SEDIMENTOLOGY AND METAMORPHISM OF A PROTEROZOIC VOLCANICLASTIC TURBIDITE SUITE THAT CROSSES THE BOUNDARY BETWEEN THE FLIN FLON AND KISSEYNEW BELTS, FILE LAKE, MANITOBA, CANADA

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Doctor of Philosophy

by

ALAN HARVEY BAILES

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ABSTRACT

The Kisseynew sedimentary gneiss belt is near the southeast corner of the Churchill Province in Manitoba. It is a large, east-trending Proterozoic sedimentary basin composed largely of greywacke-, siltstone-, and mudstone-derived paragneisses and migmatites. It is bounded on the south by the Flin Flon volcanic-sedimentary belt. In the File Lake area, well preserved, weakly recrystallized pebbly greywacke, greywacke, siltstone and mudstone of the Aphebian Amisk Group of the Flin Flon volcanic-sedimentary belt have been traced northwards across a steep metamorphic gradient directly into migmatitic Kisseynew belt paragneisses.

The Amisk Group sedimentary rocks are mainly turbidites, with minor debris and fluidized sediment flow deposits. They are 1 km thick; consist almost entirely of volcanic detritus, which is mainly felsic in composition; and overlie a thick accumulation of Amisk Group mafic subaqueous flows. The felsic volcanic detritus is texturally and compositionally variable. This indicates a level of mixing which requires subaerial transport. The detritus was probably derived from easily eroded pyroclastic deposits of contemporaneous Amisk volcanoes, rather than by dissection of an older volcanic terrain by stream activity. This is indicated by: (i) only slight rounding of clasts; (ii) local intercalation of volcanic and sedimentary rocks; (iii) direct input of some strata into the sedimentary basin from their volcanic source without reworking; and (iv) absence of plutonic or metamorphic clasts.

The debris flow deposits have a restricted occurrence and are confined to the Flin Flon belt whereas the turbidites and fluidized sediment flow deposits are widespread and are part of a subaqueous sediment dispersal system developed around major stratovolcanoes of the

Flin Flon belt. A large portion of the detritus which entered the sediment dispersal system appears to have been channeled into subaqueous fans and transported into the adjacent Kisseynew sedimentary basin.

Several prograde metamorphic reactions have been identified in muscovite-bearing metasedimentary rocks and define a steep metamorphic gradient which increases from the Flin Flon volcanic-sedimentary belt into the Kisseynew sedimentary gneiss belt. These are:

chlorite + muscovite + garnet $\rightleftharpoons$ staurolite + biotite + quartz + H_2O;

chlorite + muscovite + staurolite + quartz $\rightleftharpoons$ sillimanite + biotite + H_2O;

muscovite + staurolite + quartz $\rightleftharpoons$ sillimanite + garnet + biotite + H_2O; and

muscovite + plagioclase + quartz + H_2O $\rightleftharpoons$ melt + sillimanite.

These and other reactions indicate that metamorphism in the File Lake area took place at moderate pressures ($\sim$ 3.5 kb) in a temperature gradient that increased from 400°C to 650°C.

The metamorphic gradient of 21°C/km is too steep to be accounted for by selective uplift of more deeply buried and metamorphosed strata in the Kisseynew belt. There was probably a higher geothermal gradient in the Kisseynew belt than in the Flin Flon belt. This could have been caused by lower thermal conductivity of the volcanic rocks and consequent impedance of upward movement of heat in the Flin Flon belt relative to the Kisseynew belt. This mechanism could explain why Precambrian volcanic belts are invariably much lower grade than associated sedimentary belts, and does not require special tectonic conditions for development of this difference.

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1. INTRODUCTION

1.1 Statement of Problem

The relationship between low grade, weakly recrystallized Aphebian Amisk and Missi Group sedimentary strata of the Flin Flon belt and high grade, strongly recrystallized paragneisses of the Kisseynew belt has been a source of controversy from the time they were first mapped by Bruce (1918). Attention was focused on this problem by Harrison (1951a), who recognized four main hypotheses concerning the relationship of the Kisseynew paragneisses to the stratigraphic succession in the Flin Flon belt. These hypotheses were:

1) paragneisses of the Kisseynew belt comprise rocks of various ages, probably including both Amisk and Missi Group strata, as well as some older and/or younger strata;
2) paragneisses of the Kisseynew belt are younger than the Amisk Group, lie conformably upon them, and are older than the Missi Group;
3) paragneisses of the Kisseynew belt are younger than the Amisk Group, lie unconformably upon them, and are probably equivalent to the Missi Group; and
4) paragneisses of the Kisseynew belt are separated from the Amisk and Missi Groups by a major fault, and their relative ages cannot be determined.

Harrison (1951a) tentatively suggested that paragneisses of the Kisseynew belt could be highly recrystallized deep-basin sedimentary facies equivalents of continental sedimentary deposits of the Missi Group. He also suggested that the boundary between the two belts was a major fault, which he termed the Kisseynew lineament. He based the fault hypothesis on a persistent lineament, marked by strong local shearing, which was parallel to the belt boundary and across which there appeared to be an abrupt change in metamorphic grade and local structural discordance. The fault interpretation was emphasized in a subsequent paper by Harrison (1951b) and was strongly supported by Kalliokoski (1953), who concluded that the Kisseynew belt had been "compressed and overturned in the south by a tectogene mechanism that was strong enough to shear the gneisses off the basement and thrust them over Amisk rocks" of the Flin Flon belt.

Other investigations (Robertson, 1951; Byers and Dahlstrom, 1954; Bailes, 1971, 1975; Froese and Moore, 1978) have demonstrated that both Amisk and Missi Group rocks can be traced into paragneisses of the Kisseynew belt and have shown that, although there is local faulting, the Kisseynew lineament is not a major fault structure and is simply the trace of the boundary between dissimilar rock types. Bailes (1971) suggested that there is a direct correlation between Amisk Group sedimentary rocks of the Flin Flon belt and Nokomis Group paragneisses of the Kisseynew belt and between Missi Group sedimentary rocks and Sherridon Group paragneisses. He also suggested that the "Nokomis sequence accumulated in a relatively deep water environment, likely a trough, by submarine dumping of clastic material mostly derived from the adjacent Amisk volcanic deposits". One of the major objectives of this study has been to investigate the validity of this hypothesis through a detailed sedimentologic study of the Amisk-Nokomis sedimentary rocks of the File Lake area.

The File Lake area is particularly amenable to a sedimentologic study of the Amisk-Nokomis Group rocks and to an analysis of the stratigraphic and metamorphic nature of the boundary between the Flin Flon and Kisseynew belts. This is because a sequence of weakly recrystallized, well preserved Amisk Group pebbly greywacke, greywacke, siltstone and mudstone can be traced across a steep metamorphic gradient from the Flin Flon belt into stratigraphically equivalent Nokomis Group migmatitic paragneisses of the Kisseynew belt.

1.2 Previous Work in the Study Area

The File Lake area has been mapped several times. It was mapped originally by Alcock (1920) and later by Stockwell (1935) at 1:126,720. Harrison (1949) mapped most of it at 1:63,360 and McGlynn (1959) mapped a small strip along the western edge that was not covered by Harrison. More recently, the author mapped the File Lake area at a scale of 1:25,000 (Bailes, 1978). This study is an offshoot of the latter mapping program.

This study is the first detailed sedimentological analysis of Amisk Group sedimentary rocks and their high grade Nokomis Group equivalents. Many aspects of their metamorphic paragenesis have been dealt with previously by Harrison (1949), Froese and Gasparrini (1975), Bailes and McRitchie (1978) and Froese and Moore (1978).

1.3 Location, Access and Field Work

The File Lake area is 260 km^2 and is bounded by latitudes $54^{o}47.5'$ and $54^{o}58'$ north and longitudes $100^{o}12.5'$ and $100^{o}31'$ west. It is 130 km northeast of The Pas and 20 km west of Snow Lake (Fig. 1).

There is no road access, but there are water and portage routes from Reed Lake, on Highway 391. The most convenient method of access is by float-equipped aircraft based at The Pas, Flin Flon or Wabowden. There is also rail access to Woosey Lake on CNR trains hauling ore from the Snow Lake mining area to the Hudson Bay Mining and Smelting Co. Ltd. refinery complex in Flin Flon.

Samples, photographs and geological data for this study were collected in the summers of 1970, 1971 and 1972, during mapping of the File Lake area by the author for the Manitoba Mineral Resources Division. The mapping was conducted by standard pace and compass traverses, spaced every 150 to 300 metres. The published geological map (Bailes, 1978; Fig. 2, in pocket) is at a scale of 1:25,000. Several short stratigraphic sections were measured and numerous coarse greywacke samples were collected in weakly recrystallized, well preserved Amisk Group metasedimentary rocks on Morton Lake. Several hundred field observations of megascopic metamorphic assemblages and numerous samples of Amisk Group metasedimentary rocks were collected in a zone from the south end of Morton Lake across the metamorphic gradient to the north boundary of the map-area, north of Corley Lake.

