

THE GEOLOGY OF THE ZINC-LEAD DEPOSIT AT SITO LAKE,  
NORTHERN SASKATCHEWAN

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### ABSTRACT

The Sito West deposit at Sito Lake is one of a number of uneconomic disseminated zinc-lead and lead-zinc-quartzite deposits that have been located within the Wollaston Lake fold-belt of northern Saskatchewan.

Metasedimentary rocks belong to the Daly Lake Group which is most widespread, and the Meyers Lake Group which contains the quartzite host of the sulphides. The Meyers Lake Group apparently overlies the Daly Lake Group here.

Graded beds preserved in the Meyers Lake Group commonly show compositional gradation from basal arkose to shaly tops. Metamorphism has produced garnet-biotite-rich and sillimanite augen-biotite-garnet-rich portions near the tops of these beds. It is proposed that they indicate deposition by turbidity currents.

Three major phases of deformation produced a series of elongate, steeply inclined basins and domes. The domal structure at Sito West is like the central conical portion of an "angel-food cake-pan" if it were flattened and inclined.

Metamorphic mineral assemblages are characteristic of Abukuma-type cordierite-amphibolite facies and lower granulite facies metamorphism

The mineralization, which occurs in the upper half of the quartzite unit, consists essentially of disseminated pyrite, sphalerite, and galena. The sulphides precipitated during deposition of the host, but diagenesis and metamorphism has destroyed textural evidence. The deposits are similar to the copper-uranium-vanadium-sandstone deposits of the southwestern United States.



TABLE OF CONTENTS

ACKNOWLEDGMENTS

INTRODUCTION ..... 1.

    General Statement ..... 1.

    Location and Accessibility..... 1.

    Physiography ..... 3.

    Previous and Present Investigations ..... 3.

    Regional Geology ..... 5.

SITO LAKE GEOLOGY ..... 7.

    Introduction ..... 7.

    Daly Lake Group ..... 10.

        1. Cordierite-Garnet Rocks ..... 10.

        2. Biotite Schists, Calc Silicates, and  
           Associated Rocks ..... 12.

        3. Biotite-Hypersthene and Biotite Pyroxene  
           Schists ..... 13.

    Discussion ..... 15.

    Meyers Lake Group ..... 16.

        General ..... 16.

        4. & 5. Lower Meta-arkose Sequence ..... 16.

        6. Quartzite Sequence ..... 24.

        7. Biotite-Sillimanite Schist Sequence ..... 26.

        8. Upper Meta-arkose Sequence ..... 28.

    Discussion ..... 30.

    Other Rocks ..... 34.

        9. Garnet Pyroxenite ..... 34.

    Intrusive Rocks ..... 34.

        10. Biotite-Hornblende Granite ..... 34.

STRUCTURAL GEOLOGY ..... 36.

    Planar Structures ..... 36.

    Linear Structures ..... 39.

    Folding ..... 39.

        Earliest Folds,  $F_1$  ..... 41.

        Second Folds,  $F_2$  ..... 41.

        Third Generation Folds,  $F_3$  ..... 43.

    Sito West Structure ..... 43.

    Discussion ..... 47.

METAMORPHISM .....	51.
Metamorphic History .....	54.
Garnet Growth and Deformation .....	55.
ECONOMIC GEOLOGY .....	59.
Introduction .....	59.
Sphalerite .....	59.
Pyrite .....	60.
Galena .....	61.
Chalcopyrite .....	61.
Fluorite .....	61.
Discussion of Origin .....	62.
COMPARISONS WITH OTHER DEPOSITS .....	64.
CONCLUSIONS .....	68.
REFERENCES .....	70.

TABLES

Table 1. Table of Lithologies .....	9.
Table 2. Summary of Estimated Compositions of the Meyers Lake Group Rocks .....	18.
Table 3. Metamorphic Mineral Assemblages; Sito Lake Area .	52.

FIGURES

Figure 1. Location of Study Area .....	2.
2. Known extent of the Wollaston Lake fold-belt ...	4.
3. Southwestern third of the Wollaston fold-belt ..	8.
4. Sito Lake Area: Geology .....	Back Pocket
5. The Bouma Sequence .....	32.
6. Equal-area diagrams for the Sito Lake Area ....	38.
7. Deformation of sillimanite augen .....	40.

Figure 8.	Sito Lake Area: Structure .....	42.
9.	The "Angel-Food Cake-Pan" Analogy .....	44.
10.	Structural Analysis of the Sito West Property ..	46.
11.	Sketches showing hypothetical structural development of the Sito Lake area .....	49.
12.	Sketches showing hypothetical structural development of Sito West .....	50.
13.	Three dimensional sketch of garnet dodecahedron .....	57.
14.	Three dimensional sketch of garnet dodecahedron .....	58.

ILLUSTRATIONS

MAP	Geology of Sito West, Map A .....	Back Pocket
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PLATES

	Following page
Plate 1A. Folded and boudinaged leucocratic layers parallel to $S_1$ schistosity in cordierite-garnet rocks, 8,000 feet west of Sito West.....	11.
1B. Large blue cordierite porphyroblast in leucocratic pod in unit 1.....	11.
2A. Large sillimanite-quartz augen characteristic of the massive lower division arkoses, unit 4, of the Lower Meta-arkose Sequence, Sito West.....	17.
2B. Relief of many sillimanite-quartz augen in meta-arkose of unit 4. Note the "Life Saver" (arrow) for scale.....	17.
3A. Portion of a sillimanite augen showing a fibrous sillimanite core that contains euhedral (rectangular shaped) sillimanite grains (Photomicrograph, plane polarized light).....	19.
3B. Current bedding (below hammer head) in a quartzite bed, 4a, near the south end of the peninsula at Sito West.....	19.
4A. Compositionally graded beds with sillimanite augen (white spots) tops in upper division arkoses, unit 5, of the Lower Meta-arkose Sequence at Sito West.....	21.
4B. Compositionally graded beds with garnetiferous tops (light to dark) similar to Walker's (1967) A→E Sequence in rocks of unit 5.....	21.
5A. Highly sutured quartz and feldspar grain boundaries in rocks of the Quartzite Sequence, unit 6, Sito West (Photomicrograph, cross nicols).....	25.
5B. Fold interference pattern outlined by sillimanite augen-rich bands in the Biotite-Sillimanite Schist Sequence, unit 7, at north end of Trench 4 at Sito West.....	25.
6A. Sillimanite-quartz augen flattened into the axial plane of minor folds in the hinge zone of a major $F_3$ fold near Trench 5. The layers outlined by the dashed lines are garnet-rich zones in upper division meta-arkoses, unit 5, at Sito West.....	38.

Plate 6B. Crenulation foliation (Whitten, 1969) or strain-slip cleavage (Ramsay, 1967) depicting the development of  $S_2$  in unit 1; 4,000 feet northwest of Sito West, near Lake B..... 38.

7A. Similar style folding of upper division arkoses, unit 5, in the hinge zone of a major  $F_3$  fold at Sito West. Compass points north..... 40.

7B. Concentric style folds in unit 5 in the south-east part of the peninsula. Note the sillimanite augen remain in the plane of bedding around the nose of the fold..... 40.

8A. Fibrous sillimanite(s) has partially replaced a euhedral andalusite (a) grain which occurs in a biotite-rich part of unit 1; near the north end of the small lake north of Lake B (photomicrograph, partially crossed nicols)..... 53.

8B. Quartz-filled (Q) strain shadow behind a garnet (g) porphyroblast is outlined by swarms of sillimanite(s) needles. Note that rotation of garnet is indicated by the included and stretched out magnetite (m) grains. From unit 7 at south end of island immediately south of Sito West. (photomicrograph, plane polarized light)..... 53.

9. Early stage of snowball texture in garnet porphyroblast in unit 1 from outcrop at northwest end of "W"-shaped lake northeast of Sito Lake. (photomicrograph, crossed nicols)..... 55.

10A. Sphalerite grains (white) showing pitted margins. Quartzite Sequence, unit 6, Sito West (photomicrograph, reflected light)..... 60.

10B. Sphalerite grain (gray) containing tiny blebs of pyrite (white) that are orientated in a straight line. (photomicrograph, reflected light)..... 60.

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## INTRODUCTION

### GENERAL STATEMENT

Stratabound lead-zinc deposits within the Wollaston Lake fold-belt (Figure 1.) constitute a new metallogenic province in the Canadian Precambrian Shield. These deposits which have syngenetic and/or diagenetic origins consist of disseminated sphalerite, pyrite, galena, and some pyrrhotite. During the summer of 1972, the author had the opportunity to visit a number of these deposits and made a detailed study of one of them, the Sito West deposit at Sito Lake.

### LOCATION AND ACCESSIBILITY

The Sito Lake area is 80 miles north of La Ronge, Saskatchewan (Figure 1.) and is accessible by float or ski equipped aircraft from that community. A longer more arduous route by canoe via the Churchill and Foster Rivers is also available.

Access within the study area is limited because lakes are small and poorly connected. Much of the area was burned fifteen to twenty-five years ago making bush travel very difficult in places. Several trails and grid systems have been cut to provide easier access within the mineralized areas.

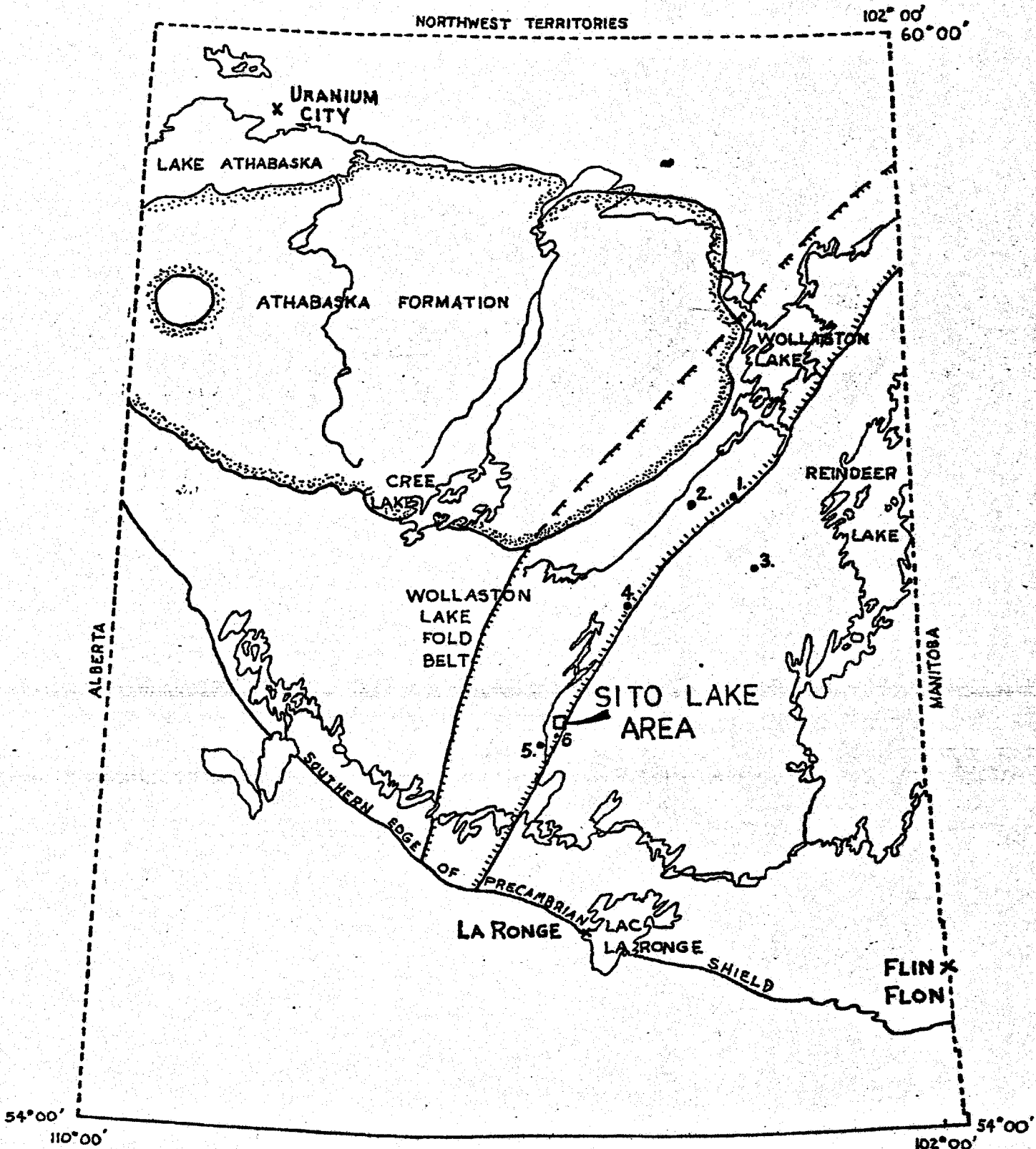


Figure 1. Location of study area in relation to other Lead-Zinc occurrences in Northern Saskatchewan. 1. George Lake, 2. Johnson Lake (Marina), 3. Campbell River, 4. Site of Wathaman River Boulder, and 5. Fable Lake, 6. George Occurrence.

Scale: 1" = 50mi.





## PHYSIOGRAPHY

The Sito Lake area has low to moderate hills and ridges that rise no more than two hundred feet above nearby lakes. Much of the area is covered by a thin veneer of glacial drift with thicker deposits of sand and silt in low lying areas. In addition, several small discontinuous eskers and small outwash plains are present. Muskeg and peat bogs are not extensively developed.

## PREVIOUS AND PRESENT INVESTIGATIONS

Exploratory geological mapping in the area was done by Tyrrell in 1892 (Tyrrell and Downing 1896). He was followed by MacMurphy (1938) who mapped the Foster Lakes area at one inch to four miles in 1936. One inch to one mile mapping in areas adjacent to and including the study area has been done by Mawdsley (1957), Money (1961, 1965, 1966), Fuh (1972 and 1973) and Forsythe (1973) (Figure 2.). The study area has also been covered by the airborne magnetic surveys of the Geological Survey of Canada (1965).

In 1952 and 1953, radioactive pegmatites were the object of exploration ventures in the Foster Lakes area (Pyke and Partridge, 1967 and Rath and Morton, 1969). In 1953, copper was discovered near Upper Foster Lake and as the search for more copper continued a quartzite boulder containing 16% lead, 1% zinc and 5 ounces of silver per ton was discovered on the Wathaman River. This sparked extensive exploration programs designed to locate the source of the boulder. From 1963 to 1965 several deposits were found to the northeast in areas 10 and 12, Figure 2. The best of these deposits is the

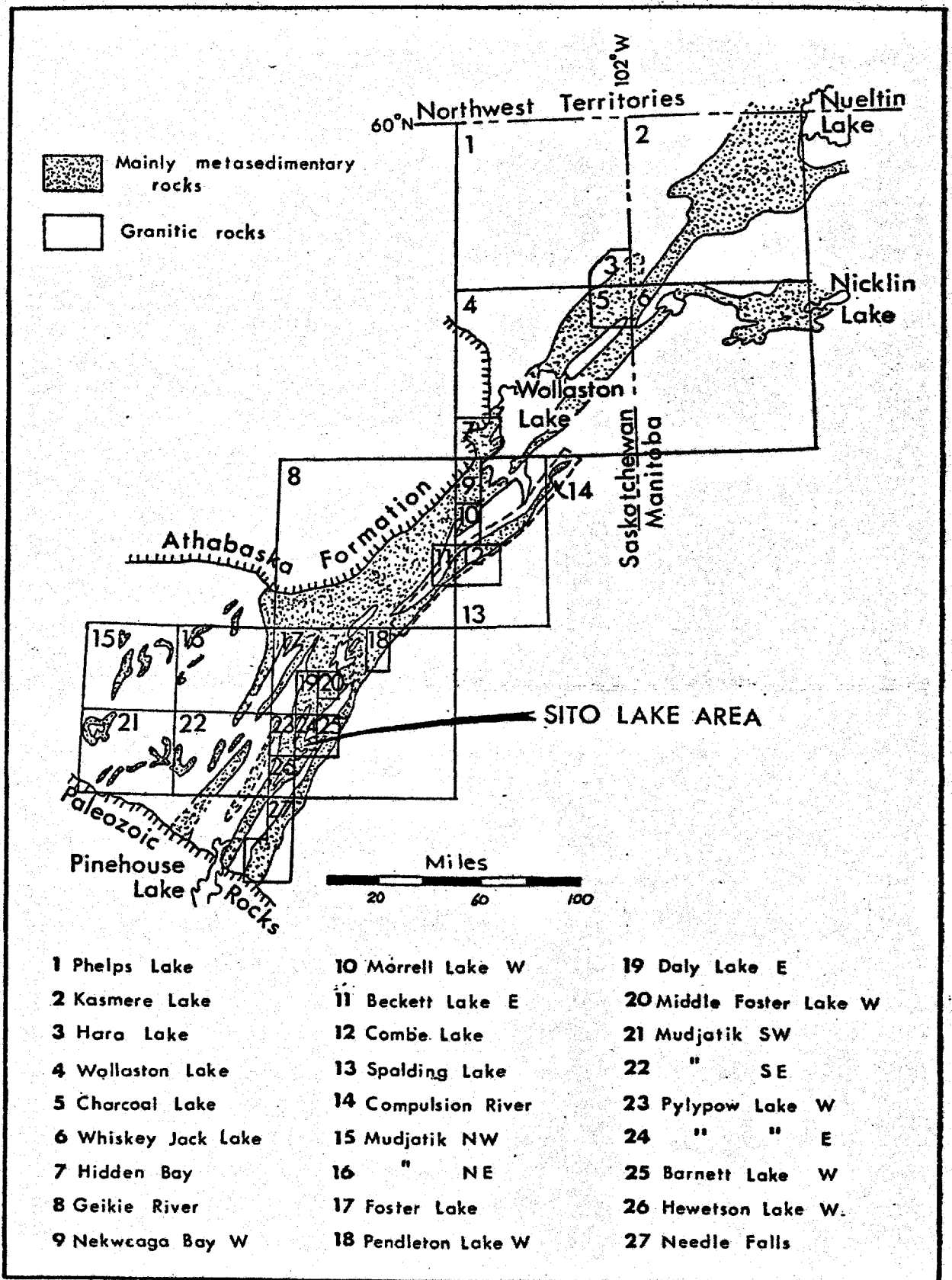


Figure 2 Known extent of the Wollaston Lake fold-belt; with the location of mapped areas. Modified from Figure 1, Money et al, 1971.

George Lake deposit (Figure 1.) which occurs in the Compulsion River fold-belt (Möller, 1970 and Möller and Brummer, 1970) a branch of the Wollaston fold-belt.

