GRANITE TECTONICS IN PART

OF

EDEN TOWNSHIP

GRANITE TECTONICS
IN PART OF EDEN TOWNSHIP,
SUDBURY DISTRICT, ONTARIO

By

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SCOPE AND CONTENTS: Structural analysis and petrographic studies have been carried out on the metasedimentary and igneous rocks of the Grenville Front in the east central part of Eden Township, Sudbury District, Ontario. Structural analysis includes detailed structural mapping of the area and petrofabric, geometric and kinematic analysis of structural elements in the rocks. Partial chemical analyses of quartzite samples from the map area were also obtained. The relationship between structural elements in metasedimentary rocks and quartz monzonite are discussed, and a tectonic history for the thesis area is proposed.

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ABSTRACT

An examination of the literature demonstrates that the Grenville Front cannot be ascribed to a single tectonic event such as faulting or a zone of metamorphic transition. It may be due to faulting or metamorphic transition, or a combination of both depending on the geographic position of the observer along the Front.

Southeast of Sudbury Ontario, the Grenville Front is defined by a zone of granitization of metasedimentary rocks of the Southern province, producing a zone of "pseudogranite" which supposedly extends to the southwest, separating low grade metamorphic rocks of the Southern province from high grade migmatitic and gneissic rocks of the Grenville province. The zone may be obscured by late faulting.

Examination of these granitoid rocks in a small area north of Wavy Lake in Eden Township, demonstrates that they are of quartz monzonite composition and that they show well-defined igneous intrusive contact relationships with rocks of the Southern province. No evidence of metasomatism or granitization is observable. The Grenville Front in Eden Township is believed to be somewhat analogous to the Front of Quirke and Collins (1930), north of Georgian Bay.

Evidence derived from fabric elements and metamorphic porphyroblasts suggests initial 'plastic' deformation of the sedimentary rocks with the production of 'low grade' metamorphic minerals such as muscovite and epidote (greenschist facies) followed by a second phase of deformation with the development of 'high grade' staurolite (low almandine-amphibolite

facies) in fracture and flow cleavage planes produced in some pelitic rocks. A late retrograde metamorphic phase followed, characterized by the alteration of staurolite to muscovite.

The age of quartz monzonite intrusion is not well defined. Retrograde metamorphism is thought to have occurred during the latter stages of the Penokean orogeny before intrusion of the quartz monzonite, rather than as a result of metamorphic effects caused by the igneous intrusion. Retrograde metamorphism of metasediments during Penokean time in the Wavy Lake area is consistent with retrograde metamorphic effects demonstrated by Card (1964) in the Agnew Lake area to the west.

Two stages of gabbro intrusion are observed in Eden Township; one phase occurring after 'plastic' deformation of the metasediments with consequent 'high grade' metamorphism of gabbro to the almandine-amphibolite facies, and a second phase, occurring after the intrusion of quartz monzonite. Metamorphism of the dike representing the second phase apparently occurred during faulting of the quartz monzonite and metasediments.

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I. INTRODUCTION

The area mapped in the present study lies approximately 13 miles south of Sudbury, Ontario, in the eastern half of Eden Township (Figure 1) and occupies a position on the Grenville Front where metasedimentary rocks of the Southern province are intruded by a quartz monzonite batholith. The intrusive quartz monzonite separates rocks of the Grenville province to the east from the metasediments of the Southern province in the map area.

The area is readily accessible by road and can be reached by proceeding south on Highway 543, a secondary highway which joins Highway 69 in the southern city limits of Sudbury.

Aerial photographs obtained from the Ontario Department of Lands and Forests were used for mapping purposes. Mapping was carried out at a scale of 8 inches to the mile except where quartzite xenoliths were encountered in the quartz monzonite. Mapping of xenoliths was accomplished using aerial photographs at a scale of 16 inches to the mile. Rock exposure is adequate for mapping purposes. Outcrops constitute approximately 40 per cent of the area.

Henderson (pers. comm.), mapping Eden and Tilton townships, felt that relationships between structural elements in the quartz monzonite and those in the metasedimentary rocks of Eden Township could be adequately shown only by large scale mapping of the field area concerned in the present work.

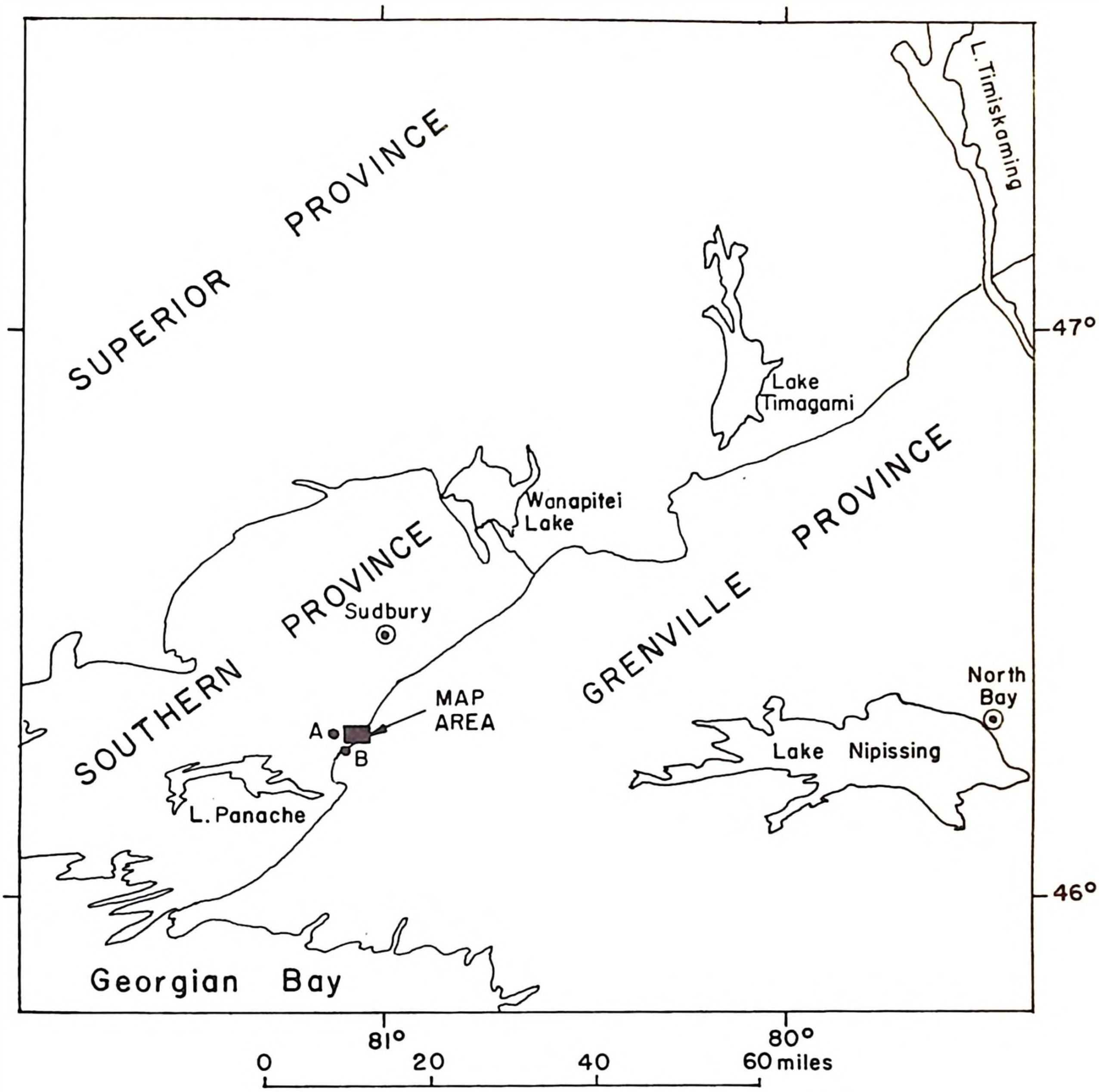


Figure 1 - Location of Map Area

Isotopic Dating - Fairbairn et al. (1960)

A.- Sr/Rb age - Granite (biotite) - 1516 m.y.

B.- Ar/K age - Granite (biotite) - 910 m.y.

(Structural province boundaries are approximate)

Henderson suggested that the writer map the area not only to show the relationships existing between structural elements in the intrusive rock and metasediments, but to define as well the contact relationships existing between the two rock types.

Names given to all lakes except Wavy and Cranberry lakes have no local validity and were given to bodies of water in the map area by the writer.

II. NATURE OF THE GRENVILLE FRONT

The Grenville Front is the well-established name for the contact zone or line between a heterogeneous volume of rocks supposedly having a community of structural styles, trends and isotopic ages and other rock volumes, each of which have their own tectonic and isotopic age characteristics. The first volume or 'block' of rocks is termed the Grenville province. The others which lie to the northwest in contact with the rocks of the Grenville province are rocks of the Southern, Superior, Churchill and Nain provinces (Figure 2).

The metasedimentary rocks of the map area lie in the Southern province as defined by Stockwell (1965) on a tectonic map of the Canadian Shield.

Arguments have arisen between workers on the nature of the Grenville Front. Derry et al. (1950) produced a tectonic map of the Canadian Shield which shows the Grenville Front to be a zone of thrust faulting over its entire length. Recent work has demonstrated that the Front is not a zone of faulting only. It may be a zone of metamorphic gradation or a fault contact. On the other hand, its position may be marked by the presence of intrusive igneous rocks bearing little or no relationship to rocks surrounding them. The Front as a whole exists, therefore, as the result of a combination of tectonic processes and should not have its gross origin ascribed to any particular tectonic effect.

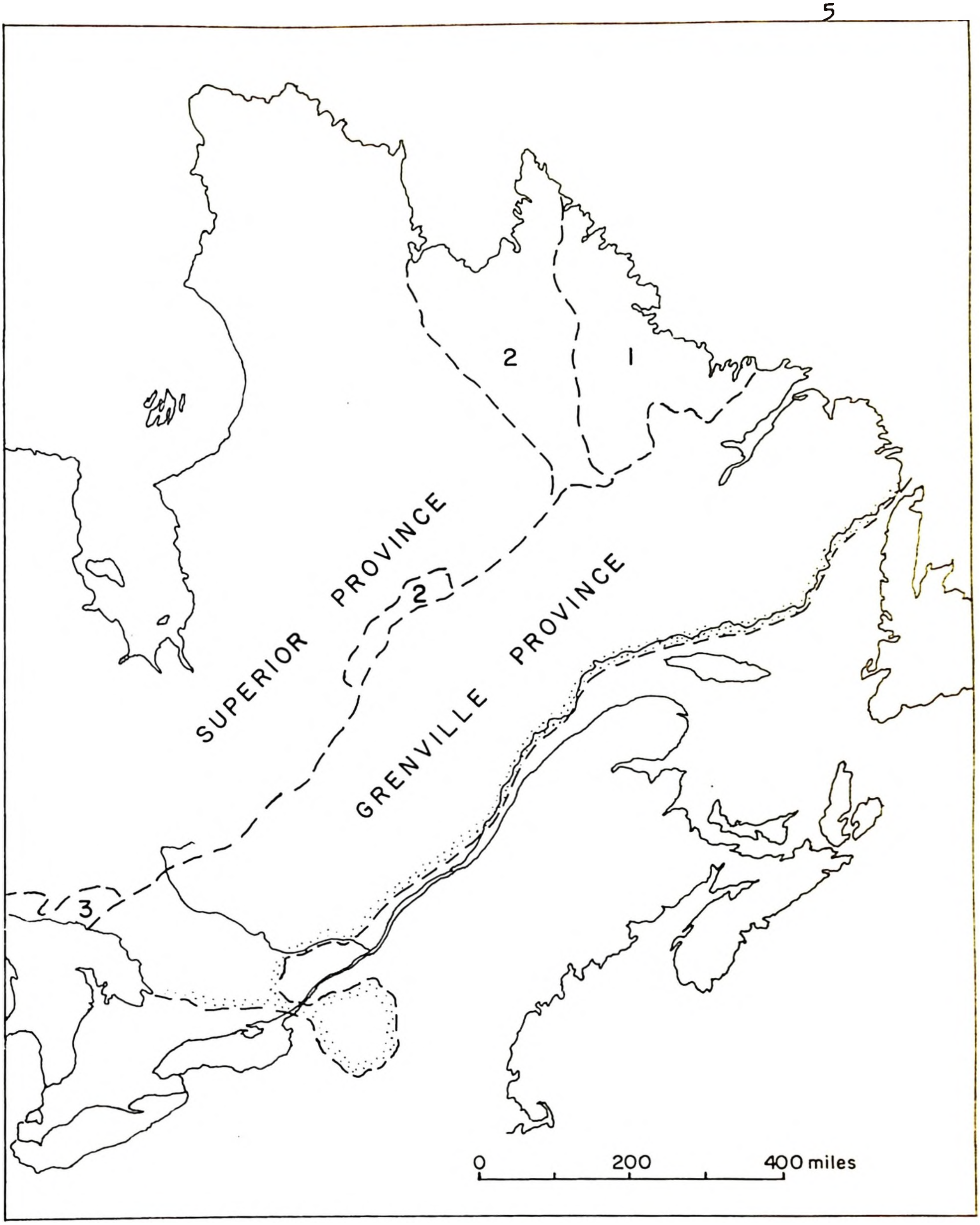


Figure 2 - Tectonic Provinces - Eastern Canadian Shield *

LEGEND

1 - NAIN PROVINCE
2 - CHURCHILL "
3 - SOUTHERN "

Boundary - structural province
Boundary - Canadian Shield

* After Stockwell & Williams (1964)

A. Survey of Previous Work

Wilson (1939) was one of the first workers to divide the rocks of the Canadian Shield into tectonic provinces. After defining the Laurentian province, he split it into two subprovinces: (a) the Timiskaming subprovince consisting of volcanics and terrigenous sediments which he regarded as being Huronian in age and (b) the Grenville subprovince consisting of a complex series of gneisses, marbles, and granitic intrusions. He considered the Grenville rocks to be pre-Huronian in age, forming a basement complex on which rocks of the Timiskaming subprovince were deposited. Wilson defined the Front as being marked by a zone of banded gneisses between the Timiskaming and Grenville rocks.

Proponents of the Grenville Front as a fault zone invoke faulting to explain the sharp contrast in rock types between rocks of the Grenville and other tectonic provinces. Norman (1940) considered the Grenville Front a fault zone extending from Lake Mistassini to Lake Huron. After mapping in the Lake Mistassini region he stated that

> "The conclusion that a fault exists in these two areas (Killarney and Chibougamau) suggests that the sudden transition from rocks of recognizable age and origin to a complex of gneisses throughout the intervening region is also due to faulting." (op. cit. p. 512)

Johnston (1954), mapping east of Lake Temagami found rocks of the Superior and Grenville provinces in contact along a northeast trending, eastward dipping zone of complex faulting. He believed that faults along the zone underwent recurrent activity and that rocks along the contact have been obscured in their relationships to one another by the movements and also that the Grenville province was the active block during faulting.

Other workers favour the view that the Grenville Front marks the northwestern boundary of a complex zone of northeasterly trending strike-slip faults along which gneissic and migmatitic rocks of the Grenville province have been produced by severe plastic deformation of pre-existing sedimentary rocks at great depths. (See Brooks, 1964, in the section on 'Previous Work in the Sudbury Area, below.)

Grant (1964) and Deland (1956), mark the Grenville Front as a zone of metamorphic transition between Grenville rocks and rocks of other tectonic provinces to the northwest.

Grant (1964) mapped the Vogt-Hobbs area south of Lake Temagami. He states that the macroscopic effects of Grenville metamorphism are not discernable more than a quarter mile north of the Front, and then only definitely in pre-Huronian rocks. He outlines the following mineralogical changes as the Grenville Front is approached from the south: the oligoclase-andesine of the metadiorite-granite complex in the area changes to albite-oligoclase and biotite in the rocks becomes lighter in colour with inclusions of sphene or rutile. Marking the Front, Grant showed muscovite and chlorite to be the stable mineral assemblage of Grenville metamorphism. Moving across the Front from south to north in the Vogt-Hobbs area, garnet found in the Grenville rocks gives way to chlorite, staurolite also common in the Grenville rocks, disappears to the north and clinozoisite occurs rather than a more iron rich epidote. A few granitic pods and veins occur in schist at the Grenville Front in the Vogt-Hobbs area; within one half mile of the Front to the south, these increase in abundance until they constitute over 30 per cent of exposures. Grant correlated this increase in granitic material to the south of the Front with the metamorphic transition.

Grant established criteria for definition of the Grenville Front in the field. These are: transition to schist from imperfectly schistose metagreywacke, recrystallization of sericitic pseudomorphs after andalusite to larger and fewer plates of white mica with no relict knots being found more than 0.2 miles south of the Front; the obliteration of igneous textures in probable equivalents of the Algoman and pre-Algoman granites and the development of structures typical of those developed in the northwestern part of the Grenville province and markedly different from those developed north of the Front.

Deland (1956) suggested that low grade metamorphic rocks of the Superior province pass through a metamorphic transition (the Grenville Front) into high grade metamorphic rocks of the Grenville province. Deland argued that a continuous zone of faulting from Lake Mistassini to Georgian Bay is not supported by petrographic and structural evidence. In the Surprise Lake area of Quebec he noted that structural features are the same on both sides of the Front, that layering and gneissosity of the Grenville rocks and stratification and schistosity of rocks of the Superior province have eastwest trends across the Grenville Front, that rocks in both provinces have steep dips and that granitic rocks are the same in their composition and structure on both sides of the Front.