2. GEOLOGIC SETTING OF STUDY AREA

2.1 Regional Setting

The Churchill Province in northern Manitoba and northeastern Saskatchewan includes several belts of highly recrystallized and complexly deformed Aphebian sedimentary rocks (Fig. 1). The largest of these belts is the east-trending 300 km long and 150 km wide Kisseynew sedimentary gneiss belt. The Kisseynew belt comprises coarsely recrystallized migmatitic paragneisses in which only simple and tentative lithostratigraphic subdivisions have been made. It is bounded to the south by the Aphebian Flin Flon volcanic-sedimentary belt and to the north by the Aphebian Lynn Lake volcanic-sedimentary belt. Archean basement gneisses and granulites, which underlie Aphebian supracrustal rocks to northwest (Weber et al, 1975), are conspicuously missing in the Kisseynew, Flin Flon and Lynn Lake belts, although some late Archean to early Aphebian strata have been identified locally at the west end of the Flin Flon belt at Hanson Lake (Coleman, 1970) and at Pelican Narrows (K. Bell and J.M. Moore, personal communication, 1978).

The supracrustal and intrusive rocks of the Flin Flon, Kisseynew, and Lynn Lake belts have been dated by a variety of radiometric isotope techniques; Sangster (1978) contains a review of these studies. They indicate that the supracrustal rocks are between 1800 to 1900 Ma old and were deformed and metamorphosed before 1750 Ma.

The nature of the boundary of the Kisseynew belt with the Lynn Lake belt, to the north, has received little attention, but Zwanzig (1976) has suggested that paragneisses of the Kisseynew belt correlate with

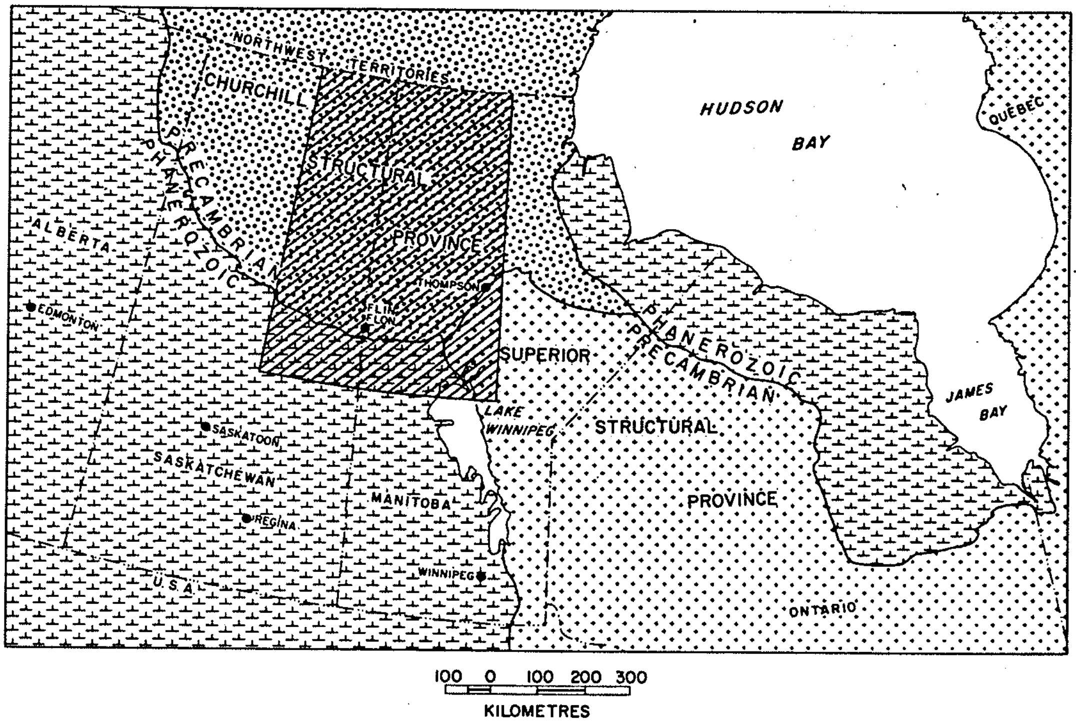
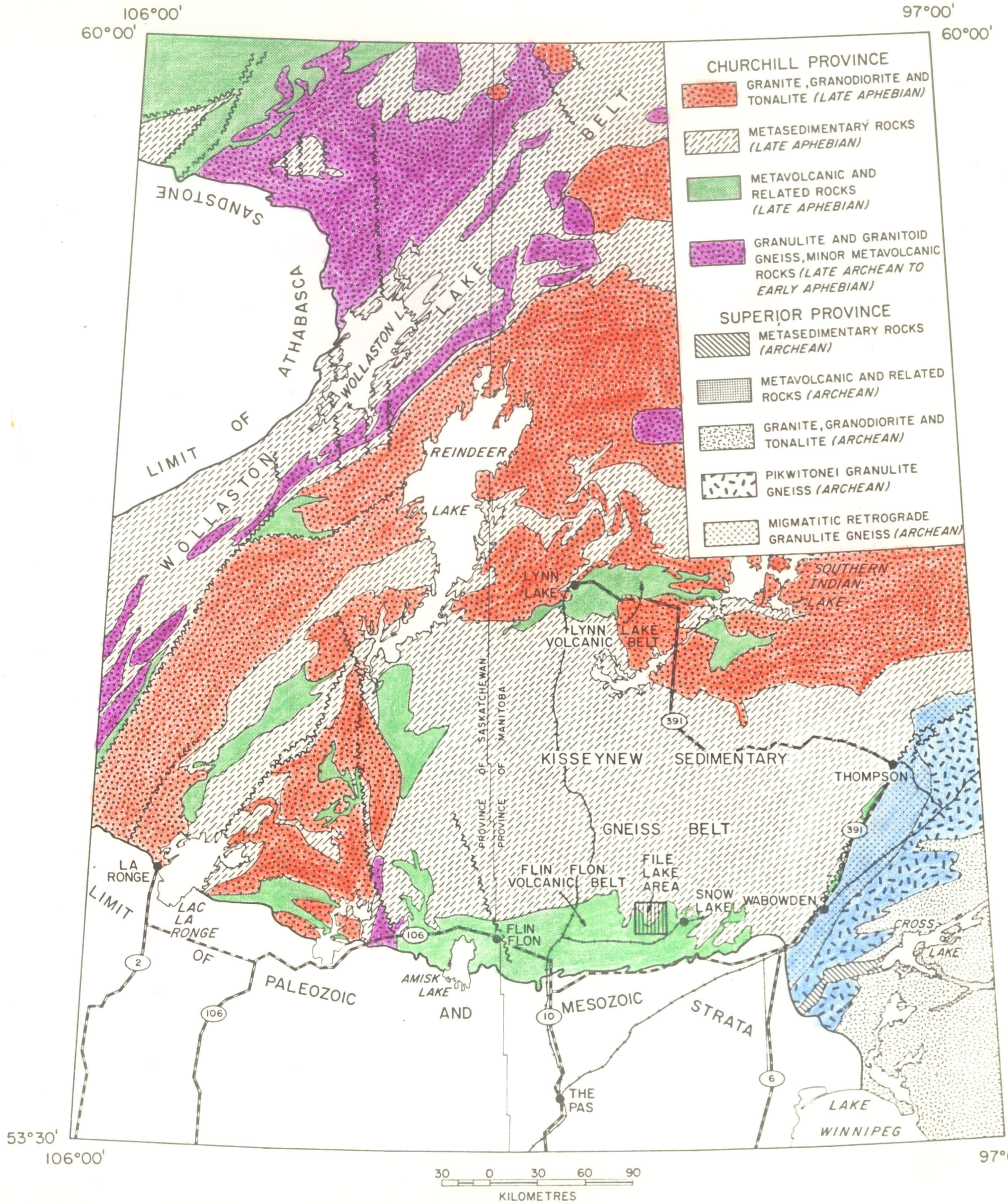


FIGURE 1: Main geological provinces in central Canada (above). Location of the File Lake area and generalized geology of the Churchill Province in western Manitoba and eastern Saskatchewan (opposite page).



106°00'
60°00'
97°00'
60°00'
CHURCHILL PROVINCE
GRANITE, GRANODIORITE AND TONALITE (LATE APHEBIAN)
METASEDIMENTARY ROCKS (LATE APHEBIAN)
METAVOLCANIC AND RELATED ROCKS (LATE APHEBIAN)
GRANULITE AND GRANITOID GNEISS, MINOR METAVOLCANIC ROCKS (LATE ARCHEAN TO EARLY APHEBIAN)
SUPERIOR PROVINCE
METASEDIMENTARY ROCKS (ARCHEAN)
METAVOLCANIC AND RELATED ROCKS (ARCHEAN)
GRANITE, GRANODIORITE AND TONALITE (ARCHEAN)
PIKWITONEI GRANULITE GNEISS (ARCHEAN)
MIGMATITIC RETROGRADE GRANULITE GNEISS (ARCHEAN)
LIMIT OF ATHABASCA SANDSTONE
WOLLASTON LAKE BELT
WOLLASTON L.
REINDEER LAKE
LYNN LAKE
LYNN LAKE VOLCANIC BELT
SOUTHERN INDIAN LAKE
KISSEYNEW SEDIMENTARY GNEISS BELT
THOMPSON
PROVINCE OF SASKATCHEWAN
PROVINCE OF MANITOBA
LA RONGE
LAC LA RONGE
FLIN FLON VOLCANIC BELT
FILE LAKE AREA
SNOW LAKE
WABOWDEN
CROSS LAKE
FLIN FLON
AMISK LAKE
LIMIT OF PALEOZOIC AND MESOZOIC STRATA
THE PAS
LAKE WINNIPEG
391
106
2
10
6
53°30'
106°00'
53°30'
97°00'
30 0 30 60 90
KILOMETRES

sediments which underlie a thick succession of volcanic strata, known as the Wasekwan Group,and with Sickle Group sediments which overlie the Wasekwan Group. To the east, the Kisseynew belt is in fault contact with Archean rocks of the Superior Province and to the west its relationship to a large area of granitic rocks is unknown.

