally laminated sandstone (Sl) are sometimes present. The cross bedded sandstone assemblage is confined to the Middle Unit, and corresponds approximately with Frarey's (1977) Lower Red Quartzite (c) and Upper Red Quartzite (e) members (see Table 2).

Interpretation

The trough cross bedded sandstones are interpreted as sinuous crested sand dune deposits that accumulated in relatively shallow and poorly defined channels. Interpretations for planar and massive sandstones are similar to those in the previous assemblage. The horizontally laminated sandstones probably represent planar bed flow in very shallow channels during upper flow regime conditions.

The cross bedded sandstone assemblage is nearly identical to the South Saskatchewan-type sandy braided river model of Miall (1978). It is also similar to the $S_{11}$-type distal braided river and alluvial plain model of Rust (1978). This assemblage is interpreted as sandy braided river deposits.

### 3.2.4 Massive Sandstone Assemblage

Description

The massive sandstone assemblage (Fig. 9, 10 and 11) is dominated by massive sandstones (Sm) with very minor amounts of planar cross bedded sandstones (Sp), rippled sandstones (Sr) and laminated shales (Ml). This assemblage occurs in both the Lower Unit and the Upper Unit of the Lorrain Formation. It corresponds approximately with the Basal Arkose Member (a), the Purple Siltstone Member (b) and the White Quartzite Member (f) of Frarey (1977) and similar units of other authors (see Table 2).

Interpretation

As previously mentioned, massive sandstones may simply contain cryptic sedimentary structures or planar bed flow deposits. Planar cross bedded sandstones are interpreted as sand waves or transverse or linguoid sand bars. Rippled sandstones probably formed during low flow regime conditions and possibly as the result of wave action in very shallow channel reaches. The horizontally laminated shales are interpreted as overbank and waning flood deposits.

The paucity of sedimentary structures permits very little sedimentologic interpretation for this assemblage. It is somewhat similar to the Bijou Creek-type and the $S_1$-type braided river models of Miall (1978) and Rust (1978), respectively. However, the fact that glaciomarine and marine sediments (Gowganda Formation) underly the assemblage (Lindsey, 1969, Miall, 1983), and shallow marine and paralic sediments (Gordon Lake Formation) overly the assemblage (Wood, 1975, Frarey, 1977, Siemiatkowska, 1977, 1978), indicates that transitional deposits (i.e. shore zone) may be represented by this assemblage. In addition, the lack of any vegetative cover during the Proterozoic implies that eolian processes were active and may have resulted in deposition of part of this assemblage.

## 3.3 Paleoflow Directions

The most comprehensive paleoflow study of the entire Lorrain Formation was by Hadley (1968) who summarized much of the available paleoflow measurements and concluded that the data consistently indicates a southeast transport direction. Paleoflow measurements indicating almost every other transport direction, including northwest, have also been reported, but these measurements are considered statistically insignificant (Hadley, 1968).

Paleoflow vector means for all strata of the Lorrain Formation include: $163^{\circ}$ (Pettijohn, 1957), $112^{\circ}$ (Pirie, 1961) and $153^{\circ}$ (Hadley, 1968) in the Desbarats-Rock Lake area; $150^{\circ}$ in the Echo Lake area (Bennett, 1982); $166^{\circ}$ in the Wakomata-Endikai Lake area (Siemiatkowska, 1977); and $145^{\circ}$ in the Rawhide Lake area (Wood, 1975). Paleoflow measurements by the author indicate a similar trend: a vector mean of $133^{\circ}$ was determined for all strata of the Lorrain Formation in the entire project area (Fig. 12).

The three regional units of the Lorrain Formation display a wide range in transport direction. Paleoflow vector means for the Lower Unit include

131$^{\circ}$ in the Desbarats-Rock Lake area (Hadley, 1968) and 105$^{\circ}$ for the entire project area (Fig. 12). For the Middle Unit they include 157$^{\circ}$ in the Desbarats-Rock Lake area (Hadley, 1968), 166$^{\circ}$ in the Wakomata-Endikai Lake area (Siemiatkowska, 1977), 110$^{\circ}$ in the Rawhide Lake area (Wood, 1975) and 113$^{\circ}$ for the entire project area (Fig. 12). Paleoflow vector means for the Upper Unit include 160$^{\circ}$ in the Rawhide Lake area (Wood, 1975) and 130$^{\circ}$ for the entire project area (Fig. 12).

Based on paleoflow measurements and clast composition of conglomerates in the Middle Unit (particularly the Jasper Conglomerate Member of Frarey, 1977, and similar units of other authors, see Table 2), Hadley (1968, Fig. 85, p.244) determined two major provenance terranes for the Lorrain Formation: a northwest jasper-rich area and a northeast quartz-rich area. Paleoflow trends merge and composition of conglomerates change in the approximate vicinity of the Wakomata-Endikai Lake area (Hadley, 1968). On a local scale, paleoflow measurements indicate that Hadley's conclusions are an oversimplification of the data (D.G.F. Long, pers. comm., 1984); but on a regional scale, particularly for the project area, moving average statistics on paleoflow data supports the concept of two major source areas (Hadley, 1968, Fig. 61, p.166).

3.4 A Depositional Model

The Lower Unit of the Lorrain Formation consists of the massive sandstone assemblage, which is interpreted as sandy braided river deposits, shore zone deposits and/or eolian deposits. Since the underlying Gowganda Formation is generally regarded as glaciomarine and marine in origin (Lindsey, 1969, Miall, 1983), a transitional environment of deposition is suggested for the Lower Unit. Lack of visible sedimentary structures does not permit the delineation of sub-environments of deposition for this unit.

The Middle Unit of the Lorrain Formation consists of the conglomerate assemblage, the pebbly sandstone assemblage and the cross bedded sandstone assemblage. The conglomerate assemblage is interpreted as gravelly braided river deposits, whereas the pebbly sandstone and cross bedded sandstone assemblages are interpreted as sandy braided river deposits. These three assemblages can be interpreted as the deposits of a single depositional system: a wet (fluvial) fan (Schumm, 1977). As the name implies wet, fluvial fans are dominated by fluvial (braided) processes, including perennial and flash flood discharge (Galloway and Hobday, 1983). They are characterized by a larger surface area, a lower gradient, higher sedimentation rates, and a general downstream reduction in grain size from gravel to sand, than dry (alluvial) fans (Galloway and Hobday, 1983).

The conglomerate assemblage is interpreted as proximal fluvial fan deposits and the pebbly sandstone and cross bedded sandstone assemblages are interpreted as distal fluvial fan deposits (Fig. 13). The pebbly sandstone assemblage may represent a gradation from the conglomerate assemblage to the cross bedded sandstone assemblage, and could thus be interpreted as midfan deposits. However, additional field work is required to substantiate this interpretation. In addition, it is unclear whether the distal fan prograded into a continental environment or a transitional marine environment. If the latter were true, then the model envisaged here would be more correctly termed a fan-delta. Again, additional field work is required to clarify the interpretation, and the proposed model will be referred to simply as a fluvial fan.

The Middle Unit probably represents the coalescence of two or more fans.

The fluvial fan model proposed for the Middle Unit of the Lorrain Formation is analagous to the present day Kosi River fan (Gole and Chitale, 1966). This fan is approximately 200 km long and 100 km across at its widest point, and covers an area of 20,700 $km^2$ (Gole and Chitale, 1966, McGowen and Groat, 1971). The proximal fan surface has a gradient of approximately lm per km and boulder size gravels are present; the distal fan has a gradient of approximately 0.6m per km and consists almost entirely of sand (Gole and Chitale, 1966, Inglis, 1967, McGowen and Groat, 1971). Rainfall for this area averages 150 cm per year (McGowen and Groat, 1971), and during floods the fan is occupied by a "flowing sea" of water 15 to 30 km wide (Inglis, 1967). Major channel reaches are thought to migrate across the fan surface every 200 years, resulting in aggradation (Gole and Chitale, 1966). Several well documented ancient fluvial fan deposits similar to those proposed for the Middle Unit include the Precambrian (?) Van Horn Sandstone, Texas (McGowen and Groat, 1971), and the Lower Proterozoic Witwatersrand Supergroup, South Africa (Pretorius, 1975).

Like the Lower Unit, the Upper Unit of the Lorrain Formation also consists of the massive sandstone assemblage. In addition, the overlying Gordon Lake Formation is interpreted as shallow marine, lagoon and tidal flat deposits (Wood, 1975, Frarey, 1977, Siemiatkowska, 1977, 1978, Chandler, 1984), and so the Upper Unit is also interpreted as being deposited in a transitional environment. Again, lack of visible sedimentary structures do not permit the delineation of sub-environments of deposition within this unit, although the high mineralogical maturity of these sandstones indicates that beach and eolian environments were important.

## 3.5 Sedimentary History

It is beyond the scope of this paper to attempt a synthesis of the tectono-sedimentary evolution of the Lorrain Formation: many exposures of the formation have not been examined and much sedimentologic data remain to be analyzed and interpreted. A recent model (Young, 1983) suggests that Huronian strata older than the Cobalt Group accumulated in a restricted, east-west trending fault-bounded trough, possibly an aulacogen, and that the Cobalt Group (including the Lorrain Formation) was deposited in a broad east-west and northeast trending basin related to regional downwarping of the aulacogen. The following outline briefly summarizes the major depositional events for the Lorrain Formation in the project area.

The Lower Unit was probably deposited rapidly in a transitional environment following the main phase of deposition of Gowganda sediments and deglaciation. Isostatic rebound, climatic change and/or tectonic uplift of the drainage basin resulted in the progradation of a series of wet, fluvial fans transverse to the depositional basin (represented by the Middle Unit). A decrease in uplift coupled with a rise in sea level resulted in an overall transgressive event, and waves and wind reworked previously deposited sediments, forming the Upper Unit. Hence, stratigraphically, the Lorrain Formation records a regressive sequence (Basal Arkose, Purple Siltstone, Lower Red Quartzite and Jasper Conglomerate members of Frarey, 1977, see Table 2), succeeded by a transgressive sequence (Jasper Conglomerate, Upper Red Quartzite and White Quartzite members). It is postulated that the Lower Red Quartzite and Upper Red Quartzite members represent the same lithologic unit (deposited by the coalescence of distal fluvial fans) and merge distally (Fig. 13). Member boundaries are thus interpreted as diachronous.

## 4. Stratiform Gold Mineralization

### 4.1 Introduction

Samples collected for gold in 1984 have yet to be geochemically analyzed. However, samples collected during the Sudbury, Timmins, Algoma Mineral Program (STAMP) cover most of the project area. This was a regional lithogeochemical sampling program designed to identify areas with anomalous metal enrichment, principally within the Lorrain Formation and primarily for gold (Tortosa, 1984). It was initiated following reconnaissance work by Colvine (1981) that identified a unit of the Lorrain Formation consistently enriched in gold and of possible regional extent. Subsequent work indicated gold values up to 1200 ppb were present (Colvine, 1982, 1983), and recently, visible gold grains were discovered in strata of the Middle Unit in the Cobalt Embayment (A.C. Colvine, pers. comm., 1984).