It was anticipated that similar disseminated deposits might occur to the southwest near the Foster River. In the autumn of 1971 Eric Partridge and his associates found several showings in this area, one of which was the Sito West deposit. The properties were optioned to a consortium of companies of which Canadian Delhi and Husky Oil were the principal companies involved. Wollex Exploration of Calgary, Alberta was contracted to do the assessment work, and they completed geological mapping and geophysical surveys of the showings with trenching and diamond drilling in selected areas.

Field mapping by the author during August and September of 1972 consisted of detailed mapping (1 inch to 50 feet) of the Sito West deposit (Map A) and pace and compass traverses at approximately one quarter mile intervals in the surrounding area.

#### REGIONAL GEOLOGY

The Sito Lake area lies within the Wollaston Lake fold-belt which is part of the Churchill (structural) province of the Canadian Shield. Potassium-argon dates of 1750 million years indicate the last phase or phases of deformation along the fold-belt occurred during the Hudsonian orogeny (Money, 1968 and Money, Baer, Scott, and Wallis, 1971). A pre-Hudsonian orogeny, the Kenoran, is also indicated by some dates from "older granitic rocks" (Money, 1968). Some lead-lead dating by Cumming, Tsony, and Gudguris (1970)

suggests galena, with an age of 2040 million years, formed contemporaneously with its host metasediments thus indicating an Apebian age for the sediments.

Money (1968) describes the Wollaston fold-belt as a system of coalescing fold belts of metasedimentary rocks separated by areas of "granitic" rocks. He has subdivided the Wollaston fold-belt into three lithological groups; the Sandfly Lake Group, Meyers Lake Group, and Daly Lake Group. He considered the Sandfly Lake Group to be the oldest and to be overlain unconformably by the Meyers Lake Group. However, diamond drilling and structural mapping (Lintott and Pyke, 1972) in the Fable Lake area (Figure 1.) indicates that metasediments similar to the Meyers Lake Group overlie metasediments correlative with the Daly Lake Group.

## SITO LAKE GEOLOGY

### INTRODUCTION

The Daly Lake Group is the most abundant and continuous group in the Wollaston fold-belt, such that correlation from the type area (Area 19, Figures 2 and 3) to other areas of the fold-belt can be made. Most of the metasedimentary rocks in the Sito Lake area are correlative with the Daly Lake Group. The metasedimentary rocks on the Sito East and Sito West Mineral Properties are similar to the Meyers Lake Group and are probably correlative with it.

The metasedimentary rocks in the study area are strongly deformed, regionally metamorphosed to the upper amphibolite and lower granulite facies, and have been intruded by granitic rocks.

The use of formal rock unit terms such as Formation, Member, etc., is not justified for Daly Lake Group and Meyers Lake Group rocks in the Sito Lake area as there has been no formal classification on this basis by Money (1965 and 1966) in either of the type areas. Therefore, the rocks comprising the Daly Lake Group in the study area will be referred to as map units (1,2, and 3, Table 1.). As the rocks comprising the Meyers Lake Group in the study area will be discussed in more detail, they will be referred to as informal rock units, such as sequence and bed (4 to 8, Table 1.)

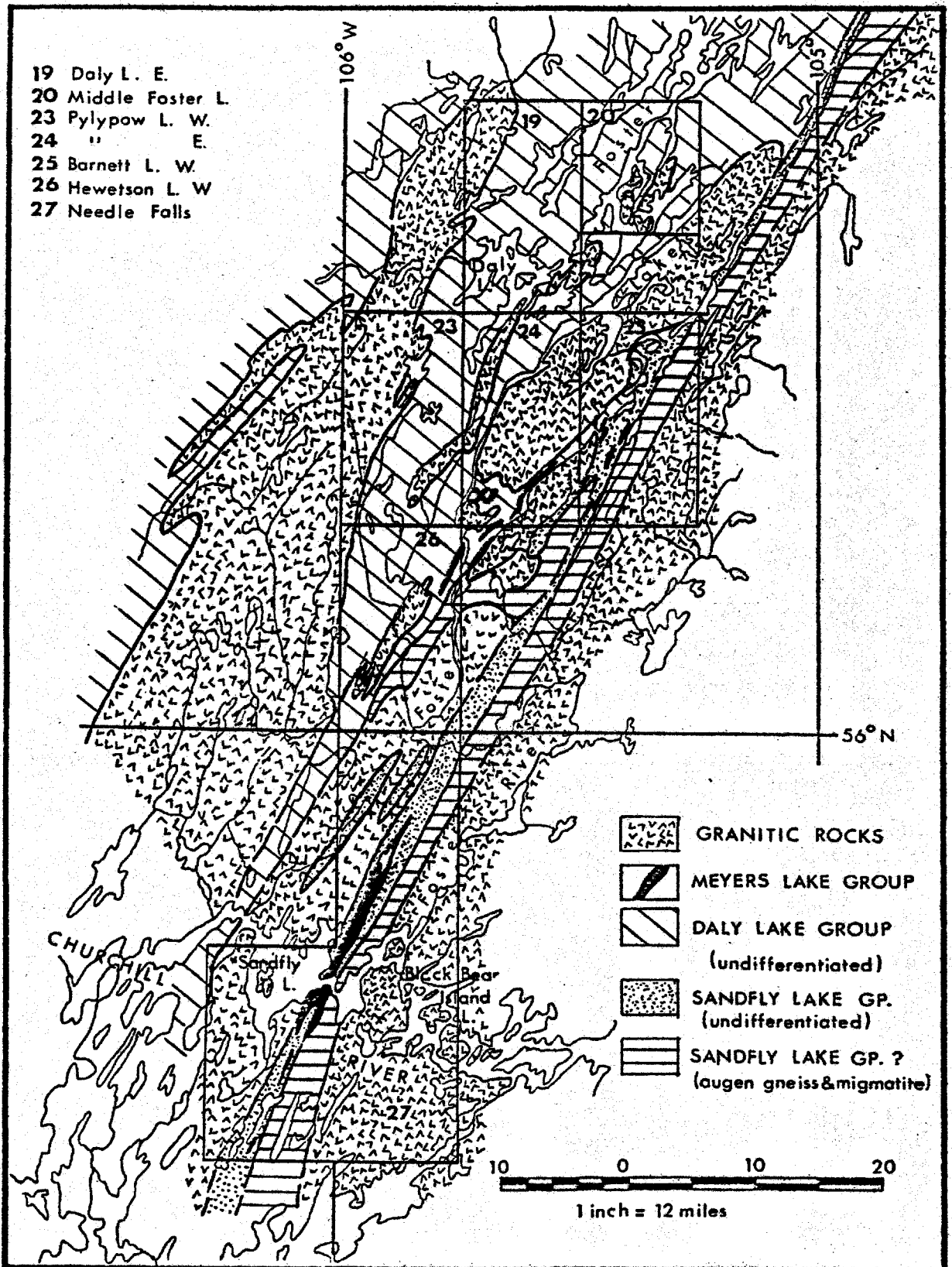


Figure 3. Southwestern third of the Wollaston fold-belt showing the distribution of the Meyers L. Group, Daly L. Group, Sandfly L. Group and granitic rocks in relation to the Sito L. area (X). Drawn from the map of N. Saskatchewan and geological reports by the Sask. Dept. of Mineral Resources.

ERA	EPOCH	NAME	DESCRIPTION
CENOZOIC*	RECENT AND PLEISTOCENE		TILL, GRAVEL, SAND, SILT, CLAY, & PEAT
GREAT UNCONFORMITY			
APHEBIAN		INTRUSIVE ROCKS	PEGMATITE BIOTITE- HORNBLENDE GRANITE 10
	INTRUSIVE CONTACTS		
		ROCKS OF UNCERTAIN ORIGIN	GARNET PYROXENITE 9
	UNCERTAIN RELATION		
		MEYERS LAKE GROUP	UPPER META-ARKOSE SEQUENCE 8 BIOTITE-SILLIMANITE SCHIST 7 QUARTZITE SEQUENCE 6 LOWER META-ARKOSE SEQUENCE Upper Division 5 Lower Division 4
	POSSIBLE UNCONFORMITY		
	DALY LAKE GROUP	BIOTITE-HYPERSTHENE & BIOTITE- PYROXENE SCHISTS 3 BIOTITE SCHIST, CALC-SILICATE ROCKS, & ASSOCIATED ROCKS 2 CORDIERITE-GARNET ROCKS 1	
ARCHEAN		?	

Table 1. Table of Lithologies. The numbers, 1-10, are map unit numbers.

\* Terminology based on Eicher (1968) & Stockwell (1972)

## DALY LAKE GROUP

### 1. Cordierite-Garnet Rocks

Rocks of unit 1 are exposed primarily to the west and northwest of Sito Lake with a narrow zone along the edge of the granitic rocks in the southeast and northeast parts of the area (Figure 4, back pocket). The cordierite-garnet rocks have a minimum exposed width of approximately 1000 feet adjacent to the granitic rocks and are exposed for more than 6000 feet in the western half of the area.

About one-half of unit 1 is a garnet-biotite-cordierite-sillimanite gneiss which is coarse-grained ( 0.5 cm ), gray on both fresh and weathered surfaces, and contains as much as 30% by volume garnet porphyroblasts as large as 5 cm across.

Cordierite is commonly present as thin wavy augen no more than 1/2 cm long and 2 mm wide and may be gray or blue. Sillimanite occurs in a similar fashion. Besides the four minerals described, the garnet-biotite-cordierite-sillimanite gneiss also contains quartz and K-feldspar with some plagioclase and andalusite. The andalusite was only observed in thin sections of rocks from the area between lakes A, B, and C (Figure 4) and it was noted that the andalusite was increasingly replaced by fibrous sillimanite from north to south across this area.

Leucocratic pods are abundant in the garnet-biotite-cordierite-sillimanite gneiss. The pods, which are generally 60 to 90 cm long and as much as 30 cm wide, commonly contain aggregates as much as 10 cm across of garnet or cordierite or both. The cordierite is easily recognized as it is a distinctive blue colour. The pods themselves are composed predominantly of K-feldspar with some quartz.





PLATE 1A. Folded and boundinaged leucocratic layers parallel to  $S_1$  schistosity in cordierite-garnet rocks, unit 1, 8,000 feet west of Sito West.



PLATE 1B. Large blue cordierite porphyroblast in leucocratic pod in unit 1.



Interlayered with the garnet-biotite-cordierite-sillimanite gneisses and considered part of unit 1 are meta-arkoses, quartzites, and biotite-cordierite schists and gneisses. The meta-arkoses and quartzites have a grain size  $\leq$  1 mm diameter, are light gray on fresh and weathered surfaces, and commonly occur in layers  $\leq$  1 cm to 1 meter thick. Both rocks contain less than 10% biotite, garnet, and plagioclase, and garnet may be absent from some layers. Feldspar augen may compose as much as 20% of some layers and cordierite is generally lacking from these rock types.

The biotite-cordierite schists and gneisses are coarse-grained (averaging 1/2 cm) and are light gray to dark gray on fresh and weathered surfaces. The schists commonly occur in layers 1 cm to 1 meter thick that are generally separated by leucocratic layers as much as 20 cm thick (Plate 1). The gneisses on the other hand, occur in layers 40 cm to 5 meters thick, and therefore, they are akin to the stromatic migmatite structures (Mehnert, 1968). The schists contain more biotite than the gneisses and may contain abundant cordierite-sillimanite augen, sillimanite augen, and feldspar augen. Cordierite-sillimanite augen occur in the gneisses as well, but are less abundant. Sillimanite is not commonly visible in the cordierite-sillimanite augen, but forms the inner core of the augen. K-feldspar, biotite, quartz, cordierite, and sillimanite are the major components of these rocks. Minor amounts of plagioclase and andalusite are present and garnet is rare.

The leucocratic layers are white, composed essentially of K-feldspar and quartz and have 2 cm grain size. Some biotite is present in these layers and coarse-grained aggregates of garnet and cordierite are common (Plate 1.).

As a whole, map unit 1 is distinguished from the rest of the Daly Lake and Meyers Lake Groups because of the presence of:

- (a) blue cordierite in augen or aggregate form;
- (b) large and numerous garnet porphyroblasts;
- (c) leucocratic layers and pods.

## 2. Biotite Schists, Calc-Silicates and Associated Rocks

Map unit 2 forms a narrow zone, 200 to 500 feet (65 m to 160 m) wide, along the western shore of Sito Lake and forms a large part of the area between Sito Lake and the Sito East deposit (Figure 4.). The unit has a maximum exposed width of 1500 feet (460 m) and is an interlayered sequence of graphitic biotite schists, biotite-hornblende schists, calc-silicates, quartzites and meta-arkoses. Unit 2 is distinguished from other rock units by the presence of graphite and layers of calc-silicate rocks, and by the prevalence of rusty weathering and granoblastic textures.

The biotite schists are brown to dark brown on fresh surfaces, pinkish where garnet is abundant, and are commonly iron stained on weathered surfaces, whereas, the biotite-hornblende schists are dark gray on both fresh and weathered surfaces. Both rock types are fine-grained (1 mm) and thin layered (2 mm to 1 meter). The biotite schists are composed essentially of biotite, plagioclase and K-feldspar with highly variable amounts of quartz, garnet, sillimanite, hornblende, graphite, hypersthene, and pyrite. The garnetiferous varieties are generally coarser in grain size averaging 2 to 3 mm and contain a few porphyroblasts as much as 5 cm across. Pyrite, where present, may be either disseminated grains, 1 mm in diameter or as veinlets.

The quartzites and meta-arkoses are white to light gray on fresh and weathered surfaces, iron stained where pyrite and graphite are present and have a grain size of  $\leq 1$  mm. These rock types vary between quartz rich quartzites and quartz poor arkoses but they generally contain as much as 10% biotite, 1 to 2% graphite and 1% pyrite. Layering in these rocks is commonly less than 2 cm thick and graded bedding was observed in two thin sections of these rocks, unfortunately the top or way-up cannot be determined because the samples were not oriented.

Calc-silicate rocks, labelled 2a on Figure 4, occur chiefly as layers, 1 cm to 3 cm thick, intercalated with the biotite schists, quartzites, and meta-arkoses, however, a sixty to one hundred foot (18 to 30 m) wide zone composed largely of calc-silicate layers occurs east of Sito Lake (Figure 4.). Calc-silicate rocks have a 2 mm to 5 mm grain size, are pale greenish-gray to dark green on both fresh and weathered surfaces and have iron stain where pyrite is present. The rocks are composed of alternating diopside-rich and diopside-poor layers which are separated by quartz-feldspar layers and/or biotite seams. As much as 1% pyrite and some carbonate are also present.

In one thin section, diopside was almost entirely altered to talc, chlorite, and amphibole. In the same thin section plagioclase was almost totally replaced by zoisite.

### 3. Biotite-Hypersthene and Biotite-Pyroxene Schists

Map unit 3 is exposed on the small island near the western shore of Sito Lake, along the entire length of the eastern shore of Sito Lake and in a narrow zone along the western edge of the Sito East picket lines (Figure 4.). The maximum exposed width of the unit is 1000 feet (300 meters).

The biotite-hypersthene schists are characterized by a coarse grain size (3 mm to 4 mm), brown to dark brown on fresh and weathered surfaces and the presence of rusty brown hypersthene. In places, the contact with the finer-grained biotite schists of map unit 2 is gradational. The biotite-hypersthene schists are generally composed of 50% plagioclase, 15% biotite, 10% K-feldspar, with as much as 20% hypersthene, 10% cordierite, and 1% clinopyroxene. Plagioclase is commonly polysynthetically twinned and has an anorthite content of  $An_{18}$  to  $An_{40}$  (oligoclase-andesine) as measured from extinction angles of the polysynthetic twins perpendicular to the X direction (Deer, Howie, and Zussman, 1966, p. 333). Hornblende occurred chiefly as a replacement of hypersthene, and one thin section had 15% hornblende and no hypersthene.

Biotite-pyroxene schist, which is similar in appearance and somewhat similar in composition to the biotite-hypersthene schists, is exposed as three elongate boudin-like bodies in the core of a major anticlinal fold at Sito West. It is the author's belief that these boudin-like bodies are related to the biotite-hypersthene schists, and that they are the upper edge of a tightly pinched and stretched portion of those schists. The differences between the two rock types may just be the result of metamorphism under slightly varying temperature and pressure conditions; thus, the relation does not seem far fetched. The biotite-pyroxene schists differ from the biotite-hypersthene schists because they contain more biotite; have two equally important pyroxenes, hypersthene and diopside; contain up to 5% sillimanite which is absent in the biotite-hypersthene schists and have very little plagioclase, no cordierite, or hornblende which are all present in the biotite-hypersthene schists. Quartz and K-feldspar are present in about the same amount in both rock types.

## DISCUSSION

According to Money (1966, 1968) the Daly Lake Group are metamorphosed sedimentary rocks. There is no indication that any of the rocks in the Sito Lake area belonging to the Daly Lake Group have an origin other than sedimentary. The cordierite-garnet rocks of unit 1 are undoubtedly derived from pelitic sediments (shales and mudstones) as the metamorphic mineral assemblages would indicate. In places pelites are interlayered with quartzose sandstones (arenite) and arkoses (Krumbein and Sloss, 1963) which are represented by the quartzites and meta-arkoses of unit 1.

The biotite schists of unit 2 may be derived from shales, shaly sandstones, shaly arkoses, or greywackes and interlayered with these sediments and included in unit 2 are arenites and arkoses.

The calc-silicate rocks, 2a, probably represent calcareous siltstones, shales, or sandstones. Money (1968, 1971) does not believe there is enough carbonate present in Daly Lake Group calc-silicate rocks to consider their derivation from impure limestones or dolomites. It is possible for all of the original carbonate to have been used up forming diopside, such that a derivation from impure limestones or dolomites is possible.

The biotite-hypersthene and biotite-pyroxene schists of unit 3 would also appear to be derived from shaly sediments or greywackes. The gradational contact between parts of unit 3 and the biotite schists of unit 2 may indicate that the pyroxene bearing rocks are higher metamorphic grade equivalents of the biotite schists.

A marine environment of deposition for the sediments of the Daly Lake Group is evident from the great thickness of pelitic sediments. Periodic influxes of more clastic material would be required for the deposition of arenites and arkoses. The presence of graphite in many of the rocks of unit 2 might suggest that reducing conditions were prevalent during that depositional episode.

## MEYERS LAKE GROUP

### General

The rocks (units 4 to 8, Table 1.) that are correlated with the Meyers Lake Group in the study area are well exposed on the large peninsula (Sito West) in Sito Lake and in the area southeast of Robyn Lake (Figure 4.). The rocks forming this group are a well layered sequence of meta-arkoses, quartzites, and meta-pelites. Graded bedding is sufficiently well preserved in many of the rocks, such that the direction of the tops of beds were determined and a thickness calculated; 550 feet (168 meters) at Sito West and approximately double that thickness at Sito East. The quartzite (unit 6) is important at Sito West because it contains the zinc mineralization.