The regional distribution of the main lithologic units in the Flin Flon belt and the southern Kisseynew belt of Manitoba is shown on Figure 3 (in pocket).

2.2 General Geology of the Flin Flon and Kisseynew Belts

2.2.1 Flin Flon volcanic-sedimentary belt

The Flin Flon volcanic-sedimentary belt comprises four main lithologic subdivisions (Fig. 3, in pocket):

Post-Missi intrusive rocks

Missi Group metasedimentary and metavolcanic rocks

Amisk Group metasedimentary rocks

Amisk Group metavolcanic and meta-intrusive rocks.

The Amisk Group metavolcanic rocks are up to 5 km thick (Byers and Dahlstrom, 1954) and comprise subalkaline basalt to rhyolite flows and fragmental rocks. Mafic flow rocks, which form most of the Amisk Group, are generally pillowed and were extruded in a subaqueous environment. However, toward the top of the Amisk succession subaerial extrusion occurred locally. In Saskatchewan, on Amisk Lake, an upward transition from subaqueous to subaerial volcanism has been identified by Ayres (1978), and at the east end of Flin Flon belt, at Snow Lake, Manitoba, a sequence of massive, unpillowed flows (E. Froese and G. Gale, personal communication, 1978) and water transported mafic volcaniclastic sediments

(Froese and Moore, 1978) suggest that late Amisk volcanism was locally subaerial. Felsic volcanic rocks comprise less than 20 percent of the Amisk Group. They are most abundant in the upper part, but do not necessarily occur at the top, of the Amisk succession. They comprise small isolated edifices and occur abundantly in two localities: south of Snow Lake, and northeast of Athapapuskow Lake (Fig. 3, in pocket). There is an upward increase of pyroclastic rocks, heterolithic laharic breccias and volcaniclastic sediments in the Amisk Group. This is probably due to an increase in explosive volcanic activity and in mass wasting of resultant loose debris as major Amisk volcanoes were built up into shallow water and, locally, subaerial environments.

Amisk Group intrusions are small, epizonal, and probably subvolcanic. They consist of plugs, stocks, sills and dykes ranging in composition from diorite to granodiorite. They include some large pre-Missi plutons of quartz-megacryst-bearing granodiorite and tonalite. These latter intrusions are not significantly different from a post-Missi suite of felsic plutons and may simply be their precursors.

The Amisk volcanic strata are overlain by and, in some localities, interlayered with a 1 to 2 km thick sequence of turbidite greywacke, siltstone, and mudstone that also belong to the Amisk Group. In the File Lake area, and probably elsewhere, they are submarine fan deposits composed predominantly of felsic volcanic detritus that was transported northward from Amisk volcanoes toward the Kisseynew sedimentary basin.

The Missi Group disconformably overlies the Amisk Group and is a 1.5 to 3 km thick sequence of metasubgreywacke and meta-arkose, typically with a basal conglomerate. It is composed of volcanic debris, and contains primary sedimentary structures and an underlying regolith which suggest that it is a continental, probably fluvial-alluvial deposit (Byers, 1953; Byers and Dahlstrom, 1954; Mukherjee, 1971; Stauffer, 1974; Shanks and Bailes, 1977; Price, 1978). East of Wekusko Lake, metavolcanic rocks, which include massive, mainly unpillowed, mafic flows and thin felsic ash flows with collapsed pumice fragments, overlie Missi metasedimentary rocks (Shanks and Bailes, 1977).

Post-Missi intrusive rocks include large tabular differentiated tholeiitic gabbro sheets and large calc-alkaline granitic plutons. The gabbro sheets and granitic plutons are largely restricted to the Flin Flon belt and rarely occur in the adjacent Kisseynew belt.

2.2.2 Kisseynew sedimentary gneiss belt

At present no unified system of stratigraphic nomenclature exists for the Kisseynew sedimentary gneiss belt. In general, however, only two main supracrustal successions have been recognized: a lower sequence of migmatitic metagreywacke, metasiltstone and metamudstone; and an overlying sequence of migmatitic metasubgreywacke and meta-arkose. On the south flank of the Kisseynew belt (Fig. 3, in pocket), these strata have been referred to, respectively, as the Nokomis and Sherridon Groups (Robertson, 1953; Pollock, 1964, 1965).

The Nokomis Group comprises repetitively layered garnet- and biotite-bearing intermediate paragneisses that are characterized by narrow sills and irregular bodies of white granodiorite and tonalite mobilizate. To the north the Nokomis Group paragneisses can be traced directly into more highly recrystallized and strongly melted equivalents that have been named the Burntwood River Supergroup by McRitchie (1974). To the south, in the File Lake and Snow Lake areas, they can be traced directly into a 1 km thick weakly recrystallized Amisk Group turbidite greywacke, siltstone and mudstone sequence belonging to the Flin Flon belt (Bailes, 1978; Froese and Moore, 1978). Mafic and felsic orthogneisses occur locally in the Nokomis Group of the Kisseynew belt and can be traced directly into Amisk Group volcanic rocks of the Flin Flon belt.

The Sherridon Group overlies the Nokomis Group and comprises thick-bedded homogeneous quartzo-feldspathic biotite-bearing paragneisses derived from metasubgreywacke and meta-arkose. These strata are probably more strongly recrystallized equivalents of the Missi Group sedimentary rocks of the Flin Flon belt (Bailes, 1971, 1978; Froese and Moore, 1978). Narrow layers of para-amphibolite occur locally at the base of and within the Sherridon Group. They likely represent periods of limited detrital sedimentation and accumulation of higher concentrations of carbonate-bearing sediments. North of Snow Lake, the Sherridon Group also includes several large domal bodies of felsic granoblastic gneisses of uncertain derivation. These strata were considered by Bailes (1971) to be a diapirically remobilized basement complex but are now interpreted to be remobilized orthogneisses belonging to the supracrustal succession (Bailes, 1975, 1978; Josse, 1974; Bell et al, 1975).

Bailes (1971) suggested that the Kisseynew belt was a sedimentary basin which was infilled by volcanic detritus shed from volcanoes and uplifted portions of the adjacent Flin Flon volcanic belt. Subsequent investigations, including this study, have generally supported this interpretation of the Kisseynew belt.

3. GENERAL GEOLOGY OF THE STUDY AREA

In the File Lake area, the boundary between the Flin Flon and Kisseynew belts traditionally has been placed along the west, south and east shores of File Lake. Harrison (1949, 1951b) considered the contact to be a fault and part of his Kisseynew lineament. According to this study, the contact is not a fault and strata can be traced across the boundary. There is a rapid increase in grade of metamorphism from the Flin Flon belt into the Kisseynew belt, but the increase is gradational and metamorphic isograds cut across the contact between the two belts and are not displaced. The same nomenclature is used for strata of both the Flin Flon and Kisseynew belts (Table 1, Fig. 2, in pocket).

3.1 Amisk Group Metavolcanic and Related Intrusive Rocks

Metavolcanic and related intrusive rocks of the Amisk Group are the oldest rocks in the study area. They outcrop in the south half of the study area (Fig. 2, in pocket), in the Flin Flon belt. The metavolcanic rocks are 2 km thick and consist of several formations (Units 1 to 8, Table 1) that range in composition from basalt to rhyolite, and comprise both flows and fragmental rocks. The related intrusive rocks (Units 9 and 10, Table 1) are small plugs, stocks, sills and dykes of diorite and quartz- and plagioclase-phyric tonalite. The intrusions are fine-grained, epizonal, and possibly feeders for Amisk volcanism. None of them intrude Amisk Group metasedimentary or