### 4.2 Stratigraphic and Lithologic Controls of Mineralization

Lithogeochemical results from the STAMP program are presented in Table 5. Stratigraphically, the Upper Red Quartzite Member (Middle Unit) contains the highest average gold content (10.6 ppb). Lithologically, the average gold content is highest in heavy mineral laminae (7.4 ppb). Although laminae are present in all units of the Lorrain Formation they are most abundant in the Upper Red Quartzite Member.

Heavy mineral laminae occur on foresets of planar cross beds (Plates 24 and 25) and on basal surfaces of trough cross beds (Plates 12 and 13). They consist predominantly of very fine-grained specularite in which the grains are subrounded to rounded, of moderate sphericity, and are smaller in grain size than the enclosing quartzose sandstones. Minor amounts of epidote, monazite, rutile, zircon, pyroxene, hematite and magnetite-ilmenite have also been reported to occur in the laminae (Hadley, 1968). The roundness and sphericity of the specularite grains, their occurrence on cross bedded surfaces, and the fact that they show no replacement textures (particularly from original magnetite or ilmenite grains) indicates that they represent syngenetic, heavy mineral concentrations or placers. The correlation between heavy mineral laminae and the highest average gold content indicates that gold grains were also deposited as placers.

Heavy mineral laminae result from the larger and generally lighter grains being entrained and transported at a higher rate than the smaller and heavier grains (Slingerland, 1984). Slingerland (1984) identified three main areas at the bedform scale where heavy mineral laminae occur: 1) on the tops of sand bars; 2) on foresets in cross strata; and 3) on scoured bases of troughs. Heavy mineral accumulations on the tops of sand bars are due to entrainment sorting (larger and lighter grains are rolled away); accumulations on foresets are due to dispersive sorting of avalanching grain flows on the downstream side of sand bars; and accumulations at the base of troughs are due to suspension sorting of the upstream side of sand bars (Slingerland, 1984).

Heavy minerals are also concentrated in the matrix of thin pebble conglomerate beds (average gold content 4.4 ppb, Table 5). The accumulation of heavy minerals in gravel bars is due to the entrapment of the heavy grains in the coarser gravel bar tops and the continual erosion of the upstream bar surface, resulting in the progressive enrichment of heavy minerals (Slingerland, 1984). Heavy mineral accumulations in channel lag gravels are probably related to a similar process.

As previously mentioned, the Upper Red Quartzite Member (Middle Unit) contains the greatest abundance of heavy mineral laminae and pebble conglomerate beds with heavy minerals. Together they account for 2 to 3.3% of the strata (Hadley, 1968). This member corresponds approximately to the pebbly sandstone assemblage and the cross bedded sandstone assemblage, which are interpreted as distal fluvial fan deposits. Proximal fluvial fan deposits, represented by the conglomerate assemblage (and corresponding approximately to the Jasper Conglomerate Member, Middle Unit) contains abundant jasper and jaspilite clasts that were interpreted by Hadley (1968) to have been eroded from Archean banded iron formations north of the project area. Specularite grains forming placers in the distal fluvial fan deposits probably had a similar provenance. Gold within these placers was likely derived from Archean greenstone belts that are also situated north of the project area and possibly from the banded iron formations. Specularite (and gold) were probably flushed from the proximal fan due to the presence of higher flow regime conditions (i.e. conglomerates) and constant reworking, and were preferentially deposited in lower flow regime conditions (i.e. sandstones) present in the distal fan. Similar trends in heavy mineral concentrations in distal and midfan facies of ancient fluvial fan deposits have been reported for the Van Horn Sandstone (McGowen and Groat, 1971) and the Witwatersrand goldfields (Pretorius, 1975, 1976).

A diagenetic origin for gold mineralization in the Lorrain Formation has been proposed by Long (Lowey and Long, 1985, Long and Colvine, 1984, Long and Leslie, 1983). Magnetite (and ilmenite) is apparently absent in heavy mineral laminae in strata of the Middle Unit in the Cobalt Embayment (Long and Leslie, 1984), leading Long to suggest that gold mineralization was related to diagenetic alteration of primary magnetite placers to specularite and hematite. By diagenetic, Long (pers. comm., 1984) implied that the gold was either derived from within the same stratigraphic sequence (i.e. the Lorrain Formation) and simply remobilized (late diagenetic mineralization, Maynard, 1983), or was supplied from outside the system (i.e. the Lorrain Formation) and precipitated from surface waters (groundwater epigenetic mineralization, Maynard, 1983). Although the author concedes that oxidation of magnetite into some specularite and hematite may have occurred, there is no evidence that this resulted in, or was related to, primary mineralization of gold. In addition, while remobilization of metals within the Lorrain Formation is indicated by the occurrence of specularite and hematite in cross-cutting quartz veins, as coatings on joint surfaces (Plate 21) and as disseminated euhedral clots (Plate 22), this was probably of secondary importance in the concentration of the gold. A placer origin for the gold is favoured by the author because of the simplicity of the model and the lack of evidence indicating primary diagenetic or epigenetic gold mineralization. The subsequent secondary remobilization of metals was probably related to later regional metamorphic events.

The development of placers in the Lorrain Formation can best be described as Witwatersrand-type mineralization. That is, they formed in "response to a high energy environment on the edge of a regressing basin, and the host rocks to the mineralization were essentially coarse clastics, although fine clastics also assumed considerable importance. Non-clastics found no place in the model of a Witwatersrand-type goldfield, and chemical precipitation of gold played a very minor role. The goldfields took the form of fluvial fans or fan deltas, ..., and developed relatively close to the source area, so that the distance of fluvial transportation was comparatively short" (Pretorius, 1976, p.16). The Lorrain Formation is unlike the type Witwatersrand goldfields in that it does not contain pyrite or thucholite, but it is nearly identical to the Tarkwa goldfield in Ghana (another Witwatersrand-type paleoplacer).

The Tarkwa goldfield formed during Early Proterozoic time from a series of coalescing alluvial fans (Sestini, 1973). Hematite, interpreted as detrital in origin (Sestini, 1973, Boyle, 1979, Pretorius, 1981), occurs with rutile and zircon as heavy mineral laminae in cross stratified sandstones and as a matrix in pebble conglomerate beds. Gold is intimately associated with the detrital hematite, averages 0.06 mm in size (silt-sized grains), and was originally derived from primary quartz veins situated west of the depositional basin (Sestini, 1973, Boyle, 1979, Pretorius, 1981). The highest ore bearing zones (or reefs) are commonly less than 1m in thickness (Sestini, 1973) and average 80m wide and 400m long (Pretorius, 1981). Within these zones, gold is concentrated in very thin conglomerate beds and thus represent relatively small exploration targets.

## 4.3 Guidelines for Exploration

Stratiform gold mineralization in the Lorrain Formation is interpreted as sedimentary placer accumulations. Successful exploration for placers must take into account the sedimentologic controls of mineralization. Minter (1979) presented some criteria for locating Witwatersrand-type paleoplacer deposits. The following additional guidelines may aid in the search for paleoplacer deposits in the Lorrain Formation:

1) Based on regional geologic setting and paleoflow trends, select areas of the Lorrain Formation that are south of (and underlain by) auriferous Archean greenstone belts and banded iron formations;

2) Within these areas, select strata of the Lorrain Formation that corresponds to the Upper Red Quartzite Member (upper Middle Unit), representing the distal fan facies (i.e. the pebbly sandstone assemblage and the cross bedded sandstone assemblage);

3) Within this strata, selectively sample hematite and specularite laminae (heavy mineral laminae) and thin hematitic pebble conglomerate beds; generally, samples should be taken near, and including, the base of the conglomerate beds (and where it is possible to determine from paleoflow measurements, from the upstream side of conglomerate beds).

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Table 1.

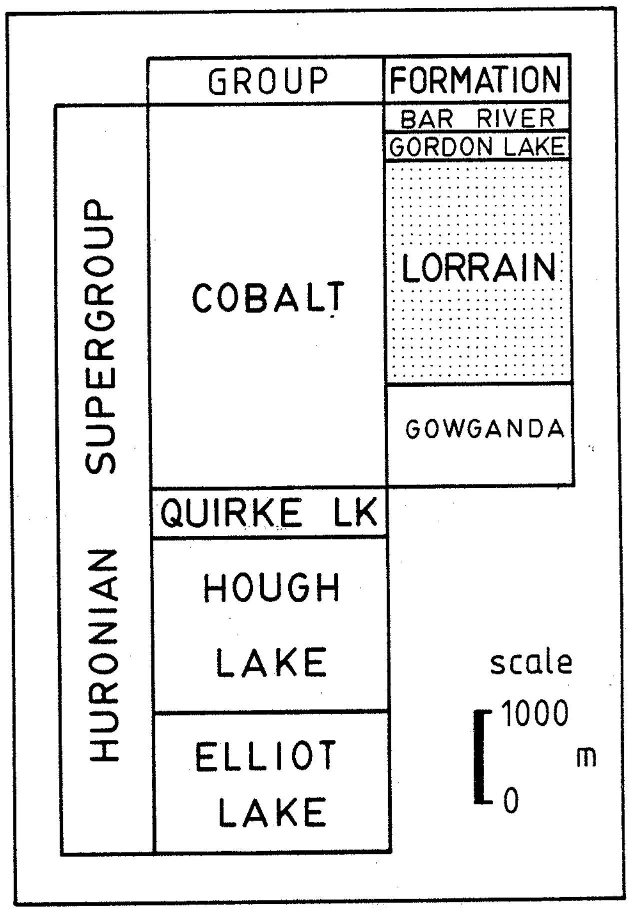

GROUP
FORMATION
BAR RIVER
GORDON LAKE
LORRAIN
GOWGANDA
COBALT
QUIRKE LK
HOUGH LAKE
ELLIOT LAKE
HURONIAN SUPERGROUP
scale
1000
0
m

Table 2.