### 4. & 5. Lower Meta-arkose Sequence

The Lower Meta-arkose Sequence consists of 85 to 115 meters of arkosic rocks which occur in the core of large reclined anticlinal folds at Sito West (Map A, back pocket). The sequence is subdivided into a lower division, unit 4, and an upper division, unit 5, based on composition and thickness of layering.

The lower division, unit 4, consists of a 30 to 60 meter thick section of thickly-layered meta-arkoses which contains a few lenses and layers of quartzite (4a) and biotite rich meta-arkose, similar to the upper division meta-arkoses (Map A).

The meta-arkoses of unit 4 are white to pink on fresh and weathered surfaces and are distinguished from other meta-arkoses of this sequence and the group by the abundant, large, white to pink,

sillimanite-quartz augen, a 1 mm to 2 mm grain size, and poorly defined layering 25 cm to 5 meters thick. The augen, which may compose as much as 30% of the rock, are from 2 to 4 cm long, 1 to 3 cm wide, and 0.4 to 2 cm thick, and stand out on the weathered surface (Plate 2). The layering, which is defined by a slightly greater concentration of biotite in thin ( $\leq 1$  mm) layers is probably bedding.

The composition of the meta-arkose, which is based on visual estimates of thin sections and stained rock slabs (Bailey and Stevens, 1960), is summarized in Table 2.

Quartz and K-feldspar form an inequigranular, interlocking mosaic of anhedral grains from 0.1 mm to 6 mm across, and very fine needles of sillimanite are present in some of the grains. A few fine grains (0.3 mm) of microcline are present in several thin sections interstitial to quartz and K-feldspar. Plagioclase, which is also interstitial to quartz and K-feldspar, is untwinned and weakly sericitized.

Biotite, which forms a weak foliation parallel to layering, occurs as fine, ragged grains, 0.2 mm long, and has pale yellow or tan to brown or dark brown pleochroism. Many flakes contain zircon inclusions with pleochroic haloes and biotite is partially altered to chlorite and white mica. In some thin sections a more poorly developed orientation of biotite occurs oblique to the preferred orientation. White mica may occur as a primary constituent of the rock, but occurs chiefly as an alteration product of biotite and feldspar.

Garnet grains average 0.5 mm, are anhedral, fractured, and are both poikiloblastic and inclusion-free. The inclusions: quartz, feldspar, and biotite, are randomly oriented. A pale green, isotropic





PLATE 2A. Large sillimanite-quartz augen characteristic of the massive, lower division arkoses, unit 4, of the Lower Meta-arkose Sequence, Sito West.



PLATE 2B. Relief of many sillimanite-quartz augen in the meta-arkoses of unit 4. Note the "Life-Saver" (arrow) for scale.



ROCK UNIT MAJOR MINERALS	LOWER META-ARKOSE SEQUENCE				QUARTZITE		BIOTITE-SILL-		UPPER META-	
	Lower Division 4		Upper Division 5		SEQUENCE 6		IMANITE SCHIST 7		ARKOSE SEQUENCE 8	
	RANGE %	AVERAGE	RANGE	AVERAGE	RANGE	AVERAGE	RANGE	AVERAGE	RANGE	AVERAGE
QUARTZ	10-50	40	1-30	8	40-82	70	Tr-2	Tr	30-70	40
K-FELDSPAR	25-60	40	15-70	50	4-40	20	20-80	55	25-60	40
PLAGIOCLASE	1-20	5	0-20	10	Tr-10	3	0-20	5	0-5	2
BIOTITE	2-10	4	3-25	12	0-5	1	10-40	15	3-15	8
GARNET	0-20	1	0-50	10	0-5	Tr	0-70	10	2-15	7
SILLIMANITE	0-25	10	0-25	10	0-5	Tr	0-70	15	0-1	Tr
OTHERS (MAX CONTENT)	WHITE MICA 1 MICROCLINE 1		CHLORITE 5 MICROCLINE 3 SULPHIDES 2 WHITE MICA 2		SULPHIDES 10 WHITE MICA 4 MICROCLINE 3 CARBONATE Tr FLUORITE Tr				WHITE MICA 2 CHLORITE 1 GRAPHITE 1	

Table 2. Summary of estimated compositions for Meyers Lake Group rocks at Sito West. Mineral compositions were made from visual estimates of thin sections and stained rock slabs.

mineral observed in two thin sections resembles garnet in all aspects except colour.

Zircon and apatite grains are mostly rounded, but are also subhedral, and average 0.05 mm diameter. The round shape may indicate that these minerals are original detrital grains. The opaque grains, magnetite, are anhedral and average 0.07 mm across. A yellow pleochroic mineral with high birefringence occurs along grain boundaries and fractures in a number of thin sections.

The augen are composed chiefly of sillimanite and quartz (Table 2.). Sillimanite occurs as acicular crystals and fibrolite aggregates (Moorhouse, 1969, Spry, 1969) which swarm around and through quartz and K-feldspar grains (Plate 3a). A zone free of biotite surrounds many of the augen and sillimanite replacement of biotite is indicated by small, very ragged flakes of biotite within the augen.

Three lenses of quartzite, 4a, which occur within the lower division meta-arkose are shown on Map A. The largest lens exposed is 18 meters in length and 7.5 meters in width. The other two lenses exposed are 4.5 to 6.0 meters long and 3.0 to 3.6 meters wide. These quartzite lenses have in part gradational contacts with the meta-arkose, but differ from it by containing neither sillimanite nor augen and by a gray rather than pink colour. This quartzite, 4a, differs from the mineralized quartzite (unit 5) by not containing any sulphide mineralization and thus lacks iron stained surfaces. The quartzite, 4a, is generally course grained (2 mm average) and lacks well defined layering, although, cross-bedding (Plate 3b) was observed in a 20 cm thick layer in the southern part of the peninsula. The cross-laminations are 2 cm to 5 cm thick and are marked by a slightly greater concentration of biotite along the foreset bedding planes. The direction of the top of the beds indicated by this sedimentary structure agrees with the





PLATE 3A. Portion of a sillimanite augen showing a fibrous core that contains euhedral (rectangular shaped) sillimanite grains (photomicrograph; plane polarized light).



PLATE 3B. Current bedding (below hammer head) in a quartzite bed, 4a, near the south end of the peninsula at Sito West.

graded bedding preserved in units 5, 7, and 8.

In one thin section, quartz and K-feldspar are anhedral and average 1.75 mm and 1.0 mm across respectively. Many grains are poikiloblastic enclosing small grains of biotite and feldspar, with some quartz in the K-feldspar.

Garnet is unevenly distributed in the quartzite, thus the content in this thin section is not representative of the rock. Garnet occurs as anhedral, fractured grains, 0.15 mm to 5 mm across, that are commonly poikiloblastic. They enclose mostly quartz grains with some biotite and feldspar. Garnet appears to have formed chiefly at the expense of biotite as many grains truncate biotite flakes.

Biotite flakes are ragged, 0.3 mm long, pleochroic from straw yellow to light brown and pale green to green adjacent to garnet grains, and tend to have no preferred orientation. Biotite contains small (0.05 mm) opaque inclusions and round zircon inclusions with pleochroic haloes. Many grains have slight white mica alteration.

The upper division (unit 5), of the Lower Meta-arkose Sequence consists of a 25 to 55 meter thick section of essentially thinly layered meta-arkoses with a few layers of quartzite and lower division meta-arkose, unit 4. Layering in the upper division is generally less than 20 cm, but ranges from 0.5 cm to 30 cm, although two layers of unit 4 meta-arkose, shown on Map A are 1.6 meters and 3.3 meters thick. The layering is considered to be parallel bedding because compositional graded beds generally with sharp upper and lower contacts are common. Layers not showing graded bedding also have sharply defined contacts, which are commonly defined by a concentration of biotite. This is best observed on unweathered surfaces, exposed by sluicing the thin cover of glacial till. Laminae, which are separated by thin seams of biotite, are also present in some beds.





PLATE 4A. Compositionally graded beds with sillimanite augen (white spots) tops in upper division arkoses, unit 5, of the Lower Meta-arkose Sequence at Sito West.



PLATE 4B. Compositionally graded beds with garnetiferous tops (light to dark) similar to Walker's (1967) A→E sequence in rocks of unit 5 at Sito West.



The upper division is distinguished from the lower division by the predominantly thinner beds, the presence of graded bedding, a finer grain size (0.5 mm average), and an increased abundance of biotite, garnet, and sillimanite which produce rusty brown, brown, gray, pinkish-gray, and greenish-gray colours on both fresh and weathered surfaces. The weathered surface is uneven because differential erosion has left light gray, white, and yellowish sillimanite-quartz augen protruding above the surface. The augen, which may compose as much as 40% of some beds, average 2.5 cm long, 1 cm wide, and 0.5 cm thick and are chiefly concentrated near the tops of beds (Plate 4a). The augen are also scattered throughout many beds and are completely absent from others. Garnet occurs in a similar fashion, and may compose as much as 40% of a bed or as much as 70% of a garnet-rich portion (Plate 4b) of a bed. The garnet-rich parts are commonly accompanied by biotite, but rarely by sillimanite-quartz augen, whereas the augen-rich portions are invariably accompanied by garnet, but in considerably less quantity and volume.

Individual beds vary in composition from metamorphosed arkoses (Krumbein and Sloss, 1963) to metamorphosed pelites (shales or mudstones) with many beds having compositions between the two. The gradual and rapid increase of garnet, biotite, and sillimanite which produce garnet-biotite-rich portions and sillimanite-biotite-garnet-rich portions of the beds represents compositional graded bedding (Plate 4a and 4b). Grain size gradation was also observed in a number of beds. A more thorough description of the compositional graded bed is described later (p. 30). The direction of the tops of the

graded beds is consistent throughout the upper division and indicates an anticlinal structure is present at Sito West.

In nine thin sections of unit 5, K-feldspar, plagioclase, and quartz (see Table 2 for compositions) form an equigranular (0.4 mm average) interlocking and granoblastic polygonal (Spry, 1969) matrix in which grain boundaries are generally straight, curved, or sutured. Granulation of grain boundaries occurs within and immediately surrounding many of the sillimanite quartz augen. Along with optical properties, staining (Bailey and Stevens, 1960) was also used to help distinguish the feldspars and quartz. All three minerals may be poikiloblastic containing small round grains of feldspar, biotite, with some sillimanite needles and a few zircon and apatite grains and the feldspars may contain some quartz. The feldspars are untwinned except for a few microcline grains, and K-feldspars are unaltered, whereas plagioclase may be weakly altered to sericite, saussurite, and kaolinite. K-feldspar is most abundant in the arkosic portions near the bottom of the beds, but the content decreases towards the top where garnet, biotite, sillimanite, and in some places quartz are more abundant. The grain size of K-feldspar and quartz is slightly greater in these parts averaging 1 mm across.

Biotite flakes are ragged, preferentially oriented, pleochroic from pale yellow to red brown and straw yellow to dark brown and contain small apatite and haloed zircon inclusions. The flakes average 0.25 mm long in the arkosic parts of the rock and 0.75 mm to 1.0 mm in the garnet and sillimanite-rich parts. The major preferred orientation of biotite is parallel to bedding, however, a weaker direction of preferred orientation intersects the major direction between  $60^{\circ}$  and  $90^{\circ}$ . Biotite is slightly altered to white mica and hematite, but extensive chloritization



occurs in places and appears to have been replaced by garnet and sillimanite. These replacements are indicated by truncated flakes and small flakes within garnet and by ragged, partially replaced flakes and pleochroic spots in the sillimanite augen.

Garnet grains are 0.5 mm to 2 mm diameter, anhedral to euhedral, pale pink, fractured, and both poikiloblastic and inclusion-free. The inclusions, quartz, feldspar, biotite, apatite and opaques, are usually randomly oriented within the central zone of the grains. The central inclusion zone is surrounded by an inclusion-free zone which produces the idiomorphic shape of many of the grains. This suggests post-tectonic crystallization when inclusions did not remain in the crystals (Spry, 1969).

In four of the nine thin sections, pale green, isotropic, anhedral, inclusion-free grains were observed. These grains do not appear to be chloritized, therefore, the colour must be related to its composition. The mineral has a pock-marked or "pebbly surface" (Moorhouse, 1959, page 82, and Figure 92) and indicates garnet. The mineral does not appear to be fluorite because the grains lack cleavage and the relief is too great, and spinel is unlikely because the mineral association is wrong (Kerr, 1959).

Sillimanite commonly occurs in augen either as fibrolite wrapped around elongate quartz grains or as a coarse-grained core of the augen. Many of the augen have feathery or wispy ends composed of sillimanite needle aggregates that extend into the matrix. Less commonly sillimanite occurs as sheet-like masses along feldspar and quartz grain boundaries.

Zircon and apatite may be original detrital grains. They are round to subhedral, average 0.05 mm in diameter, and occur as inclusions

in all the principal minerals. Anhedral grains of magnetite and pyrite are closely associated with garnet-biotite layers and in some of the layers pyrite occurs as veinlets 2 to 3 mm long and 0.75 mm wide.

## 6. Quartzite Sequence

The Quartzite Sequence, unit 6, is economically the most important rock unit in the study area, because it contains the zinc-lead mineralization. This mineralization is generally restricted to the upper half of the unit which varies from 9.6 to 10.2 meters thick. Internally the Quartzite Sequence appears massive, as there is little evidence of bedding. However, a compositional gradation from bottom to top (arkose to quartzite) does occur.

Rocks of the Quartzite Sequence have a 1 mm to 5 mm grain size, are greenish gray, light gray and white on fresh surfaces, heavily iron stained on weathered and fractured surfaces, and have some thin films of pyrite on a few joint surfaces. The weathered surface is pitted where the sulphides have been leached and a conspicuous rusty zone, 1 mm to 10 mm thick, extends inward from the weathered surfaces. A vuggy porosity, which may be the result of leaching, was observed in many hand specimens.

In outcrop, unit 6 appears to be composed almost entirely of quartz with minor amounts of biotite, garnet, sillimanite and sulphides. The rock has been called an orthoquartzite by Lintott and Pyke (1972), however, the K-feldspar content which was determined by thin section examination and by staining rock slabs (Bailey, *et al*, 1960) may be as high as 40%. Feldspar, biotite, garnet, and sillimanite are most abundant in the lower part of the sequence (the arkosic part) and decrease

in volume upward, as quartz and the sulphides increase. The sulphides, which consist of disseminated sphalerite, pyrite, and galena, will be discussed later (pp. 64 to 67).

From the fifteen thin sections examined, it was observed that quartz and K-feldspar form an interlocking mosaic of anhedral grains 0.2 mm to 1 cm across that generally have sutured grain boundaries (Plate 5A). Both minerals contain some small inclusions of feldspar, zircon, apatite, and fine sillimanite needles. K-feldspar is generally interstitial to quartz and is slightly argillized and sericitized. Anhedral grains of plagioclase are interstitial to quartz and are weakly saussuritized and sericitized.

White mica, the most persistent mica present, occurs as ragged flakes, less than 0.3 mm long, that appear to have replaced feldspar and biotite. Fine, ragged flakes of biotite are pleochroic from pale yellow to red brown and less commonly colourless to light brown. The micas generally have a preferred orientation that is parallel to bedding. This is intersected by a less well developed preferred direction between  $60^{\circ}$  and  $90^{\circ}$ . Biotite is moderately to extensively altered to chlorite, white mica, and hematite. Penninite chlorite (Moorhouse, 1959) was identified in several thin sections by its anomalous birefringence.

Pale pink and pale green garnets occur as anhedral, fractured, relatively inclusion-free grains that vary from 0.1 mm to 0.75 mm diameter. A few grains contain fine-grained inclusions of quartz, biotite, and opaques. Sillimanite usually occurs as fine inclusions in quartz, but also occurs as fibrolite masses along grain boundaries and as augen. The augen occur near the contact between units 5 and 6.



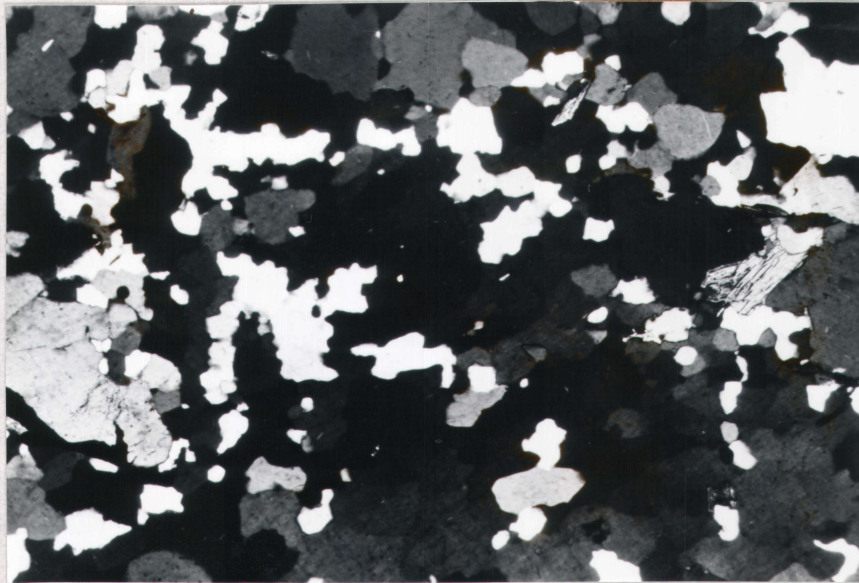


PLATE 5A. Highly sutured quartz and feldspar grain boundaries in rocks of the Quartzite Sequence, unit 6, at Sito West.



PLATE 5B. Fold interference pattern outlined by sillimanite augen-rich bands in the Biotite - Sillimanite Schist Sequence, unit 7, at the north end of Trench 4 at Sito West.



Zircon with some apatite and fluorite are the principal accessory minerals. An unidentified yellow material with high birefringence was observed along grain boundaries and fractures in several thin sections.

#### 7. Biotite-Sillimanite Schist Sequence

Unit 7 overlies unit 5 and is exposed on the peninsula (Map A) as well as on the island immediately south of the peninsula (Figure 4). The latter exposures could be important in determining the extension of the mineralized rocks, unfortunately, no other rocks were exposed on the island. Unit 7 has a thickness of 9.0 m to 15 m. Internally the unit consists of layers 2 cm to 40 cm thick, which have compositional graded beds similar to those in unit 5. The bed tops in the biotite-sillimanite schist are commonly marked by 0.5 mm to 10 cm wide concentrations of sillimanite augen and the direction of the tops in unit 7 agrees with the tops determined in unit 5. The size of the augen varies from 1 cm to 4 cm long, 5 mm to 2 cm wide, and 1 mm to 5 mm thick.

The biotite-sillimanite schist is distinguished by a very rough, knobbly surface produced by the preferential weathering of the groundmass leaving the augen standing out; a dark brown to black weathered surface that is studded with numerous gray or cream coloured augen, a fine grained ( $\leq 1$  mm diameter) groundmass composed largely of feldspar and biotite, and numerous fold interference patterns that are outlined by the augen concentrations (Plate 5b).