Other workers postulate that the Grenville Front is a combination of a fault zone and a zone of metamorphic transition. Grant et al. (1962) state that the Front south of Sudbury is marked by the Wanapitei Fault and by zones of metamorphic transition and metasomatism. Their ideas are discussed at length in the following section on Previous Work - Sudbury Area.

B. Previous Work - Sudbury Area

Quirke and Collins (1930) suggested that the Huronian rocks of the Southern province in the Lake Panache area of Northern Ontario are obliterated south of the Grenville Front by a combination of batholithic invasion of Killarney granite and dip-slip faulting with consequent uplift and erosion of the Grenville rocks. They believed it possible that the Grenville series of rocks are the metamorphic equivalent of Huronian rocks and traced metamorphosed Huronian rocks into the Grenville province. They pointed out that

> "A profound contrast exists between rocks on either side of the line of contact [the Grenville Front] that extends northeastward from Killarney. Huronian sediments and Killarnean intrusives occur in each, but in very different proportions and relations. On the northwest, Huronian sediments predominate and the metamorphic effects of the Killarnean intrusives are not great. On the southeast the sediments are subordinate and extraordinarily altered." (op. cit. p. 102)

Grant et al. (1962), mapping Broder, Dill, Neelon and Dryden townships stated that a fault zone and a metamorphic transition zone defines the Grenville Front south of Sudbury. In Dryden Township they found that metasedimentary rocks of the Sudbury group are separated from the Killarnean metamorphic complex to the southeast by the Wanapitei Fault. To the southwest in Neelon, Dill and Broder townships, the fault system swings to the west, away from the Front and enters the metasedimentary rocks of the Sudbury group. The Grenville Front in Dill and Broder townships is marked by a metamorphic front and a zone of metasomatism. The zone of metasomatism lies between the Huronian rocks of the Southern province and the metamorphic front.

Grant suggested that metasomatism or 'feldspathization' has altered the Wanapitei Quartzite of the Sudbury group in an irregular manner with accompanying development of microcline porphyroblasts and shearing. He stated that in the zone of metasomatism

> ". . . there is generally a patchwork of Wanapitei Quartzite and pseudogranite in which the bedding of the quartzite is preserved. The feldspathization is sometimes in bands along the strike of the beds, sometimes across it so that very irregular patterns are produced." (op. cit. p. 16)

Grant favoured the idea that the zone of feldspathization of Wanapitei Quartzite extends to the southwest and is nearly 2 miles wide in Broder Township (Figure 1a). He also said that

> ". . . no batholithic masses of intrusive Killarnean granite have been found; even small plutons of homogeneous granite are absent from the map area." (ibid. p. 22)

Southeast of the zone of feldspathization an irregular metamorphic boundary occurs marked by the growth of biotite and garnet and the infiltration of granitic material into the Grenville rocks. No further increase in metamorphic grade occurs to the south and east.

G r a n t described the rocks of the Sudbury group as being intricately folded and faulted, differing in structural style from rocks of the Grenville province across the Front. The Grenville rocks have undergone widespread plastic deformation, are complexly folded and dip southeast at steep angles. Rocks of the Southern province are steeply folded and plunge north of east at angles between 20 and 40 degrees. They have not been subjected to the extensive plastic deformation imposed on rocks of the Grenville province.

Brooks (1964), mapping north of Georgian Bay on Lake Huron, interpreted the Grenville Front as a strike-slip fault zone analogous to the San Andreas fault in California. Actual displacement of the Grenville rocks may have been small, but the Front as a shear zone

> ". . . includes only the northwestern edge of a wide zone of shear/flow and the cumulative movement across this zone may have been great." (op. cit. p. 179)

He added that

> ". . . the sense of movement along the Grenville Front of rocks to the southeast was left lateral and more or less horizontal." (ibid. p.179)

He suggested that the Grenville block moved to the northeast along the fault zone in relation to the Southern province during the Killarnean orogeny.

Brooks favoured the view that the gneisses and migmatitic rocks of the Grenville province were developed by 'shear melting' and reconstitution of deeply buried Huronian rocks along the fault zones. He suggested that at the surface in a fault zone, release of energy occurs by brittle shear failure accompanied by crushing and milling of rocks. Heat is rapidly dissipated and recrystallization of rocks is insignificant. At great depths the physical and chemical environments change significantly and recrystallization of rocks becomes important. Uplift, and erosion of the area to great depths, apparently exposed the recrystallized rocks of the Grenville province and the relatively un-metamorphosed rocks of the Southern province they are found against.

C. Discussion

The preceding survey of previous work serves as clear amplification of the point made above that the origin of the entire Grenville

Front should not lie ascribed to one tectonic process. The Front is a complex tectonic boundary between rocks of the Southern and Grenville provinces which involves faulting, metasomatism, igneous intrusion and metamorphic transition. These processes occur singly or in various combinations depending on the geographic position of the observer along the Front.

In the Lake Panache area southwest of Sudbury, Quirke and Collins (1930) marked the position of the Grenville Front by the obliteration of Southern rocks due to a combination of dip slip faulting and intrusion of Killarney granite. Grant et al. (1962) mark the Front in the Sudbury area by faulting, a zone of metasomatism and a zone of metamorphism. They would extend the zone of metasomatism to the southwest into Eden and Tilton townships and beyond. The Grenville Front defined by Grant et al. (1962) does not agree with the Front defined by Quirke and Collins (1930) in the Sudbury region.

Henderson (pers. comm. 1965), mapping Eden and Tilton townships, found that feldspathization of quartzite to form a metasomatic zone of rocks between Southern and Grenville metamorphic rocks did not exist in the area, but that the rocks of the two provinces were separated by a quartz monzonite batholith. Fairbairn et al. (1960) dated 'porphyritic granite' in the area mapped by Henderson as being 910 million years old.

The Grenville Front in Eden and Tilton townships is therefore consistent with the Front defined by Quirke and Collins in that granite of possible Killarnean or Grenville age separates rocks of the Southern Province from rocks of the Grenville province.

Detailed structural mapping of the east central part of Eden Township in the present work was carried out to demonstrate the igneous contact relationships existing between the quartz monzonite and metasedimentary rocks of the Southern province in the area.

III. PETROGRAPHY, STRATIGRAPHY AND METAMORPHISM

A. Local Geological Setting

The Southern metasedimentary rocks in the map area form a stratigraphic sequence of alternating metagreywacke, feldspathic quartzite and quartzite units and are typical of the low grade metamorphic rocks of the Southern province found throughout the area around Sudbury. The metasediments dip steeply and are cut by a massive body of quartz monzonite on the east. Quartzite xenoliths of varying dimensions are common in the quartz monzonite where it directly intrudes the metasedimentary rocks. Gabbro stocks penetrate the metasediments and a large gabbro body borders the metasedimentary sequence on its western side. Gabbro xenoliths occur in the quartz monzonite.

Two strike slip faults of small displacement are present in the area. These are termed faults A and B, and the larger of the two, fault A, forms a stream valley between Duck, Cranberry and Grassy lakes.

B. Petrography and Stratigraphy

- Metasedimentary Rocks

Metasedimentary rocks form a continuous stratigraphic sequence approximately 6000 feet thick in the map area and no apparent structural inversions occur in the rocks. Bedding planes dip steeply and cross-bedding in arenaceous horizons indicates "younging" to the northeast.

Stratigraphic relationships existing between rock units in the metasedimentary sequence are displayed in the stratigraphic column in Figure 3. Averaged modal analyses for each rock unit in the metasedimentary sequence are presented in Table 1.

1. Metagreywacke (MGw-1)

Metagreywacke is the lowest observed rock unit of the metasedimentary sequence. The intrusion of a large gabbro body to the west has obliterated most of the metagreywacke unit in the Duck Lake region.

In outcrop, MGw-1 is a thin-bedded, very fine-grained metagreywacke of dark grey colour. In thin section, the rock consists of a fine-grained quartz framework with nearly equal amounts of biotite and muscovite filling interstices between quartz grains. Quartz grains show undulose extinction but do not appear to be highly strained. Biotite and muscovite plates are green-brown and colourless to pale green, respectively, in plain light. Small grains of pyrite commonly altering to limonite are the accessory minerals in the rock. Small amounts of plagioclase are present, and appear to be unaltered.

2. Feldspathic Quartzite (FQ-1)

The basal metagreywacke unit grades into feldspathic quartzite to the east. The gradational contact zone between the two units is relatively narrow, the change from argillaceous to arenaceous rock occurring over a distance of approximately 30 feet. In the zone of gradational contact, thin beds of metagreywacke alternate with lenses of feldspathic quartzite. Metagreywacke dies out to the east into the feldspathic quartzite.

Figure 3 - Stratigraphic Column - Metasediments

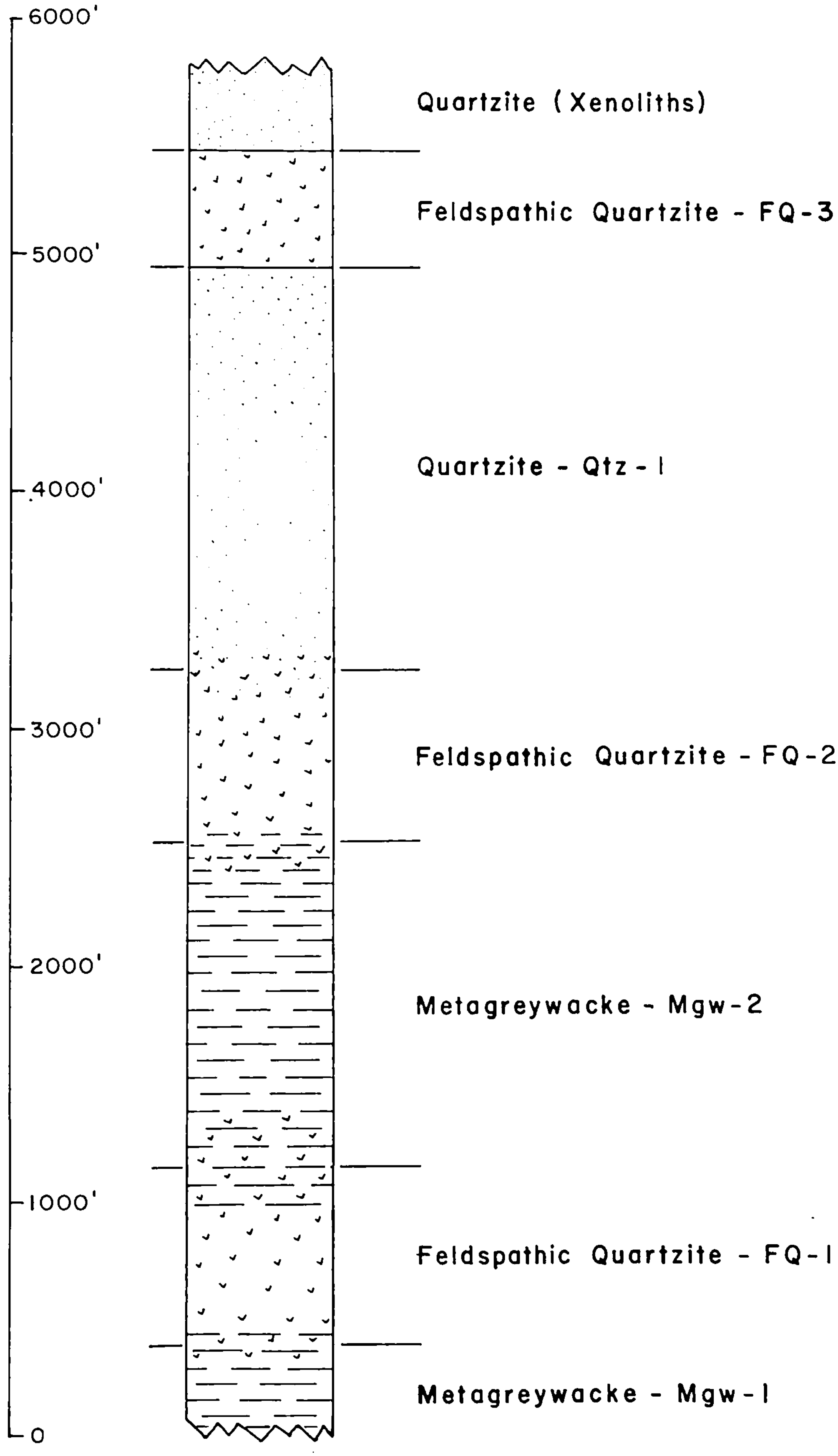


TABLE 1. MODAL ANALYSES - METASEDIMENTS

Lithologic Unit	Quartz (%)	Plagioclase (%)	Microcline (%)	Biotite (%)	Muscovite (%)	Epidote (%)	Accessories (%)
MGw-1	63.0	4.0	-	22.3	10.2	-	0.5 (pyrite)
FQ-1	67.0	20.3	4.5	4.5	-	2.0	1.7 (magnetite (?))
MGw-2	62.6	5.2	-	24.3	6.0	1.2	0.7 (magnetite (?))
FQ-2	74.3	2.4	5.2	6.2	10.8	-	1.1 (pyrite)
Qtz-1	86.0	1.3	-	-	12.7	-	-
FQ-3	56.9	9.9	8.0	5.0	18.3	-	1.9 (pyrite-magnetite
Qx (Xenoliths)	93.2	0.8	-	-	5.0	-	1.0 (magnetite)

Beds in the feldspathic quartzite range between 2 inches and 2 feet in thickness and small scale cross-bedding occurs in the thicker beds in places (see Map 1a).

FQ-1 is a fine-to medium-grained rock which weathers dark brown to buff in exposures. Quartz is the most abundant mineral in thin section, followed by biotite and plagioclase of variable anorthite composition. All quartz grains show undulose extinction and the mutual intergrowth of quartz grain boundaries is common. Small amounts of microcline and epidote occur in thin section, and pyrite, commonly altering to limonite, is the main accessory mineral in the rock. Small amounts of magnetite occur as the secondary accessory mineral.

3. Metagreywacke (MGw-2)

The feldspathic quartzite grades eastward into a second unit of metagreywacke. The gradation zone is approximately 100 yards wide, with alternating thin beds of feldspathic quartzite and metagreywacke. Feldspathic quartzite lenses die out to the east. The gradation zone between feldspathic quartzite and metagreywacke may indicate a facies change between the two units. One bed of metagreywacke in the gradation zone contains pebbles of granitic material. It was unfortunately impossible to trace the bed along strike due to the presence of heavy overburden and vegetation. Beds in the metagreywacke range from 1 inch to 1.0 feet in thickness.

Examination of MGw-2 in thin section shows quartz to be the most abundant constituent of the rock, followed by biotite, microcline and plagioclase. Small amounts of epidote, pyrite altering to limonite, and magnetite are present as accessory minerals.

Quartz grains are not highly strained but do show undulose extinction. Biotite and muscovite fill interstices between grains of quartz and feldspar, and micaceous plates are arranged in parallel relationships to each other developing a foliation in the metagreywacke.

Southwest of Grebe Lake in the area of quartz monzonite intrusion into the metagreywacke, sericitization of feldspar is common and quartz grains show cataclastic effects.

The disruptive effect of quartz monzonite on the metagreywacke is illustrated by the presence of microfaults in some thin sections.

Relict pseudomorphs of muscovite, apparently after staurolite are observed in flow cleavage planes and local concentrations of muscovite plates are common. The presence of muscovite pseudomorphs after staurolite apparently represents retrograde metamorphism of the metagreywacke.

4. Feldspathic Quartzite (FQ-2)

The second metagreywacke unit grades eastward into feldspathic quartzite. The gradation zone is approximately 20 feet across in the field consisting of alternating lenses of feldspathic quartzite and metagreywacke.

The second feldspathic quartzite unit is medium grained and weathers brown to red brown in outcrop. Beds range from 2 inches to 1.5 feet in thickness.

Quartz is the most abundant mineral in thin section followed by muscovite, microcline and varying amounts of plagioclase and biotite. Plagioclase is albite with an approximate anorthite content of 10 per cent. Pyrite altering to limonite and magnetite are common accessory minerals. Grains of epidote are also present in small amounts.

Quartz grains are generally anhedral and strained and grains commonly show mutually intergrown boundaries.

Microcline and plagioclase grains are fresh or slightly altered to sericite. Muscovite and biotite plates are aligned, producing faint foliation in the rock. Shredding of micaceous minerals is observed in thin sections.

5. Quartzite (Qtz-1)

A sharp decrease in feldspar and biotite content is observed across the contact of the feldspathic quartzite with the quartzite unit to the east. Beds in the quartzite range from 2 inches to 2 feet in thickness and the rock in outcrop is white with a faint green tinge due to its muscovite content.

The quartzite is composed of 2 minerals: quartz and muscovite. Quartz grains are strained and zoned and adjacent grains show mutually intergrown borders. Grain size of quartz ranges from 0.1 millimetres to 0.75 millimetres. Muscovite plates occur interstitially between quartz grains and shredding of micaceous plates is commonly observed in thin sections. The parallel alignment of muscovite plates produces a faint foliation generally parallel to bedding in the rocks.

Small amounts of plagioclase occur in the quartzite.

6. Feldspathic Quartzite (FQ-3)

The feldspathic quartzite unit in contact with quartz monzonite to the east is mineralogically similar to feldspathic quartzite in other parts of the map area. Crushing and straining of quartz grains and widespread sericitization of feldspar in FQ-3 is more pronounced than in other metasedimentary units apparently indicating physical and chemical changes in the rock effected by the intruding quartz monzonite. The gneissic appearance of the rock may also have been caused by the quartz monzonite.

Quartz is the most abundant mineral in FQ-3 and grains in contact display mutually intergrown borders.

Most of the plagioclase is andesine in composition with an approximate anorthite content of 45 per cent. Plagioclase is not fresh but has undergone extensive sericitization, along with microcline.