TABLE 1 : Table of Formations, File Lake area

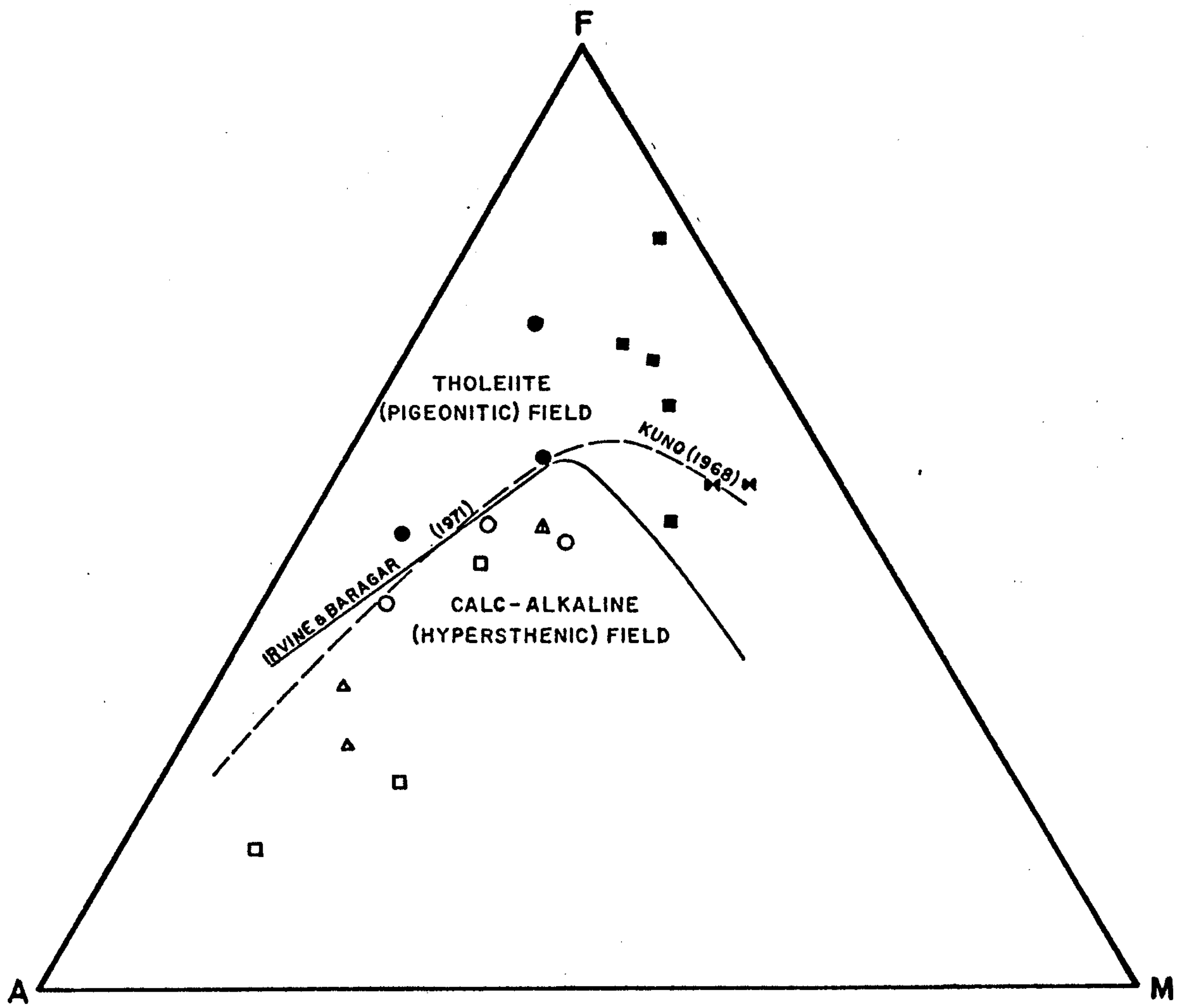
Age	Division	Unit	Rock units	Unit	Rock units
PLEISTOCENE AND RECENT			Surficial Deposits of Gravel, Sand and Clay		
			UNCONFORMITY		
PRECAMBRIAN – PROTEROZOIC – PALEO-HELIKIAN?	INTRUSIVE AND METAMORPHIC ROCKS – Post-kinematic	28	Felsic pegmatite dykes		
			INTRUSIVE CONTACT		
PRECAMBRIAN – PROTEROZOIC – APHEBIAN	INTRUSIVE AND METAMORPHIC ROCKS – Syn- to late kinematic	24	Barron Lake Pluton: Granite and leucogranite		Metamorphic and anatectic rocks
		23	Norris Lake Pluton: Plagioclase-rich leucotonalite	27	Loonhead Lake Intrusions: Gneissic, pegmatitic granodiorite and monzogranite
		22	Reed Lake Pluton: Plagioclase-rich leucotonalite and quartz leucodiorite		Nelson Bay Gneiss Dome (units 25-26):
		21	Ham Lake Pluton: Granodiorite, leucotonalite and tonalite, in part gneissic	26	Granoblastic oligoclase-quartz-microcline gneiss
		20	Woosey Lake Pluton: Gneissic quartz-rich leucotonalite and granodiorite	25	Granoblastic oligoclase-quartz gneiss
			INTRUSIVE CONTACT		
	INTRUSIVE AND METAMORPHIC ROCKS – Pre- to early kinematic	18 & 19	JOSLAND LAKE GABBRO: Gabbro and meta-gabbro		
			INTRUSIVE CONTACT		
	MISSI GROUP	16 & 17	Meta-subgreywacke and meta-arkose		
			DISCONFORMITY		
	Metasedimentary Rocks		FILE LAKE FORMATION (units 13-15):		
		15	Corley Lake Member: Mudstone		
		14	Mafic and felsic volcanic rocks		
		13	Lithic greywacke, feldspathic greywacke, siltstone and mudstone		
		12	YAKYMIW FORMATION: Laminated mudstone, siltstone and sandstone interbedded with pebbly volcaniclastic sandstone		
		11	PARISIAN FORMATION: Polymictic volcaniclastic conglomerate		
			? DISCONFORMITY ?		
	AMISK GROUP – Intrusive Rocks	10	Quartz feldspar tonalite porphyry		
			——— Intrusive Contact		
		9	Diorite		
			INTRUSIVE CONTACT		

AMISK GROUP – Metavolcanic Rocks					
Storozuk-Morton Lakes area		Butler-Fussey Lakes area		Woosey Lake area	
4	Dacite flows	6	Dacite fragmental	8	Felsic volcanic rocks
3	STOROZUK FORMATION: Basalt and andesite flows and breccia; minor dacite and rhyolite flows and tuff	5	Basalt and andesite flows	7	Mafic fragmental rocks
2	DICKSTONE FORMATION: Rhyolite and dacite flows and pyroclastic rocks				
1	PREASTON FORMATION: Basalt and andesite flows				

younger rocks. The main features of the Amisk metavolcanic rocks are summarized in Table A-1 and those of the Amisk intrusive rocks are summarized in Tables A-2a and A-2b.

Pillowed and massive tholeiitic mafic flows (Units 1, 3, 5 and 7) comprise 80 percent of the exposed metavolcanic succession (Fig. 2, in pocket). Tholeiitic to calc-alkaline intermediate to felsic flows and fragmental rocks (Units 2, 3b, 3d, 4, 6 and 8),which occur in small edifices and isolated narrow layers, comprise the remainder. Chemical analyses of the volcanic rocks show considerable scatter on chemical variation diagrams, for example on the FMA plot (Fig. 4), possibly because samples from several volcanic formations were analyzed and also because many of the samples are strongly altered (Bailes, 1978). The mafic metavolcanic rocks are similar to low K tholeiites from modern island arcs (Bailes, 1978).

The stratigraphy of the metavolcanic rocks has been delineated locally but for much of the study area no reliable correlations of the volcanic formations could be made due to lack of marker units, lensy stratigraphy and complex deformation. For this reason, the volcanic formations in the study area have been arbitrarily subdivided into three geographic subgroups (Fig. 2, in pocket; Table 1): Storozuk-Morton Lakes area (west of Morton Lake); Butler and Fussey Lakes area (between Morton and Woosey Lakes); and Woosey Lake area (east of fault on northwest arm of Woosey Lake). Typical stratigraphic sections of the metavolcanic and overlying metasedimentary rocks from these areas are shown schematically in Figure 5. In the Storozuk-Morton Lakes area, the volcanic stratigraphy is most reliably determined and three well defined formations, the Preaston, Dickstone and Storozuk Formations (Table 1, Fig. 5a), have



● Mafic to intermediate metavolcanic rocks, Preaston Formation, units 1 and 1a

○ Felsic metavolcanic rocks, Dickstone Formation, unit 2

■ Mafic metavolcanic rocks, Storozuk Formation, unit 3

□ Felsic to intermediate metavolcanic rocks, units 4 & 4a

⧓ Mafic metavolcanic rocks, unit 5

⚠ Intermediate metavolcanic fragmental rock, unit 7

△ Felsic metavolcanic rocks, unit 8

FIGURE 4. FMA chemical variation diagram, Amisk metavolcanic rocks, File Lake area. Data from Bailes (1978).

MISSI GROUP

16(3) Thick-bedded meta-arkose

26a Felsic orthogneiss, possibly metavolcanic

16(2) Thick-bedded metasubgreywacke

16(1) Laminated metasubgreywacke

AMISK GROUP

Metasedimentary Rocks

File Lake Formation (13-15):

15 *Corley Lake member:* Mudstone

14 Mafic volcanic rocks

13 Greywacke, siltstone and mudstone

12 *Yakymiw Formation:* Laminated mudstone, siltstone and fine sandstone interbedded with pebbly volcanogenic sandstone

11 *Parisian Formation:* Polymictic volcanogenic paraconglomerate

Meta-Intrusive Rocks

10 Quartz- and plagioclase-phyric tonalite

9 Diorite

Metavolcanic Rocks

8 Felsic volcanic rocks

7 Mafic fragmental volcanic rocks

6 Dacite fragmental

5 Basalt and andesite flows

4 Dacite flows

3 *Storozuk Formation:* Basalt and andesite flows and breccia; minor dacite and rhyolite flows and tuff