In thin sections of the biotite-sillimanite schist the composition is variable (Table 2) because of the graded bedding. Biotite is evenly distributed throughout the feldspathic groundmass, but increases towards the tops of beds. Garnet which is difficult to identify in hand specimen, may compose up to 30% of this rock and is also concentrated near the tops of the beds.

K-feldspar forms the bulk of the equigranular (0.5 mm average) granoblastic polygonal groundmass, and also occurs within the sillimanite augen. Plagioclase, which is commonly weakly sericitized, may compose as much as 20% of the groundmass. A few per cent of quartz is present as interstitial grains to the feldspar grains. Most feldspar grains which surround the augen are strongly fractured.

Biotite flakes are ragged, average 0.3 mm long, are pleochroic from straw yellow to dark red brown and dark brown, contain apatite and pleochroic haloed zircon inclusions, and commonly occur in narrow bands 1 to 2 mm wide through the groundmass and around the augen. Biotite is preferentially oriented parallel to bedding and a less well developed direction intersects the major direction (schistosity) from high oblique to right angles. Biotite flakes that are truncated and enclosed by garnet indicate garnet replacement of biotite. Sillimanite replacement of biotite is indicated by the presence of ragged, partially destroyed flakes within and surrounding sillimanite augen.

Garnets are commonly 0.25 mm in diameter, pale pink, anhedral to euhedral, fractured, and contain very fine quartz, feldspar, and biotite inclusions. The inclusions are usually clustered in a central zone which is invariably surrounded by an inclusion-free rim. Some grains are completely free of inclusions while others have inclusions that are oriented at angles oblique to and perpendicular to the major schistosity. This might suggest that at least 90° rotation has occurred since these garnets crystallized. A few garnets have been incorporated into the augen structures.

Sillimanite occurs as fibrous aggregates which form the augen. Square-shaped sillimanite crystals also occur in the augen and very fine needles occur in garnet and feldspar.

Round to subhedral zircon and apatite grains (0.5 mm diameter) occur as inclusions in the principal groundmass minerals. Powdery opaques occur as inclusions in garnet whereas platy opaques, probably graphite, occur in the matrix.

#### 8. Upper Meta-arkose Sequence

The Upper Meta-arkose Sequence outcrops at the northeast end of the baseline and in the southeast part of the peninsula (Map A). It is 185 feet (62 meters) or more thick.

The Upper Meta-arkose Sequence is distinguished from the Lower Meta-arkose Sequence (map units 4 and 5) because:

- (a) It is finer-grained ( $\leq 1$ mm average), has thinner layers, 1 cm to 10 cm thick, and contains slightly more biotite and garnet than the lower division of the Lower Meta-arkose Sequence;
- (b) In contrast to the lower division (unit 4), unit 8 does not contain any sillimanite augen except for a few layers at its base, and has hematite stain on some surfaces;
- (c) It contains less biotite, garnet, and sillimanite but more quartz than the upper division (unit 5) of the Lower Meta-arkose Sequence.

The Upper Meta-arkose Sequence rocks are light gray to pink on fresh and weathered surfaces, darker pink where garnet is concentrated, and has a pitted weathered surface where biotite and garnet are concentrated. As in the Lower Meta-arkose Sequence, layering represents bedding because

many of the layers have primary graded bedding preserved. Compositional gradation also occurs, but the change occurs within a few millimeters of the top. Sillimanite augen were only observed in the lower 4.5 meters of the unit where they may form as much as 30% of an individual bed or layer.

In thin section, quartz and feldspar commonly form an equigranular granoblastic polygonal (Spry, 1969) texture. A few quartz grains up to 5 mm across also occur. Staining of rock slabs indicates that most of the feldspar is K-feldspar of which microcline is weakly sericitized. Microcline and plagioclase are commonly interstitial to quartz and orthoclase. Plagioclase is untwinned, weakly to moderately sericitized, saussuritized and argillized, and a few grains are antiperthitic.

Biotite flakes are ragged, 0.3 mm to 1.5 mm long, evenly distributed throughout the rock except for narrow bands (1 mm to 2 mm wide) that mark bedding planes, they are pleochroic from yellow to brown, and have pleochroic haloes about zircon inclusions. Pleochroism is paler where chlorite, white mica, and hematitic alteration is more extensive. The major direction of orientation is parallel to bedding and in places appears to be folded. A secondary orientation is oblique to, and perpendicular to the first.

Garnet occurs chiefly in narrow concentrations 1 mm to 5 mm wide. at the tops of beds. Garnets are pale pink, 0.75 mm in diameter, anhedral to euhedral, fractured and generally inclusion-free. Poikiloblastic grains enclose unoriented quartz, feldspar, and biotite grains that are clustered in the central part of the garnet. Truncation and deflection of biotite flakes by garnet is explained by a single phase of crystallization. Growth during a nondeformational (static) interval would cause truncation of the flakes and continued growth could



cause the flakes to be deflected. Chloritization of some of the garnets is indicated by ragged, discontinuous grains that are partially to wholly surrounded by chlorite.

Sillimanite is anhedral to euhedral, 0.2 mm long, and appears to replace biotite.

Round zircon grains (0.05 mm) are scattered throughout and fine-grained opaques (magnetite) are commonly associated with biotite.

### DISCUSSION

The Meyers Lake Group are metasedimentary rocks. Unit 7 is assumed to be metamorphosed shales and feldspathic shales and units 4, 5, 6, and 8 are arkoses, shaly arkoses, quartz arenites, and some minor shaly sediments.

Compositional graded beds mentioned previously in units 5, 7, and 8 (p. 20, 21, 26, and 29) are essentially of two types; those with garnet-biotite-rich portions and those with sillimanite augen-biotite-garnet-rich portions near the tops of the beds. Typically these beds have relatively sharp contacts with the beds above and below. The base of these beds is commonly of arkosic composition and grades upward to a pelitic top.

In the garnet-biotite-rich beds, the gradation from arkose to more pelitic sediment is indicated by the appearance of and increase in garnets. As the sediment becomes more pelitic, garnet and biotite increase steadily in content until garnet composes as much as 70% of the garnet-rich portion near the top of bed. As garnet and biotite increases, the feldspar content decreases.

The sillimanite augen-rich beds have a similar change from a biotitic arkose base to the more pelitic top. The increase in sillimanite augen towards the top of the bed is accompanied by a corresponding increase in garnet and biotite.

The top of the graded beds is then followed by the arkosic base of either another garnet-rich or sillimanite augen-rich graded bed or by ungraded arkosic beds.

The beds with the garnet-rich tops resemble some Precambrian turbidite deposits (Henderson, 1972; and Turner and Walker, 1973). The classic turbidite, Bouma Sequence (Bouma, 1962), consists of five divisions as shown in Figure 5. As many of the important sedimentary structures in turbidites are destroyed by deformation and metamorphism, it is not surprising that a complete sequence was not observed at Sito West. Furthermore, incomplete sequences are the rule rather than the exception (ibid.).

The graded division of the Bouma Sequence, Division A, is most commonly represented at Sito West. According to Henderson (1972) beds of this type vary from homogeneous massive beds, which show little or no indication of grain size gradation (as in unit 4, p. 17) to beds which have a rapid gradation near the top or a continuous gradation from base to top (as in some beds of both 5 and 8). Beds of the latter type, which have a gradation from sandy material to pelitic material, are described by Walker (1965 and 1967) as beds in which the structures of Divisions B, C, and D of the Bouma Sequence are not formed (Plate 4a) and he refers to these as the A→E sequence.

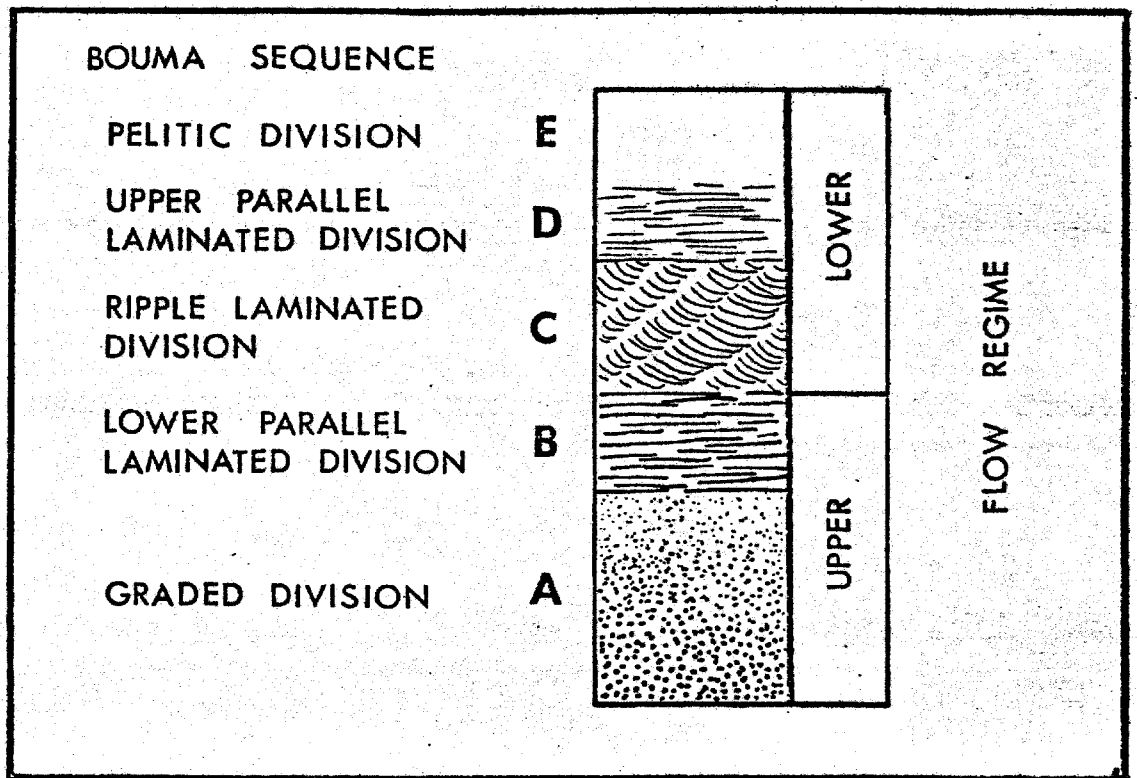


Figure 5. The Bouma Sequence; the 'complete' turbidite (Bouma, 1962) showing the associated sedimentary structures and the interpretation of their flow regime (Walker, 1967).

He believes that beds formed in this manner result from a quiet settling of the finer fraction held in suspension after the current has passed or by settling in a distal environment after the current has become motionless.

Walker (1967) distinguishes between proximal and distal turbidite deposits. The sedimentary rocks at Sito West do not correlate with either extreme, but contain characteristics of both. Sediments of apparently distal locations can be formed close to the source under low flow regime conditions, therefore, it is not a simple matter of choosing one or the other extreme. Conglomerate beds are not exposed at Sito West, but Money (1965) observed conglomerates and cross-bedding, in the type area of the Meyer's Lake Group. Money assumed that the presence of cross-bedding indicated deposition above wave base and possibly even aeolian (i.e. beach dune sands). However, cross-bedding has been observed at considerable depths in present day deep sea turbidite deposits (Walker, 1973). It is the author's opinion that the Meyers Lake Group represent marine fan deposits, perhaps similar in style to alluvial fans, which coalesced with neighboring fans thus forming elongate bodies of sediment. The composition of the Meyers Lake Group sediments, that of arkoses and quartzites, might suggest they were derived from an old, weathered granitic terrain, or from old arkosic or quartzitic sediments. One possible source area may be the granitic and migmatic area that occurs along the eastern margin of the Wollaston fold-belt. However, no directional evidence is available to substantiate this area or any other at the source. Money's (1965) suggestion that deposition occurred on or near a stable shelf during crustal stability may still apply, but deposition above wave base need not apply.

## OTHER ROCKS

### 9. Garnet-Pyroxenite

This unit is exposed north of Sito Lake in a body that is at least 100 feet (30 meters) wide and several hundred feet (60-90 meters) long (Figure 4). It is coarse grained (1 mm to 2 cm), dark green to black on fresh and weathered surfaces, and is spotted by porphyroblasts up to 2 cm across of pink garnet and white quartz.

In thin section, it is composed of clinopyroxene, diopside 55%, garnet 30%, quartz and K-feldspar 5 to 10%, and amphibole 5%, with some apatite and opaques, probably magnetite. Hornblende, which has partially replaced diopside, occurs as narrow rims around the grains. Another amphibole (possibly anthophyllite) may also be a replacement of diopside. Quartz and feldspar are interstitial to diopside and garnet.

The garnet pyroxenite is probably the metamorphosed equivalent of basic to ultrabasic rocks.

## INTRUSIVE ROCKS

In the study area intrusive rocks include biotite-hornblende granite (map unit 10) and pegmatite. Pegmatite dykes which occur in both Daly Lake and Meyers Lake Groups, are rare and commonly less than two feet (0.6 meters) wide, although several dykes or bodies ten to twenty feet (3-6 meters) wide were observed. Pegmatite is white to pink, and is composed essentially of feldspar and quartz with some biotite and white mica.

### 10. Biotite-Hornblende Granite

Biotite-hornblende granite is exposed along the southwestern part of the study area with part of the pluton extending northeasterly toward Place Lake (Figure 4.) where a small granite boss occurs. Granitic rocks that occur north and east of the area are labelled 10a because they were mapped by McMurchy (1936) and Fuh (1973).

Generally, the contact zone between the granite and metasedimentary rocks is marked by narrow, steep-sided, muskeg-filled valleys. On the granite side of the contact are numerous metasedimentary xenoliths, which show various stages of assimilation to granite. Many of the xenoliths are deformed and some are several hundred feet in length and width. The granite is pink to red on fresh and weathered surface and shades of gray where contamination from the surrounding rocks and xenoliths has occurred. The grain size is fine to coarse, averaging 0.75 mm to 1 cm, and locally contains grains up to 3 cm.

From twelve thin sections examined, the granite is composed of an interlocking mosaic of fine to coarse-grained K-feldspar (60%), plagioclase (15%), and quartz (15%), with minor biotite and hornblende. Apatite, zircon, opaques (magnetite) and some sphene and fluorite are the accessory minerals. The K-feldspar includes an average of 10% microcline and 10% perthite with the remainder being orthoclase. Much of the plagioclase occurs as antiperthite (Moorhouse, 1959). White mica, chlorite, opaques, saussurite, and clay minerals are the chief alteration products, generally composing only one or two per cent of the rock.

These rocks are igneous intrusions and not the products of metamorphism because they contain numerous xenoliths exhibiting various stages of assimilation to granite. The size and number of xenoliths suggests that stoping was important in providing room for the rising magma (Larson, 1948), which was sufficiently crystallized and viscous to prevent settling and assimilation of large xenoliths. A lack of radial fracturing and a scant number of dykes around the intrusion indicates that it was emplaced permissively (Stringham, 1960). However, some

cross-cutting relationships probably exist. The edges of the pluton are generally parallel to the surrounding structures which may suggest the structures were present before the intrusion occurred (ibid).

## STRUCTURAL GEOLOGY

### PLANAR STRUCTURES

In the Meyers Lake Group, parallel bedding with graded beds is common but cross-bedding is rare. Bedding with graded beds occur in rock unit 2 of the Daly Lake Group, but graded beds were only observed in thin sections. Tops of beds were determined in the Meyers Lake Group, but the direction of the tops could not be determined for the Daly Lake Group.

For simplicity and ease in writing, bedding and its related fabric are designated as  $S_0$ . Succeeding planar structures (foliation, schistosity, gneissosity, compositional layering, and cleavage) that were produced by succeeding episodes of deformation and metamorphism, are designated  $S_1$ ,  $S_2$ , etc. Similarly, the first period of deformation and the first formed folds are designated  $F_1$  and succeeding episodes are designated  $F_2$ ,  $F_3$ , etc.

The dominant foliation observed in the Sito Lake area is  $S_1$ , which is related to the earliest period of deformation,  $F_1$ .  $S_1$  is chiefly defined by the orientation of biotite flakes and is generally parallel to  $S_0$ .  $S_1$  is also defined by the orientation of graphite and hornblende, compositional layering, and the direction of flattening of most augen and garnet porphyroblasts.

The production of second folds,  $F_2$ , which fold  $S_0$  and  $S_1$ , created a penetrative foliation,  $S_2$ , which is chiefly observed in  $F_2$  fold hinges.  $S_2$  which intersects  $S_0$  and  $S_1$  at angles of  $60^\circ$  to  $90^\circ$  is defined by oriented biotite flakes and flattened  $S_1$  augen.

A good example of this relation is the crenulation foliation (Whitten, 1969) or strain-slip cleavage (Ramsay, 1967) observed in cordierite-garnet rocks, unit 1, (Plate 6B). Away from hinge zones  $S_2$  is not as strongly developed, but is observed in many thin sections as a secondary direction of biotite orientation. In some  $F_2$  hinge zones,  $S_2$  obliterates the earlier fabrics, and becomes the dominant foliation thereby imparting a trend that is characteristic of the Wollaston Lake fold-belt.

Refolding of earlier fabrics by third generation folds has not produced a readily recognizable foliation. Flattening of augen and development of fracture cleavage in  $F_3$  fold hinges appears to be the only planar elements developed.

The apparent gneissosity of the biotite-hornblende granite, unit 10, may be original flow layering. However, if that is not the case, then it would presumably be an  $S_1$  foliation as it parallels the structure of the surrounding rocks. An  $S_2$  foliation may have developed in the granite, but it was not observed.

The wide dispersion of poles to planar structures shown on the contoured equal-area diagram in Figure 6A reflects the refolding of  $S_0$  and  $S_1$ . The axis of rotation to the eyeball best-fit great-circle girdle, B plunges steeply in a north-northeast direction. There is a noticeable concentration of poles to foliation in the southeast quarter of Figure 6A. By taking the center of this concentration the average foliation which strikes  $031^\circ$  and dips  $79^\circ$  NW is consistent with the northeast-southwest trend of the Wollaston Lake fold-belt. Therefore, the concentration on the equal-area diagram must be produced by  $S_2$ .