Muscovite plates are present in the unit along with lesser amounts of green-brown biotite. Muscovite and biotite plates are aligned to produce foliation in the feldspathic quartzite. Pleochroic haloes amount very small zircon crystals in biotite are observed in thin sections, and muscovite and biotite plates appear to have been crushed and shredded in many places.

Pyrite altering to limonite, and magnetite are the two main accessory minerals present in FQ-3.

7. Quartzite Xenoliths (Qx)

Quartzite xenoliths closely resemble rocks of the quartzite unit in the metasedimentary sequence to the west described above. Xenoliths have the same distinctive white colour as quartzite to the west and beds range from 2 inches to 2 feet in thickness. Xenoliths have sharply defined borders in the quartz monzonite and assimilation of the quartzite blocks by the igneous rock has not occurred except on a very minor scale.

Quartz grains in xenoliths range from 0.2 millimetres to 1.5 millimetres across and are therefore larger than the grains in quartzite to the west. Quartz grains are strained and mutually intergrown borders are common between grains in contact. Larger grain size of this rock is apparently not due to recrystallization because undulose extinction of quartz grains suggests straining. Grain growth by recrystallization does not occur until most of the strain has been eliminated from the grains (Carter et al., 1964).

Muscovite plates in parallel alignment occur interstitially between quartz grains and are responsible for the development of faint foliation parallel or sub-parallel to bedding planes in xenoliths.

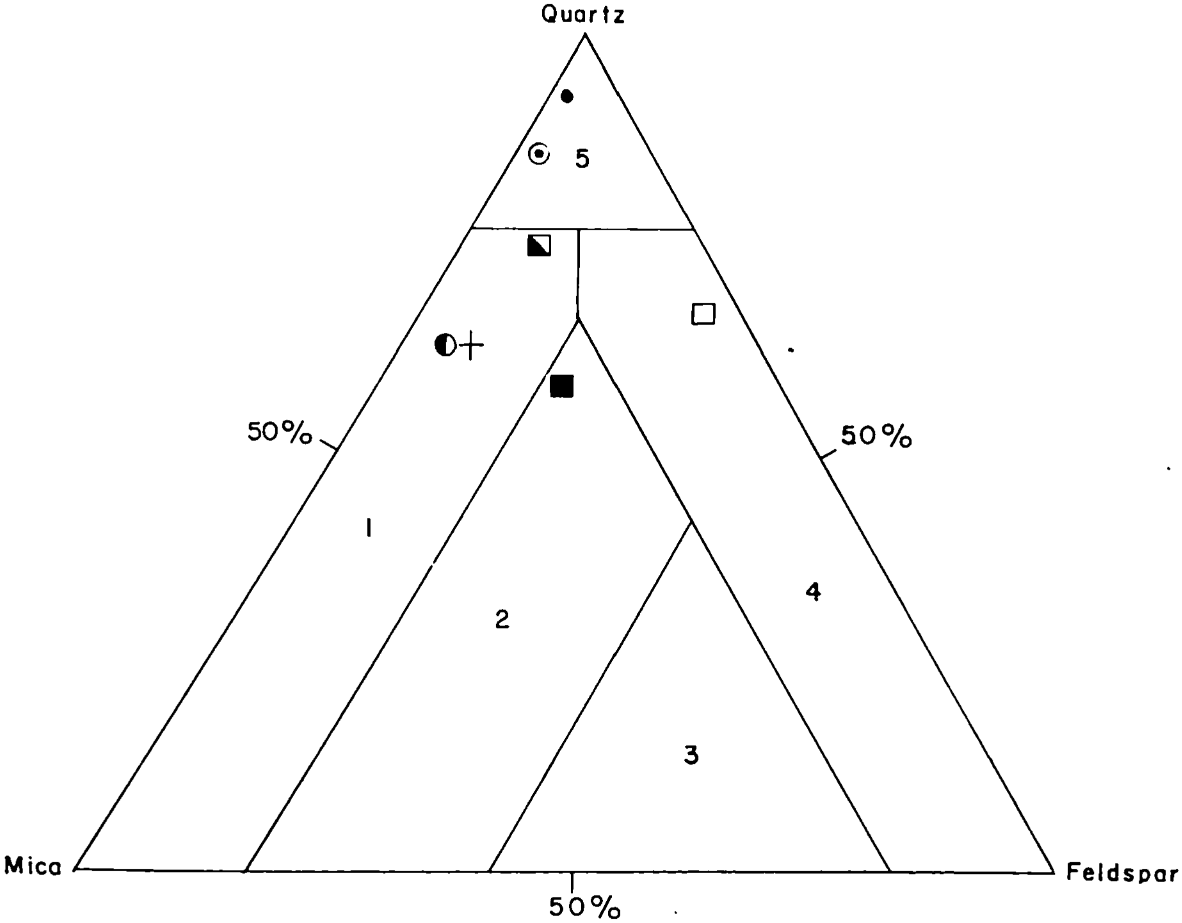
Magnetite is usually only an accessory mineral in the xenoliths. Two xenoliths, however, located on Map 1a, contain magnetite bands approximately 2 inches in thickness along the strike of bedding.

8. Discussion

A triangular diagram of mineral composition for the detrital fraction of the major petrographic series of sedimentary rocks, after Krynine (1954), is presented in Figure 4, and averaged mineralogical compositions of 4 samples from each metasedimentary rock unit in the map are plotted in the diagram. Since the metasedimentary rocks are characteristic of rocks subjected to low grade regional metamorphism, it was felt that a plot such as Figure 4 would be instructive as an indicator of the approximate original sedimentary rock type of each of the metasedimentary units.

According to the diagram metagreywacke units were originally "low rank greywackes", quartzite units represented by Qtz-1 and Qx (quartzite xenoliths), were derived from sedimentary orthoquartzites, FQ-1 was originally an arkose and FQ-3 was 'high rank greywacke'.

Figure 4



□	Feldspathic Quartzite - FQ-1	1 - Low Rank Greywacke
◪	" " FQ-2	2 - High Rank Greywacke
▣	" " FQ-3	3 - Impure Arkose
◐	Metagreywacke - Mgw-1	4 - Arkose
+	" - Mgw-2	5 - Orthoquartzite
⊙	Quartzite - Qtz-1	
•	" - Qx	

(Diagram After Krynine - 1954)

FQ-2 in relation to petrographic fields in the diagram plots as a quartzose 'low rank greywacke'. The feldspar content of FQ-2 varies greatly in the field area and the unit differs significantly from MGw-1 and MGw-2 in appearance in exposures, such that the writer feels the name 'feldspathic quartzite' should be retained for it.

The metagreywacke and feldspathic quartzite sequence may have been laid down in broad deltaic plains (Kay, 1951). The presence of cross-bedding in feldspathic quartzites and thin beds in metagreywacke are apparently indicative of shallow water deposition rather than an environment of dumping of sediments into rapidly deepening water (op. cit. p. 87). Orthoquartzite is indicative of an environment which allowed the sorting of source rock constituents and is characteristic of the depositional environment of miogeosynclines (ibid. p. 87).

C. Petrography - Igneous Rocks

1. Quartz Monzonite

The rocks to the east of the paragneiss unit, excluding quartzite xenoliths and gabbro intrusives, are characterized by phenocrysts of pink microcline in a groundmass of smaller grains of plagioclase, biotite and quartz. The microcline phenocrysts give a distinctive speckled appearance to outcrops, and range from 0.25 inches to 0.75 inches in size.

An examination of thin sections reveals well-developed igneous textures in feldspars such as perthitic intergrowths of sodic plagioclase in microcline phenocrysts. Modal analysis of 14 thin sections shows an average quartz content of 19.0 per cent, average microcline content of 26.5 per cent, and an average plagioclase content of 46.5

per cent. Six of the fourteen thin sections contain approximately equal amounts of plagioclase and microcline.

Williams et al. (1958) define monzonite as an igneous rock having approximately equal amounts of potash feldspar (microcline) and plagioclase. By increase in quartz content above 10 per cent they pass into adamellites (quartz monzonites). The porphyritic intrusive rock of the map area may therefore be defined as quartz monzonite.

In thin sections, plagioclase, generally An_8, shows strain effects by the slight bending of twin lamellae. Sericitization of albite is also observed. Microcline phenocrysts usually contain perthitic intergrowths of sodic plagioclase, and unmixing illustrated by the two phases in microcline may be due to autometamorphism or post-consolidation regional metamorphism of the quartz monzonite (op. cit. p. 133). Microcline phenocrysts are subhedral to anhedral in shape.

Quartz grains demonstrate flow effects around plagioclase grains and microcline phenocrysts. Flow in quartz is thought to be related to post-consolidation regional metamorphism of the quartz monzonite.

Green-brown biotite is the most common mafic mineral in the rock. Biotite is generally observed 'flowing' around other minerals in the rock and is shredded in places.

Small irregular grains of hornblende, epidote, apatite and magnetite are common accessory minerals in the quartz monzonite.

2. Gabbro

Small bodies of gabbro occur in the map area in the metasedimentary rocks. The gabbro bodies in the quartz monzonite are related mineralogically to stocks in the metasediments and are believed to be xenoliths of gabbro stock remnants which suffered disruption by the intrusive quartz monzonite. Gabbro dikes and dike remnants are present in the metasedimentary rocks in the form of boudinage structures (Figure 5) and small scale continuous gabbro bodies disrupted by faulting.

The eastern portion of the gabbro stock north of Beaver Lake illustrates that gabbro stocks in the metasedimentary sequence predate the intrusion of quartz monzonite. Here, the gabbro contains a complex stockwork of granitic veins derived from the quartz monzonite sill and dike system in the area. The gabbro contains porphyroblasts of microcline which may illustrate recrystallization of the basic intrusive due to the proximity of the intruding granitic material. The gabbro was apparently rich enough in potassium to permit the crystallization of microcline porphyroblasts or potassium was added by the quartz monzonite.

The gabbro dike east of Beaver Lake cuts feldspathic quartzite, quartz monzonite and quartzite xenoliths and therefore post-dates the intrusion of quartz monzonite.

Two sets of gabbro intrusives are therefore postulated: one set invaded the metasedimentary rocks before intrusion of the quartz monzonite involving the emplacement of stocks and dikes in the rocks; the second set involved the intrusion of a dike in the quartz monzonite.

The large gabbro body on the western border of the map area was not mapped in detail and cannot, therefore, be related to either phase of gabbro intrusion.

All gabbro bodies in the map area contain hornblende, plagioclase (approximately An_{40}) and small amounts of quartz, sphene, epidote and

Figure 5 - Gabbro Boudinage In Quartzite

magnetite as accessory minerals. Hornblende is subhedral to anhedral in shape and commonly has a poikilitic texture with small grains of quartz and plagioclase as inclusions. Saussuritization of plagioclase is common. The gabbro dike related to the second period of gabbro intrusion differs from all other gabbro in that it contains significant amounts of biotite. The biotite is pale to red-brown in colour and red-brown biotite commonly mantles and replaces hornblende in the rock. Distinct plates of the pale brown biotite are seen between grains of plagioclase, bearing no apparent relationship to hornblende grains. The pale brown biotite is thought to represent original biotite, the red-brown variety is believed to be an alteration product of hornblende formed during post-consolidation deformation.

Modal analysis of 4 thin sections from gabbro bodies in the map area shows an average plagioclase content of 41.8 per cent and an average hornblende content of 53.9 per cent. Quartz, sphene and magnetite and small amounts of epidote make up the remaining 5.3 per cent of the rock.

Modal analysis of a thin section from the gabbro dike east of Beaver Lake reveals a hornblende content of 46.0 per cent, a plagioclase content of 42.5 per cent and a biotite content of 10.5 per cent. The remaining 1.0 per cent of the rock is composed of accessory quartz, sphene and magnetite.

D. Metamorphism

1. Metasedimentary Rocks

The metasedimentary rocks of the map area have not been subjected to intense metamorphism. Bedding planes have been preserved in the rocks, and other primary structures such as cross-bedding, have suffered little apparent distortion or disruption.

Critical metamorphic mineral assemblages are not well-developed in the rocks, but the presence of quartz, plagioclase (generally more calcium rich than albite), biotite and small amounts of epidote, suggests that the metasedimentary rocks may be placed in the quartz-albite-epidote biotite subfacies of the greenschist facies of regionally metamorphosed rocks.

Pseudomorphs of muscovite, apparently after staurolite in meta-greywacke, indicate that some of the rocks of the area were at one time subjected to metamorphic conditions that would place them in the staurolite-quartz subfacies of the almandine-amphibolite facies.

Two major phases of metamorphism are therefore apparent. The first phase was initially low-grade, with the production of biotite and epidote in the rocks. During the late stages of the first phase, metamorphic grade increased, transforming the mineral assemblages in some rocks into those characteristic of the staurolite-quartz subfacies of the almandine-amphibolite facies.

The second phase involved retrograde metamorphism which altered staurolite to muscovite, changing the mineral assemblages typical of the low almandine-amphibolite facies to those of the greenschist facies.

2. Gabbro

Gabbro intrusives in the metasedimentary rocks have been subjected to regional metamorphism. The main mineral indicating that metamorphic effects have taken place is poikilitic hornblende which has apparently replaced pyroxene in the gabbro. A small amount of quartz occurs, generally forming inclusions in hornblende crystals, plagioclase is andesine in composition and no albite and only small amounts of epidote are observed in thin sections.

The presence of amphibole, epidote, and saussuritized andesine suggests metamorphism of the rocks to the low almandine-amphibolite facies.

Gabbro xenoliths in the quartz monzonite also belong in the almandine-amphibolite facies and were apparently metamorphosed before intrusion of the quartz monzonite and at the same time as 'unmoved' gabbro in the metasedimentary rocks.

3. Quartz Monzonite

Metamorphic effects observed in the quartz monzonite are chiefly seen in the sericitization and bending of twinned plagioclase grains and the flow and strain effects demonstrated by quartz. These effects are all attributed to post-consolidation deformation of the quartz monzonite.

Aureole development in the metasedimentary rocks due to quartz monzonite intrusion is not well-developed, but may be represented by the degradation of plagioclase and staurolite and the growth of porphyroblasts of mica. Plagioclase alteration to sericite is most pronounced in FQ-3 and FQ-2 and dies out to the west. Development of mica is best observed in MGw-2.

4. Discussion

Card (1964), working in the Agnew Lake area west of Sudbury stated that

> ". . .mafic igneous, pelitic metasedimentary and quartzofeldspathic rocks were metamorphosed under conditions ranging from the low greenschist (chlorite-grade) to low almandine-amphibolite (staurolite-grade) facies."

Continuity of metamorphic grade therefore exists between Southern rocks south of Sudbury in proximity to the Grenville Front and rocks of the Southern province away from the Front in the Agnew Lake area.

IV. STRUCTURAL GEOLOGY

A. Introduction

In the map area under consideration, two phases of penetrative deformation have been imposed on the metasedimentary rocks. The two phases of penetrative deformation have their expression first in a foliation developed nearly parallel to bedding and marked by parallel alignment of micaceous plates in the metasedimentary rocks, and secondly by the development of fracture and flow cleavage, consisting of discrete parallel fractures in arenaceous horizons and flow cleavage planes producing small scale folding in argillaceous horizons.

The non-penetrative phase of deformation is expressed by the two major strike-slip faults in the map area.

B. Structural Analysis - Definition

Structural analysis concerns itself with the study of those internal structural elements of rocks which have a regular configuration in space. One of the main concerns of a structural geologist is the interpretation of this regularity of configuration on scales ranging from microscopic to regional.

Structural analysis involves two distinct procedures, the first of which is

> ". . . the study and description of a rock body in the present state - a study as free as possible from inference and extrapolation except to the extent imposed by limitations of poor exposure in the field. Then comes genetic interpretation of the descriptive data, an attempt to reconstruct the structural evolution of the body in question." (Turner and Weiss, 1963)

Analysis of tectonites proceeds under three main headings. The three headings are:

1) Geometric Analysis: consisting of direct measurement and observation of the geometric and physical properties of the deformed body;

2) Kinematic Analysis: concerning information on strain, rotation and so forth derived from data presented in geometric analysis; and

3) Dynamic Analysis: more uncertain than the previous analyses by virtue of the fact that it tries to reconstruct physical stresses on rock masses during deformation and hence concerns processes which are imperfectly understood.

Structural analysis of data from the map area will concern itself chiefly with geometric analysis of structural elements in the meta-sedimentary rocks and quartz monzonite. Kinematic structural analysis will be concerned with rotation of quartzite xenoliths in quartz monzonite and interpretation of fracture and flow cleavage, lineation and foliation and their relationships to phases of deformation in the region south of Sudbury. The intrusion of quartz monzonite will also be treated in the section on kinematic structural analysis.

Since information on stress systems during deformation are largely indeterminate for the rocks of the map area, the dynamic analysis of the rocks is not prosecuted below.

C. Geometric Structural Analysis - Map Area

Geometric analysis of tectonites is made at 3 distinct levels (Turner and Weiss, 1963). These levels are:

1) Macroscopic: applied to structural elements whose properties can only be determined by geological mapping. These structural elements include folds, faults, unconformities and igneous intrusive contacts.

2) Mesoscopic: applied to structures occurring in individual rock outcrops and hand specimens, including structures such as foliations, lineations, bedding and cleavages. Structures such as drag folds on a small scale are included in mesoscopic analysis.

3) Microscopic: provides amplification and verification of the structural analysis of mesoscopic bodies and obtains additional information accessible only through use of the microscope, such as c-axis studies on quartz grains of a tectonite.