2 *Dickstone Formation:* Rhyolite and dacite flows, breccia and tuff

1 *Preaston Formation:* Basalt and andesite flows

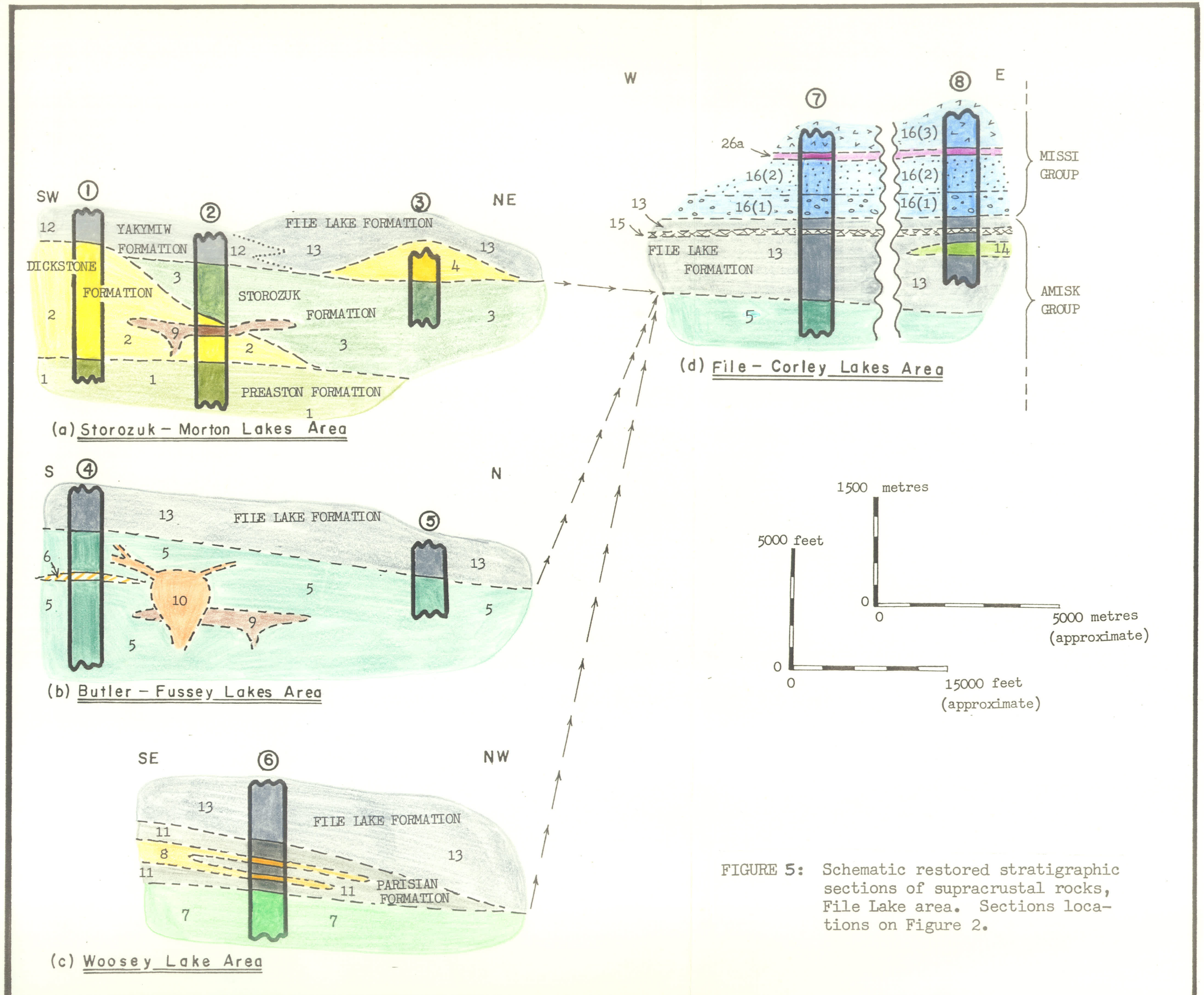


FIGURE 5: Schematic restored stratigraphic sections of supracrustal rocks, File Lake area. Sections locations on Figure 2.

been named. Elsewhere the formations are less reliably defined. Some of the formations are probably stratigraphically equivalent to those in adjacent subareas. For example, the basalt and andesite flows of Unit 5 of the Fussey-Butler Lakes area are probably equivalent to basalt and andesite flows of the Preaston and Storozuk Formations, Units 1 and 3, of the Storozuk-Morton Lakes area. A full discussion of the volcanic stratigraphy and a complete description of the volcanic formations is presented by Bailes (1978).

Primary structures and textures in the metavolcanic rocks are summarized in Table 2. Photographs of several of the structures are shown in Plates 1 to 4. According to criteria from Ayres (1969) these primary structures and textures suggest that the metavolcanic rocks were extruded in a shallow water depositional environment, probably less than 500 metres deep, but possibly including some slightly deeper water environments. The shallow water extrusion of the metavolcanic rocks infers subsidence during their deposition, since the volcanic succession is over 2,000 metres thick. This also indicates that local subaerial volcanism may have occurred in or adjacent to the study area, because any high profile stratovolcanoes that were constructed on this shallow water volcanic platform would likely have been built up above water level.

The mafic flow sequences in the File Lake area are widespread, thick, and probably were extruded from a major subaqueous tholeiitic shield volcano. The small, isolated tholeiitic to calc-alkaline felsic volcanic units probably represent small domes and stratovolcanoes that were constructed at various times during build up of the mafic shield volcano. The absence of thick accummulations of pyroclastic units and laharic breccias indicates that no major subaerial stratovolcanoes were constructed in or directly adjacent to the File Lake area. An exception is the Woosey Lake area, which contains heterolithologic

TABLE 2: Primary structures and textures of Amisk Group metavolcanic rocks, File Lake area

Primary structure or texture	Preaston Formation	Dickstone Formation	Storozuk Formation	Unit 4	Unit 5	Unit 6	Unit 7	Unit 8
Pillows	XX	R	XXX	R	XXX	–	X	–
Pillow fragment breccia and hyaloclastite	–	–	XX	–	XXX	–	–	–
Flow breccia	–	–	–	XX	X	–	–	–
Amygdules	XX	XX	XX	R	XX	–	–	–
Mafic pyroclastic breccia	X	–	XX	–	–	–	XX	–
Felsic pyroclastic breccia	–	XXX	–	–	–	XX	–	XXX

XXX – abundant
XX – common
X – present, but not widespread
R – rare
– – not observed

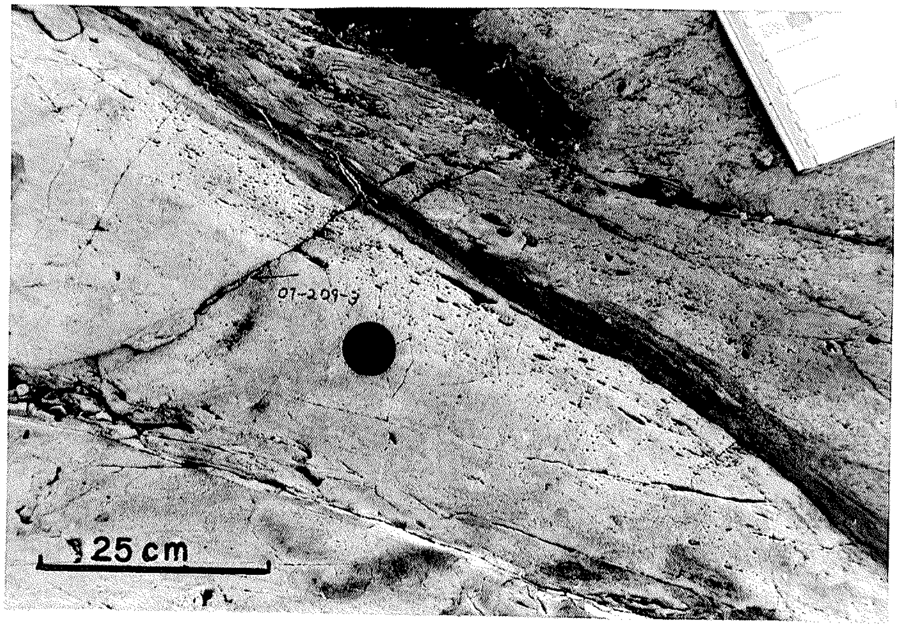


PLATE 1: Felsic flow with vesicular top (Unit 2a), Dickstone Formation, 2.8 km southwest of Yakymiw Lake.

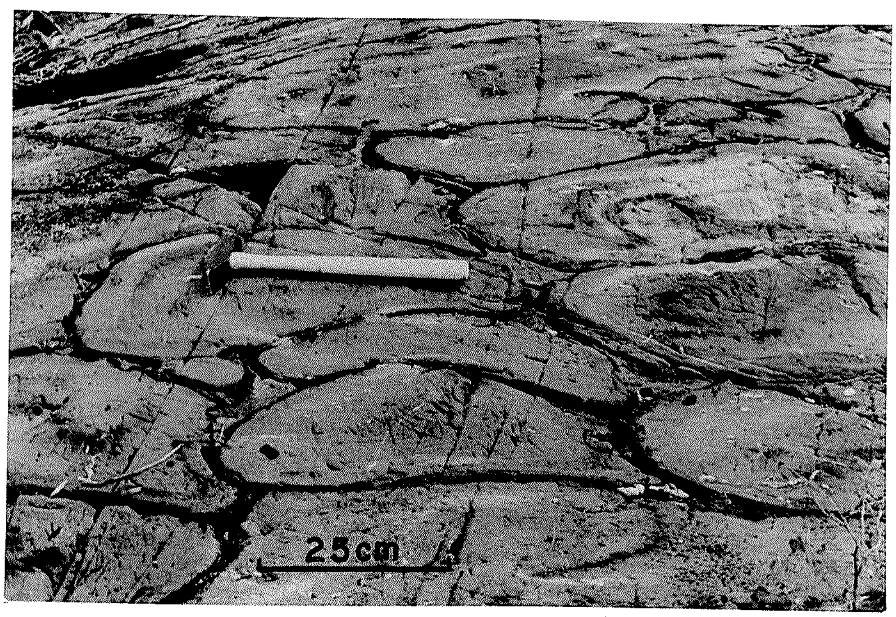


PLATE 2. Bun-shaped pillows in basalt flow (Unit 3), Storozuk Formation, southeast shore of Storozuk Lake.