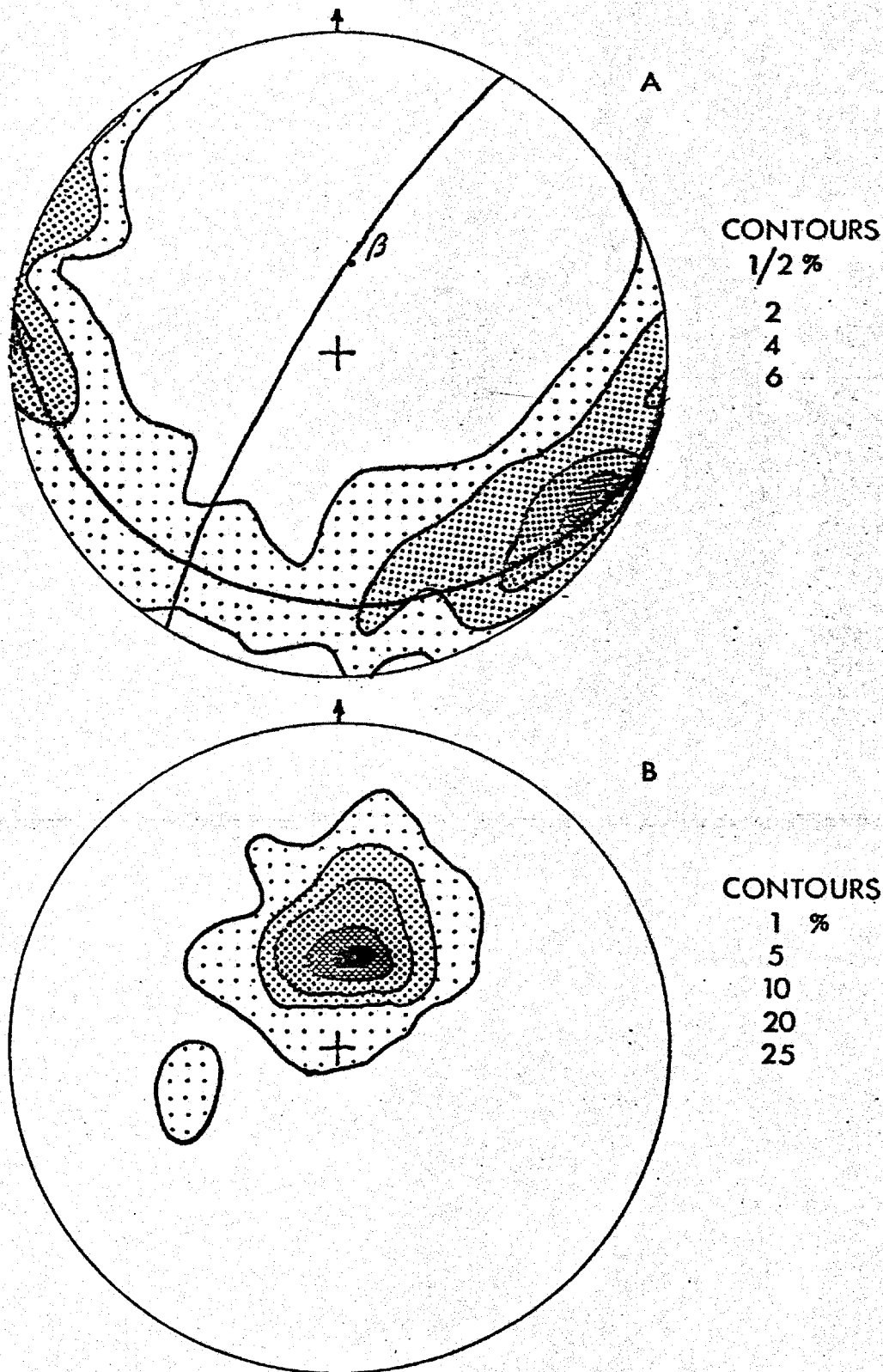


Figure 6. Equal-area diagrams for the Sito Lake area.

A. 630 poles to bedding, layering & schistosity distributed in a great-circle girdle whose axis of rotation plunges  $62^\circ$  to  $010^\circ$ .

Average axial plane is  $031^\circ$  azimuth with  $79^\circ$  dip.

B. 112 points for all mineral lineations have an average plunge of  $68^\circ$  to  $010^\circ$  azimuth.

Contours done by using a 100-cell squared-grid counter (Stauffer, 1966).





PLATE 6A. Sillimanite-quartz augen flattened into the axial plane of minor folds in the hinge zone of a major  $F_3$  fold near Trench 5. The layers outlined by the dashed lines are garnet-rich zones in the upper division meta-arkoses, unit 5, at Sito West.



PLATE 6B. Crenulation foliation (Whitten, 1969) or strain-slip cleavage (Ramsay, 1967) depicting the development of  $S_2$  in unit 1; 4000 feet northwest of Sito West, near Lake B.



## LINEAR STRUCTURES

Sillimanite augen with or without quartz, cordierite-sillimanite augen, feldspar augen, leucocratic pods, and small scale fold hinges constitute the linear structures in the Sito Lake area. The majority of linear structures, except fold hinges, were formed during the production of  $F_1$  folds and lie in the plane of  $S_1$  and presumably cross  $S_0$  in  $F_1$  fold hinges. Many augen that lie in the plane of  $F_2$  and  $F_3$  fold hinges were flattened into that direction during the production of those folds (Figure 7.), but the growth of some sillimanite augen also seems to have occurred synchronous with  $F_2$  folding.

All the augen measured in the study area are shown in the contoured equal-area diagram in Figure 6B. They cluster about a point with a plunge of  $68^\circ$  to  $010^\circ$ . This attitude generally corresponds with the axis of rotation calculated from the eyeball best-fit curve in Figure 6A.

The leucocratic pods were not very useful in determining the structural events of the area because their linear elements could not be measured.

## FOLDING

Folding in the Sito Lake area occurred during at least three major phases of deformation. Folds are generally similar style folds (Plate 7a.), although many small scale folds are concentric in character (Plate 7b.).

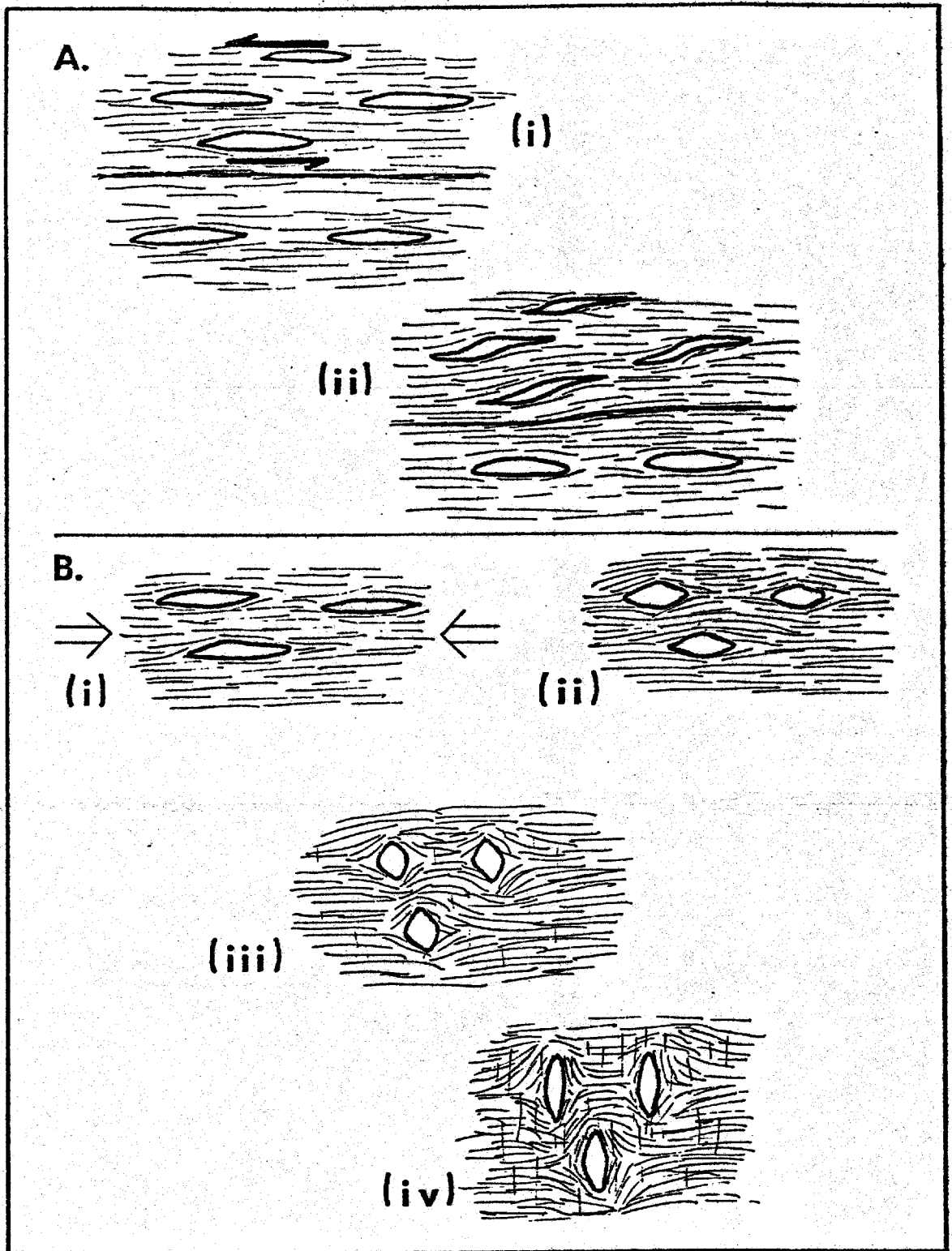


Figure 7. Deformation of sillimanite augen.

A. Augen developed parallel to bedding and schistosity in fold limbs, however, continued shear stress within some beds or layers will produce sigmoidal shaped augen.

B. Compressive deformation will cause flattening of the augen roughly parallel to the new fold axis.



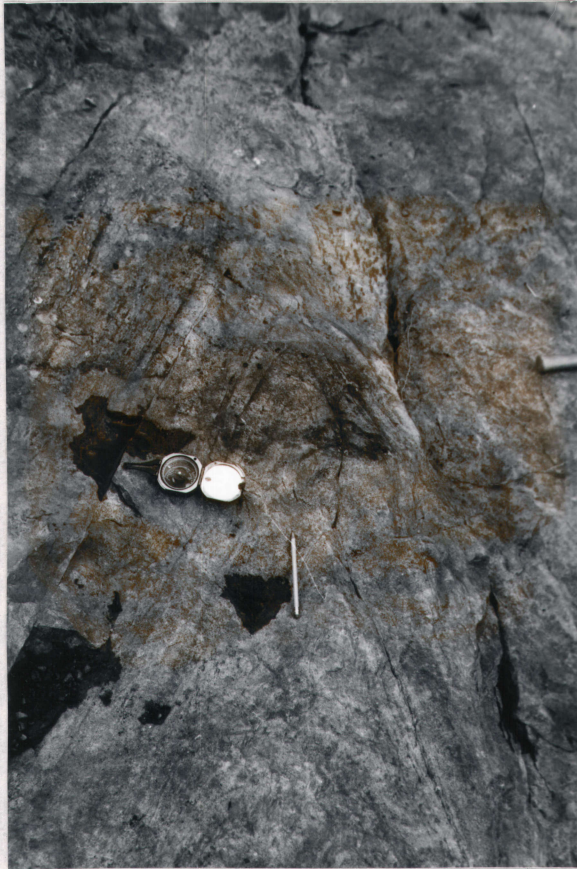


PLATE 7A. Similar style folding of upper division arkoses, unit 5, in the hinge zone of a major  $F_3$  fold at Sito West. Compass points north.

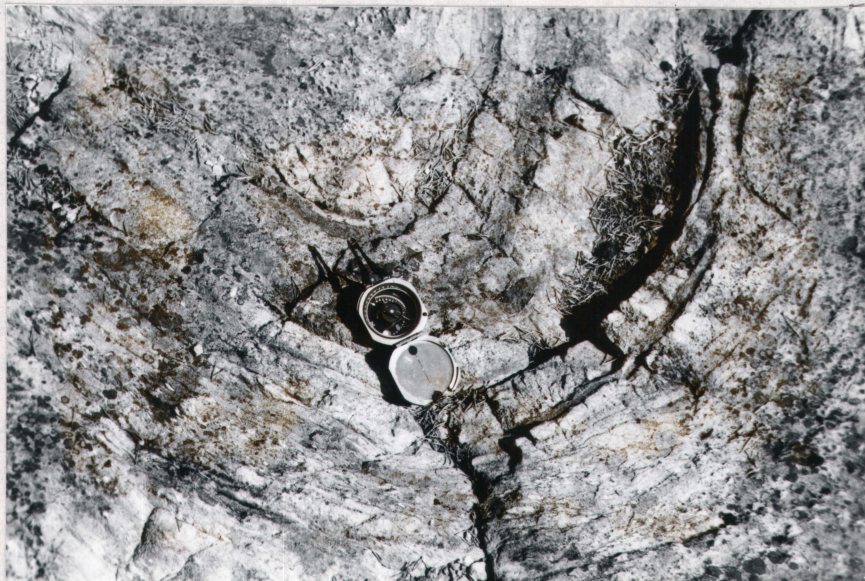


PLATE 7B. Concentric style folds in unit 5 in the southeast part of the peninsula. Note the sillimanite augen remain in the plane of bedding around the nose of the fold.



### Earliest Folds, $F_1$

Major  $F_1$  folds were not identified, however, some small scale isoclinal, rootless folds, and refolded folds were observed.

### Second Folds, $F_2$

$F_2$  folds are the dominant folds observed in the area, and are outlined by folded  $S_1$  (Figure 8.). The production of  $S_2$  has obliterated almost all traces of earlier fabrics in major  $F_2$  folds and has disrupted many earlier small scale structures. The  $F_2$  axial planes generally trend northeast-southwest and dip steeply to the northwest. Calculated plunges of  $F_2$  folds are steep to the northwest. Small scale  $F_2$  folds are tight, but not isoclinal and although the  $S_2$  foliation is not strongly developed in the small scale folds flattening of  $F_1$  augen has occurred (Figure 7.).

The intersection of the northeast trending  $F_2$  folds with the  $F_1$  folds has produced a pattern of elongate fold structures that are similar to some experimental fold interference (dome-and-basin type) patterns produced by O'Driscoll (1962) and to Ramsay's (1967) Type 1. interference pattern. To produce this type of pattern the major  $F_1$  folds must have had a northwest-southeast trend. The major folds in the Sito Lake area are not true domes and basins because the axial planes are inclined and in most cases do not have opposing plunges.

At least four "basin-like" and three "dome-like" structures are present in the Sito Lake area (Figure 8.). The major structure

through Sito Lake is designated as being "basin-like", however, the structure is not that simple. Calculated fold hinges at the south and north ends of the Sito Lake structure plunge steeply to the northwest. The problem arises on the Sito West property where large fold hinges of  $F_2$  and  $F_3$  age plunge northwest at the north end of the peninsula and swing around to southwesterly plunges at the southern end. This indicates a "dome-like" structure is present at Sito West and this concept is supported by the way-up (tops of beds) data.

Using an angel-food cake-pan as an analogy, the Sito Lake structure would be comparable if the pan were flattened and inclined. The Sito West "dome-like" structure would then be comparable to the central conical portion of the pan and the  $F_2$  axial plane would have variable plunges because of the attitude of the major  $F_1$  structures (Figure 9.).

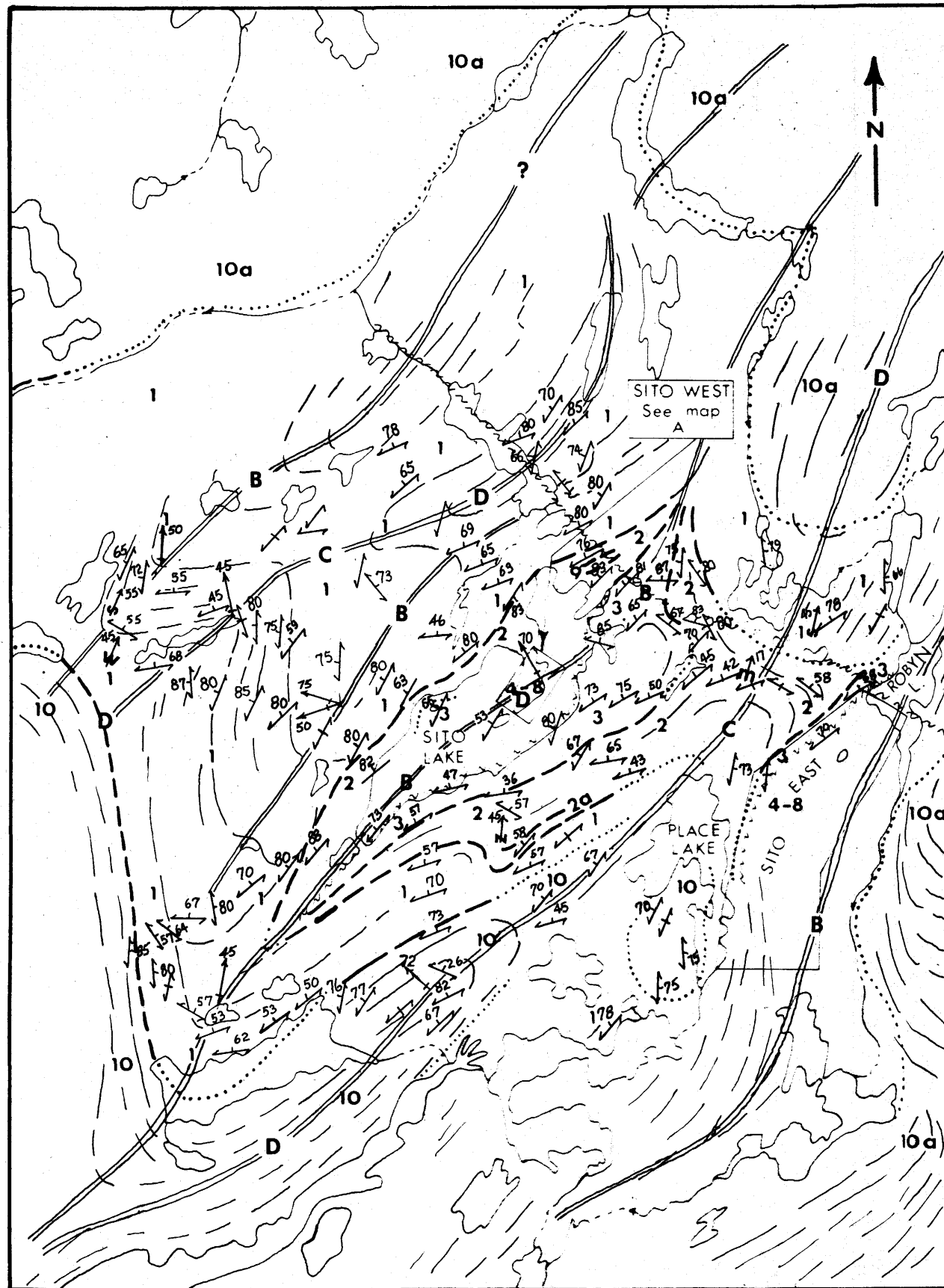
### Third Generation Folds, $F_3$

$F_3$  folds caused minor extension of  $F_2$  folds, as well as refolding them and  $F_1$  folds.  $F_3$  folds trend east-northeast, but like the  $F_2$  folds they plunge northwesterly. Small scale  $F_3$  folds are present in the hinge zones of the larger  $F_3$  folds and flattening of augen into the plane of the  $F_3$  axial plane has occurred.