Geometric structural analysis of the map area will be organized in the following manner: mesoscopic analysis of structural elements will be considered first, followed by macroscopic and microscopic analyses. Divergence from the logical order macroscopic analysis - mesoscopic analysis - microscopic analysis, is necessitated by the observation that a clear analysis of macroscopic elements in the area depends largely on their relationship to structural element patterns used in mesoscopic analysis. For example, to be able to discuss with clarity the apparent movement of the faulted block bounded by faults A and B (Maps 1a and 1b) north of Beaver Lake, a comparison of mesoscopic structural elements such as foliation and fracture cleavage in the block with similar elements in adjacent rocks, is essential.

For convenience, two areas of metasedimentary rocks are considered. The first of these areas contains the metasediments west of the quartz monzonite-feldspathic quartzite contact, the second area encompasses xenoliths of quartzite engulfed by the quartz monzonite east of the quartz monzonite-feldspathic quartzite contact. The rocks of the first area are termed 'unmoved metasedimentary rocks'. Xenoliths in the second area are termed 'moved metasedimentary rocks'. In a consideration of the nature of structural elements in the metasedimentary rocks no distinction will be made between moved and unmoved metasediments, the structural elements being the same in both cases.

(a) Nature of Structural Elements

1. Metasedimentary Rocks

Structural elements in the metasediments consist of foliation, generally parallel or sub-parallel to bedding, fracture and flow cleavage, and lineation.

Bedding:

The following field observations demonstrate that bedding planes have not been obliterated in the metasediments. In metagreywacke, bedding planes are marked by subtle changes in muscovite and biotite content across strike. These zones of gradation in mica content are parallel to arenaceous lenses of feldspathic quartzite in gradational contact zones between metagreywacke and feldspathic quartzite units. The zones also have consistent northwest or west of north strikes.

The strike of bedding in feldspathic quartzite conforms to the strike of bedding in metagreywacke. Bedding is distinctly marked in feldspathic quartzite by the presence of cross-bedding (Figure 6). In quartzite, bedding is marked by bands of slight colour change which run parallel to strike. Bands of colour change are apparently due to

Figure 6 - Cross-bedding And Fracture/Flow Cleavage (S2)

changes in muscovite content across the strike of the beds.

Foliation:

Foliation throughout the metasediments is marked by the parallel alignment of micaceous mineral plates in, or sub-parallel to, bedding planes. The foliation cuts bedding planes in small folds in the metasediments and is therefore assumed to have been formed during folding of the rocks.

Fracture and Flow Cleavage:

Fracture and flow cleavage consist of discrete, closely spaced parallel fracture planes in arenaceous horizons (Figure 6), and densely spaced parallel planes of displacement in argillaceous horizons.

Lineation:

Lineation in all metasedimentary rocks is due to the development of quartz rodding in the planes of foliation of the rocks. In one metagreywacke outcrop pseudomorphs of muscovite after staurolite lie parallel to lineation at foliation and flow cleavage plane intersections, and are apparently indicative of a later set of lineations which developed in a stress field similar to that which produced rodding of quartz in the rocks during plastic deformation. The two sets of lineations will be examined in more detail below.

2. Igneous Rocks

Structural elements in the quartz monzonite consist of a foliation defined by the long dimensions of microcline phenocrysts and biotite plates, and a generally ill-defined lineation, again due to alignment of microcline phenocrysts and biotite. Foliation in the quartz monzonite in two linear and narrow zones which may be defined as possible shear zones. Foliation and lineation in these zones are both developed by the streaking out of microcline phenocrysts and sympathetic alignment of biotite plates parallel to the microcline.

Structural elements in the quartz monzonite, except for those developed in the postulated shear zones, are considered to be essentially primary features developed by flow effects in a molten igneous mass. Post-consolidation deformation, exhibited by faults and possible shear zones, has not obliterated the primary flow structures in the rock.

Structural elements in gabbro stocks, xenoliths and dikes are poorly developed or absent.

(b) Mesoscopic Structural Analysis

For purposes of macroscopic structural analysis of the map area, 10 subareas were defined to establish whether consistency of symmetry of fabric elements existed between them, or whether local variations between each existed.

In the unmoved metasedimentary rocks, subareas were drawn along lithological boundaries. Subarea 3 in Figure 7 and 8 was the exception. It was felt that a subarea defined and bounded by faults A and B might reveal apparent movement in the block of rocks so delineated.

In the region of metasedimentary inclusions in the quartz monzonite (the area of moved metasedimentary rocks), subareas were defined with respect to structural boundaries and the change in gross trend of xenoliths.

π pole plots of foliation planes and π pole plots of fracture and flow cleavage with lineations were made for each subarea on the lower hemisphere of a Schmidt equal area projection according to accepted

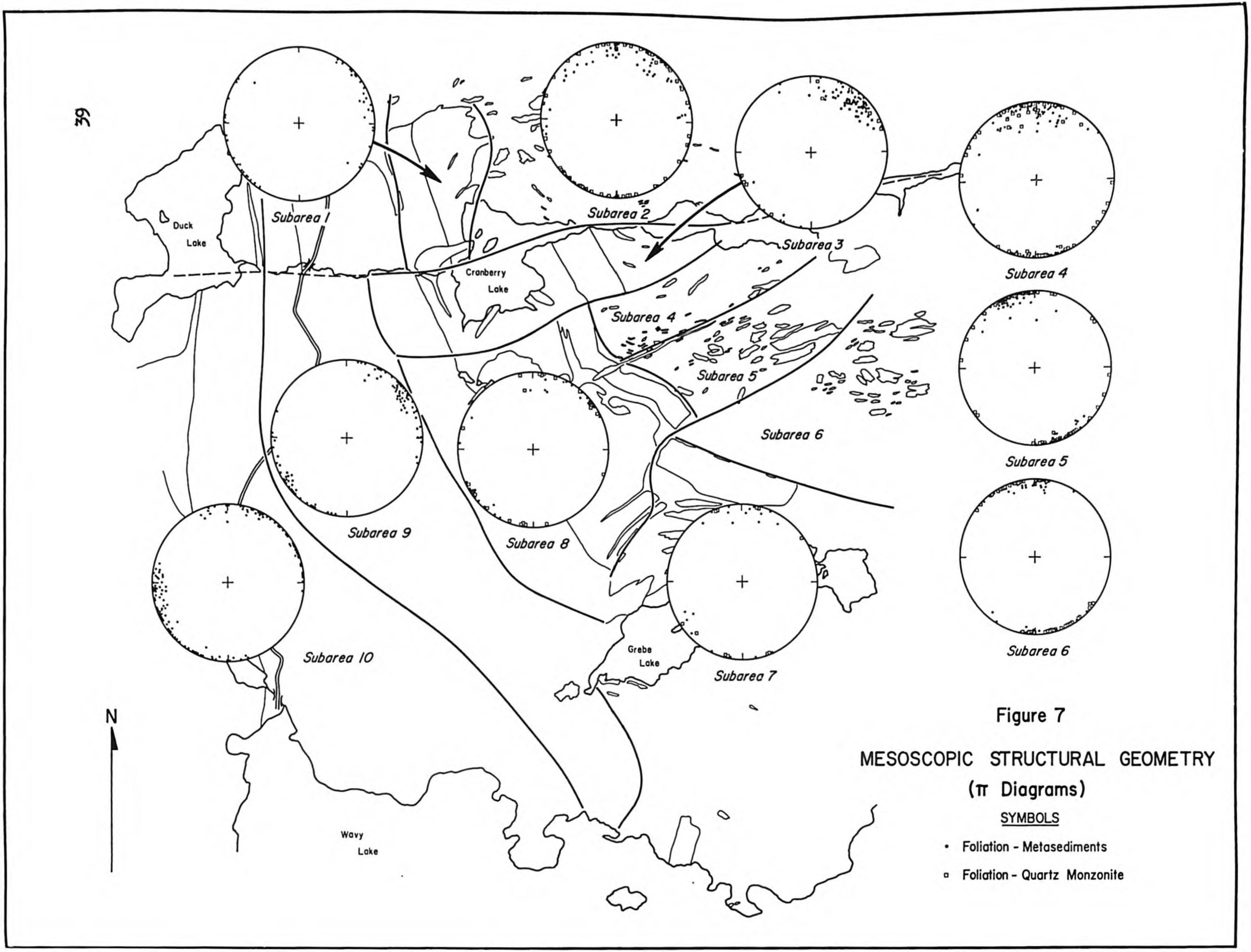


Figure 7

MESOSCOPIC STRUCTURAL GEOMETRY
(π Diagrams)

SYMBOLS

• Foliation - Metasediments

▫ Foliation - Quartz Monzonite

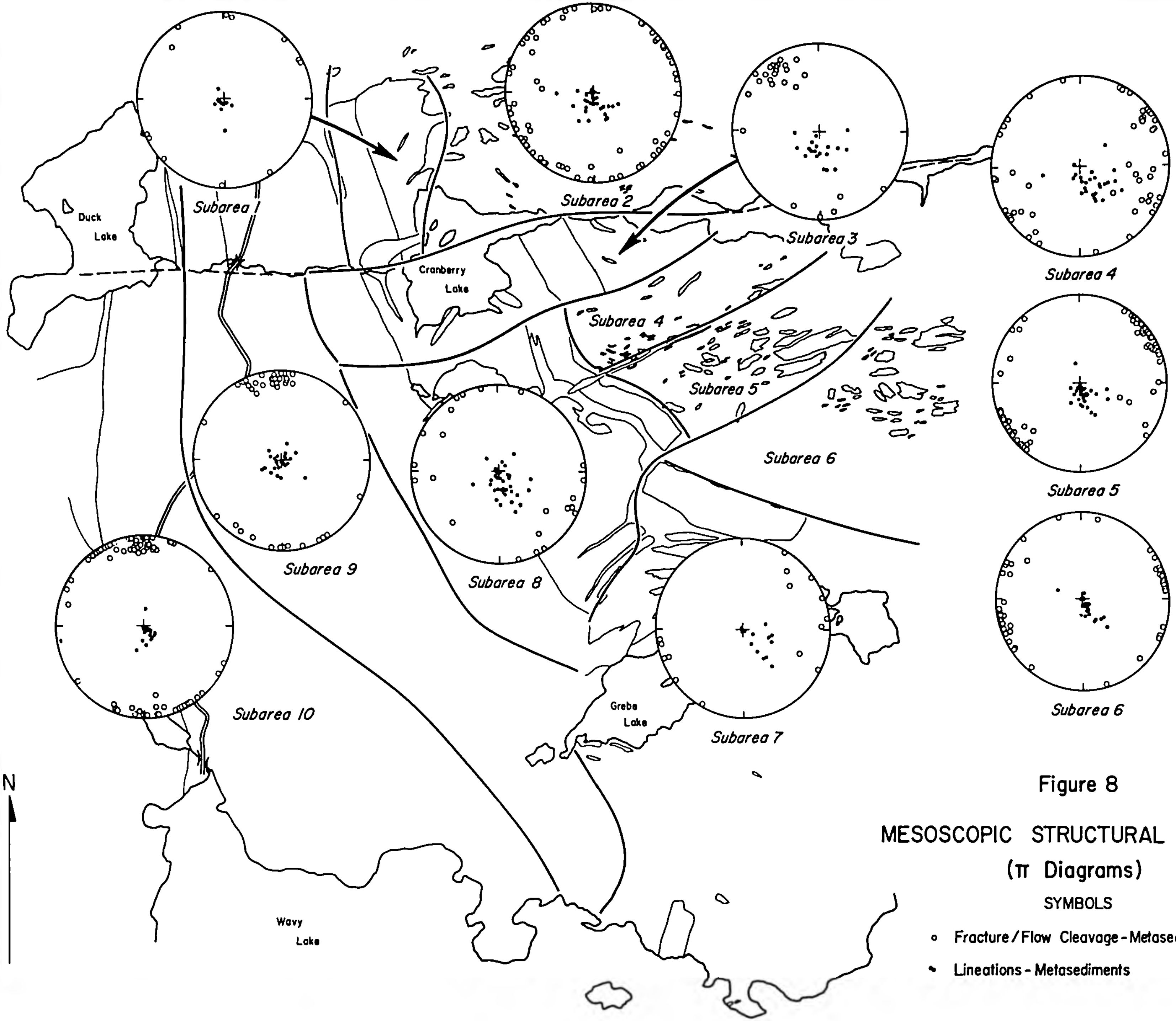


Figure 8

MESOSCOPIC STRUCTURAL GEOMETRY
(π Diagrams)

SYMBOLS

∘ Fracture / Flow Cleavage - Metasediments

• Lineations - Metasediments

convention, and these were superimposed on maps of the field area in Figures 7 and 8 respectively.

The necessity of dividing the map area into subareas to study the symmetry of fabric elements is well illustrated by consideration of a π pole plot of 779 foliation plane measurements taken from across the map area. This plot is shown in Figure 9. Diffuse monoclinic symmetry is shown for foliation planes in the map area with the plane of symmetry of the plot striking 280 degrees. Comparing Figure 7 and Figure 9, monoclinic symmetry occurs throughout the map area when individual subareas are considered, but symmetry planes of foliation diverge rather widely in subareas when compared to the average regional trend. An ancillary effect of the division of the map area into subareas is seen in the reduction of pole scatter inherent in the regional plot. Subareas are more distinctly monoclinic in symmetry with respect to foliation than the regional plot would indicate.

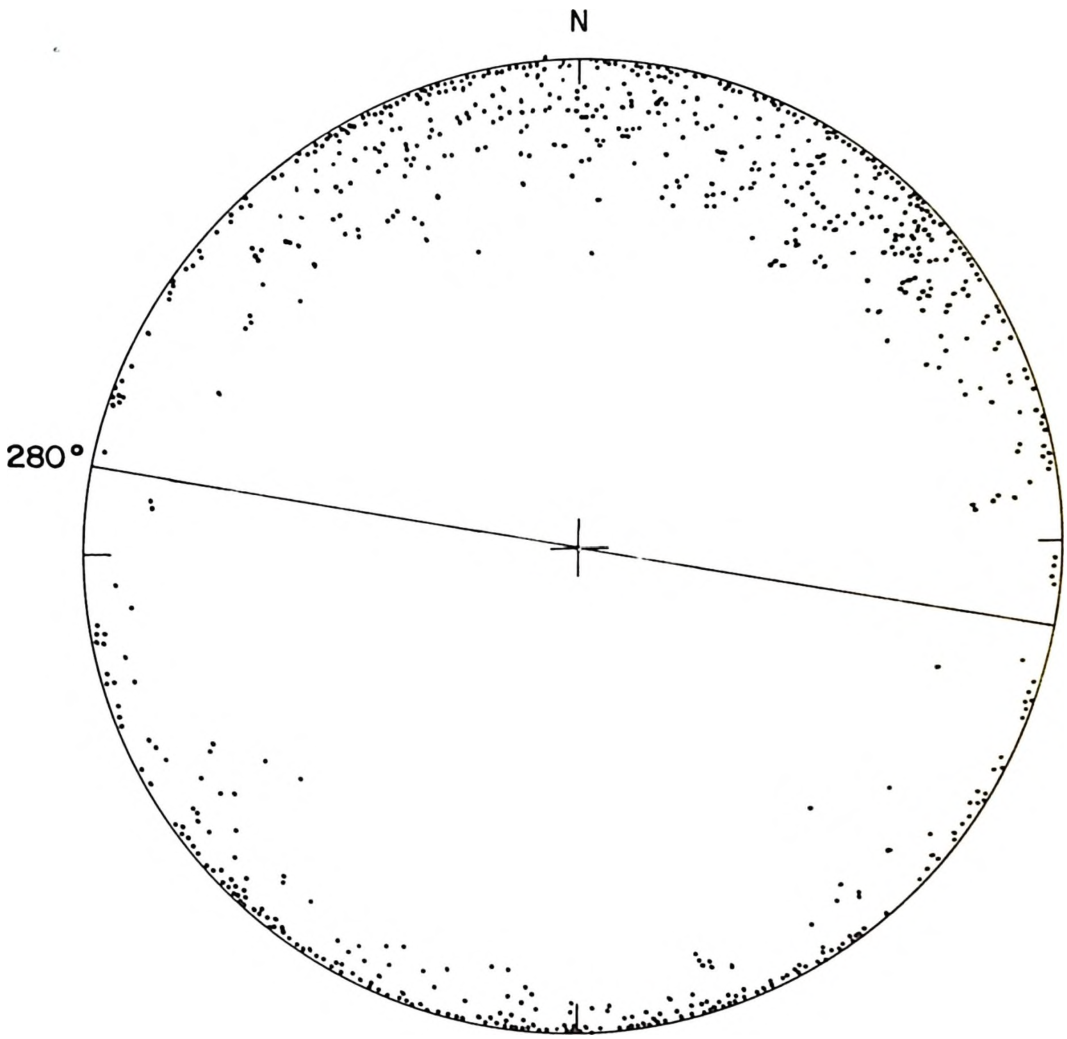
1. Structural Analysis - Unmoved Metasediments

Subareas dealt with in this section are those numbered 1, 3, 8, 9 and 10 in Figures 7 and 8.

(i) Bedding and Foliation

Since foliation planes in the rocks largely coincide with bedding planes, foliation and bedding are grouped together for the purposes of structural analysis. Foliation and bedding planes describe a gentle curve in the map area trending approximately northwest near Wavy Lake to west of north, east of Duck Lake. Foliation and bedding plots in pole presentations of subareas 1, 8, 9 and 10 in Figure 7 graphically illustrate the change in trend outlined above.

Figure 9 - Metasedimentary Foliation (S_1) - π Pole Plot



779 Poles

In all subareas, except subarea 3, fabric symmetry in the unmoved metasediments is monoclinic and the average dip value for foliation and bedding planes is approximately 90 degrees. In subarea 3 fabric symmetry is monoclinic with respect to foliation and bedding planes. The strike and dip of averaged foliation and bedding planes from the π pole presentation in Figure 7 is to the southwest at 75 degrees.