PLATE 3: Isolated pillow breccia on top of massive basalt flow (Unit 3), Storozuk Formation, 600 m southeast of Storozuk Lake

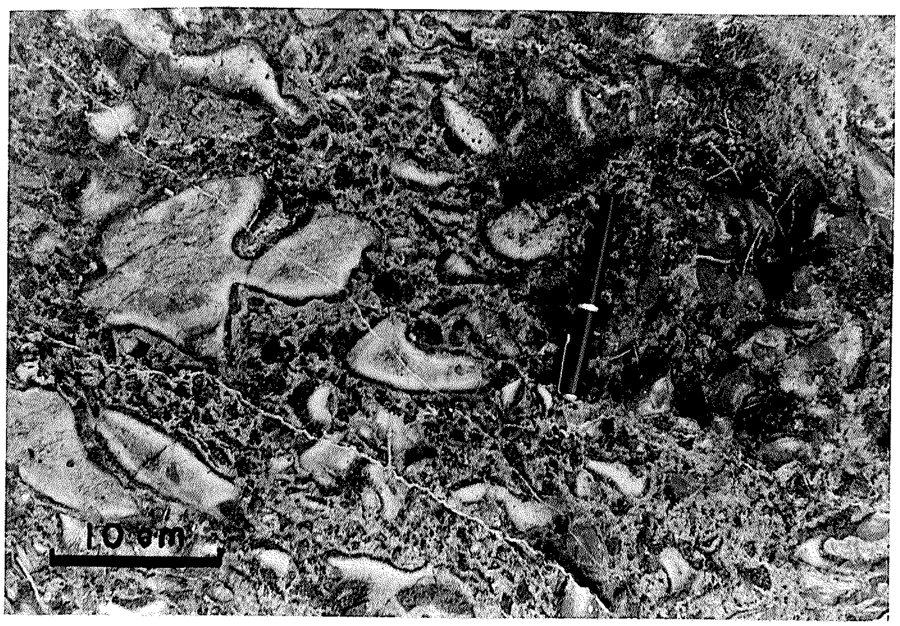


PLATE 4: Closeup of isolated pillow breccia in Plate 3. Note miniature ameboid pillows and spalled dark angular fragments in matrix from glassy rim of pillows.

volcanic breccias and overlying debris flow deposits which may have been derived from a major stratovolcano east of the study area.

3.2 Amisk Group Metasedimentary Rocks

The Amisk Group metasedimentary rocks are a 1 km thick re-sedimented greywacke, siltstone, mudstone and pebbly greywacke sequence deposited by subaqueous gravity flows, mainly turbidity currents. They conformably overlie Amisk Group volcanic strata in the study area, but are composed of detritus which was derived from contemporaneous up-slope felsic Amisk stratovolcanoes.

The Amisk Group sedimentary rocks comprise three formations (Fig. 2, in pocket; Table 1): the Parisian Formation (Unit 11); the Yakymiw Formation (Unit 12); and the File Lake Formation (Units 13 to 15). The File Lake Formation is the most widespread and prominent. The main features of Amisk metasedimentary rocks are summarized in Table A-3.

The Parisian Formation is a lensoid, 0 to 600 m thick unit which occurs only on Woosey Lake (Fig. 2, in pocket). It is a polymictic pebble paraconglomerate composed of volcanic detritus that was deposited by debris flows. It is underlain by mafic fragmental volcanic rocks, containing a heterogeneous clast population, and is overlain by turbidite greywacke, siltstone and mudstone of the File Lake Formation (Fig. 5c).

The Yakymiw Formation outcrops west of Morton Lake and is composed of hemipelagic deposits of thin-bedded mudstone, siltstone and fine sandstone that are intercalated with 1 to 3 m thick beds of matrix-supported pebbly volcanic greywacke; the latter are probably products of debris flows and possibly, subaqueous pyroclastic flows. The maximum measured thickness of the Yakymiw Formation is 330 m, but its total thickness is unknown as it has no exposed top. It directly overlies Amisk Group metavolcanic rocks and may be a lateral facies equivalent of the File Lake Formation (Fig. 5a).

The File Lake Formation is 1 km thick and is composed of interbedded greywacke, siltstone and mudstone (Unit 13), minor thin volcanic layers (Units 14 and 14a), and the Corley Lake member (Unit 15), a 30 m thick unit of potash-poor, aluminous mudstone. Exceptionally large, up to 1 cm, garnet porphyroblasts developed in the Corley Lake member during almandine-amphibolite facies regional metamorphism. The normal greywacke, siltstone and mudstone of the File Lake Formation were deposited mainly by turbidity currents. These rocks have been traced northwards from weakly recrystallized well-preserved greywacke, siltstone, and mudstone, on southern Morton Lake, across a steep metamorphic gradient that coincides with the boundary between the Flin Flon and Kisseynew belts, into strongly recrystallized migmatitic paragneisses of the Nokomis Group north of Corley Lake.

3.3 Missi Group Metasedimentary Rocks

The Missi Group is a 1.3 km thick sequence of quartzo-feldspathic magnetite-bearing paragneisses derived from subgreywacke and arkose. It disconformably overlies Amisk Group rocks and outcrops only north of File Lake, entirely within the Kisseynew belt (Fig. 5d). The lower 300 m of the Missi Group is laminated and locally, cross laminated (Plate 5) metasubgreywacke (Unit 16 (1)); the laminations are defined by concentrations of biotite and magnetite. The next 600 m is massive thick-bedded, generally unlaminated metasubgreywacke (Unit 16 (2)).

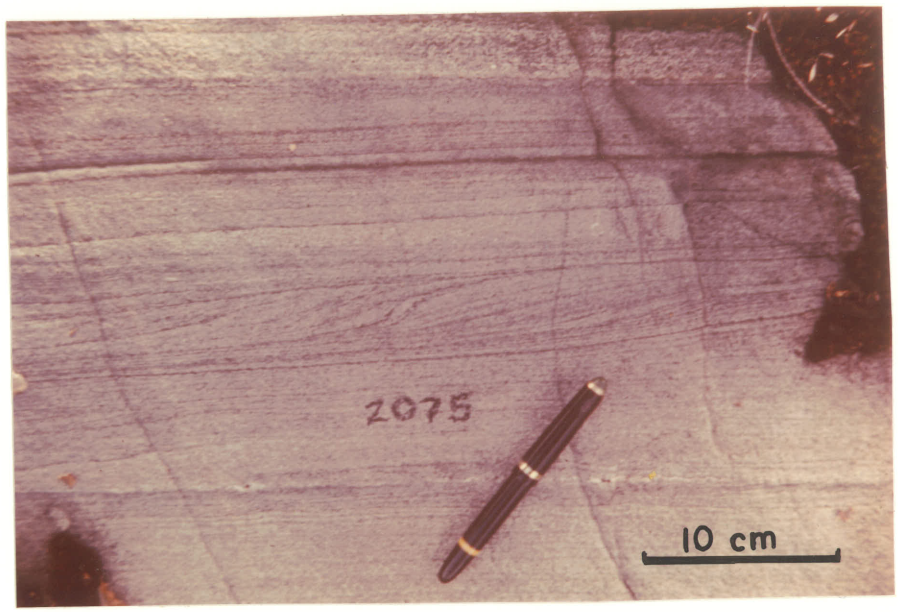


PLATE 5: Ripple cross-stratification in metasubgreywacke (Unit 16 (1)), Missi Group, 300 m south of Corley Lake.

This unit is overlain by massive, thick-bedded, unlaminated meta-arkose (Unit 16 (3)). The main features of Missi Group rocks are summarized in Table A-4.

There are no reliable indicators of depositional environment in the Missi Group of the File Lake area. Elsewhere, Byers (1953), Byers and Dahlstrom (1954), Mukherjee (1971), Stauffer (1974) and Shanks and Bailes (1977) have interpreted the Missi Group to be a fluvial-alluvial deposit.

3.4 Post-Missi Intrusive and Metamorphic Rocks

Post-Missi igneous rocks intruded volcanic-sedimentary strata belonging to both the Flin Flon and Kisseynew belts, but are more abundant in the Flin Flon belt. Three main age groups of intrusions have been recognized (Fig. 2, in pocket; Table 1):

1) early kinematic, large, differentiated, concordant bodies of tholeiitic gabbro (Unit 18) and derived amphibolite (Unit 19);
2) syn- to late-kinematic, large, calc-alkaline felsic plutons (Units 20 to 24); and
3) post-kinematic, small dykes of felsic pegmatite (Unit 28).