| AREA | PROJECT AREA | PROJECT AREA | ECHO, DESBARATS-ROCK LAKES | ECHO LAKE | WAKOMATA-ENDIKAI LAKE | MOUNT LAKE | RAWHIDE LAKE |
|---|---|---|---|---|---|---|---|
| AUTHOR | YOUNG (1973) | HADLEY (1968) | FRAREY (1977) | BENNETT (1982) | SIEMIATKOWSKA (1977, 1978) | ROBERTSON (1970) | WOOD (1975) |
| SUB-DIVISIONS | REGIONAL UNITS | LOCAL MEMBERS AND/OR MAP UNITS | | | | | |
| LORRAIN FORMATION | UPPER 762 | e) WHITE ORTHOQUARTZITE | 14f) WHITE QUARTZITE 762 | 9a) WHITE PEBBLY SANDSTONE 300 | 5,11f) WHITE ORTHOQUARTZITE 460 | 5a) WHITE ORTHOQUARTZITE | 7a) QUARTZ ARENITE (WHITE) |
| | MIDDLE 1311 | c) RED QUARTZITE | 14e) UPPER RED QARTZITE 518 | 9b) UPPER RED PEBBLY SANDSTONE 180 | 5,11e) PINK TO BUFF PEBBLY SANDSTONE 430<br>5,11d) HEMATITIC SANDSTONE 30 | 5b) PINK, BUFF, GREEN QUARTZITE WITH HEMATITE, FELDSPAR | 7b) QUARTZ WACKE, QUARTZ-JASPER PEBBLE CONGLOMERATE |
| | | d) JASPER-QUARTZ PEBBLE CONGLOMERATE | 14d) JASPER CONGOMERATE 183 | 9c) JASPER PEBBLE CONGLOMERATE 120 | 5,11c) QUARTZ-JASPER PEBBLE CONGLOMERATE 30 | 5c) QUARTZ-JASPER PEBBLE CONGLOMERATE | |
| | | c) RED QUARTZITE | 14c) LOWER RED QUARTZITE 610 | 9d) LOWER RED PEBBLY SANDSTONE 860<br>9e) PINK TO PURPLE SANDSTONE 60 | 5,11b) PINK HEMATITIC PEBBLY SANDSTONE 37 | 5d) FERRUGINOUS RADIOACTIVE QUARTZ CONGLOMERATE | 7c) HEMATITIC CONGLOMERATE AND ARKOSE |
| | LOWER 638 | b) PURPLE QUARTZITE | 14b) PURPLE SILTSTONE 120 | 9f) RED AND PURPLE SILTSTONE 60 | 5,11e) BASAL PURPLE AND GREEN SANDSTONE AND FELDSPATHIC SANDSTONE 55 | 5e) BUFF QUARTZITE AND FELDSPATHIC QUARTZITE | 7d) YELLOW ARKOSIC ROCKS |
| | | a) BASAL ARGILLITE AND ARKOSE | 14a) BASAL ARKOSE 518 | 9g) PINK ARKOSE 300 | | 5f) YELLOW, BUFF, PINK ARKOSE, QUARTZITE | |
| | | | | | | 5g) YELLOW-GREEN ARKOSE | 7e) GREEN ARKOSIC ROCKS |
| | | | | | | 5h) FELDSPATIC QUARTZITE, SILTSTONE | 7f) RED ARKOSE |

Table 3.

## LITHOFACIES TYPES

| CODE | TEXTURE | SEDIMENTARY STRUCTURES |
|---|---|---|
| Gm | gravel | massive |
| Gp | gravel | planar cross bedded |
| Sm | sand | massive |
| Sp | sand | planar cross bedded |
| St | sand | trough cross bedded |
| Sl | sand | laminated |
| Sr | sand | rippled |
| Ml | mud | laminated |

Table 4.

## LITHOFACIES ASSEMBLAGES

| ASSEMBLAGE NAME | MAJOR LITHOFACIES | MINOR LITHOFACIES | ENVIRONMENTAL INTERPRETATION |
|---|---|---|---|
| CONGLOMERATE | Gm, Sm | Gp, Sp | gravelly braided river |
| PEBBLY SANDSTONE | Sp, Sm | Gm, St | sandy braided river |
| CROSS BEDDED SANDSTONE | St, Sp | Gm, Sm, Sl | sandy braided river |
| MASSIVE SANDSTONE | Sm | Sp, Sr, Ml | ? sandy braided river and/or shore-zone and/or eolian |

Table 5.

| Regional Units | Local Members | Number of Samples | Range | Mean | Standard Deviation |
|---|---|---|---|---|---|
| UPPER | White Quartzite | 331 | 0 - 192 | 1.5 | 11.8 |
| MIDDLE | Upper Red Quartzite | 103 | 0 - 197 | 10.6 | 26.4 |
| | Jasper Conglomerate | 74 | 0 - 20 | 1.4 | 3.3 |
| | Lower Red Quartzite | 248 | 0 - 60 | 2.4 | 8.0 |
| LOWER | Purple Siltstone and Basal Arkose | 102 | 0 - 160 | 6.9 | 22.4 |
| Lithology | | | | | |
| heavy mineral laminae (mostly specularite) | | 94 | 0 - 192 | 7.4 | 25.0 |
| pebble conglomerate beds | | 191 | 0 - 87 | 2.2 | 8.2 |
| pebble conglomerate beds with heavy minerals | | 94 | 0 - 62 | 4.4 | 12.0 |
| unclassified samples | | 500 | 0 - 197 | 3.3 | 4.7 |

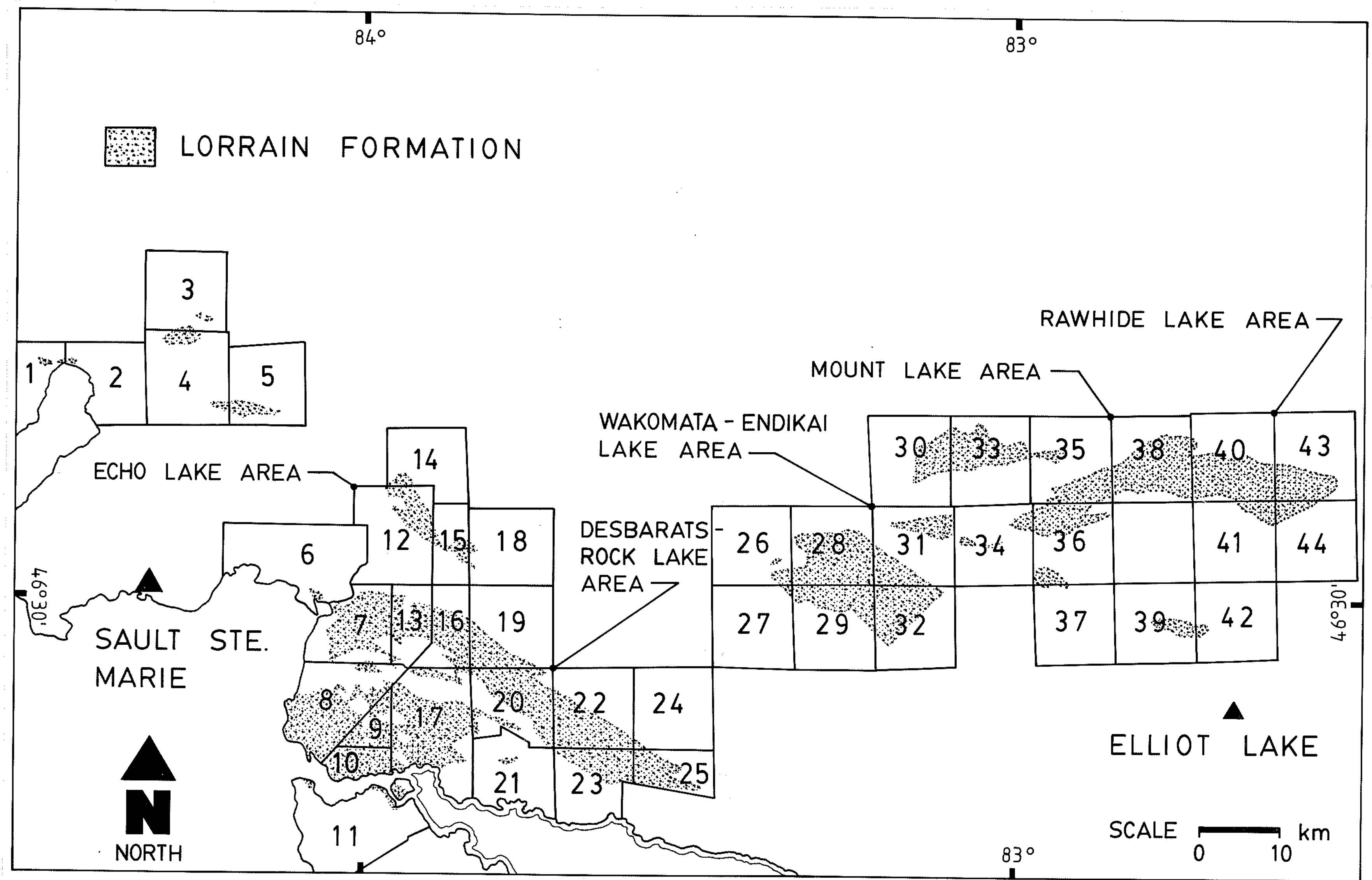

84°
83°
LORRAIN FORMATION
RAWHIDE LAKE AREA
MOUNT LAKE AREA
WAKOMATA - ENDIKAI
LAKE AREA
ECHO LAKE AREA
DESBARATS-
ROCK LAKE
AREA
SAULT STE.
MARIE
NORTH
ELLIOT LAKE
SCALE 0 10 km
46°30'
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44