Foliation extends through noses of small folds in the map area and lies in their axial planes. In Figure 10 the trace of foliation (S_1) has been outlined on a faulted small fold nose in a quartzite outcrop. The axis of the fold has a strike of 200 degrees and plunges in that direction at 60 degrees. Foliation strike and dip is 290°-60°S. The foregoing data illustrates that foliation can be considered axial plane cleavage in small folds.

(ii) Fracture and Flow Cleavage

Poles to fracture and flow cleavage planes for each of the five subareas in the unmoved metasedimentary rocks are presented in Figure 8. Fracture and flow cleavage in the unmoved metasediments are essentially monoclinic fabric elements whose planes of symmetry are approximately vertical throughout the thesis area. Strike of symmetry planes is southwest or south of west.

The attitude of fracture and flow cleavage planes is nearly constant. In the north where foliation and bedding trend west of north, fracture and flow cleavage planes intersect foliation and bedding at angles of between 70 and 90 degrees. In the southern part of the map area near Wavy Lake, bedding and foliation planes trend west and fracture

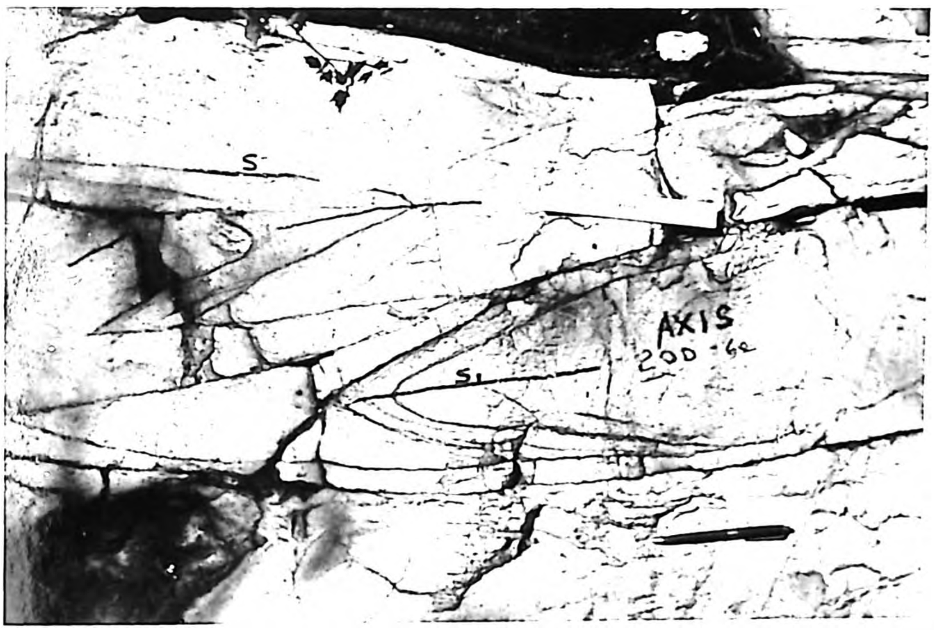


Figure 10 - Small Fold In Quartzite

and flow cleavage retain a south of west strike and cut foliation and bedding planes at angles of between 20 and 35 degrees. Dip of fracture and flow cleavage planes is either vertical or to the southeast at between 70 and 85 degrees.

The constant trends of fracture and flow cleavage planes and their relationships to bedding and foliation planes can be readily seen by a comparison of Maps 1a and 1b and Figures 7 and 8.

Refraction of fracture and flow cleavage is observed in outcrop in the gradational contact zone between the metagreywacke and first feldspathic quartzite units, where in successive argillaceous and arenaceous lenses, fracture cleavage in arenaceous bands changes to flow cleavage in argillaceous bands. Fracture cleavage striking 253 degrees in lenses of feldspathic quartzite, changes in argillaceous lenses to flow cleavage with a strike of 284 degrees (Figure 11b). Fracture cleavage planes in Figure 11b are vertical, as are flow cleavage planes in the argillaceous lenses. Fracture and flow cleavage planes were formed, therefore, in response to the same stress field and the refraction of their strike directions was in response to differences in competency between arenaceous and argillaceous lenses. Flow cleavage produces 'crinkle' folds in sandy partings in argillaceous horizons (Figure 11a).

Fracture and flow cleavage data for subarea 1 is sparse. The reason for paucity of data from the subarea is explained by extensive shattering of rocks which prevented the taking of measurements of distinct fracture cleavage planes.

In subarea 3, the π pole plot of fracture cleavage planes demonstrates monoclinic fabric symmetry. The average plane of fracture

Figure II

Figure IIa - 'Crinkle' Folds In Metagreywacke

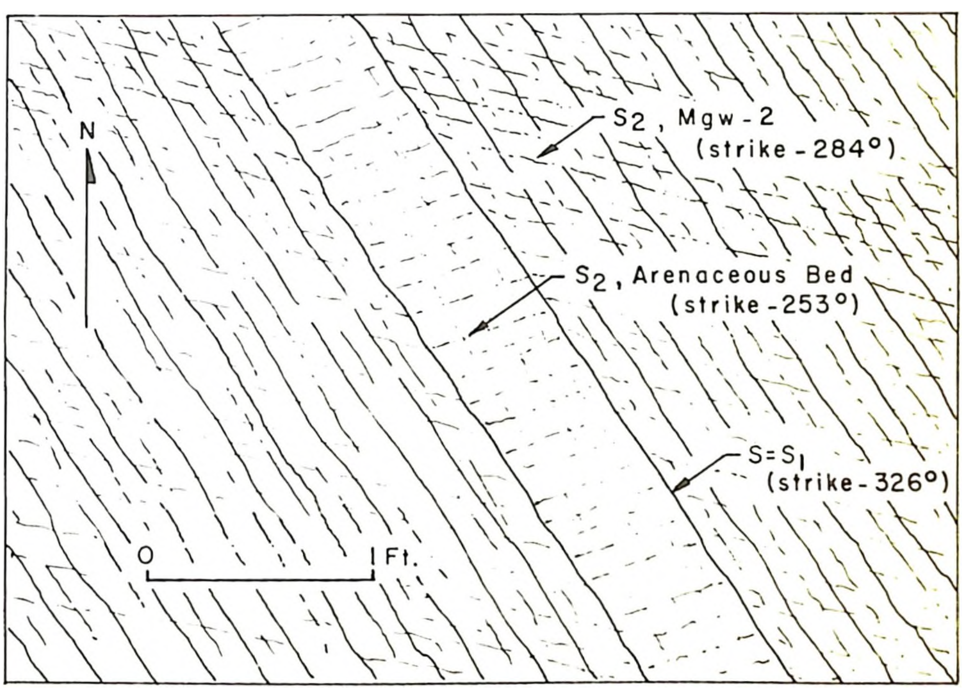


Figure IIb - Refraction Of Fracture Cleavage - (S2) and flow cleavage strikes approximately 055 degrees and dips to the southeast at about 75 degrees.

(iii) Lineation

Lineations for unmoved metasedimentary rocks are plotted with fracture and flow cleavage planes in Figure 8. In all subareas lineations are vertical or dip to the south at high angles. In Table 2 the average foliation and fracture and flow cleavage planes for each of the five subareas in the unmoved metasediments are presented as great circles.

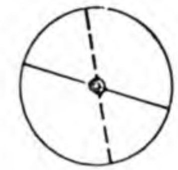
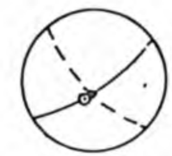
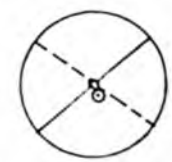
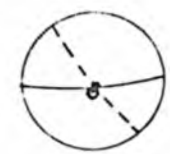
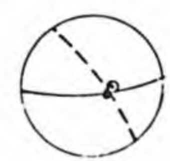
Calculated lineations ($\bar{L}_c$), derived from the intersections of average planes of foliation and fracture and flow cleavage for each subarea, are compared in tabular and diagrammatic form with averaged observed lineations ($\bar{L}_o$), for corresponding subareas. Results are indicative of a definite relationship existing between the intersections of fracture and flow cleavage planes and foliation planes, and lineation orientation.

Discrepancies between $\bar{L}_c$ and $\bar{L}_o$ values lie in the azimuth of dip of the lineations. The discrepancies are attributed to observational error inherent in measuring the azimuths of steeply dipping lineations in the field with a Brunton pocket transit.

2. Structural Analysis - Moved Metasediments

Subareas concerned in the structural analysis of moved metasedimentary rocks or quartzite xenoliths are subareas 2, 4, 5, 6 and 7, in Figures 7 and 8. Distribution of quartzite xenoliths is clearly shown on Maps 1a and 1b.

TABLE 2. UNMOVED METASEDIMENTS

Subarea	Strike & Dip $\bar{S}_1$	Strike & Dip $\bar{S}_2$	Attitude - $\bar{L}_c$	Attitude - $\bar{L}_o$	Diagram
Subarea 1	350° - 90°	106° - 90°	Vertical	Vertical	
Subarea 3	315° - 75°S	055° - 75°S	191° - 70°	194° - 70°	
Subarea 8	306° - 90°	050° - 90°	Vertical	174° - 80°	
Subarea 9	323° - 88°SW	086° - 85°S	170° - 85°	180° - 85°	
Subarea 10	350° - 85°NE	084° - 80°S	147° - 79°	137° - 80°	

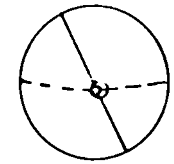
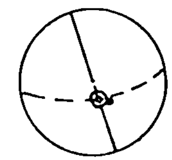
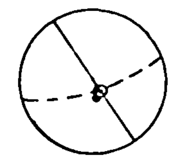
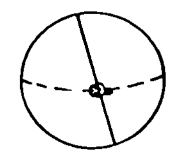
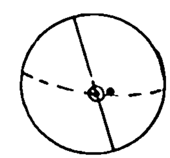
- - - $\bar{S}_1$ = average foliation planes

—— $\bar{S}_2$ = average fracture/flow cleavage plane

⊙ $\bar{L}_c$ = average calculated lineation at intersection of $\bar{S}_1$ and $\bar{S}_2$

• $\bar{L}_o$ = average observed lineation

TABLE 3. MOVED METASEDIMENTS (INCLUSIONS)

Subarea	Strike & Dip $\bar{S}_1$	Strike & Dip $\bar{S}_2$	Attitude - $\bar{L}_c$	Attitude - $\bar{L}_o$	Diagram
Subarea 2	090° - 80°S	334° - 90° (approx.)	153° - 79°	152° - 80°	
Subarea 4	080° - 70°S	342° - 90°	159° - 70°	152° - 67°	
Subarea 5	071° - 80°S	326° - 90°	148° - 80°	155° - 81°	
Subarea 6	086° - 82°S	344° - 90°	164° - 82°	154° - 80°	
Subarea 7	095° - 80°S	344° - 90°	164° - 80°	144° - 70°	

- - - $\bar{S}_1$ = average foliation planes

——— $\bar{S}_2$ = average fracture/flow cleavage plane

⊙ $\bar{L}_c$ = average calculated lineation at intersection of $\bar{S}_1$ and $\bar{S}_2$

• $\bar{L}_o$ = average observed lineation

Subareas 4, 5, 6 and 7 demonstrate monoclinic fabric symmetry for foliation and bedding planes and for fracture and flow cleavage planes in xenoliths, in π pole plots of the subareas. Angular relationships between fracture and flow cleavage planes and foliation and bedding planes are analogous to those observed in quartzite in subarea 8 of the unmoved metasedimentary rocks. Foliation and bedding planes in quartzite xenoliths are generally parallel to the long dimensions of xenoliths south of fault A.

An examination of Table 3 shows that lineations in quartzite xenoliths are again related to the intersections of foliation and bedding planes and fracture and flow cleavage planes and that the spatial orientation of lineations in xenoliths is analogous to the orientation of lineations in the unmoved metasedimentary rocks.

(c) Macroscopic Structural Analysis

Structures considered under this heading in the map area consist of the two nearly eastwest trending faults, A and B, and the apparent fold remnant delineated by quartzite xenoliths in quartz monzonite. Intrusive contact relationships of the quartz monzonite with the unmoved metasedimentary rocks in the map area are dealt with in Chapter 5, entitled 'Intrusion of Quartz Monzonite'.

1. Faults

The larger fault of the two major ones existing in the map area, fault A, is essentially a strike slip fault in the dextral sense. This fact is shown on maps of the area by the relative displacement of rock units between Duck and Cranberry lakes. That apparent vertical displacement accompanied lateral movement on the fault plane, is shown by an examination of discrepancies in thickness of the first feldspathic quartzite unit (FQ-1) near the southeastern corner of Duck Lake. Discrepancies in thickness between other rock units north and south of fault A exist, but are not as pronounced as thickness differences in the feldspathic quartzite.

Since fault A lies in a swampy stream-cut valley, no fault plane with accompanying structures such as slickensides is exposed to enable vertical sense of movement to be determined with confidence. For the same reason, dip of the fault plane cannot be found, but is assumed to be nearly vertical.

The second fault in the area, fault B, has the same apparent sense of movement as fault A, and again, an examination of the fault plane is not possible due to lack of exposure.

Subarea 3 is bound by faults A and B. Lineation plots in Table 2 for subareas 3, 1 and 8 suggest that the rocks of subarea 3 have undergone rotation 20 degrees to the south about a horizontal axis striking 275 degrees in comparison with the rocks of subareas 1 and 8, where no apparent displacement is observed. The rocks of subarea 3, therefore, belong to a fault block moved during the formation of faults A and B.

Fault B may extend into the region west of Cranberry and Beaver lakes. No outcrop is present, however, along the projected strike of the fault and extension of the fault to the west cannot be proved. Geomorphic evidence, the development of boggy ground to the west of Beaver Lake, is suggestive of low relief formed by erosion of the disrupted rocks of a fault zone, but extension of fault B into the area can only be surmised.

2. Apparent Fold Remnant

In an examination of the apparent fold remnant outlined by quartzite xenoliths in the quartz monzonite, it is evident from map relationships that opposite limbs of the hypothetical structure are composed of white quartzite. If a fold exists, petrographic and chemical properties of quartzite xenoliths should be nearly identical with those of the quartzite in the unmoved metasedimentary rocks. Petrographic and chemical properties of quartzite xenoliths are compared with those of the quartzite in the unmoved metasediments below. Pertinent structural features such as small folds and cross-bedding are briefly discussed.

(i) Petrography

An examination of three thin sections, one from each of three quartzite xenoliths and four representative thin sections from the unmoved quartzite, shows that mineralogically the quartzite xenoliths are similar to the unmoved quartzite. Both xenoliths and unmoved quartzite are made up of essentially two minerals - quartz and muscovite. The significant difference between the two lies in their muscovite content. The four thin sections from the unmoved quartzite have a muscovite content averaging 25.5 per cent while three thin sections from inclusions have an average muscovite content of 12.5 per cent.

Grain size also differs between quartzite xenoliths and unmoved quartzite. Quartz grains are generally larger in the xenoliths, their sizes ranging from 0.2 millimetres to greater than 1.5 millimetres across. In the unmoved quartzite, quartz grain size ranges from 0.1 millimetres to 0.75 millimetres.

(ii) Chemical Analysis

Since muscovite was present in both inclusions or xenoliths and unmoved quartzite, and significance was placed on the fact that xenoliths had half as much muscovite as unmoved quartzite, it was decided that a more accurate and more representative procedure was needed to amplify apparent differences in muscovite content observed under the microscope.

Twelve samples of unmoved quartzite and twenty-four samples of xenolith quartzite were subjected to analysis for K_2O and Na_2O by flame photometry. Results of the analyses are presented in Table 4.

Twelve analyses for unmoved quartzite show an average K_2O content of 1.73 weight per cent and an average Na_2O content of 0.14 weight per cent. Averaged K_2O values for 24 samples of xenolith quartzite show a weight percentage of 0.44 and Na_2O values for the same samples show a weight percentage of 0.28. Error of the flame-photometric measurements is approximately ± .005% from the reported values. Table 4 illustrates that xenoliths and Qtz-1 are fundamentally different with regard to alkali content and are not stratigraphically related as opposite fold limbs.

(iii) Structural Features

Small folds are z-form in relation to bedding in the unmoved quartzite. The same relationship is shown for small folds in xenolith: small folds are again z-form with respect to bedding. If the xenoliths are stratigraphically connected to the unmoved quartzite by folding and comprise the opposite limb of the fold, small folds in the xenoliths should be S-form (Figure 12). Quartzite xenoliths, therefore, do not represent the northeastern limb of a partly engulfed fold in the map area.