Metamorphic rocks (Fig. 2, in pocket; Table 1), which formed during a syn- to late-kinematic episode of high grade regional metamorphism, include a large domal complex of coarsely recrystallized felsic orthogneisses (Units 25 and 26) and a suite of anatectic granodiorite and tonalite (Unit 27). The latter was formed by partial melting of Amisk Group mudstones. The origin of the felsic ortho-

TABLE 3 : Summary of Major Metamorphic, Deformational and Intrusive Events, File Lake Area (from Bailes, 1978)

DEFORMATION	METAMORPHISM	INTRUSIVE ROCKS
D_4 : Late fractures and north-trending shear zones	M_3 : Local retrograde low grade (greenschist facies) metamorphism, largely restricted to D_4 structures	Intrusion of small dykes of felsic pegmatite (unit 28)
D_3 : East-trending upright flexural folds (F_3) of S_1 and S_0 surfaces. F_3 folds locally have an axial planar biotite schistosity (S_3)		
	M_2 : Strong regional metamorphic event which increases in intensity from south to north from greenschist facies to upper almandine-amphibolite facies	Intrusion of anatectic granodiorite and monzogranite (unit 27) Emplacement of Nelson Bay Gneiss Dome (units 25 and 26)
D_2 : Major north-northeast-trending open folds (F_2) of S_1 and S_0 surfaces. Some flattening of F_1 folds was likely during D_2. In the Snow Lake area, F_2 folds have an axial planar biotite foliation (S_2); F_2 folds in the File Lake area do not have an S_2 foliation		Intrusion of large felsic plutons (units 20 to 24: Barron Lake pluton (may be post-M_2) Norris Lake pluton (prominent thermal contact aureole) Reed Lake pluton (prominent thermal contact aureole) Ham Lake pluton Woosey Lake pluton
		Intrusion of post-F_1 Josland Lake Gabbro sheets (unit 18) and albite-epidote hornsfels facies contact metamorphism of adjacent strata
D_1 : Large isoclinal folds (F_1) of primary layering (S_0). F_1 folds have an axial planar schistosity (S_1). Deformed fragments are flattened in S_1 and elongated parallel to F_1 fold axes. F_1 folds are interpreted to have been recumbent structures	M_1 : Muscovite, chlorite and biotite define S_1. They were largely recrystallized and annealled during M_2	
		Intrusion of pre-F_1 Josland Lake Gabbro sills (unit 18) and albite-epidote hornsfels facies contact metamorphism of adjacent strata

gneisses of Units 25 and 26 is uncertain, but they may belong to the supracrustal succession, as shown in Figure 5d, and may possibly be a strongly recrystallized and partially remobilized Missi Group felsic metavolcanic unit. This is discussed in more detail by Bailes (1978).

3.5 Deformation and Metamorphism

The Amisk and Missi Groups are strongly deformed and four main events have been recognized (Table 3). The metamorphic grade increases from middle greenschist facies in the south to upper almandine-amphibolite facies in the north. Three regional metamorphic episodes have been identified and contact metamorphic aureoles surround many of the larger syn-kinematic felsic plutons (Table 3).

Deformational and regional metamorphic episodes, similar to those recognized in the File Lake area, have been observed throughout the Flin Flon and Kisseynew belts (Moore and Froese, 1972; Bailes, 1975; Bailes and McRitchie, 1978).

3.6 Geochronology

Five Rb/Sr whole rock isochron ages have been obtained from units in the File Lake area (Josse, 1974). Four of these date the time of regional metamorphism and range from 1715 $\pm$ 83 m.y. to 1760 $\pm$ 43 m.y. The other (1860 $\pm$ 112 m.y.) dates the time of emplacement of the syn-kinematic Ham Lake pluton. These dates support other geochronological studies by Mukherjee (1971), Sangster (1972, 1978), Anderson (1974) and McQuarrie (1977). Initial $^{87}Sr/^{86}Sr$ ratios on the four metamorphically updated rocks are low and indicate that they had a short crustal history prior to metamorphism.

4. STRATIGRAPHY, SEDIMENTOLOGY AND DEPOSITIONAL ENVIRONMENT OF AMISK GROUP METASEDIMENTARY ROCKS, FILE LAKE AREA

4.1 General Statement

The File Lake area is the most suitable locality along the boundary between the Flin Flon and Kisseynew belts for a stratigraphic and sedimentologic study of Amisk Group metasedimentary rocks. The area has the most completely documented structural and stratigraphic framework in either the Flin Flon or Kisseynew belts and it has some of the least recrystallized and best preserved exposures of Amisk Group metasedimentary rocks.

The scope of this stratigraphic-sedimentologic analysis is limited by three factors:

1) metamorphic welding of bed contacts such that no sole marks and,hence, almost no paleocurrent data are available;
2) metamorphic recrystallization which, except in the Morton Lake area, has largely destroyed primary mineralogy, textures, and structures; and
3) complex folding and local faulting, which combined with lack of distinctive marker units, hampers correlation between the various formations.

The three formations of the Amisk Group metasedimentary sequence vary in thickness and comprise a succession with lateral and vertical facies variations (Figs. 5a, 5b and 5c). The Parisian and Yakymiw Formations are restricted to the Flin Flon belt and local in their occurrence, whereas the File Lake Formation is a widespread thick unit that extends from the Flin Flon into the Kisseynew belt.

During this study almost all exposures of Amisk Group metasedimentary rocks in the File Lake map area were examined for stratigraphic and sedimentological data. However, emphasis has been placed on the File Lake Formation because it is the only formation which can be traced directly into the Kisseynew belt.

4.2 Parisian Formation

The Parisian Formation (Unit 11) is a 0 to 600 m thick, wedge-shaped deposit of polymictic paraconglomerate which outcrops on the west side of Woosey Lake and is not present elsewhere in the study area. It overlies a heterolithic fragmental mafic metavolcanic formation (Unit 7) of the Amisk Group, and contains two 100 to 200 m thick lensoid felsic fragmental metavolcanic layers (Unit 8). It is overlain conformably by greywacke, siltstone and mudstone of the File Lake Formation (Unit 13b). Metamorphic grade is lower to middle almandine-amphibolite facies and primary textures and structures are generally poorly preserved. Garnet porphyroblasts and a biotite foliation are common.

The paraconglomerate is a chaotic unsorted deposit that consists of 20 to 80 percent pebble-sized clasts in a completely recrystallized matrix. The matrix is a fine-grained granoblastic mixture of quartz and plagioclase, with up to 20 percent combined red-brown biotite, green hornblende and mauve garnet. It was probably a siltstone or very fine-grained greywacke. Bedding in the paraconglomerate is rare and has diffuse contacts. Contacts are defined by variations in clast size populations, in clast type populations, in clast to matrix ratios and in rounding of clasts.

Most clasts in the paraconglomerates are 1 to 3 cm in size, but some are up to 20 cm. They vary from subangular to rounded (Plate 6). The following clast types, in order of decreasing abundance, have been identified in cut and etched rock slabs and in thin sections from an outcrop on the south shore of the large island 1 km north-northeast of Biebrick Island:

- fine-grained felsic, probably volcanic fragments;
- quartz and plagioclase-phyric felsic volcanic fragments;
- plagioclase cleavage fragments;
- single crystal quartz grains;
- medium-grained granophyric tonalite;
- vein quartz;
- chert fragments rich in disseminated graphite and pyrite; and
- mafic hornblende-rich fragments of uncertain origin.

Felsic fragments greatly predominate and indicate a felsic volcanic provenance. The individual plagioclase and quartz grains are likely to have been derived from phenocrysts in the felsic volcanic sequence. The granophyric tonalite fragments could have been derived from subvolcanic intrusions or from extrusive spines or domes.

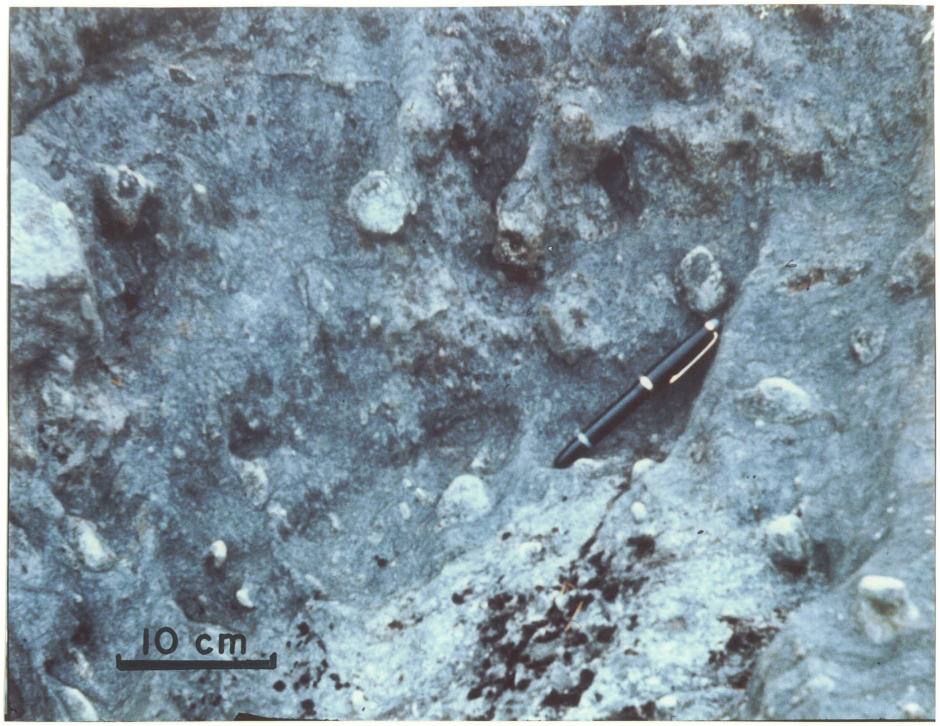


PLATE 6: Polymictic paraconglomerate with rounded pebble- to cobble-sized clasts supported in a sandstone matrix, Parisian Formation, small island 1.4 km northeast of Biebrick Island on Woosey Lake.