### SITO WEST STRUCTURE

The attitude of bedding,  $S_0$ , and foliation  $S_1$ , accompanied by way-up data, indicates that the rocks at Sito West are tightly to almost isoclinally folded with steeply inclined axial surfaces.





**LEGEND**

- 10 Biotite-hornblende granite; 10a other granitic rocks
- 9 Garnet pyroxenite
- MEYERS LAKE GROUP**
- 4-8 Meta-arkoses & quartzites
- DALY LAKE GROUP**
- 3 Biotite-hypersthene & biotite-pyroxene schists
- 2 Biotite schists & associated rocks; 2a calc-silicate rocks
- 1 Cordierite-garnet rocks

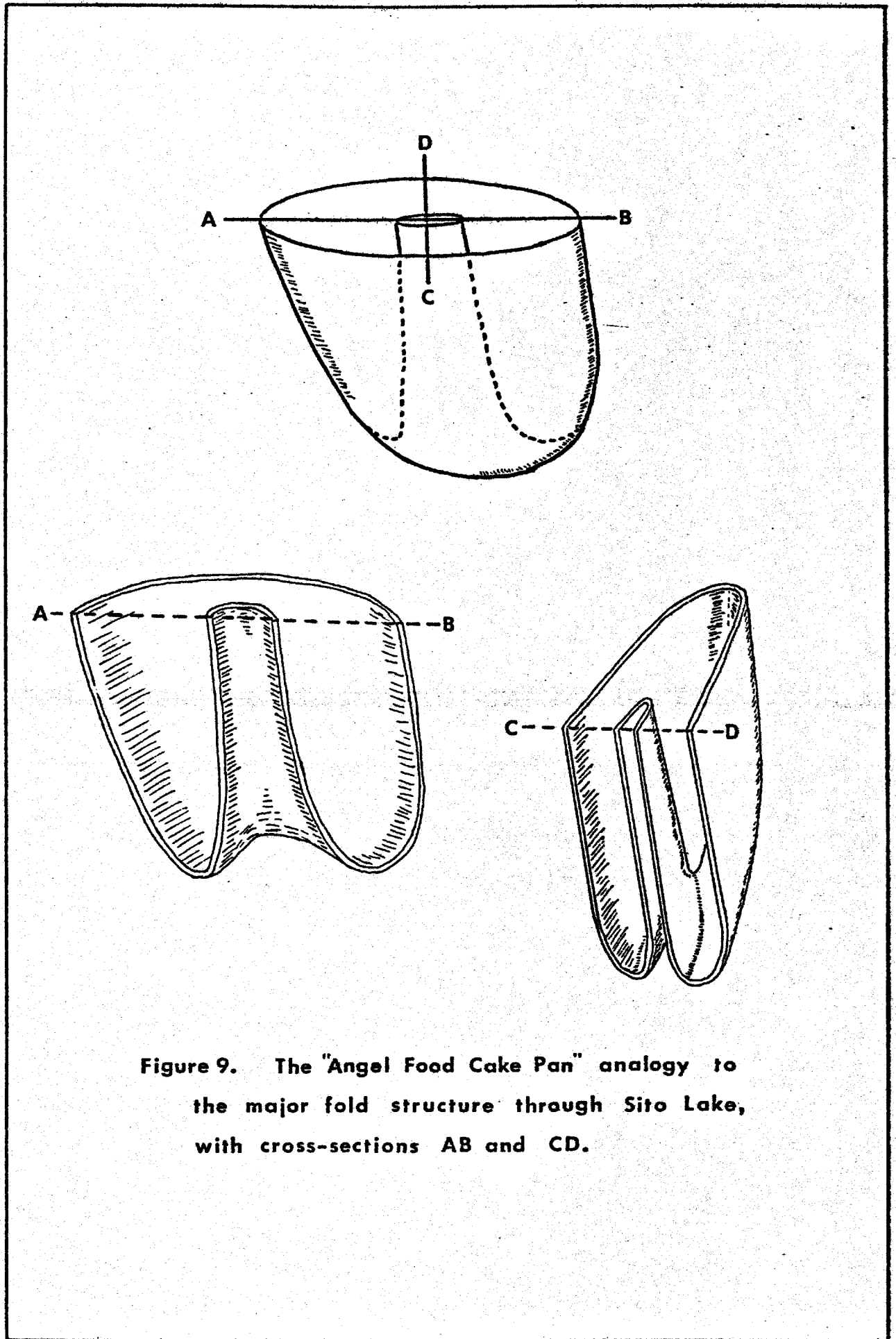
**SYMBOLS**

- Geological boundaries (assumed, inferred)
- Bedding (inclined) 80/
- Foliation (inclined, vertical, dip unknown) 75/ ↗ ↘
- Plunge of minor folds (s, z, m & w) ↘ 45 ↗ 30 ↘ 50
- Faults (assumed) ~~~~~
- Axial planes (basin, dome, col) — B D C —
- Major fold plunge ↘ 45
- Structural trend lines ( )
- Drainage ~~~~~



SCALE 1 inch = 3000 feet

**Figure 8. The Sito Lake Area: Structure**  
 Map drawn from Sask. Dept. of Natural Resources Mineral Claim Map 74-A-5 and aerial photographs from the National Air Photographic Library, Ottawa. Geology by C. Harper, 1972.



**Figure 9. The "Angel Food Cake Pan" analogy to the major fold structure through Sito Lake, with cross-sections AB and CD.**

The calculation of the plunge of the large folds at Sito West indicates the folds plunge steeply northwest at the north end of the property and southwest at the south end. The folds may be classed as neutral folds (Figure 10), although there is a possibility that a "dome-like" structure exists.

At the north end of the Sito West property there are several fold hinges. The  $F_2$  fold in subarea I (Figure 10.) and the  $F_3$  fold in subarea II (Figure 10.) have almost identical axes; plunging  $70^\circ$  at  $327^\circ$  and  $65^\circ$  at  $330^\circ$  (Figure 10., B and C) respectively. Although the folds are nearly coaxial they are not coplanar, as the  $F_3$  fold axial plane strikes  $081^\circ$  whereas, the  $F_2$  axial plane strikes  $040^\circ$ . The two axial planes appear to merge, but this is probably the result of  $F_3$  folding the  $F_2$  axial plane.

Another  $F_3$  fold is present in subarea III and parallels the fold in subarea II, however, this fold plunges less steeply,  $60^\circ$  and in a more westerly direction,  $307^\circ$  azimuth, than the previous  $F_2$  and  $F_3$  folds. The folds in subarea IV are of uncertain age, as they may be either  $F_2$  or  $F_3$ . There are two possible fold axes for this subarea; one plunging  $75^\circ$  to  $309^\circ$  and another plunging  $70^\circ$  to  $260^\circ$  (Figure 10E). It is perplexing that the majority of small scale folds in this subarea plunge southwesterly, but the augen plunge to the north. The significance of this relation is difficult to assess. The fold closure of subarea IV is probably an  $F_2$  fold or at least related to  $F_2$  because the calculated axial plane for the subarea strikes  $044^\circ$  and dips  $75^\circ$  to the west, which is similar to the  $F_2$  fold in subarea I.

Several small scale closed folds with shallow doubly plunging axes were observed at Sito West (Plate 8A). The relation of these folds is uncertain, but they may represent the intersection of the

early  $F_1$  folds with  $F_3$  or younger folds,  $F_4$ .

## DISCUSSION

The structural complexity of the Sito Lake area is somewhat different from the strong linearity of the Wollaston Lake fold-belt. Generally, "dome-like" and basin-like" structures are difficult to define throughout most of the fold-belt. Munday (1972 and 1973) noted that the tight  $F_2$  folds of the Wollaston fold-belt have the same age as the northeasterly trending  $F_3$  folds in the Mudjatik River area (Areas 15, 16, 21, and 22, Figure 2.), an area dominated by closed fold interference structures. Geologists with the Saskatchewan Department of Mineral Resources have stated that the dome-and-basin folding in the Mudjatik River area has resulted from cross-folding as in Ramsay's (1967) Type I pattern, on a set of north to northwest,  $F_2$ , and northeast,  $F_3$ , trending fold axes (Munday, 1972, 1973; Pearson, 1972; Pearson and Lewry, 1974; and Sibbald, 1973). Pearson and Lewry (1974, pp. 633) have suggested three possibilities for the relation or distinction between the two fold phases between the Mudjatik River area and the Wollaston fold-belt. These are summarized below:

- "a. The important  $F_2$  structures, which are primarily responsible for the closed interference patterns in the Mudjatik River area have not been recognized in the Wollaston Lake fold-belt.
- b. The  $F_2$  structures of the Mudjatik River area may be absent or they may swing around into a northeasterly trend and become coaxial with  $F_2$  structures of the Wollaston fold-belt.



- c. The  $F_2$  northerly trending folds continued into the Wollaston Lake fold-belt on the same trend, but have been almost totally obliterated by the intense  $F_3$  folding."

The present writer suggests that the Sito Lake area may represent an area where the earlier structures, whether they be  $F_1$  or  $F_2$ , were sufficiently preserved to produce a dome-and-basin structural pattern. Furthermore, the writer suggests that the presence of granitic plutons, north and south of the present lake, acted as protective barriers or shock absorbers to the intense deformation producing the northeast trend of the Wollaston Lake fold-belt. Thus, the metasedimentary rocks, now forming the Sito Lake area, were not flattened nor extended as much as the metasedimentary rocks flanking the granitic masses (Figure 11A).

The series of sketches in Figure 11 show two possible sequence of events leading to the formation of the major structures in the Sito Lake area. In either case, the earliest structure has a northwesterly trend and may be either an overturned synclinorium or an inclined recumbent fold. The overturned synclinorium is favoured by the writer because the recumbent fold model places the Sito West rocks in a lower stratigraphic position. The writer also suggests that an anticlinal fold occupied part of the synclinorium to produce the "angel-food cake-pan" structure previously described. Several alternatives for the formation of the Sito West fold structures are shown in Figure 12 of which the writer favours the first. Sito West folds probably continue through the island immediately south of the peninsula, but exposure is inadequate to delineate it further.

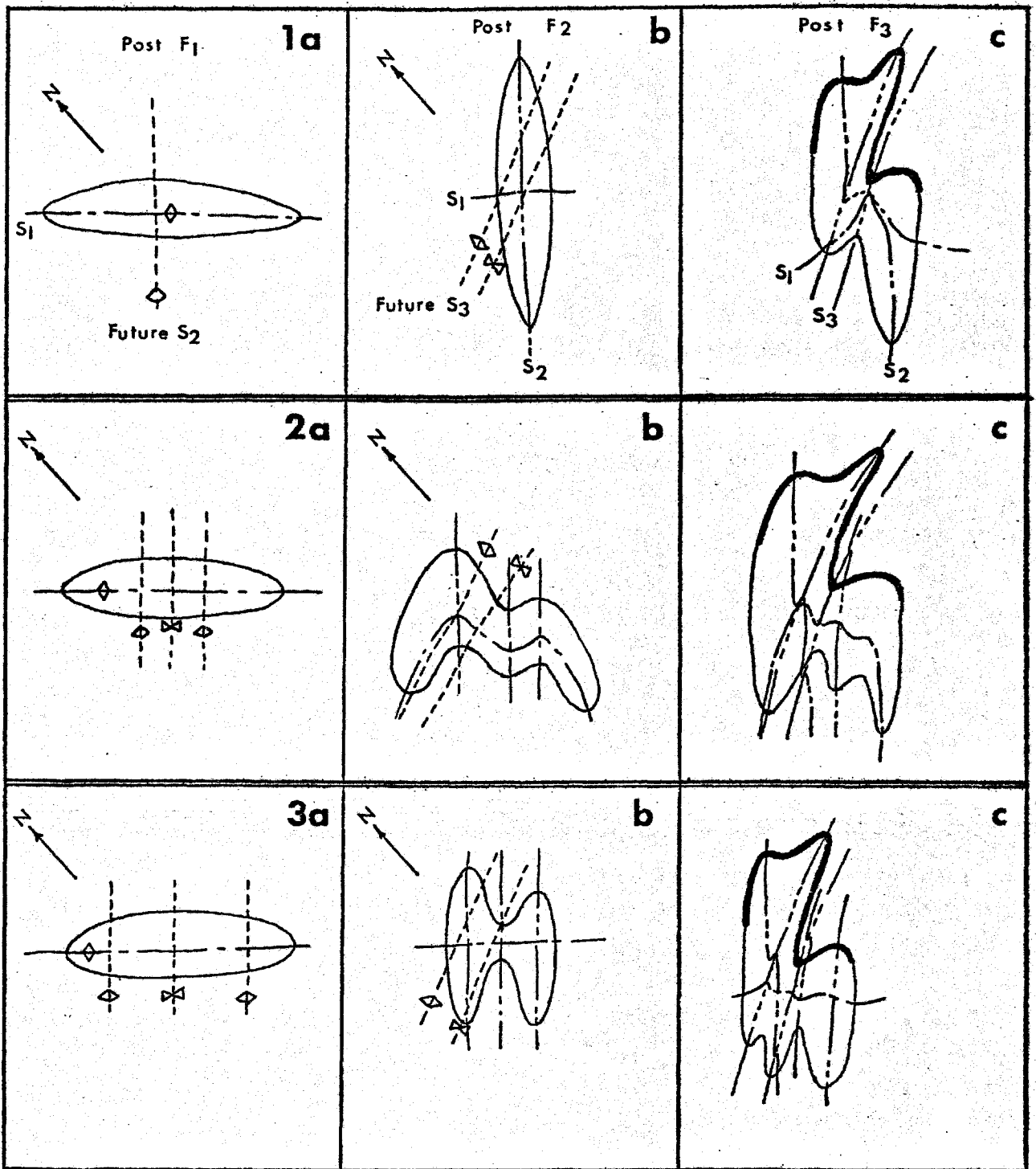


Figure 12. Sketches showing hypothetical structural development of Sito West. Series a shows structural development following the first phase of deformation,  $F_1$ , and the location of future  $F_2$  axial planes,  $S_2$ . Series b shows post  $F_2$  structures with the position of future  $F_3$  axial planes,  $S_3$ , and Series c shows the post  $F_3$  structural interpretation. The thickened line in c represents the known extent of the Quartzite Sequence, unit 6.

METAMORPHISM

The rocks of the Sito Lake area have been regionally metamorphosed to the upper amphibolite to lower granulite facies. Subsequent retrogressive metamorphism produced some greenschist and lower amphibolite facies minerals. The mineral assemblages listed in Table 3 are intended to represent the assemblages before retrogression occurred, and are based on thin section examination. Some assemblages are only represented by a single thin section.

The anorthite content of plagioclase, where possible, was determined by the measurement of extinction angles in sections perpendicular to  $X$  (Deer, Howie, and Zussman, 1966, p. 333). It varied from  $An_{18}$  to  $An_{40}$ . Potash feldspar which included some microcline was generally present as orthoclase. The term "white mica" has been used throughout this text as it is difficult to differentiate muscovite from paragonite in thin section.

Most of the mineral assemblages characteristic of pelitic rocks (units 1, 2, 5, and 7) correspond to Miyashiro's (1961) mineral zone C of the amphibolite facies, "andalusite-sillimanite type" of regional metamorphism or to Winkler's (1967) A2.3 subfacies of the cordierite-amphibolite facies (Abukuma-type). Assemblage G, without andalusite, is stable in these conditions of metamorphism whereby garnet, cordierite, sillimanite, and K-feldspar can coexist (Barker, 1962, p. 902; Dallmeyer 1972, p. 32; Hyndman 1972, p. 354; and Winkler 1967, p. 122). Assemblage D represents calc-silicate rocks and assemblages A, B, and C represent granulite facies rocks that belong to Winkler's (1972, p. 132) granulite subfacies "1b" (hornblende-orthopyroxene-plagioclase-granulite subfacies), in which the addition of a little water to the system permits hornblende

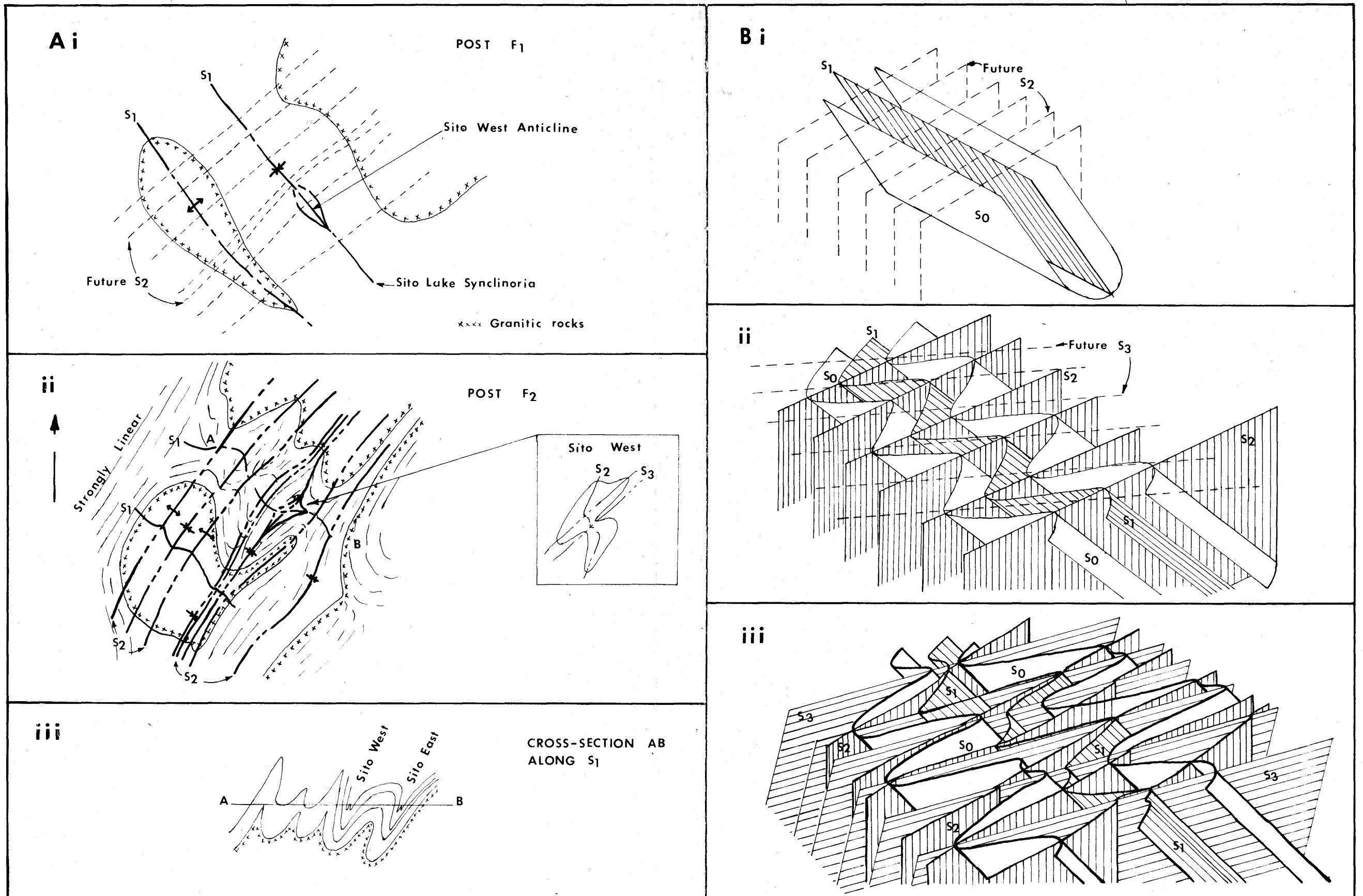


Figure 11. Sketches showing hypothetical structural development of the Sito Lake area. Series A shows only two major episodes of folding with minor extension during a third episode.