Figure 1

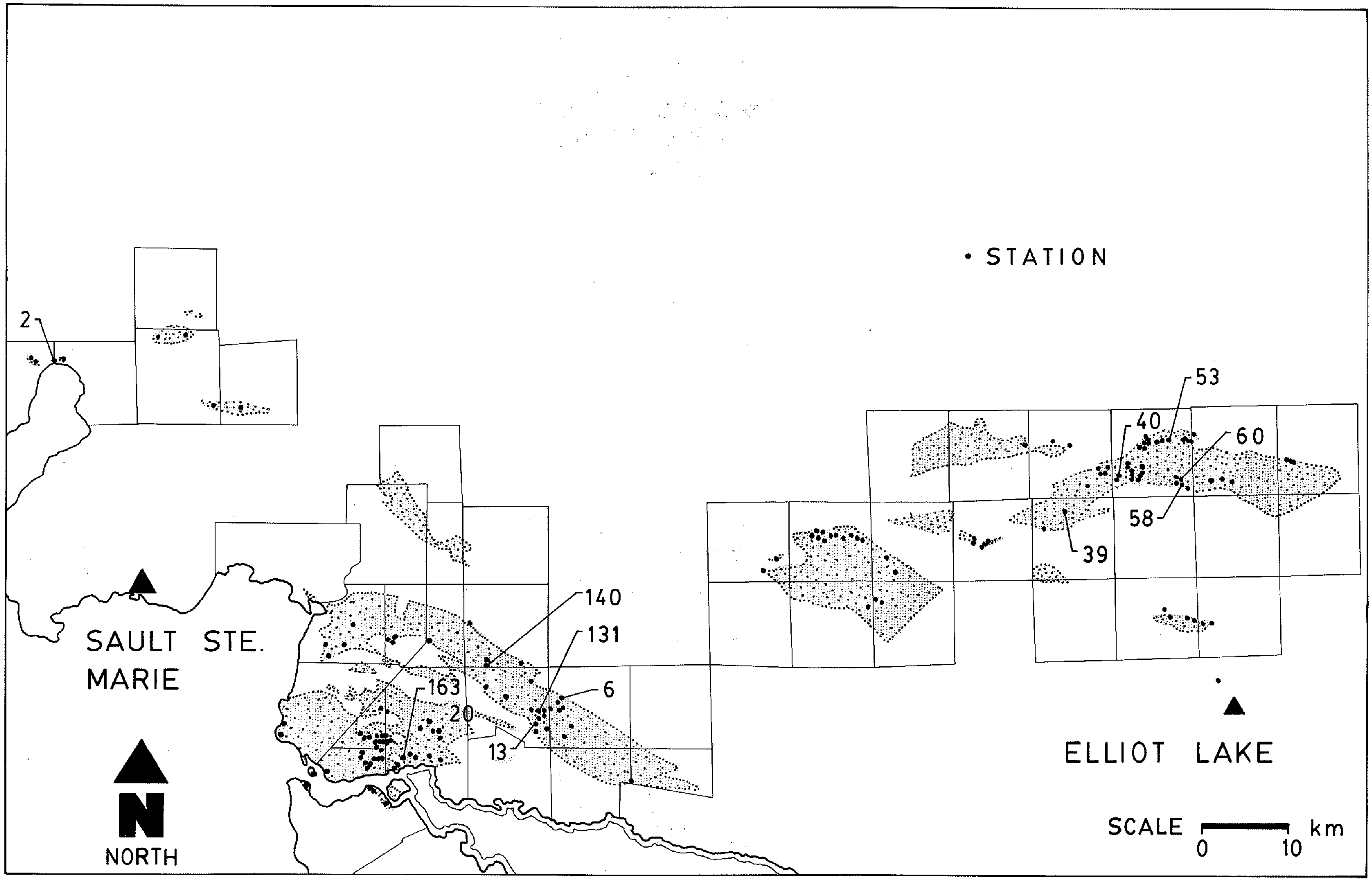

STATION
2
53
40
60
58
39
140
131
6
163
20
13
SAULT STE.
MARIE
ELLIOT LAKE
NORTH
SCALE
0
10
km

Figure 2

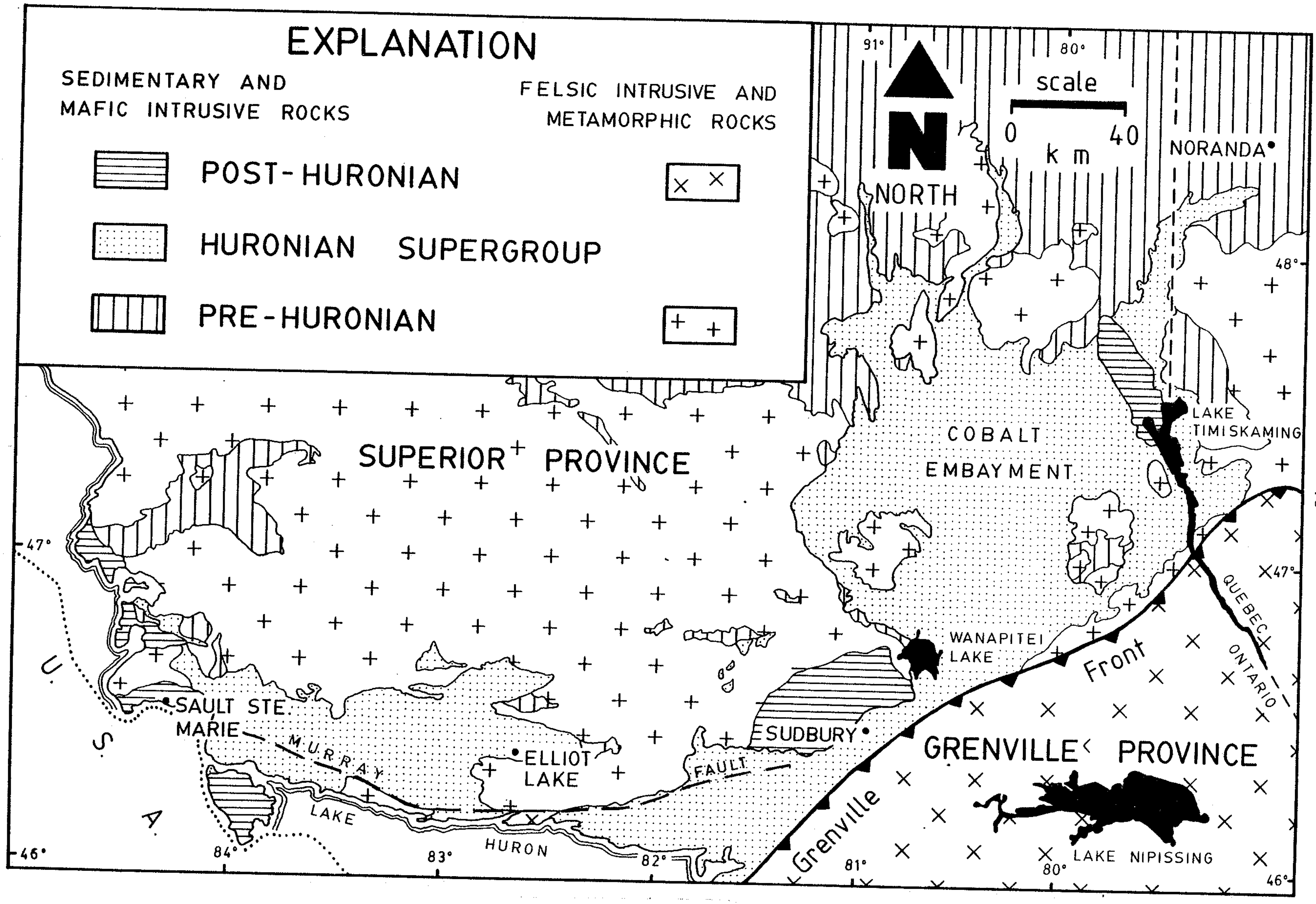

EXPLANATION
SEDIMENTARY AND
MAFIC INTRUSIVE ROCKS
FELSIC INTRUSIVE AND
METAMORPHIC ROCKS
POST-HURONIAN
HURONIAN SUPERGROUP
PRE-HURONIAN
NORTH
scale
0 km 40
NORANDA
LAKE TIMISKAMING
COBALT EMBAYMENT
SUPERIOR PROVINCE
WANAPITEI LAKE
QUEBEC
ONTARIO
Grenville Front
GRENVILLE PROVINCE
LAKE NIPISSING
SUDBURY
ELLIOT LAKE
MURRAY FAULT
SAULT STE MARIE
LAKE HURON
U. S. A.
91°
80°
48°
47°
46°
84°
83°
82°
81°

Figure 3.

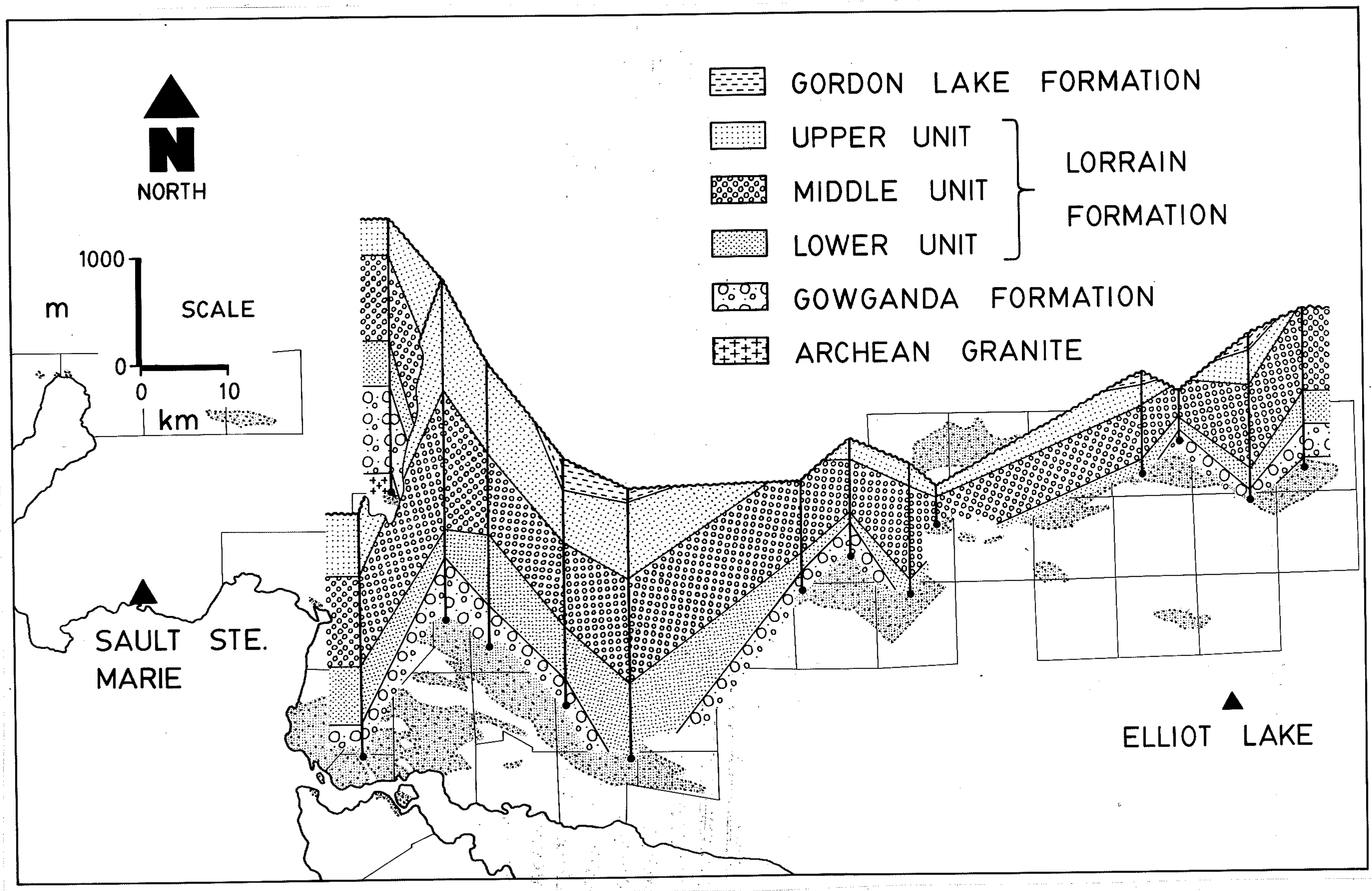

GORDON LAKE FORMATION
UPPER UNIT
MIDDLE UNIT
LOWER UNIT
LORRAIN FORMATION
GOWGANDA FORMATION
ARCHEAN GRANITE
NORTH
m
1000
0
SCALE
0
10
km
SAULT STE. MARIE
ELLIOT LAKE

Figure 4.