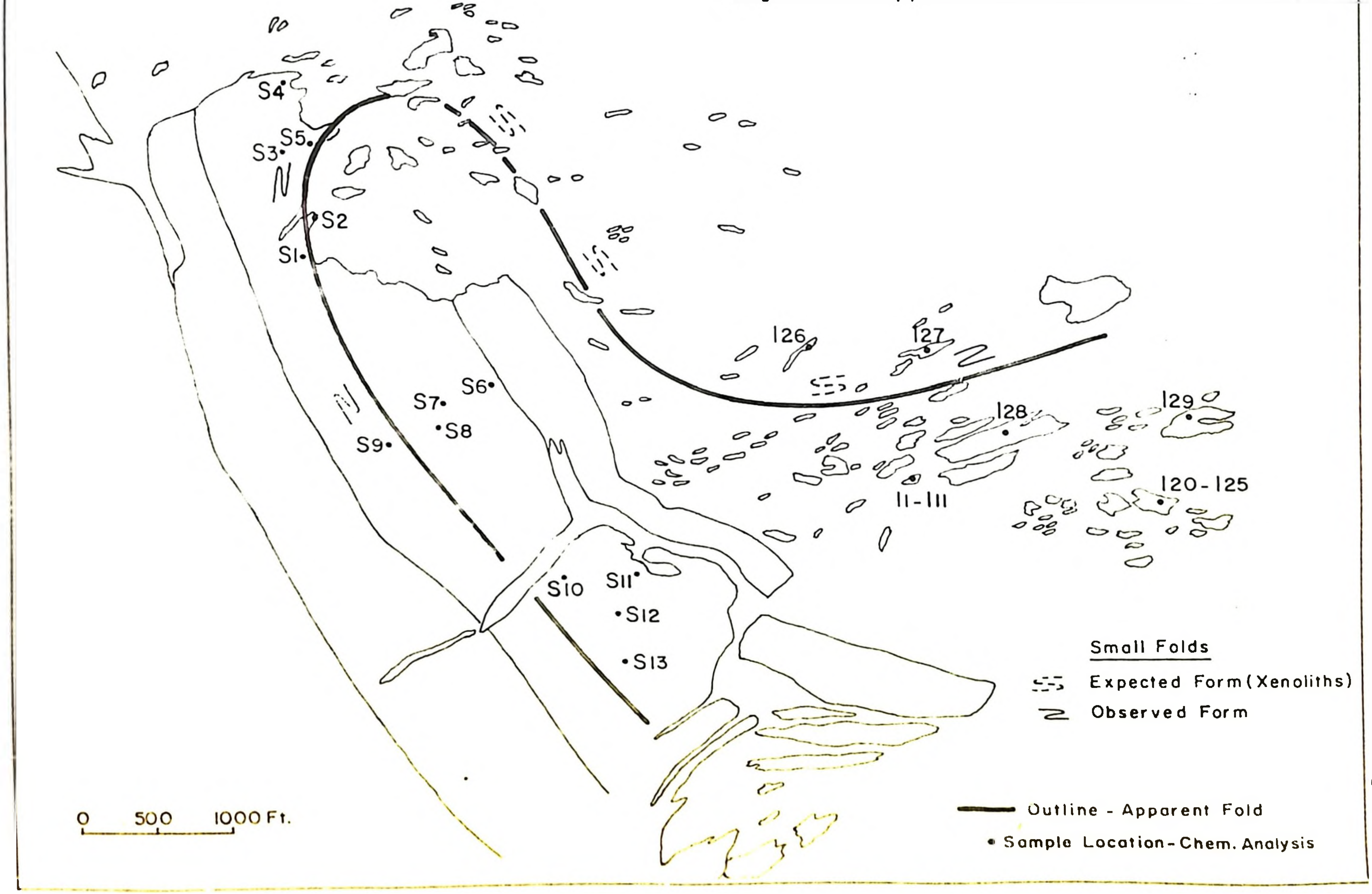


Figure 12 - Apparent Fold Remnant

TABLE 4. Flame Photometric Analysis - Quartzite and Quartzite Xenoliths

UNMOVED METASEDIMENTS			XENOLITHS					
	Wt.%			Wt.%			Wt.%	
Sample No.	Na_2O	K_2O	Sample No.	Na_2O	K_2O	Sample No.	Na_2O	K_2O
S1	.14	1.88	I1	.14	.29	I10	.27	.50
S2	.15	1.27	I2	.37	.94	I11	.47	.41
S3	.23	2.09	I3	1.01	1.63	I20	.07	.17
S4	.22	1.68	I4	.19	.59	I21	.09	.15
S5	.16	1.29	I5	.19	.13	I22	.25	.21
S6	.07	.24	I6	.44	.83	I23	.26	.18
S7	.13	1.23	I7	.25	.43	I24	.03	.12
S9	.12	1.92	I7a	.24	.35	I25	.29	.30
S10	.09	2.73	I8	.17	.22	I26	.10	.02
S11	.21	1.79	I8a	.27	.71	I27	.12	.36
S12	.09	2.43	I9	.20	.35	I28	.38	.91
S13	.07	2.10	I9a	.59	.70	I29	.40	.19

The metasedimentary rocks of the map area were apparently a part of the western limb of a steeply plunging syncline which existed in the area before intrusion of the quartz monzonite, and whose axial plane lay to the northeast. The uppermost quartzite unit became disrupted and moved by the intruding quartz monzonite (see Chapter 5 - 'Intrusion of Quartz Monzonite').

(d) Microscopic Structural Analysis

To determine whether quartzite inclusions or xenoliths had undergone the same deforming stresses as quartzite in the unmoved metasedimentary sequence to the west, seven oriented hand specimens, four from unmoved quartzite and three from quartzite xenoliths were taken in the field and oriented thin sections were made from each hand specimen. Thin sections were cut from the horizontal plane of samples, or approximately normal to foliation.

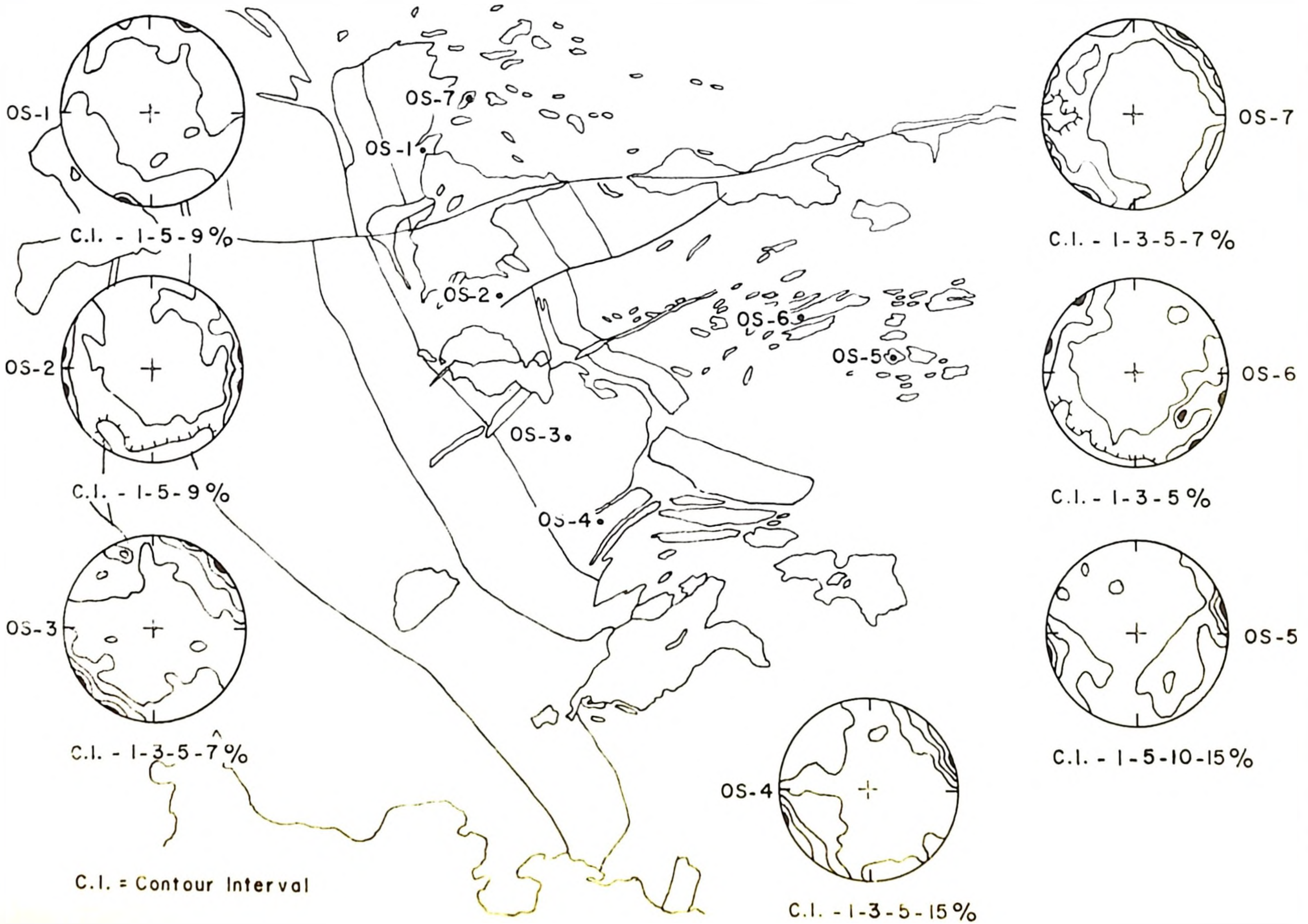
Two hundred quartz c-axis determinations were obtained for each thin section using a 4-axis universal stage. Resulting c-axis data for each thin section were plotted in polar presentations and resulting pole plots were contoured.

Locations of oriented hand specimens and corresponding quartz c-axis plots for each are presented in Figure 13.

(i) Results and Conclusions

The quartz sub-fabric of xenoliths and unmoved quartzite is monoclinic and c-axis maxima in both cases occur at acute angles to foliation. Angular relationships of c-axis maxima to foliation are not consistent between oriented thin sections in unmoved quartzite or in xenoliths. Overall similarity of c-axis patterns in quartz grains does

Figure 13 - Petrofabric Diagram - Quartz c axes In Quartzite



however suggest that xenoliths and unmoved quartzite suffered the same deforming stresses in a stress field superimposed on them before quartz monzonite was intruded.

The c-axis plot for quartz grains in sample OS-7 from xenoliths north of fault A is essentially monoclinic, but c-axis maxima are more diffuse for it than for other plots. The c-axis pattern for OS-7 may reflect a more intense disruptive effect of quartz monzonite on xenoliths north of fault A than on xenoliths south of fault A where a more pronounced apparent flow relationship exists between inclusions and igneous rock.

The relationships of quartz sub-fabric to quartz rodding (lineation) are presented below in the section entitled 'Kinematic Structural Analysis'.

(e) Kinematic Structural Analysis

1. Deformation Phases - Metasedimentary Rocks

Two phases of deformation of metasedimentary rocks are postulated. The first phase is indicated by development of foliation in the metasedimentary rocks well before the intrusion of quartz monzonite. The second phase of deformation is illustrated by fracture cleavage development in the metasediments.

(i) Foliation

Foliation planes in the metasedimentary rocks generally lie parallel, or sub-parallel to planes of bedding in the map area. Foliation is axial plane cleavage in small folds and is characterized by monoclinic symmetry and was apparently produced by compressive stress normal to axial plane cleavage which caused alignment by recrystallization of micaceous mineral plates in bedding planes, or in planes sub-parallel to bedding (Turner and Weiss, 1963, p. 467).

(ii) Fracture and Flow Cleavage

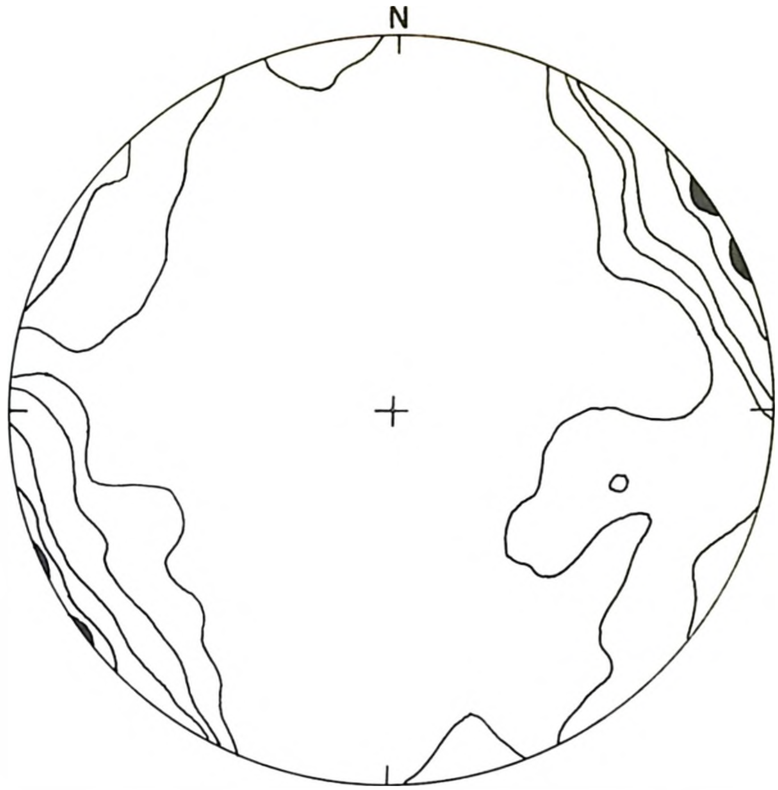
Fracture and flow cleavage, the most obvious penetrative structural element in the map area, maintains a regular though not necessarily constant geographic orientation in the metasedimentary rocks. It bears no apparent genetic relationship to foliation in the rocks, maintaining its orientation regardless of changes in trend of foliation.

Fracture and flow cleavage planes cut across the noses of small folds in the map area. In areas of great ductility contrast such as the gradational contact zone between feldspathic quartzite and metagreywacke, refraction of fracture and flow cleavage occurs (Figure 11).

That fracture and flow cleavage was formed before the intrusion of quartz monzonite, is demonstrated by contoured π pole plots of 159 fracture cleavage planes derived from xenoliths south of fault A, compared with a π pole plot of 200 poles of fracture and flow cleavage planes in unmoved metasediments south of fault A. These plots are presented in Figure 14. Contour intervals in the plots are shown in per cent per 1 per cent of the total area of the stereonets. The symmetry of fracture and flow cleavage planes in both plots is monoclinic and closely spaced double maxima are present in both cases. Both plots are similar in the overall aspect of their patterns.

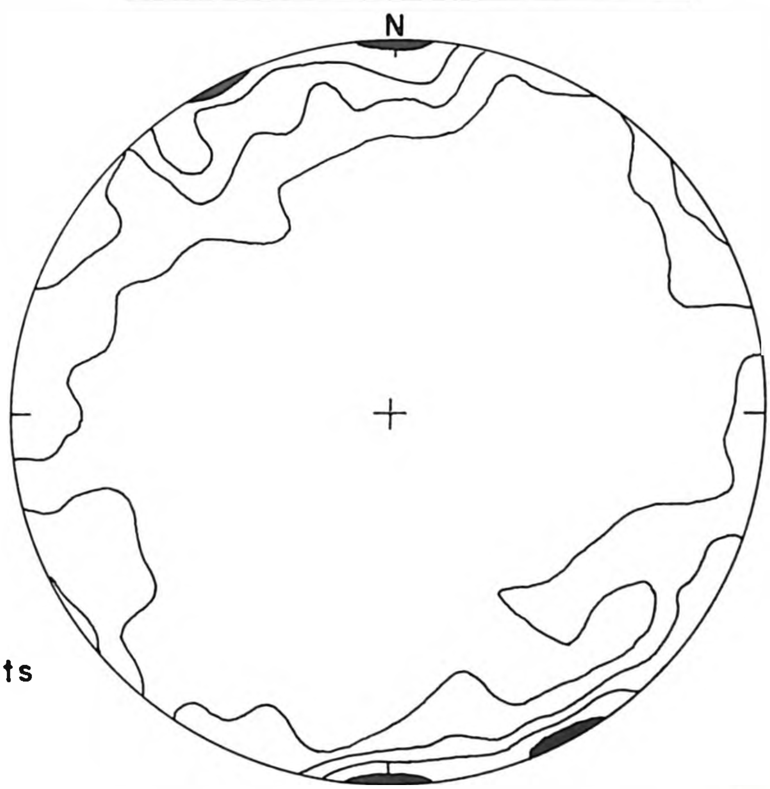
From Figure 14, it is clear that clockwise rotation of the contoured plot of fracture cleavage in xenoliths by 106 degrees brings its maxima into conjunction with the plot of maxima for fracture cleavage

Figure 14 - Contoured π Pole Plots - Fracture/Flow Cleavage



Xenoliths
-159 Poles

Contour Interval: 1-3-5-10-15 %



Unmoved
Metasediments
-200 Poles

Contour Interval: 1-3-5-7 %

planes in the unmoved metasedimentary rocks.

An examination of Map 1b shows that rotation of fracture cleavage clockwise by 106 degrees would effectively restore the quartzite unit represented by xenoliths to its original conformable relationship adjacent to paragneiss in the map area. Fracture cleavage, in the light of the above analysis, was present in the metasedimentary rocks before intrusion of the quartz monzonite, and before rotational displacement to the north of stoped-off remnants of a quartzite unit originally conformable with metasediments to the west.

(iii) Conclusions

As already stated above, two deformation phases are indicated for metasediments of the map area. The first phase involved plastic deformation and folding of the metasediments. The second phase involved deformation of the rocks long before intrusion of the quartz monzonite. Initial deformation and folding is postulated to have occurred during the Penokean orogeny. The second phase of deformation, producing fracture and flow cleavage in the rocks, is believed to have taken place during the Hudsonian orogeny as well and was apparently produced by local re-orientation of the stress field which produced initial deformation of the rocks. A more detailed account of the relationship of deformation phases to geochronology of the map area will be presented in Chapter 6.

2. Formation of Lineation

Lineation due to rodding of quartz grains of the metasedimentary rocks, occurs in the foliation planes of the rocks and in the axes of small folds. Lineation is most pronounced in feldspathic quartzite and quartzite.

The lineated metasedimentary rocks are examples of the lineated schistose (foliated) tectonites of Flinn (1965). Flinn's L-S (lineated-schistose) tectonites are characterized by partial girdles of foliation or schistosity (S) elements about point concentrations of lineations, a geometric relationship which is illustrated in Figures 7 and 8.