Series B invokes three major episodes of deformation of which F<sub>3</sub> may have been much stronger than F<sub>2</sub>.

TABLE 3

METAMORPHIC MINERAL ASSEMBLAGES; SITO LAKE AREA

<u>MINERAL ASSEMBLAGE</u>	<u>ROCK UNIT(S)</u>
A. Hypersthene - clinopyroxene - sillimanite - biotite - K-feldspar - quartz .....	3
B. Hypersthene - garnet - sillimanite - biotite - plagioclase - K-feldspar - quartz .....	2
C. Hypersthene - biotite - plagioclase - K-feldspar ± cordierite ± quartz ± hornblende .....	3
D. Diopside - K-feldspar - quartz ± plagioclase ± biotite ± carbonate .....	2a
E. Clinopyroxene - amphibole - garnet - K-feldspar - quartz .....	9
F. Hornblende - biotite - plagioclase - K-feldspar ± quartz .....	2
G. Biotite - sillimanite - cordierite - plagioclase - K-feldspar - quartz ± garnet ± andalusite.	1
H. Biotite - garnet - cordierite - plagioclase - K-feldspar - quartz .....	1
J. Biotite - garnet - plagioclase - K-feldspar - quartz ± sillimanite .....	1,2,4,5,6,7,8
K. Biotite - sillimanite - plagioclase - K-feldspar - quartz ± white mica .....	1,2,4,5,6
L. Biotite - plagioclase - K-feldspar - quartz ± white mica .....	2,4,6
M. Quartz - K-feldspar - plagioclase ± white mica .....	6

Table 3.



and biotite to coexist with orthopyroxene. Winkler (p. 133) also states:

"that each of subfacies la  $\overline{}$ orthopyroxene-plagioclase granulite subfacies $\overline{}$  and lb may contain cordierite along with almandine, provided a suitable bulk composition. Such cordierite-bearing granulites must have originated under lower pressure  $P_s$  if cordierite grew stably and is not a relict."

Thus, according to Winkler, assemblage C can also be considered to be in equilibrium.

Assemblage E is not definitive and may belong to either Winkler's (1967) granulite subfacies "1b" or "2b", hornblende-clinopyroxene-almandine granulite, or to Hyndman's (1972) sillimanite-orthoclase zone of the amphibolite facies.

Thin sections from rocks of assemblage G, that contain andalusite, reveal that andalusite grains are marginally replaced by sillimanite (Plate 8A).





PLATE 8A. Fibrous sillimanite (s) has partially replaced a euhedral andalusite (a) grain, which occurs in a biotite-rich part of unit 1, near the north end of the small lake north of Lake B (photomicrograph; partially crossed nicols).

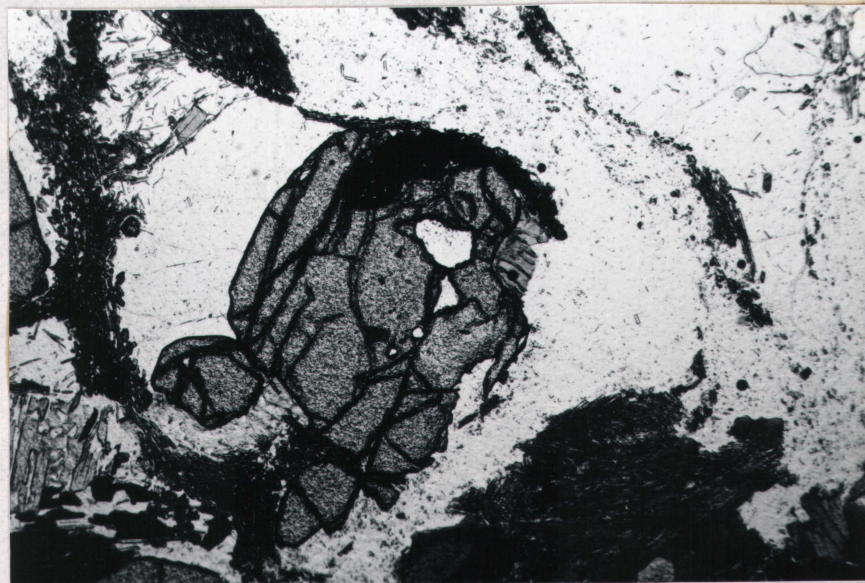


PLATE 8B. Quartz-filled (Q) strain shadow behind a garnet (g) porphyroblast is outlined by swarms of sillimanite needles (S). Note that rotation of garnet is indicated by the included and stretched out magnetite (M) grain. From unit 7 at the south end of island south of Sito West.



## METAMORPHIC HISTORY

The earliest metamorphic event recognizable in the rocks of the Sito Lake area was synchronous with the earliest deformational phase,  $F_1$ . This earliest metamorphism produced the dominant foliation,  $S_1$ , and was responsible for crystallization of such high temperature minerals as sillimanite and hypersthene, as well as localized melting.

Recrystallization related to the production of  $F_2$  folds resulted in the growth of new biotite, and possible sillimanite. If sillimanite did crystallize during the  $F_2$  period then the temperature must have been nearly the same as during the earlier metamorphic event. However, it cannot be demonstrated whether the first and second fold phases,  $F_1$  and  $F_2$ , occurred during a continuous episode; or whether there was a static interval between the two fold phases, during which the temperature was maintained and crystallization continued; or whether there was a long interval between the two fold phases with temperature dropping, then rising again during the second fold phase,  $F_2$ .

Crystallization associated with the production of  $F_3$  folds was very limited, apparently confined to the growth of biotite in  $F_3$  fold hinges. Again the relationship between the second and third phases of folding is not known, Post-tectonic crystallization was evidently widespread as many of the rocks have granoblastic textures (Spry, 1969).

Retrogressive metamorphism resulted in the replacement of hypersthene by hornblende and biotite; diopside by hornblende, some talc, and chlorite; hornblende by biotite; cordierite by pinite; plagioclase by ziosite, sericite, some carbonate and epidote; garnet by chlorite; and biotite by chlorite, white mica and iron oxides.

### GARNET GROWTH AND DEFORMATION

An examination of the textural fabric of garnet porphyroblasts can reveal a great deal of information about the history of metamorphism and deformation for a given area. In areas of polyphase deformation and metamorphism, the textures can become complex. In the Sito Lake area, it appears that the bulk of garnet crystallization occurred during the metamorphic event accompanying the first phase of folding.

Pre-tectonic garnets commonly have pressure shadows and are fractured (Spry, 1967; Stauffer, 1970). Garnets with pressure shadows were observed in several thin sections (Plate 8B) but fracturing is of little help, because with polyphase deformation, almost all garnets are fractured.

Syntectonic garnets commonly produce snowball textures (Spry, 1967) because the crystals are rotated while they are growing. Some snowball garnets (Plate 9) were observed in the cordierite-garnet rocks of unit 1, and in some of the garnetiferous biotite schists of unit 2. These syntectonic garnets are anhedral and commonly are the largest garnets observed. Some syntectonic garnets in the study area have sieve textures, which suggests that rotation was not an important factor during the deformation of the study area.

Post-tectonic growth appears to have accounted for the bulk of garnet crystallization and is represented by garnets that:

- (a) contain randomly orientated inclusions in the central region of the garnet;



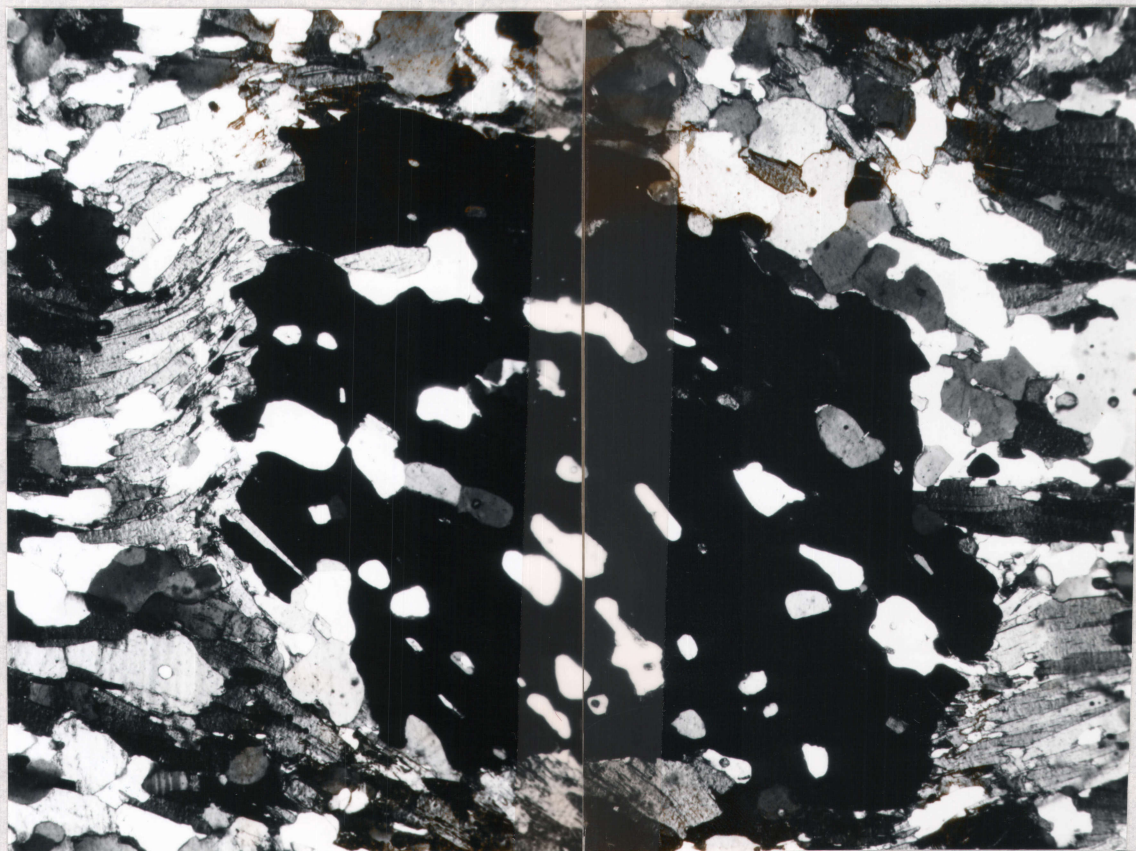


PLATE 9. Early stage of snowball texture in garnet porphyroblast in unit 1 from outcrop at northwest end of "W" shaped lake north of Sito Lake (photomicrograph; crossed nicols).



- (b) contain orientated inclusions which reflect an earlier fabric; and
- (c) contain symmetrically arranged inclusions that reflect a dodecahedral symmetry.

Garnets of type (a) should not be confused with the coarser syntectonic porphyroblasts because the inclusions in (a) garnets are much finer grained as are the garnets themselves. Type (b) garnets could have crystallized after the first or second phases of folding and rotated later. Type (c) garnets were observed in some graphitic garnet schists of the biotite-schists of unit 2. Successive cuts through these garnets produce different inclusion patterns (Figures 14 and 15). These inclusion patterns are similar in nature to inclusion patterns observed in other minerals, such as: chiastolite (Harker, 1932; Spry, 1967); staurolite (Harker, 1932; Hollister and Bence, 1967); cordierite (Harker, 1932); and idocrase (Arem, 1973).

A continuation of post-tectonic crystallization of garnet produced an inclusion-free idioblastic rim around most of the garnets.

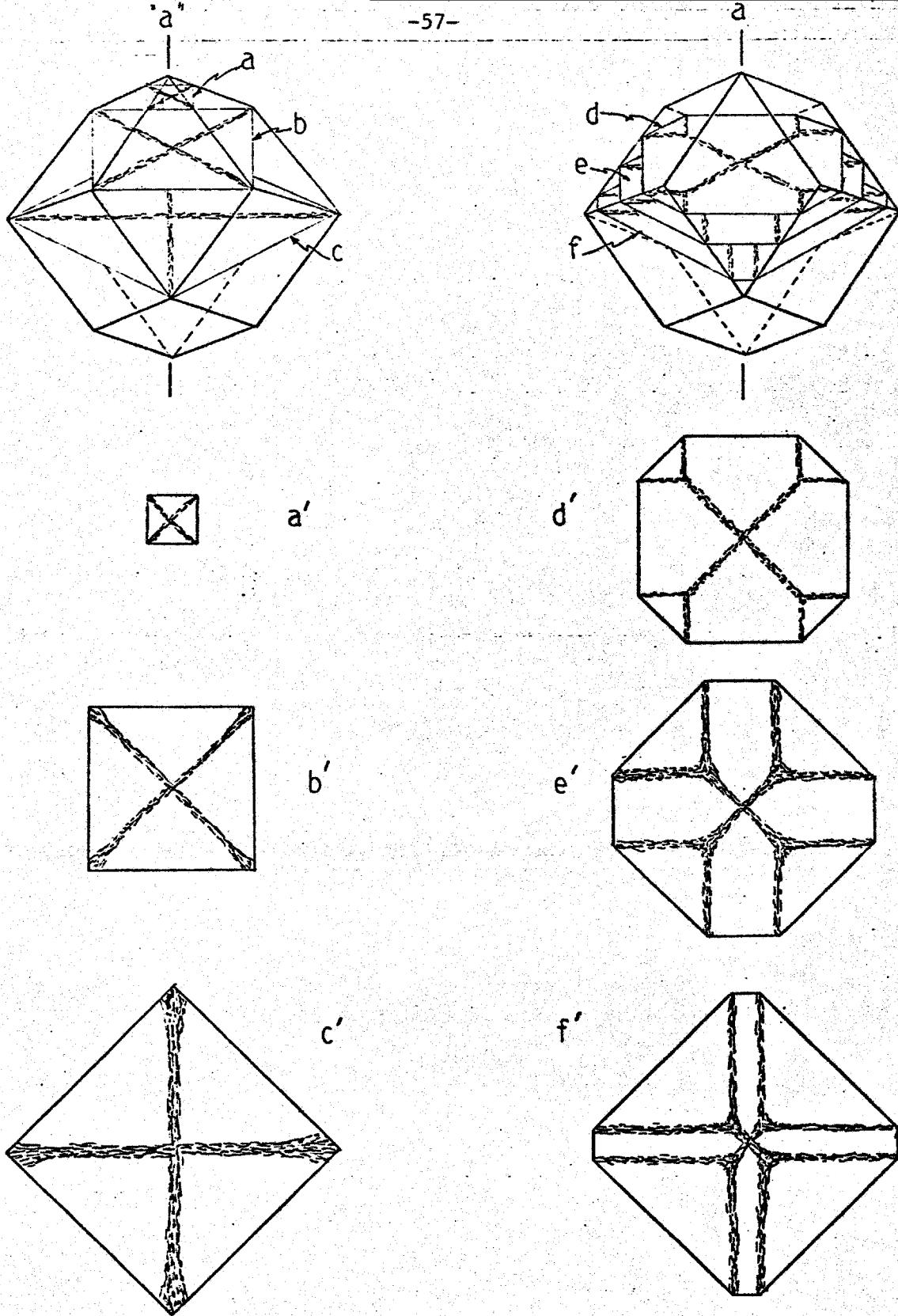


Figure 13. Three Dimensional Sketch of Garnet Dodecahedron. Sections a-f are taken perpendicular to an "a" crystallographic axis and a'-f' show the true section shape and the arrangement of inclusion patterns from more rapid growth along preferred crystallographic planes. (Harker, 1932)

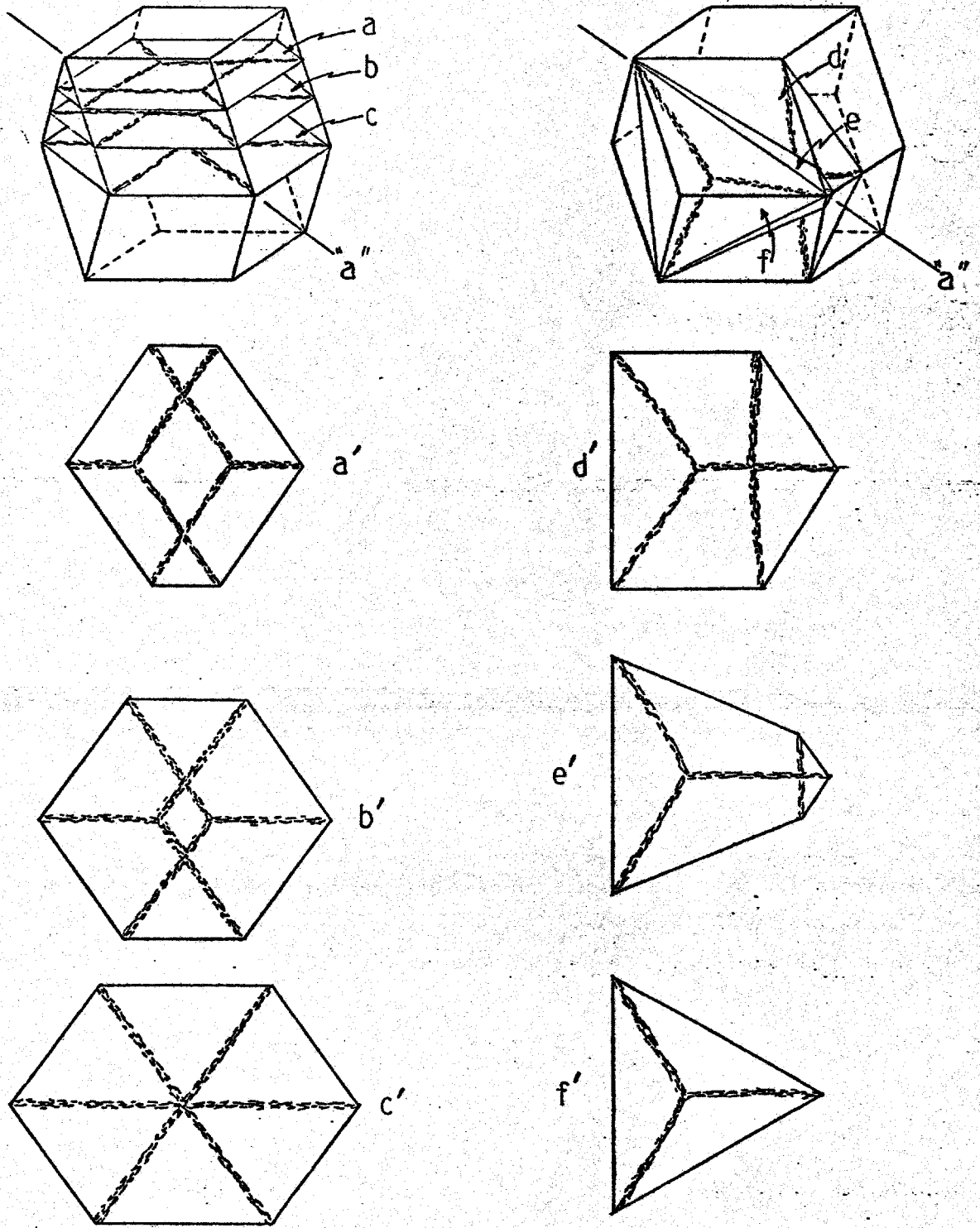


Figure 14. Three Dimensional Sketch of Garnet Dodecahedron. Sections a,b,c are parallel to an "a" axis whereas d,e,f are oblique to the "a" axis, a'-f' show the section shape and the inclusion patterns.