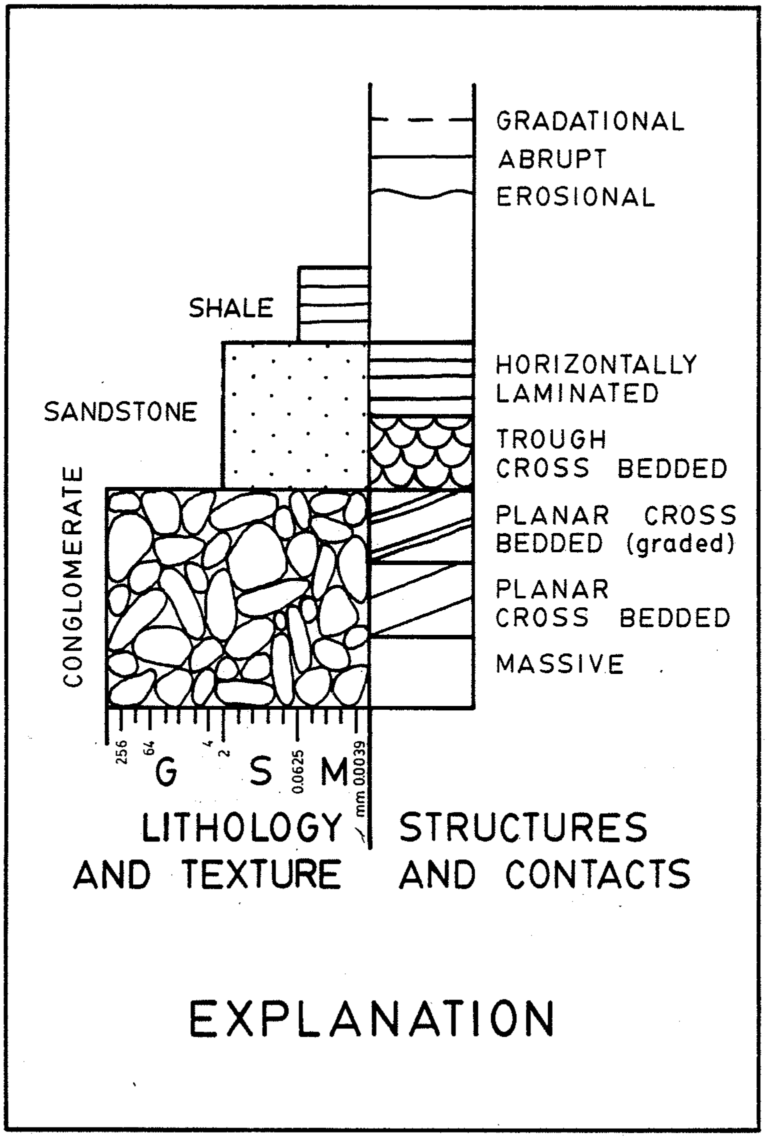

GRADATIONAL
ABRUPT
EROSIONAL
SHALE
SANDSTONE
CONGLOMERATE
HORIZONTALLY LAMINATED
TROUGH CROSS BEDDED
PLANAR CROSS BEDDED (graded)
PLANAR CROSS BEDDED
MASSIVE
256 64 4 2 0.0625 mm 0.0039
G S M
LITHOLOGY AND TEXTURE
STRUCTURES AND CONTACTS
EXPLANATION

Figure 5.

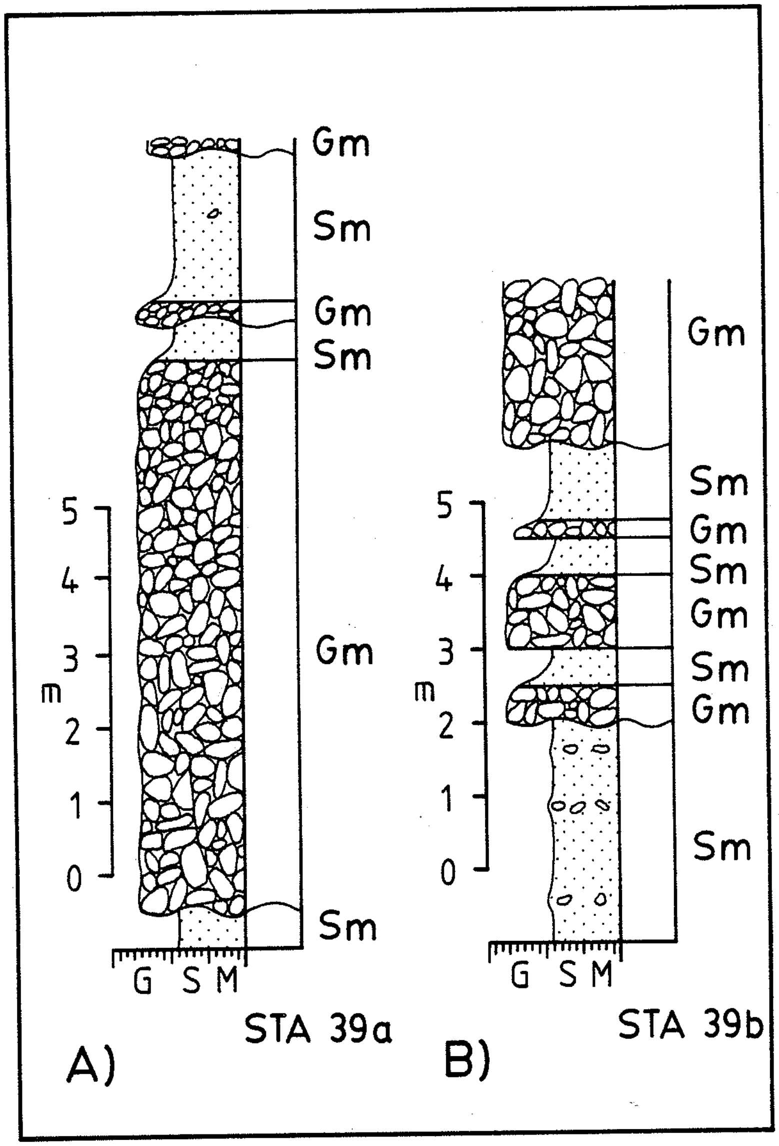

Gm
Sm
Gm
Sm
Gm
Sm
5
4
3
m
2
1
0
G S M
STA 39a
A)
Gm
Sm
Gm
Sm
Gm
Sm
Gm
Sm
5
4
3
m
2
1
0
G S M
STA 39b
B)

Figure 6.

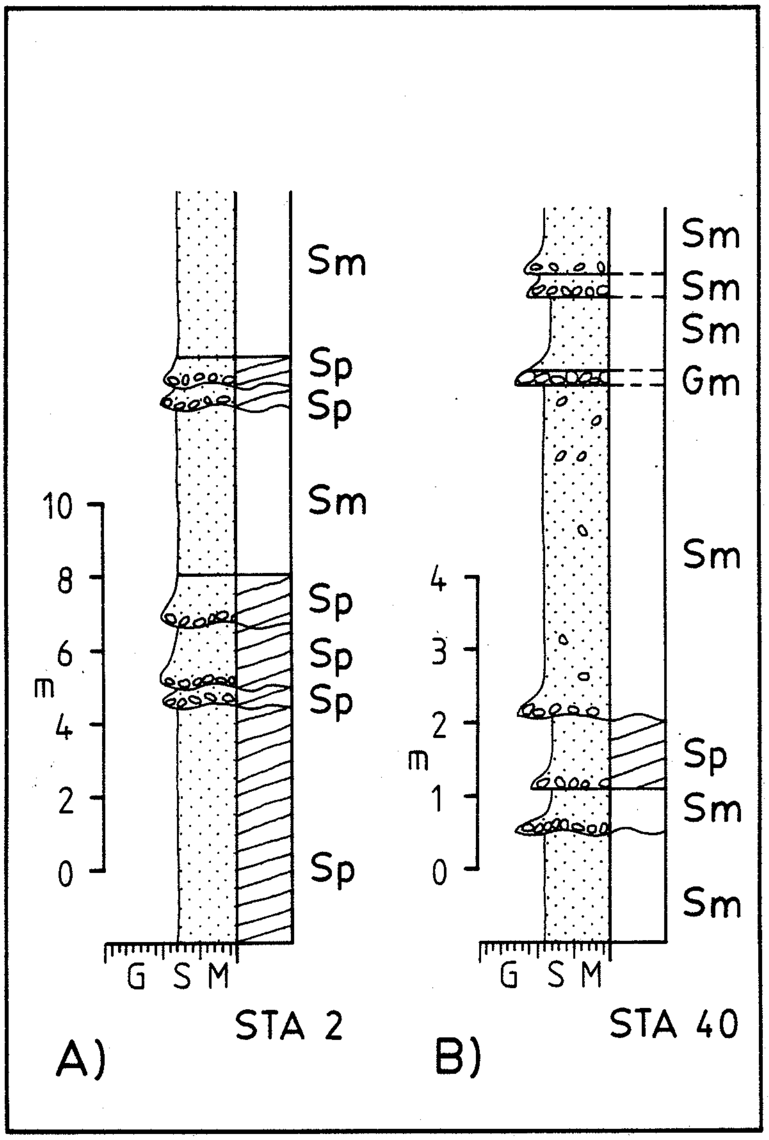

Sm
Sp
Sp
Sm
Sp
Sp
Sp
Sp
10
8
6
m
4
2
0
G S M
STA 2
A)
Sm
Sm
Sm
Gm
Sm
Sp
Sm
Sm
4
3
2
m
1
0
G S M
STA 40
B)

Figure 7.

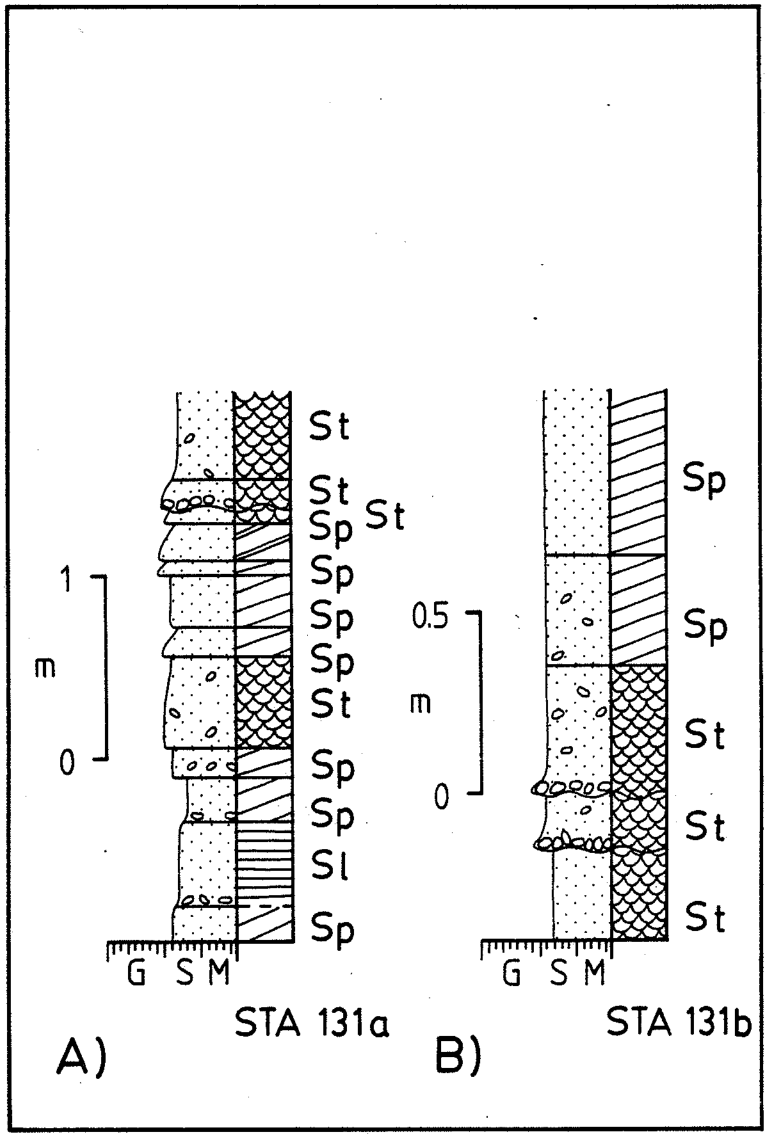

St
St
St
Sp
Sp
Sp
Sp
St
Sp
Sp
Sl
Sp
1
m
0
G S M
STA 131a
A)
Sp
Sp
St
St
St
0.5
m
0
G S M
STA 131b
B)

Figure 8.