Flinn maintains that for every fabric pattern in L-S tectonites a triaxial deformation ellipsoid of particular form and orientation occurs. In the present case, the long dimensions of quartz rods in foliation planes may be parallel to the axis of maximum strain in the deformation ellipsoid which is simultaneously the direction of least compressive stress. The maximum stress vector is perpendicular to planes of foliation.

Figure 13 illustrates that c-axis maxima of quartz grains form monoclinic symmetry patterns which bear rather random orientation relationships with respect to foliation. It is felt that the assymmetric distribution of c-axis maxima of quartz rods with respect to foliation is suggestive of their formation by rotation of quartz grains in the foliation planes of quartzite.

Evidence derived from small folds in the map area suggests that tectonic transport occurred in the axial planes of the folds. Figure 10 is useful in illustrating this conclusion. The axial plane of the fold lies in the foliation of quartzite and limbs of the fold are interrupted by a small fault in the plane of foliation. Tectonic transport in the direction of strike of foliation is assumed to have been the cause of the fault. This direction is therefore the 'a' kinematic direction of the rocks. The 'c' kinematic vector is normal to planes of foliation in the quartzite, and also normal, therefore, to the long dimensions of quartz rodding.

The long dimensions of quartz rods in the rocks which produce the pronounced lineation in quartzite and more subtle lineation in other rock types is therefore the 'b' kinematic direction of metasedimentary rocks. Lineation was apparently produced by 'rolling' of quartz grains in the direction of tectonic transport with accompanying passive deformation of quartz grains in the 'b' kinematic direction. Lineation developed by quartz rodding is termed L_1.

Quartz rods in the metasedimentary rocks are assumed to have developed during the first phase of deformation during initial folding of the rocks because they coincide with the intersection of planes of bedding and foliation in the rocks.

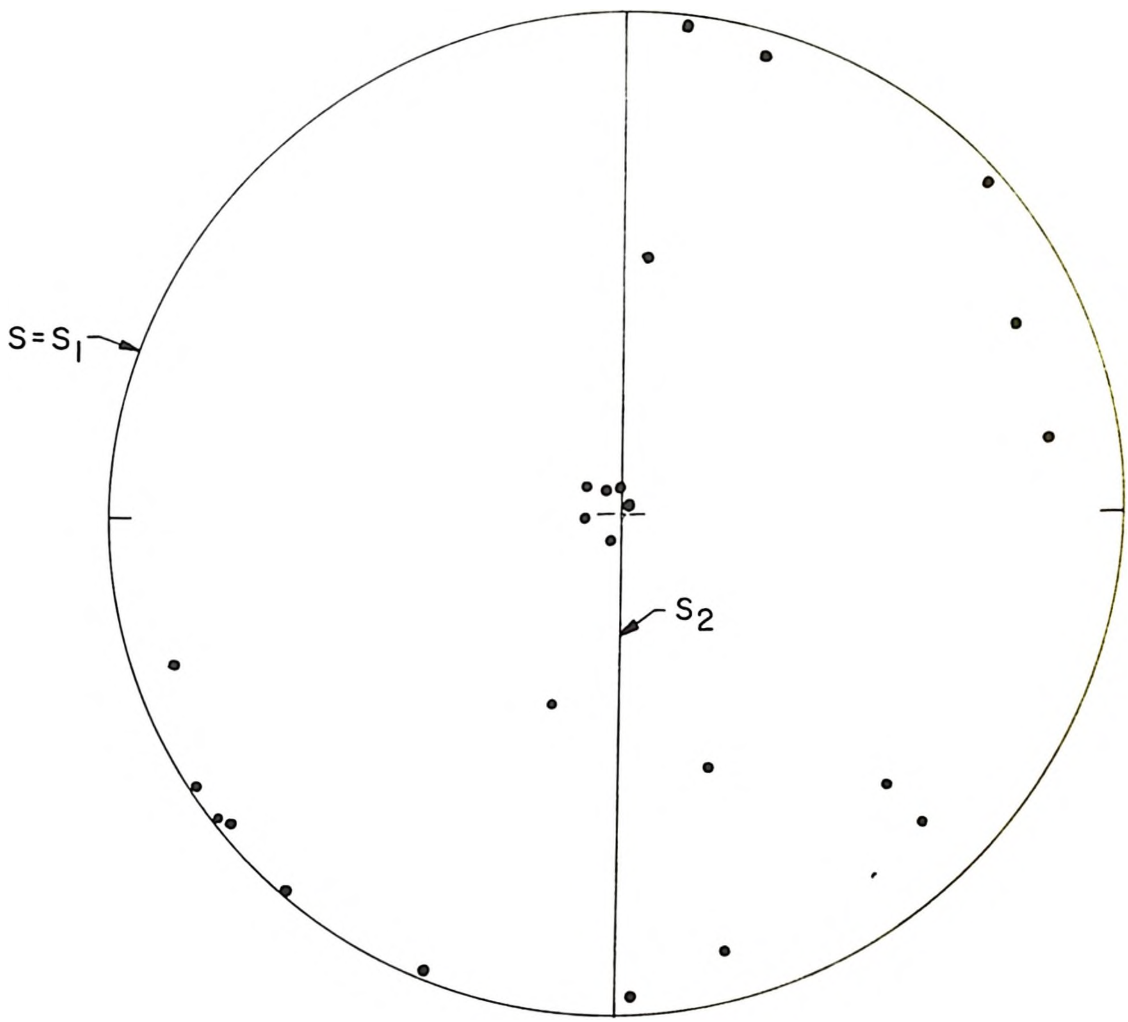
In Tables 2 and 3 calculated lineations, $\bar{L}_c$, caused by the intersection of fracture and flow cleavage planes with the earlier-formed foliation, are defined as L_2 in the metasediments. L_2 in metagreywacke is marked by the presence of muscovite pseudomorphs after staurolite in the late flow cleavage planes. The pseudomorphs are not disrupted by the flow cleavage, are rod-like in shape and have the same orientation as quartz rods in the metagreywacke.

To determine the relationship of muscovite pseudomorphs after staurolite to penetrative structural elements in the metagreywacke an oriented hand specimen of metagreywacke, containing pseudomorphs, was collected. A thin section cut normal to planes of flow cleavage and parallel to foliation planes, was obtained and a muscovite pseudomorph cross-section was included in the slice constituting the section.

A π pole plot of poles to [001] planes of muscovite plates in the pseudomorph, compared with great circles representing foliation and flow cleavage planes in the hand specimen, is presented in Figure 15.

Figure 15 - π Pole Plot - Poles To [001] Planes - Muscovite Flakes

Muscovite Pseudomorph After Staurolite



• Pole To [001] Plane - Muscovite

Poles to [001] planes of muscovite plates do not lie on the great circles for foliation or flow cleavage planes and are randomly oriented.

(i) Conclusions

Two periods of deformation involving the formation of lineation in the metasediments are postulated. The first period involved the rolling of quartz grains in the plane of tectonic transport during folding and resulted in lineation L_1 formed by rodding of quartz grains in foliation planes. The second period of deformation involved the formation of fracture and flow cleavage planes in the rocks, followed by the development of staurolite in flow cleavage planes in the metagreywacke. That staurolite, retrograded to muscovite, grew after the formation of both fracture and flow cleavage, and foliation, is held to be true because muscovite plates in the pseudomorph of muscovite after staurolite are randomly oriented with respect to foliation and flow cleavage planes in Figure 15, thus reflecting later development.

Since lineation L_2, reflected by muscovite pseudomorphs, has the same orientation as quartz rodding and occurs at the intersection of foliation and fracture and flow cleavage planes, stress vectors developed during the second deformation period were apparently similar to those imposed on the rocks during the first period. Fracture and flow cleavage planar orientation was controlled by the first lineation, L_1. Quartz rods formed a structural array with axial symmetry exerting physical control on the attitude of fracture and flow cleavage planes during the second phase of deformation. The effect of such an array is analogous to the effect of a set of planar discontinuities on subsequent failure directions (Donath, 1961). The preferred failure direction for the second stress field would be modified by the axially symmetric array probably for angles up to 45 degrees removed from the theoretical angles for failure in an isotropic medium.

V. INTRUSION OF QUARTZ MONZONITE

This chapter deals with contact relationships and foliation patterns in the quartz monzonite with respect to metasedimentary rocks in the map area.

A. <u>Igneous Intrusive Contact</u>

In an examination of the nature of the contact relationships shown by the quartz monzonite with respect to the metasedimentary rocks of the area, foliation in quartz monzonite, a mesoscopic feature, must be combined with the macroscopic aspects of the igneous intrusive contact to enable its significant features to be shown.

1. South of Fault A

Foliation planes in the quartz monzonite, where measurable, are generally vertical or dip at angles of the order of 85 degrees. Away from the area of contact of quartz monzonite and paragneiss, quartzite xenoliths are parallel or sub-parallel to the north of east foliation trend in the quartz monzonite. Nearing the metasedimentary sequence, the strike of foliation in the quartz monzonite turns to the northwest against FQ-3, except in the vicinity of the large block of FQ-3 to the north of Grebe and Gull lakes, where foliation maintains its northeastern trend adjacent to the block.

East of Beaver Lake a sill-like tongue of quartz monzonite extends northward to fault B separating FQ-3 from quartzite, its foliation paralleling metasedimentary foliation. Near the eastern shore of Beaver

Lake, the tongue of quartz monzonite turns through nearly 90 degrees and cuts discordantly through the quartzite and second feldspathic quartzite units in a southwesterly direction parallel to second cleavage. Foliation in quartz monzonite is parallel to this change of trend.

North of Grebe Lake a wedge of quartz monzonite cuts discordantly into quartzite and the second feldspathic quartzite unit, its foliation cutting foliation in the two metasedimentary units at angles of between 60 and 80 degrees. Xenoliths of metasediments and gabbro have their long dimensions and foliations parallel or sub-parallel to foliation in the surrounding quartz monzonite in the area north of Grebe Lake.

Foliation in the quartz monzonite, where it comes into contact with metagreywacke near the west end of Grebe Lake, swings in trend to conform to the barrier imposed by the metagreywacke.

Foliation and bedding planes in the quartzite xenoliths are parallel or sub-parallel to the long dimensions of xenoliths. Foliation in the quartz monzonite parallels the long dimensions of xenoliths as stated above. A composite plot of quartz monzonite flow foliation and xenolith foliation is presented in Figure 7. In Figure 7, symmetry of fabric elements for quartz monzonite and xenoliths is monoclinic, and arrangement of quartzite xenoliths into linear groups south of fault A is suggested as the response of xenolith shape to the monoclinic fabric symmetry of flow planes in fluid quartz monzonite magma.

2. North of Fault A

North of fault A, quartz monzonite foliation trends northwest and retains its vertical attitude as it approaches and intrudes the quartzite unit north of Cranberry Lake. Northwest of Cranberry Lake foliation in the quartz monzonite swings to the southwest and then to the south in conformity with the feldspathic quartzite-metagreywacke contact.

North of fault A, no apparent symmetry exists in foliation between inclusions, but monoclinic symmetry exists for flow foliation poles in the quartz monzonite (subarea 2, Figure 7). Xenolith shapes north of fault A are, for the most part, more irregular than the shapes of their counterparts to the south.

Compared to the orientation of xenoliths to the south, xenoliths north of fault A are more randomly oriented in space. Intrusion of quartz monzonite magma into the quartzite unit north of Cranberry Lake apparently caused widespread shattering of the unit, a fact reflected by the presence of random and irregular fracture planes in outcrops. Xenoliths derived from the shattered rocks might be expected to have more irregular shapes when compared to xenoliths south of fault A, which were moved into their present positions by more uniform flow in the quartz monzonite than that which occurred north of fault A.

3. Discussion

Where quartz monzonite encounters a solid physical barrier such as the feldspathic quartzite unit on the eastern border of the unmoved metasedimentary rocks, its foliation trend changes, swinging along the strike of the contact. Quartzite inclusions or xenoliths near physical barriers affecting the quartz monzonite have their long dimensions arranged parallel to the change in strike of quartz monzonite foliation. Where quartz monzonite embays the unmoved metasedimentary rocks, its foliation is oriented directly into the embayment, suggesting apparent forcible injection of quartz monzonite into the country rocks.

Quartzite and other xenoliths do not act as a physical barrier to quartz monzonite and the flow foliation of the igneous rock is not affected by them. This relationship holds true even for large xenoliths such as the block of feldspathic quartzite northwest of Gull Lake. The block was apparently connected with the remainder of the feldspathic quartzite unit to the northwest before intrusion of the quartz monzonite. After intrusion of the quartz monzonite into the unmoved quartzite, the southern section of the feldspathic quartzite unit was broken off and moved to the southwest into its present position.

A diagram, showing apparent flow structures in quartz monzonite and their relationship to the metasedimentary rocks and xenoliths of the map area, is presented in Figure 16.

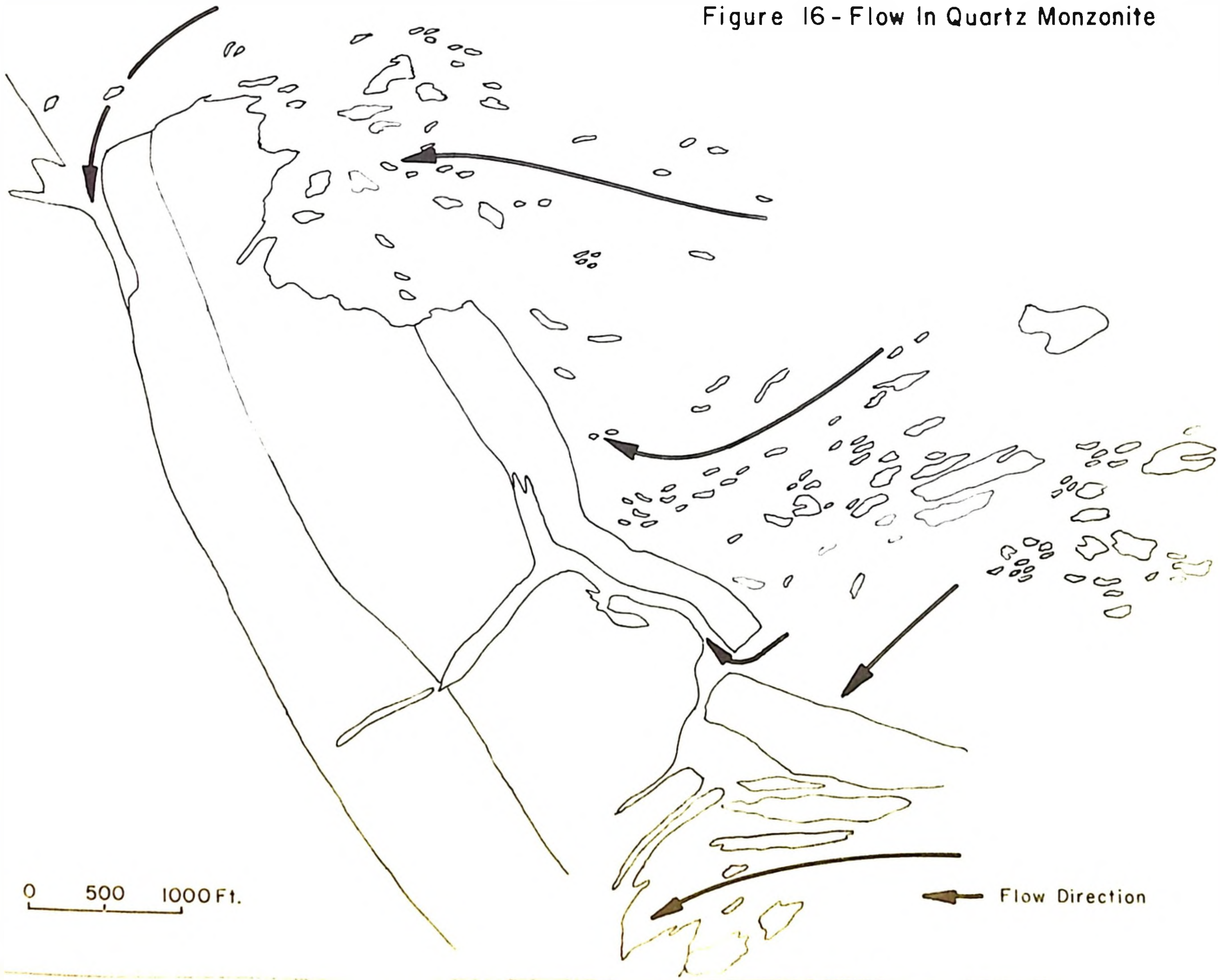
Figure 17 shows the metasedimentary rocks as they may have been before intrusion of the quartz monzonite and before faulting occurred.

4. Conclusions

Field relationships illustrated above are highly suggestive of igneous intrusion of quartz monzonite into essentially 'brittle' country rocks. Quartzite xenoliths are apparently the stoped-off remnants of what was once a conformable quartzite unit which was deposited on top of the feldspathic quartzite unit to the west. The best evidence for rotation of a once conformable quartzite unit in contact originally with FQ-3 has been presented in Chapter 4 with a comparison in Figure 14 of π pole plots of fracture cleavage planes in the unmoved metasediments and fracture cleavage planes in xenoliths.