## ECONOMIC GEOLOGY

### INTRODUCTION

Mineralization in the Sito Lake area occurs chiefly in the Sito West and East deposits, which consist of disseminated pyrite, sphalerite, some galena and a few grains of fluorite and chalcopyrite. Pyrrhotite is reported by Lintott and Pyke (1972) apart from this, only trace amounts of disseminated and vein pyrite were observed in the other rocks, particularly the calc-silicate rocks and graphitic arkoses of unit 2.

The mineralization in the Sito West deposit occurs in the upper half of the Quartzite Sequence, unit 6, and there is no evidence of remobilization of the sulphides into the fold closures during deformation. As the host has been described in some detail, it will not be discussed further.

### SPHALERITE

In outcrop and hand specimen, sphalerite grains are black, anhedral to euhedral, and vary from 0.5 mm to 4.0 mm across, although some "bleb-like aggregates up to 1½ inches (3.8 cm) by ½ inch (1.3 cm) by ¼ inch (0.65 cm)" occur (Pyke, Lintott, and Thiel, 1971, p. 15). Sphalerite content varies from less than 1% to 5% by volume (Pyke, et al, 1971) with the highest content occurring in samples from trenches 3 and 4 (Map A) which also corresponds to the coarsest sphalerite grains observed. In places that may mark original bedding planes, sphalerite grains form aggregates several centimeters long and a single grain thick. The black colour indicates the sphalerite has a high iron content.

In polished sections, sphalerite is identified by the characteristics listed in Schouten (1962) and Short (1940). In thin section, it is commonly a deep blood-red colour, although rarely yellow brown, and

in most grains traces of cleavage directions are observed when the polarizer is introduced.

Sphalerite occurs in the following ways:

- (a) as grains interstitial to quartz, most commonly in finer grained parts of the rock;
- (b) filling fractures in quartz grains;
- (c) round blebs within quartz grains;
- (d) narrow rims around pyrite grains;
- (e) fine blebs within pyrite;
- (f) surrounded by or containing fine grained carbonate.

Many grains appear pitted around the edges (Plate 10a), but it is not clear whether this is due to recent weathering or to the preparation of thin sections and polished surfaces. Not only does sphalerite occur as inclusions in quartz and pyrite but a few sphalerite grains enclose tiny blebs of pyrite that in one case appear to have a preferred orientation (Plate 10b). These inclusion relationships are probably all the result of recrystallization during metamorphism.

#### PYRITE

Pyrite occurs as fine grains (0.5 mm) near the base of the Quartzite Sequence, unit 6, and generally increases in size and content towards the top of the unit, with some grains up to 4 mm across. As with sphalerite, the coarsest pyrite occurs in trenches 3 and 4 (Map A) where it composes up to 7% by volume of the quartzite. Pyrite grains are commonly euhedral and occur in the following ways:

- (a) as grains interstitial to quartz, most commonly occurring in the finer grained parts of the rock;



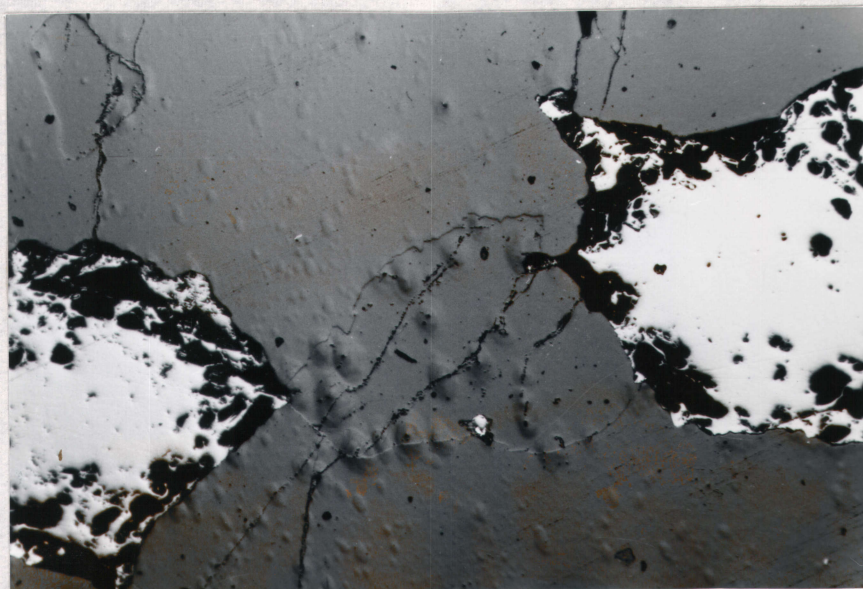


PLATE 10A. Sphalerite grains (white) showing pitted margins; Quartzite Sequence, unit 6, Sito West (photomicrograph; reflected light).

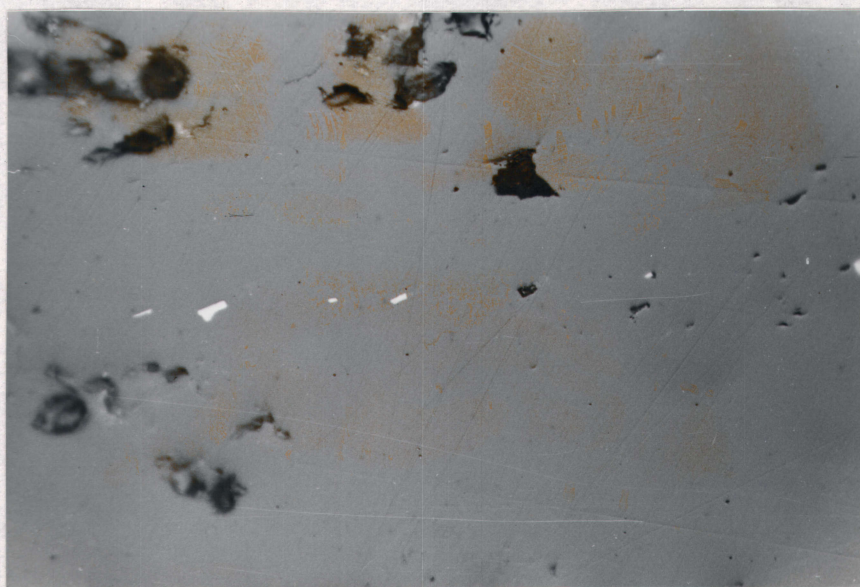


PLATE 10B. Sphalerite grain (gray) containing tiny blebs of pyrite (white) that are orientated in a straight line (photomicrograph; reflected light).



- (b) as round grains within quartz grains;
- (c) filling fractures in quartz grains;
- (d) as thin films on some joint surfaces;
- (e) as tiny blebs within sphalerite;
- (f) associated with the same carbonate material as sphalerite;
- (g) containing tiny blebs of quartz, feldspar, galena, and sphalerite.

The fact that most of the pyrite is euhedral, fills fractures in quartz grains, and contains inclusions of quartz, feldspar, galena and sphalerite may indicate that pyrite was late in crystallizing or re-crystallized from existing pyrite or pyrrhotite grains.

#### GALENA

Galena can be observed in parts of unit 6 which contain the greatest sulphide concentrations. Galena varies from 1 mm to 4 mm across; is generally anhedral, although cubic faces are not uncommon; it occurs interstitial to quartz, sphalerite and pyrite, and as tiny blebs (< 0.1 mm) within pyrite.

#### CHALCOPYRITE

A few tiny blebs (< 0.1 mm) of chalcopryrite were observed during electron microprobe reconnaissance along the grain boundaries of the other sulphides.

#### FLUORITE

Some fine-grained (< 0.1 mm), anhedral fluorite was observed in several thin sections as grains interstitial to quartz.

## DISCUSSION OF ORIGIN

Syngenetic, diagenetic, syngenetic-diagenetic, and epigenetic origins are considered in this discussion. A volcanogenic origin is not considered because volcanic rocks are extremely rare within the Wollaston Lake fold-belt, and are not present in the study area.

Present textural relations between sulphides and gangue minerals may be entirely the result of metamorphic recrystallization; thus, their use in this discussion may not be truly justified. One of the major difficulties in understanding the origin of the Sito West deposit is explaining the restrictive character of the mineralization to the upper half of the Quartzite Sequence.

The disseminated character of the mineralization and the presence of the thin sphalerite aggregates marking bedding planes tend to support a syngenetic origin. However, a diagenetic origin may provide an acceptable explanation for the restriction of the mineralization to the upper half of the Quartzite Sequence, unit 6. The upper half of unit 6 may have acted as an aquifer since pelitic material is more abundant above and below the upper half of unit 6, thus, mineralized connate water would be more restricted to open pore spaces in the quartzite. One drawback to the aquifer idea is that none of the other quartzite beds at Sito West contain mineralization. Perhaps, the solution to the origin involves a combination of both syngensis and diagenesis, whereby the mineralization was initially precipitated syngenetically then reworked during diagenesis.

The latter suggestion is similar to the process suggested for the origin of some copper-uranium-vanadium-sandstone deposits in the southwestern United States (Stanton, 1972). Deposits of this nature have

recently been discovered in meta-arkoses and conglomerates of the Meyers Lake Group (Northern Miner, 1974) south of the study area. Stanton (1972) also mentions that many of the southwestern United States deposits contain pyrite and/or marcasite as well as trace amounts of galena and sphalerite. Perhaps the process which produces the copper-uranium-vanadium-sandstone deposits can be extended to include the zinc-lead quartzite deposits of northern Saskatchewan.

Epigenetic solutions of magmatic origin could have been responsible for producing the disseminated mineralization because there are several igneous intrusions in the area. However, there is no decisive evidence such as veining, or alteration zones or haloes, thus it seems unlikely that the Sito West deposit originated by epigenesis.

A detrital origin is a possibility but again there is no direct evidence to support this idea. According to Samama (1973) a detrital deposit requires selective concentration of heavy minerals from an older land mass with subsequent erosion and reconcentration in a new sedimentary basin.

Neither of the last two alternatives adequately explain the restricted distribution of the mineralization. The writer favours the combination of syngenetic precipitation of the mineralization with subsequent redistribution during diagenesis.

One problem that has arisen out of this study and is not readily explainable is the high iron content of the sphalerite. Recent experimental data indicates that sphalerite cannot contain more than 20 mole per cent FeS when it coexists with pyrite, but it may contain as much as 50 mole per cent FeS when it coexists with pyrrhotite or pyrrhotite and pyrite (Barton and Skinner, 1967; Scott and Barnes, 1971; and Boorman, Sutherland, and Chernyshev, 1971). The results of an electron



probe microanalysis by the writer indicates that the Sito West sphalerites contain approximately 40 mole per cent FeS. This value fits the range of values for sphalerite coexisting with pyrrhotite or pyrrhotite and pyrite, but is obviously too high for sphalerite coexisting with pyrite alone. Although some pyrrhotite has been reported (p. 62) none of the samples examined by the writer contained pyrrhotite. Perhaps the solution to the problem will have some bearing on the origin of the mineralization.

#### COMPARISON WITH OTHER DEPOSITS

A number of other deposits in northern Saskatchewan are similar to the Sito West deposit. These include deposits at Sito East, Robyn Lake (Figure 4), and the George Occurrence, Fable Lake, Johnson Lake, and George Lake (Figure 1). Several small deposits were located in the Morell Lake area (Area 10, Figure 2) (Pyke and Partridge, 1967), but there is no information available on these. Most of the above deposits are predominantly zinc deposits and taken as a whole they have in common:

- (a) a quartzite host rock;
- (b) a disseminated or granular nature of the sulphides;
- (c) an apparent syngenetic or diagenetic origin;
- (d) a location near the eastern margin of the Wollaston fold belt;
- (e) a general correlation to areas of aeromagnetic lows in relation to the surrounding rocks.

Compared to Sito West there are distinct differences, which are briefly outlined below.

The Sito East deposit, which is the nearest deposit to Sito West, is perhaps the most similar because it has essentially the same sedimentary sequence, but has some facies variation and greater thickness.

The two deposits differ in that the Sito East deposit contains mainly red or brown sphalerite (up to 10% by volume) although some black sphalerite does occur, and in places galena is more abundant than at Sito West (Pyke et al, 1971). The quartzite host at Sito East is finer grained ( 1 to 2 mm) and contains more mica, sillimanite, and garnet than the Sito West quartzite. The sphalerite is yellow brown under plane light and commonly occurs in elongate grains that suggest some remobilization may have occurred. The Robyn Lake deposit and the George occurrence which lie to the north and south of Sito East respectively (Figure 1) are considered to be extensions of Sito East.

The Fable Lake deposit (Figure 1) which is eight miles (13 km) southwest of Sito Lake has a similar sedimentary sequence, but the quartzites are not as pure as at Sito West. The mineralization extends for several kilometers in this predominantly zinc deposit but is mostly low grade, although locally sphalerite may compose up to 18% (in some boulders) and galena 5% (Pyke et al, 1971).

The Johnson Lake deposit is located about 100 miles (160 km) to the northeast of Sito Lake (Figure 1). This deposit is essentially a galena deposit contained within a quartzite host that is in contact with granitic rocks. Patches of green amazonite within the quartzite suggest hydrothermal or metasomatic activity was involved. The galena occurs as anhedral masses interstitial to large quartz grains, 5 mm across, which have been recrystallized but still retain an oval shape. There is a close similarity between parts of this deposit and the Wathaman River Boulder which started the exploration for these deposits.

The George Lake deposit, which is about twenty miles (32 km) east of Johnson Lake, occurs in a subsidiary fold-belt, the Compulsion River fold-belt (Möller, 1970 and Möller and Brummer, 1970). The deposit occurs

in a fine grained ( $\leq 1$  mm) gray quartzite and contains disseminated sphalerite, pyrite, and galena. Zinc is more widespread in the surrounding rocks than in the surrounding rocks at Sito West. Black pyritic argillites which overlie the quartzite at George Lake contain some pyrite grains with sphalerite cores. These pyritic argillites resemble another zinc deposit which is located south of George Lake on Campbell River (Figure 1).

The Campbell River deposit contains some disseminated sphalerite in black pyritic argillites which have undergone less deformation and metamorphism than Sito West. It was suggested by Lintott and Pyke (personal communication) that the presence of the sphalerite in the argillites in this deposit might represent an earlier evolutionary stage of these zinc deposits; that is, the metal ions were not remobilized and concentrated in the quartzites. However, this does not appear to be the case for all the deposits because the deposits are not all associated with pyritic argillites or their metamorphosed equivalents.

Möller and Brummer (1970) compared the George Lake deposit to the galena occurrences along the Caledonian border land of Scandinavia. Grip (1967) described the Scandinavian deposits as disseminated and vein types in Eocambrian to Cambro-Silurian sandstone and he related the deposits to epigenetic solutions that travelled along thrust faults and precipitated in the sandstones. There is no evidence to support an origin of this nature for the deposits in northern Saskatchewan.

Möller and Brummer (1970) analyzed the George Lake sphalerite for its trace element content and compared the results to "Mississippi Valley Type" sphalerites. They found that more discrepancies than similarities exist between the two sphalerites, however, as the host

rocks (carbonate for Mississippi Valley and quartzite for George Lake) are very different this was not surprising. An accurate determination of trace elements was not made for Sino West sphalerite, thus, a comparison with Mississippi Valley Type deposits cannot be made.

As previously stated the zinc-lead deposits of northern Saskatchewan are similar in some respects to the copper-uranium-vanadium-deposits of the southwestern United States. Both types of deposits have a sandstone host and are probably formed by the same process.



## CONCLUSIONS

From the writer's study of the Sito West deposit a number of conclusions are made:

1. The rocks that contain the Sito West deposit have been correlated to the Meyers Lake Group (Money, 1965, 1968) of the Wollaston Lake fold-belt and overlie the Daly Lake Group rather than underlying that group.
2. Sedimentary structures observed at Sito West are consistent with structures of sediments deposited towards the distal end of marine fans possibly by turbidity currents. Evidence to determine source areas of the fan(s) is inconclusive but the source may have been from the dominantly granitic terrain to the east.
3. The structure of the Sito Lake area involved three major phases of deformation. The first phase produced the dominant foliation that is completely obliterated in areas of second phase fold hinges. The combination of the first two phases produced the major structural features of the area, that is; elongate, northeast-southwest trending, "dome-like" and "basin-like" structures. The third phase produced an east-northeast extension of the earlier structures.
4. The major structural feature through Sito Lake is interpreted as a basin-dome-basin structure that is compared to a flattened and inclined "angel-food cake-pan".

5. Rocks in the Sito Lake area were regionally metamorphosed to the upper amphibolite and lower granulite facies. The observed mineral assemblages are consistent with a low pressure environment involving pressures of 2 to 5 kilobars and at temperatures between 650° and 750°C.
6. The major episode of mineral growth was associated with the first phase of deformation and the high degree of metamorphism may have continued on through to the second phase of deformation.
7. The sulphide mineralization at Sito West was probably syngenetic but underwent changes during diagenesis, producing the restricted distribution observed.
8. The Sito West deposit is similar to many other zinc-lead deposits within the Wollaston Lake fold-belt of northern Saskatchewan and some galena deposits in the Caledonian borderland of Scandinavia. There is also a good comparison to copper-uranium-vanadium-sandstone deposits of the southwestern United States.

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