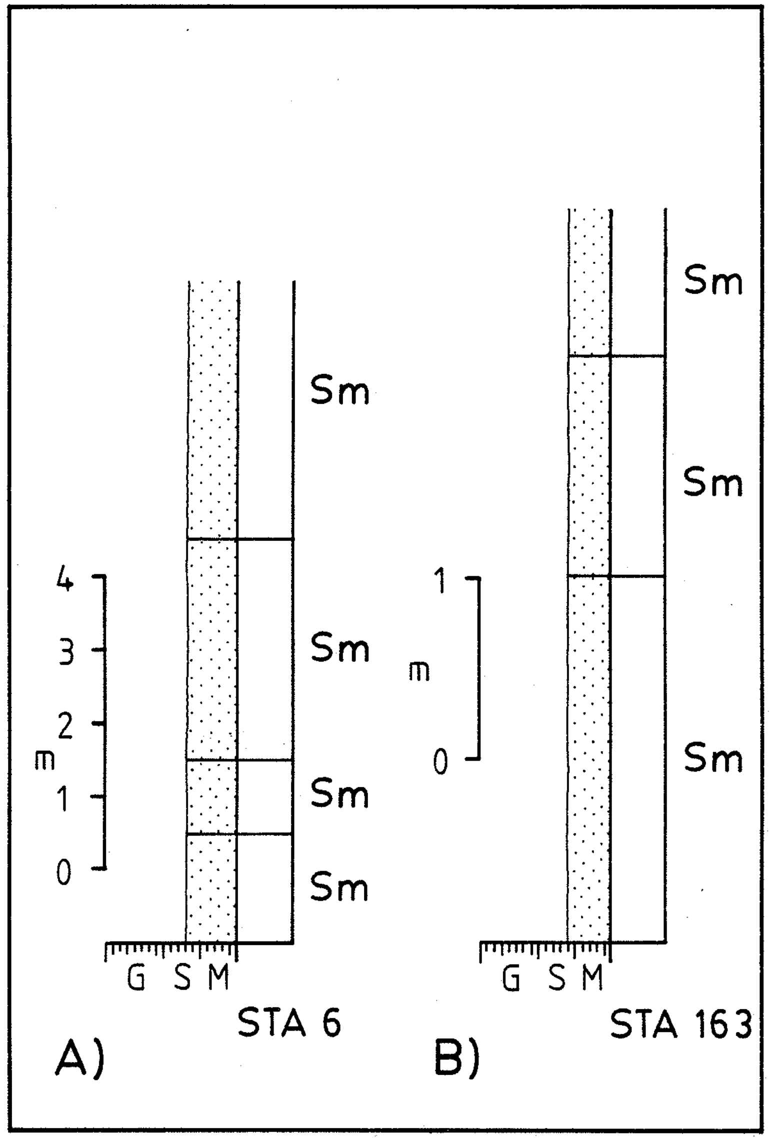



Figure 9.

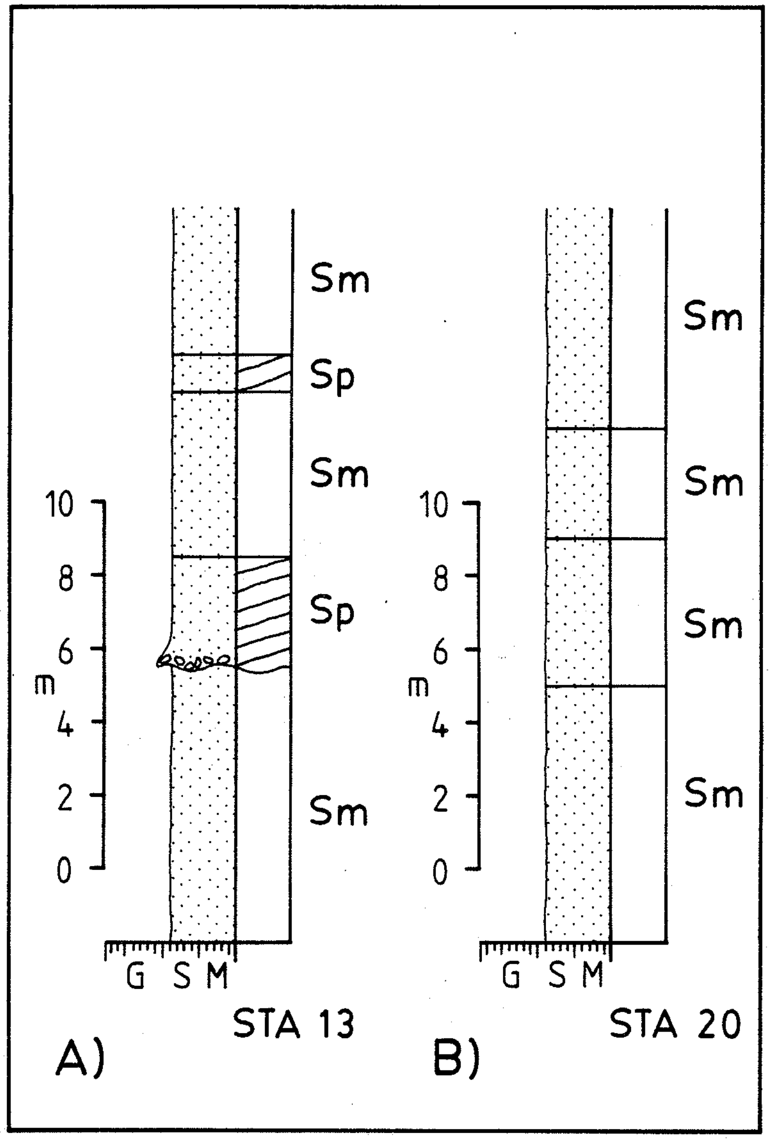

Sm
Sp
Sm
Sp
Sm
10
8
6
m
4
2
0
G S M
STA 13
A)
Sm
Sm
Sm
Sm
10
8
6
m
4
2
0
G S M
STA 20
B)

Figure 10.

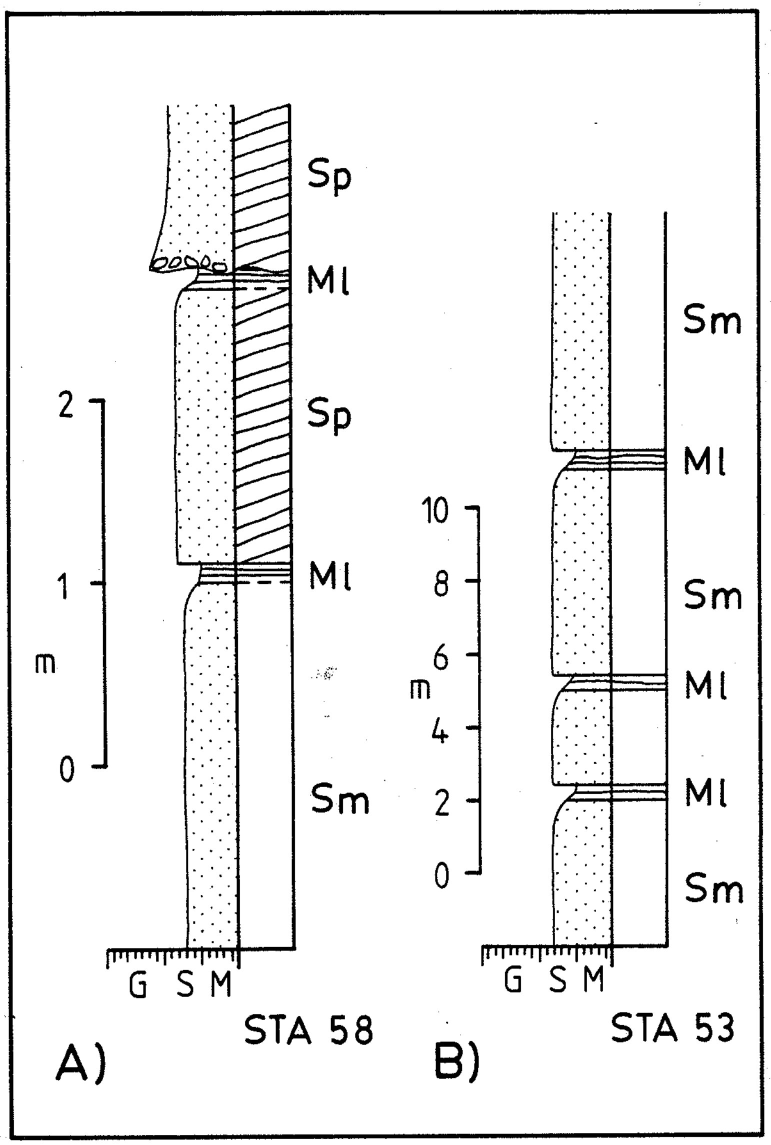

Sp
Ml
2
Sp
1
Ml
m
0
Sm
G S M
STA 58
A)
Sm
Ml
10
8
Sm
6
Ml
m
4
2
Ml
0
Sm
G S M
STA 53
B)

Figure 11.