A definite streaming effect is shown by the alignment of xenoliths south of fault A in response to flow foliation in the quartz monzonite. A hydrodynamic relationship between xenoliths and quartz monzonite is shown north of fault A, but flow foliation trends in quartz monzonite are not quite as uniform north of fault A as they are to the south. A

Figure 16 - Flow In Quartz Monzonite



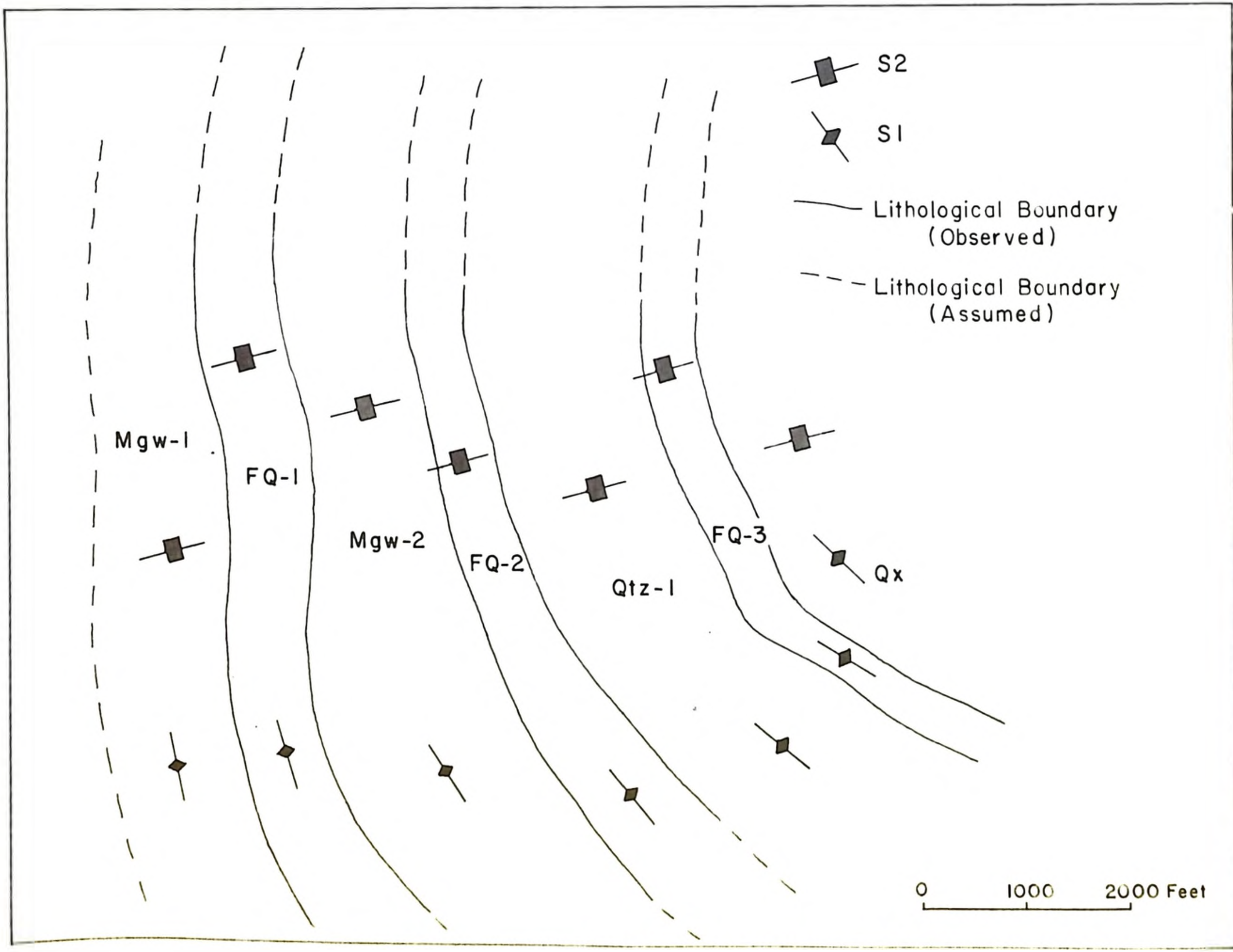


Figure 17 - Metasediments Before Igneous Intrusion And Faulting

change in flow pattern due to forcible penetration of magma into 'brittle' country rocks, accompanied by shattering of the quartzite and feldspathic quartzite units of the region to produce xenoliths seems to be indicated. South of fault A, penetration of quartz monzonite magma between feldspathic quartzite and quartzite units and rotation of the quartzite into its present position in response to more uniform flow in the fluid intrusive rock is indicated.

Faults in the map area occurred after intrusion of the quartz monzonite. An examination of quartz monzonite foliation trends in proximity to the feldspathic quartzite unit FQ-3 and the relationship of igneous foliation with quartzite xenoliths in that area, suggests that the above statement is tenable. As the quartz monzonite foliation trend swings from south of west to north of west near the feldspathic quartzite unit, xenoliths of quartzite swing in trend an equal amount. The northwest trend of quartz monzonite foliation is effectively disrupted by fault B northeast of Beaver Lake. The trend in igneous foliation to the northwest continues against FQ-3 west of Grassy Lake and xenoliths again follow the foliation in quartz monzonite.

Before faulting, therefore, the swing of xenoliths in response to quartz monzonite flow foliation in a west of north to northwest direction was effectively continuous along the entire zone of contact of quartz monzonite with the feldspathic quartzite.

North of fault A, severe disruption of metasediments has occurred, but foliation in the quartz monzonite retains a generally northwesterly trend northeast of Cranberry Lake.

Metamorphic effects are observed in thin sections of the quartz monzonite. These apparently occurred after consolidation of the igneous mass but were not extreme enough to obliterate primary flow foliation in the quartz monzonite. Post-consolidational deformation was apparently responsible for development of faults A and B and shear zones observed in the rocks of the map area.

Cataclastic effects on mineral grains and sericitization of feldspar are more pronounced near shear zones. Sampling of sheared quartz monzonite was not extensive and therefore spatial relationships of metamorphic effects to shear zones cannot be thoroughly demonstrated.

Lineation in xenoliths and unmoved metasedimentary rocks have similar spatial orientations - Figure 8. Since lineations reflect foliation plane and fracture and flow cleavage plane orientations, control of the direction of intrusion of quartz monzonite may have been exerted to some extent by structural elements in the metasedimentary rocks.

VI. GEOCHRONOLOGY AND TECTONIC HISTORY

A. Geochronology

In a paper by Stockwell and Williams (1964), potassium-argon dates of rocks in the Canadian Shield are presented. Dates obtained indicate that metamorphism of rocks of the Grenville province occurred ~950 million years ago. Potassium-argon dating places metamorphism of rocks of the Superior province at 2500 million years.

Metasedimentary rocks of the map area in the present work lie in the Penokian fold belt of the Southern province of Stockwell and Williams where dates obtained from potassium-argon studies range between 1395 and 2220 million years. An average age of 1704 million years has been determined for metamorphism in the Southern province and hence in the map area, which lies on the border between the Grenville province and Southern province.

Fairbairn et al. (1960) obtained two metamorphic ages for rocks around Wavy Lake south of the map area. A granite sample in metasediments on the northwest shore of Wavy Lake yielded a rubidium-strontium age for biotite of 1516 ± 58 million years. Another sample from the southeastern shore of Wavy Lake yielded a potassium-argon date from biotite of 910 million years. The sample from the southeastern shore of Wavy Lake was taken from porphyritic granite (quartz monzonite (?)) intruding quartzite. Sample locations are shown in Figure 1.

Two major phases of metamorphism are indicated by age data in the map area. The first phase corresponds to the Penokean orogeny. The second apparently reflects either deformation of the quartz monzonite during the Grenville orogeny, or emplacement of the intrusive at the time indicated. If metamorphism occurred in quartz monzonite during the Grenville orogeny, then the intrusive may have been emplaced before Grenville time presumably during the latter stages of the Penokian orogeny. Gabbro in metasedimentary rocks of the map area, and xenoliths of gabbro in the quartz monzonite are apparently related to metagabbros in the Agnew Lake area. Gabbros in the Agnew Lake area are approximately 1800 million years old (Fairbairn et al., 1960) and were affected by a period of metamorphism and deformation occurring about 1600-1700 million years ago.

B. Tectonic History

Tectonic events occurring in the map area are summarized in Table 5. Retrograde metamorphism of staurolite to muscovite may have occurred as a result of quartz monzonite intrusion during the early phase of Grenville orogeny. On the other hand, retrograde effects may have occurred during the Penokean orogeny before quartz monzonite intrusion.

Card (1964), working in the Agnew Lake area to the west of the map area, states that

> "Study of the inter-relationships of metamorphic porphyroblasts and fabric elements provides evidence for a three-fold division of events; [in the Penokean orogeny in the Agnew Lake area] an early "plastic" phase of deformation accompanied by growth of low grade minerals such as muscovite and chlorite; the major period of metamorphism and the growth of "high-grade" minerals such as staurolite in a static environment; a late "brittle" deformation phase with minor "retrograde" metamorphism." (op. cit. p. 1101)

Tectonic events postulated in the present work are analogous to those observed by Card with one exception: muscovite pseudomorphs after staurolite developed in, and are apparently later than, fracture and flow

TABLE 5. Tectonic History of the Area

ISOTOPIC AGE (m.y.)*	LITHOLOGIC UNIT	EVENT
910		Killarnean Orogeny
		(g) Deformation of quartz monzonite. - Faulting and shear zone development
	quartz monzonite and gabbro dike (age uncertain)	(f) Intrusion of gabbro dike
1000 ± 50		(e) Intrusion of quartz monzonite and xenolith production (?) (quartzite and pre-Killarnean gabbro) - possible retrograde metamorphism (?
1600 ± 50		Penokian Orogeny
		(d) Retrograde metamorphism - staurolite altering to muscovite
		(c) Formation of S_2 and L_2 - 'brittle' deformation. 'High grade' metamorphism and staurolite production in L_2
1700 ± 100	gabbro	(b) Gabbro intrusion
	metasedimentary rocks	(a) Plastic deformation and folding of Southern rocks. - Production of low grade minerals (muscovite and epidote) - Formation of S_1 and L_1

* Modified after Fairbairn et al. (1960)

cleavage in metagreywacke. Fracture and flow cleavage may be related to the stage of "brittle" deformation of metasediments in the Agnew Lake area observed by Card.

Since the area mapped in the present work is close to Agnew Lake, the view favoured by the author is that retrograde metamorphism of metasediments and the formation of muscovite pseudomorphs after staurolite occurred late in the Penokean orogeny.

VII. CONCLUSIONS

The study undertaken in the map area indicates that the Grenville Front south of Sudbury is marked by an igneous intrusive mass of quartz monzonite which separates Grenville rocks to the east from rocks of the Southern province to the west. The quartz monzonite bears unmistakable igneous intrusive relationships to metasedimentary rocks of the Southern province. The zone of metasomatism separating Grenville and Southern rocks postulated by Grant et al. (1962) does not exist in Eden Township.

The Grenville Front in Eden Township, with granitic intrusive rocks separating relatively unmetamorphosed rocks to the west from highly deformed and metamorphosed rocks to the east, is thought to be somewhat analogous to the 'Front' proposed by Quirke and Collins (1930) to the southwest in the Lake Panache region.

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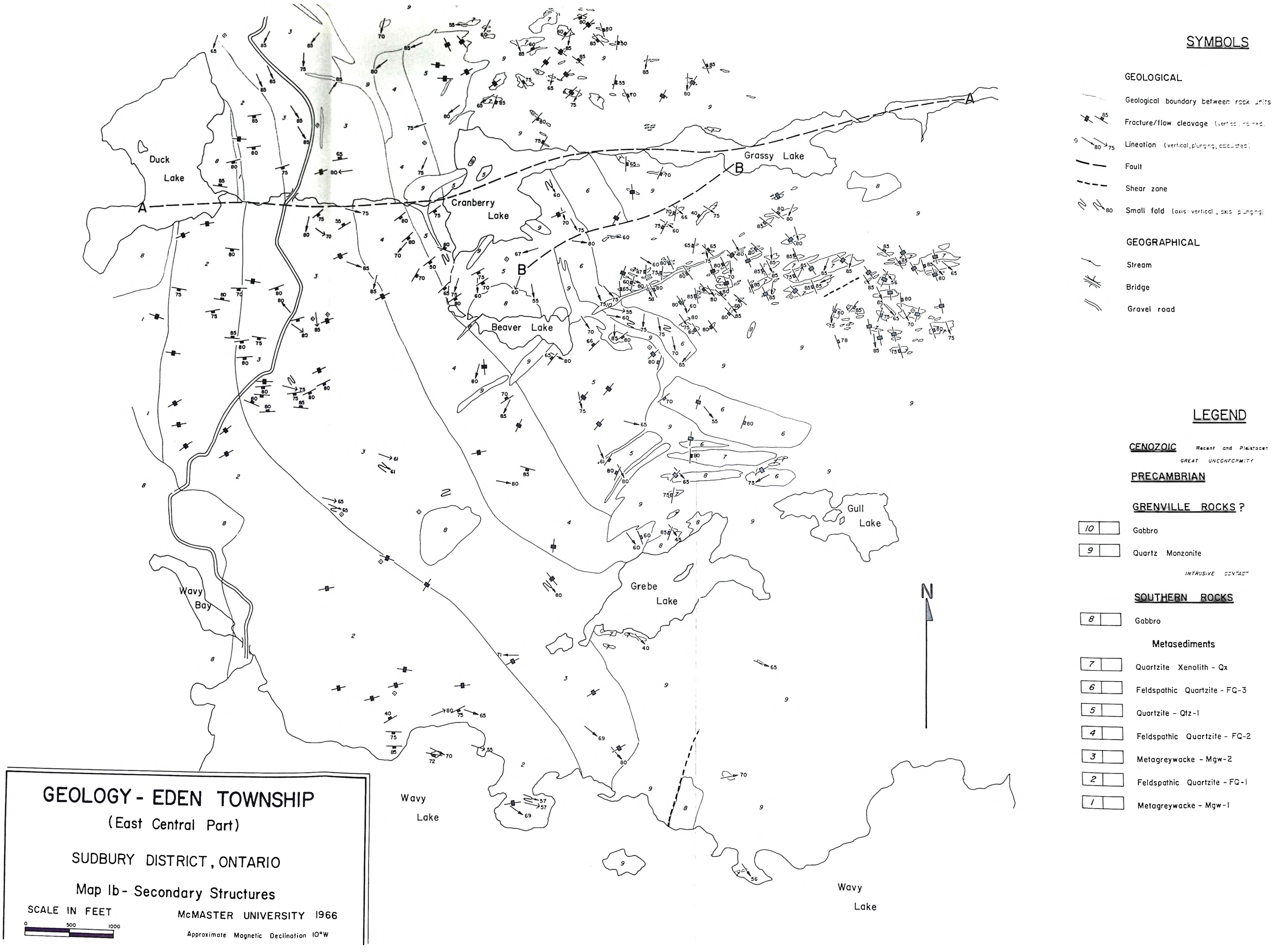
GEOLOGY - EDEN TOWNSHIP
(East Central Part)
SUDBURY DISTRICT, ONTARIO
Map Ia - Primary Structures
SCALE IN FEET
0 500 1000
McMASTER UNIVERSITY 1966
Approximate Magnetic Declination 10° W
Duck Lake
Cranberry Lake
Grassy Lake
Beaver Lake
Gull Lake
Grebe Lake
Wavy Bay
Wavy Lake
Wavy Lake
A
A
B
B
N
SY
GEOLOGICAL
Outcrop area boundary
Geological boundaries
between rock units (defined, approximate)
gradational, between rock units (interbeds of feldspathic quartzite and metagreywacke in an approx. 1 ratio)
Bedding and foliation - metasediments (vertical, inclined)
foliation is parallel or sub-parallel to bedding
Foliation - quartz monzonite (vertical, inclined)
Stratigraphic top
arrow indicates top direction derived from crossbed
Fault
Shear zone
Fe
Iron mineralization
GEOGRAPHICAL
Gravel road
Swamp
Bridge
Stream
LEGEND
CENOZOIC
Recent and Pleistocene
GREAT UNCONFORMITY
PRECAMBRIAN
GRENVILLE ROCKS?
10 Gabbro
9 Quartz Monzonite
INTRUSIVE CONTACT
SOUTHERN ROCKS
8 Gabbro
Metasediments
7 Quartzite Xenolith - Qx
6 Feldspathic Quartzite - FQ-3
5 Quartzite - Qtz-1
4 Feldspathic Quartzite - FQ-2
3 Metagreywacke - Mgw-2
2 Feldspathic Quartzite - FQ-1
1 Metagreywacke - Mgw-1


GEOLOGY - EDEN TOWNSHIP
(East Central Part)
SUDBURY DISTRICT, ONTARIO
Map Ib - Secondary Structures
SCALE IN FEET
0 500 1000
McMASTER UNIVERSITY 1966
Approximate Magnetic Declination 10°W
SYMBOLS
GEOLOGICAL
Geological boundary between rock units
Fracture/flow cleavage
Lineation (vertical, plunging, calculated)
Fault
Shear zone
Small fold (axis vertical, axis plunging)
GEOGRAPHICAL
Stream
Bridge
Gravel road
LEGEND
CENOZOIC Recent and Pleistocene
GREAT UNCONFORMITY
PRECAMBRIAN
GRENVILLE ROCKS ?
10 Gabbro
9 Quartz Monzonite
INTRUSIVE CONTACT
SOUTHERN ROCKS
8 Gabbro
Metasediments
7 Quartzite Xenolith - Qx
6 Feldspathic Quartzite - FQ-3
5 Quartzite - Qtz-1
4 Feldspathic Quartzite - FQ-2
3 Metagreywacke - Mgw-2
2 Feldspathic Quartzite - FQ-1
1 Metagreywacke - Mgw-1
N
Duck Lake
Cranberry Lake
Grassy Lake
Beaver Lake
Gull Lake
Grebe Lake
Wavy Bay
Wavy Lake
Wavy Lake
A
A
B
B