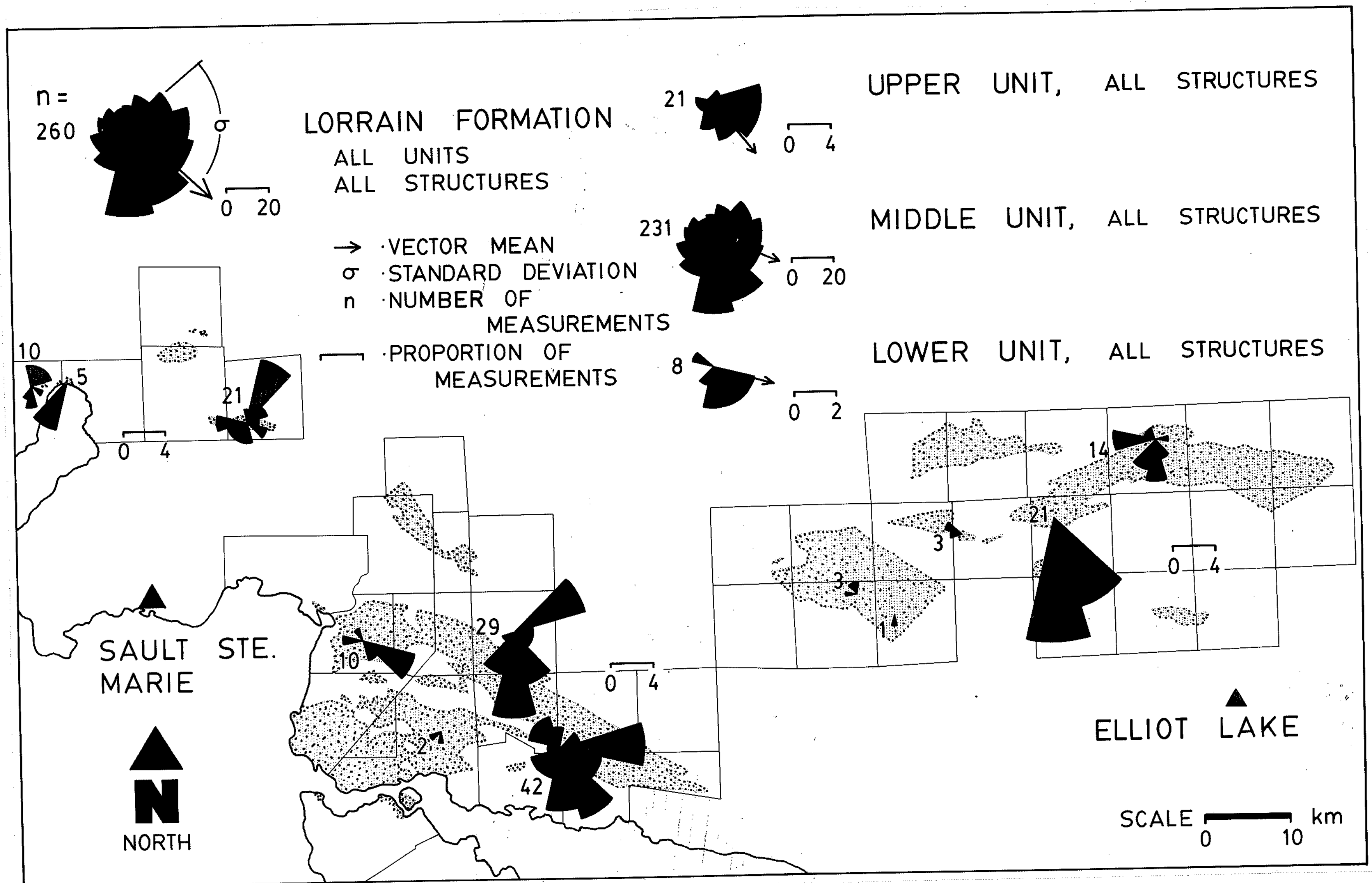

n =
260
σ
0 20
LORRAIN FORMATION
ALL UNITS
ALL STRUCTURES
→ ·VECTOR MEAN
σ ·STANDARD DEVIATION
n ·NUMBER OF MEASUREMENTS
·PROPORTION OF MEASUREMENTS
21
0 4
UPPER UNIT, ALL STRUCTURES
231
0 20
MIDDLE UNIT, ALL STRUCTURES
8
0 2
LOWER UNIT, ALL STRUCTURES
10
5
21
0 4
29
10
2
42
14
21
3
3
1
SAULT STE. MARIE
NORTH
ELLIOT LAKE
SCALE 0 10 km

Figure 12.

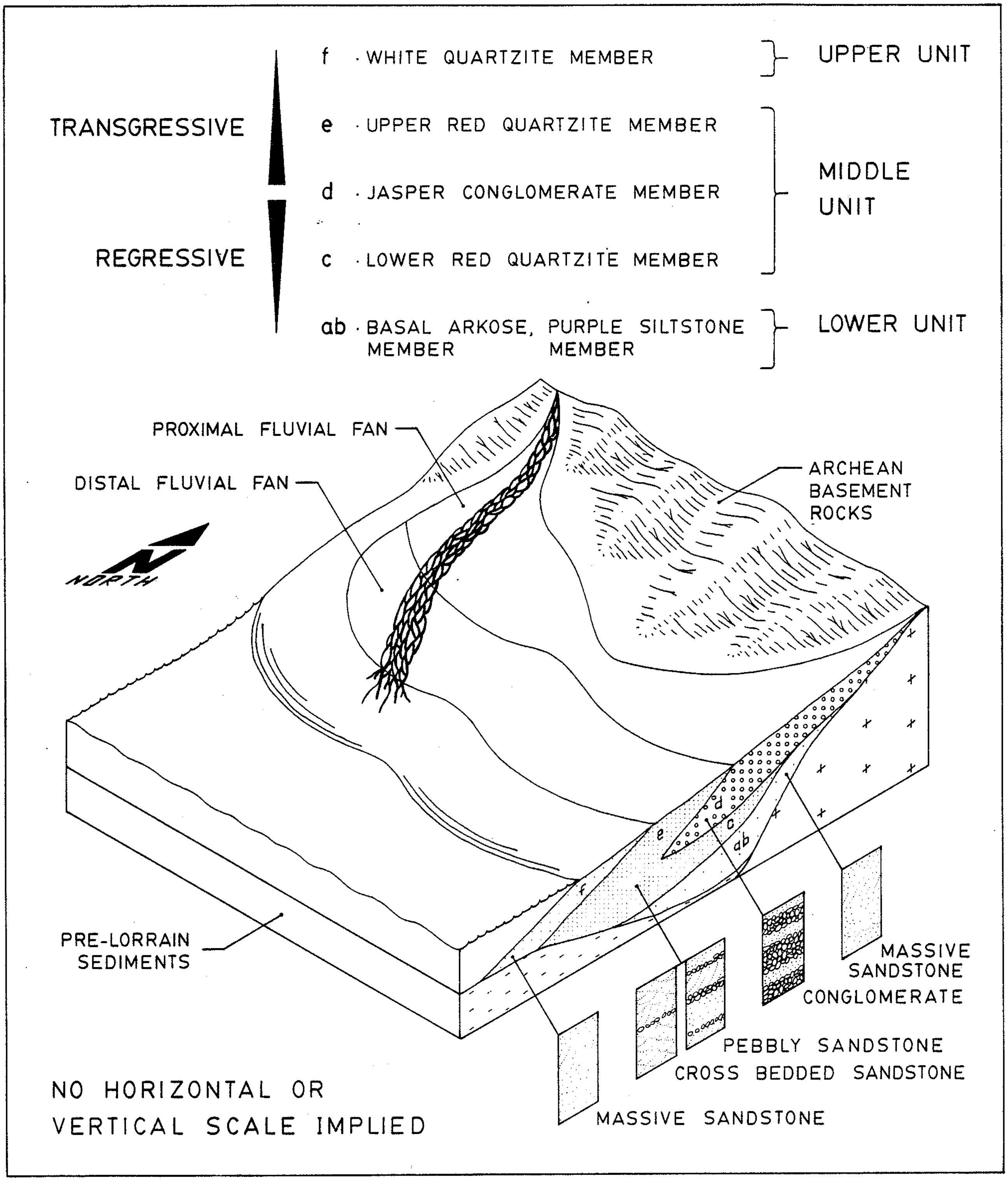
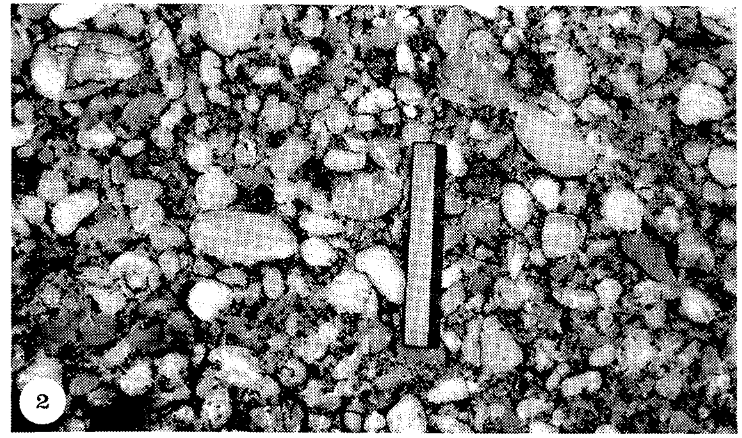
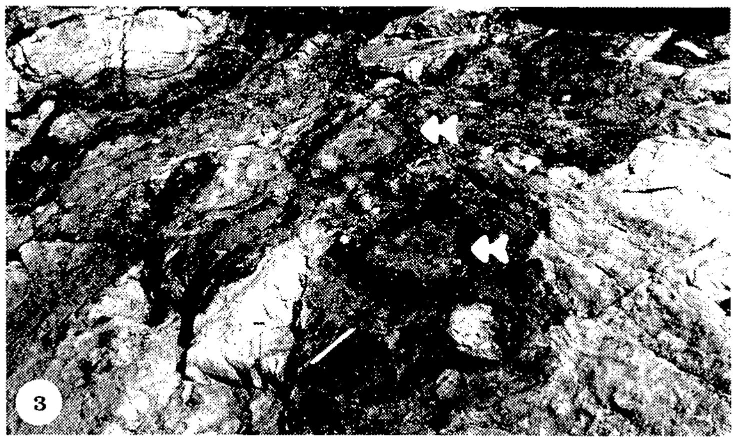

f · WHITE QUARTZITE MEMBER
UPPER UNIT
TRANSGRESSIVE
e · UPPER RED QUARTZITE MEMBER
d · JASPER CONGLOMERATE MEMBER
MIDDLE UNIT
REGRESSIVE
c · LOWER RED QUARTZITE MEMBER
ab · BASAL ARKOSE, PURPLE SILTSTONE MEMBER MEMBER
LOWER UNIT
PROXIMAL FLUVIAL FAN
DISTAL FLUVIAL FAN
ARCHEAN BASEMENT ROCKS
NORTH
PRE-LORRAIN SEDIMENTS
MASSIVE SANDSTONE
CONGLOMERATE
PEBBLY SANDSTONE
CROSS BEDDED SANDSTONE
MASSIVE SANDSTONE
NO HORIZONTAL OR VERTICAL SCALE IMPLIED

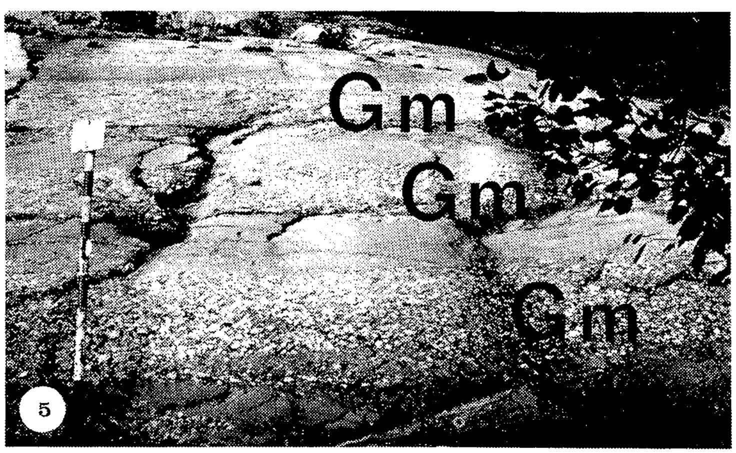
Figure 13.


1


2


3

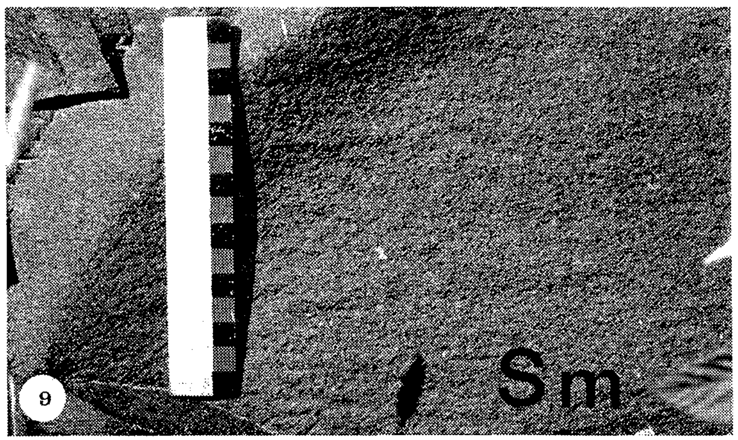

Gm
4

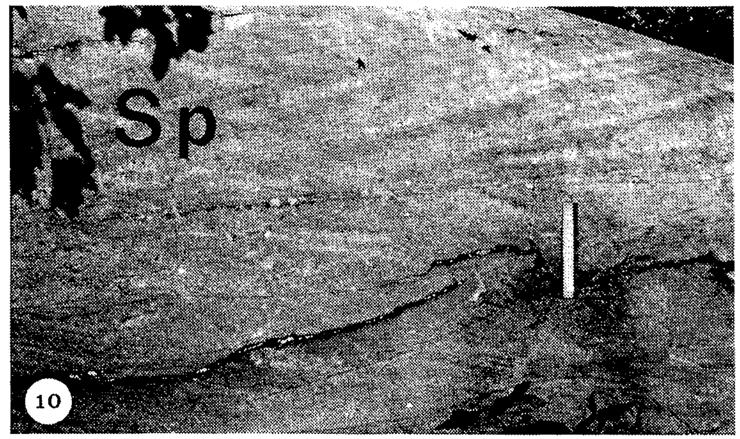

Gm
Gm
Gm
5


6


7
Gp

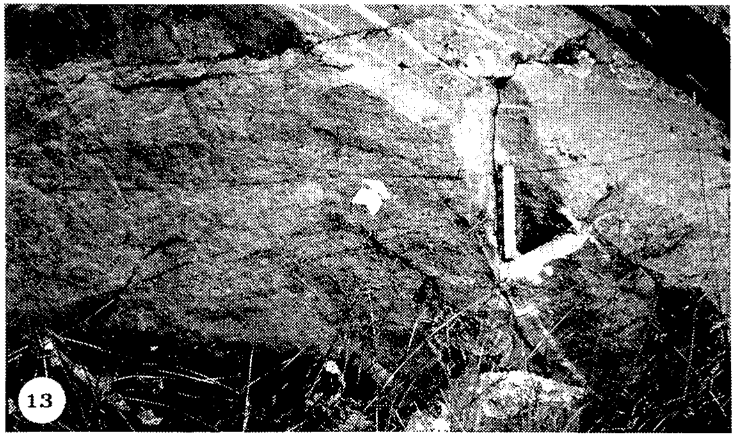

8
Sm

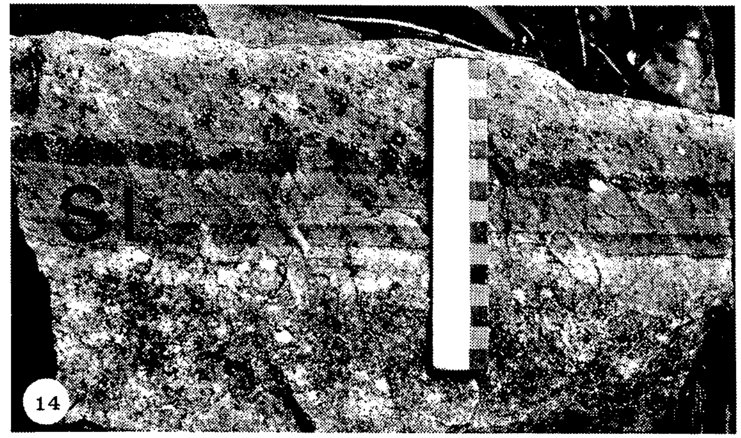

9
Sm

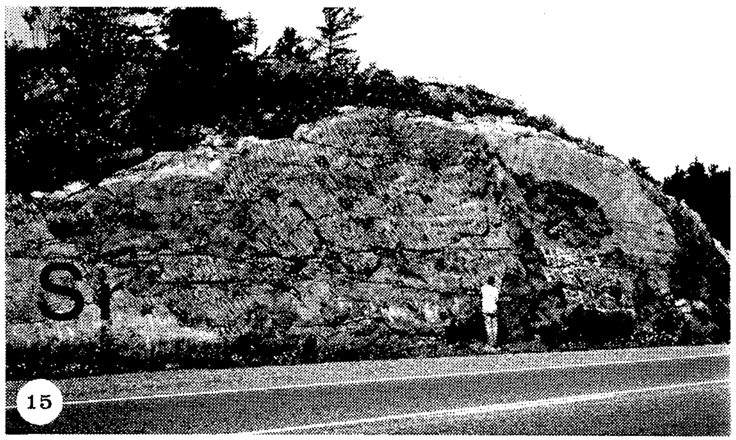

10
Sp


11
Sp


12
St

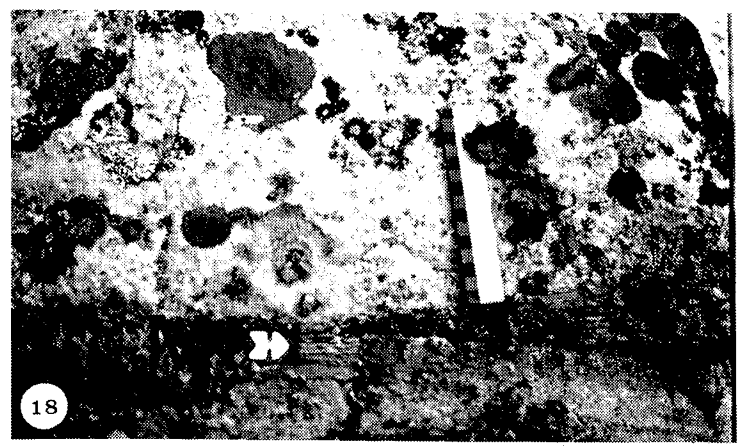

13


S1
14


S1
15


S1
16


M1
M1
17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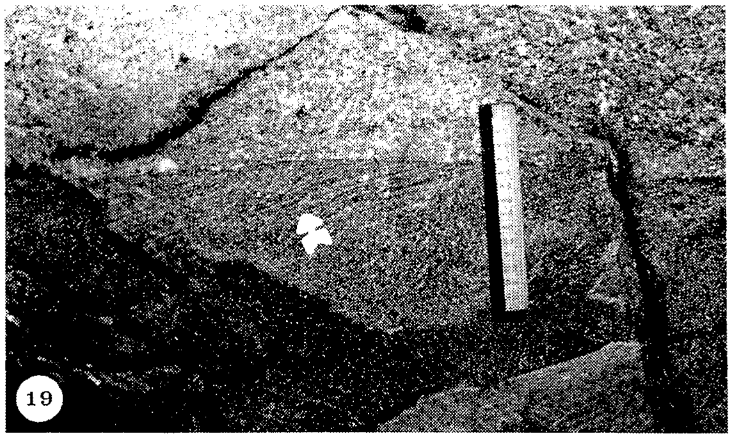
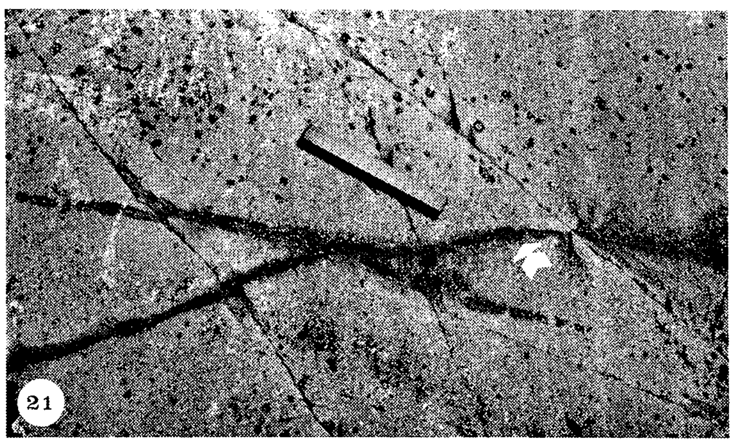
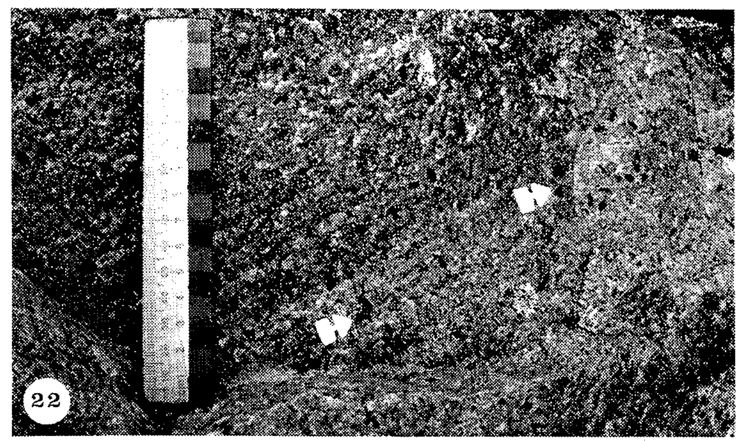

19


20


21


22