The paraconglomerates were most likely deposited by debris flows. The debris flows were probably derived from, and intimately associated with volcanism because they are interbedded with felsic volcanic rocks (Unit 8) and are composed almost entirely of volcanic debris. Several features suggest a subaerial source terrain:

1) the wide variety of clast lithologies indicates a level of mixing that requires subaerial transport;
2) the thickness of the paraconglomerate sequence (600 m) is consistent with subaerial build up, because such an extensive coarse epiclastic unit is not likely to have been derived from a subaqueous source;
3) the partial rounding of pebbles suggests subaerial transport or beach abrasion, although this rounding could also occur during shallow wave agitation, in the vent, or during avalanching down submarine slopes; and
4) granophyric tonalite clasts indicate that there may have been subaerial unroofing of subvolcanic intrusions.

The paraconglomerate consists of a pebble- and cobble-sized coarse fraction and a recrystallized fine fraction; it contains no intermediate medium to coarse sand fraction. Similar deposits in modern submarine fan systems have been interpreted to form by rapid deposition of sand and gravel on top of unstable water-logged muds (Crowell, 1957). The loading of the muds creates an excess pore pressure because water cannot escape from the impermeable muds. The consequent reduction in shear strength leads to slump failure and debris flows. The Parisian Formation paraconglomerates could have been formed by this mechanism; for example by covering a subaqueous mud deposit with loose gravel and pyroclastic debris transported from a subaerial environment by a flash flood. However, this origin requires a pre-existing subaqueous mud deposit and this is inconsistent with the lack of interbeds of mudstone, siltstone and fine sandstone in the Parisian Fromation. However, if the mud was diagenetic, formed in the volcanic environment from volcanic glass of sand-size, then a flash flood or slumping of this detritus could lead directly to a debris flow deposit of the type observed in the Parisian Formation.

Debris flows have a cohesive matrix and a tendency for rapid deposition once the angle of the slope they are traversing is reduced. For this reason, the Parisian Formation is probably close to its source and close to the margin of the Amisk sedimentary basin.

The restricted extent and wedge shape of the Parisian Formation most likely represent confinement of this deposit by the pre-existing topography of the underlying Amisk volcanic terrain. However, as the underlying volcanic rocks were not investigated during this study, and are complexly deformed and intruded, this cannot be proven.

4.3 Yakymiw Formation

The Yakymiw Formation (Unit 12) outcrops west of Morton Lake and occupies the core of a tight syncline which has been disrupted by intrusion of an axial planar sheet of gabbro (Unit 18). The formation is composed of sequences of laminated mudstone, siltstone and very fine sandstone that are interlayered with sequences of thick-bedded matrix-supported pebbly greywacke. It overlies, with apparent structural conformity, felsic flow and pyroclastic rocks (Unit 2) and mafic sub-aqueous flow rocks (Unit 3) of the Amisk Group. The maximum exposed thickness of the Yakymiw Formation is 330 m; no top is exposed.

Yakymiw Formation rocks are weakly recrystallized and contain middle to upper greenschist facies mineral assemblages, except near the Norris Lake pluton (Unit 23) where they are more strongly recrystallized and contain lower to middle almandine-amphibolite facies mineral assemblages. Primary sedimentary textures and structures are generally well preserved.

The sequences of laminated mudstone, siltstone and very fine sandstone are usually a few metres thick, but locally are tens of metres thick. Their bedding is continuous, parallel-sided, repetitive and varies from a fraction to three centimetres thick (Plate 7). Primary textures are not preserved due to recrystallization. Bedding and rare graded bedding and syn-depositional slump structures (Plate 7) are the only primary structures preserved.

The pebbly greywacke beds are lensy and range in thickness from a few centimetres to 3 m, averaging 1 m. Pebble content is variable from bed to bed and ranges from 0 to 70 percent (Plates 8 and 9). In some beds, pebble content varies laterally from 70 percent in one part to less than 10 percent several centimetres away. Pebbles range in size from 0.5 to 3 cm, vary from subangular to rounded, and are wholly supported in a greywacke matrix. In many beds the pebbles are all aphyric felsic volcanic clasts that are uniform in composition, roundness and size. In such beds, large fragmental cobbles and pebbles, consisting of aggregates of aphyric felsic volcanic clasts that are identical in composition, size and shape, to the discrete clasts in the same bed, are present (Plate 9). The pebble types are, in order of decreasing abundance:

PLATE 7: Sequence of laminated mudstone and siltstone between two thick coarse greywacke beds, Yakymiw Formation, north shore of Yakymiw Lake. Bottom of laminated mudstone and siltstone sequence has penecontemporaneous slump folds. A series of closely spaced faults transects bedding in upper part of photo.

PLATE 8: Beds of pebbly volcanic greywacke, Yakymiw Formation. Note erratic and variable distribution of pebbles in beds. West shore of Morton Lake, 2.3 km north of bottom edge of File Lake map sheet (Fig. 2).

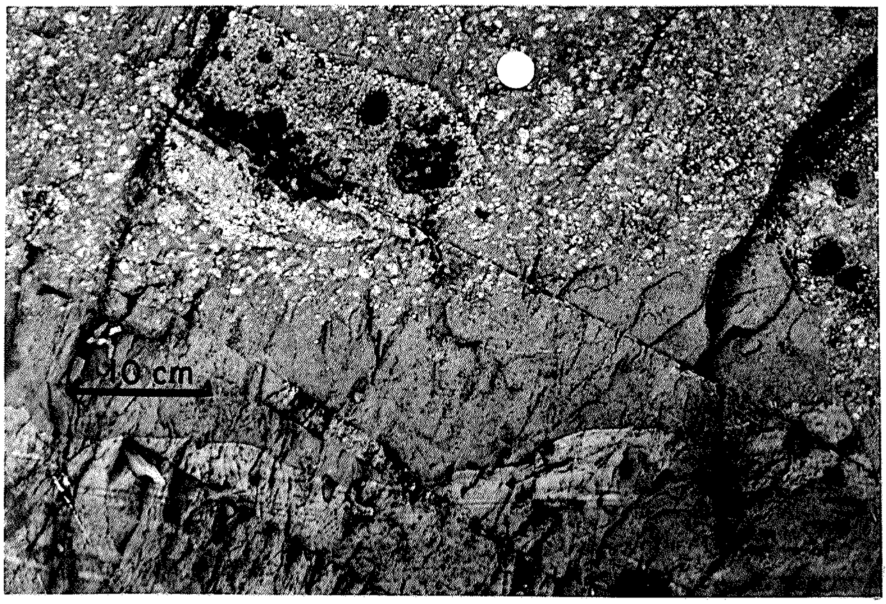


PLATE 9: Laminated mudstone, siltstone and fine sandstone beds (bottom), massive medium sandstone bed (centre) and pebbly sandstone bed (top), Yakymiw Formation, 700 m northeast of Yakymiw Lake. Pebble bed at top of photo contains a large fragmental cobble which consists of felsic fragments that are similar in size, shape, and composition to smaller discrete clasts in same bed. Massive sandstone bed (centre) has small scour mark at base. Fault with right lateral offset displaces bedding on right side of photo.

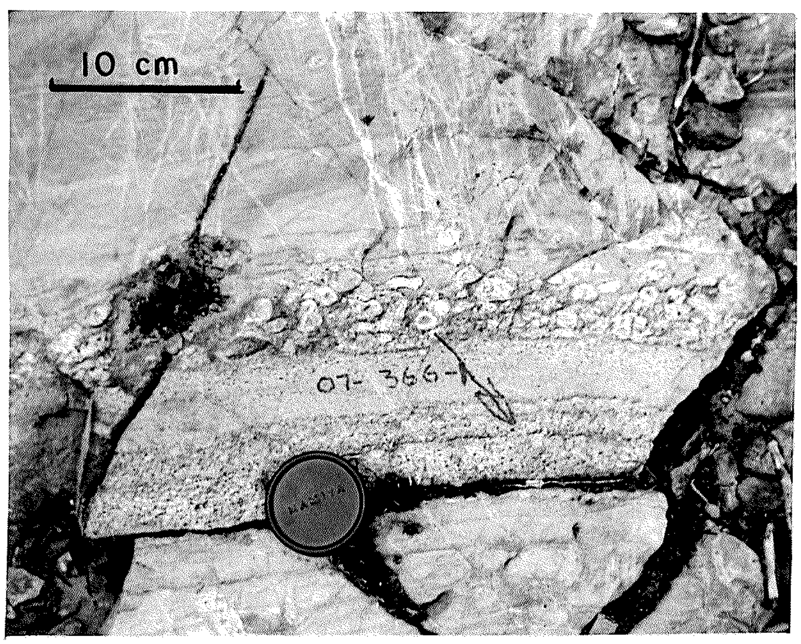


PLATE 10: Three greywacke beds, Yakymiw Formation, 700 m northeast of Yakymiw Lake. Note gradual grain gradation in centre bed and aphyric felsic pebbles concentrated at base of top bed.

- felsic aphyric volcanic fragments;
- quartz- and plagioclase-phyric felsic volcanic fragments;
- single crystal quartz grains, which locally have embayed margins and adhering fine-grained felsic material;
- plagioclase (now albite) crystals; and
- microcline crystals.

The greywacke matrix is a fine sand to siltstone, and contains recrystallized plagioclase, quartz and 20 to 40 percent biotite. In many beds, the distinction between matrix and pebbles, which is well defined in hand specimens, is diffuse in thin sections and is defined solely by the higher biotite content of the matrix.

Primary sedimentary structures, other than bedding, are not common in the pebbly greywacke beds. Graded bedding is present locally. Several varieties were observed: gradual size grading in thick pebbly beds (Plates 10 and 11); concentration of large pebbles at the base of thick massive sandstone-sized greywacke beds (Plate 10); irregular poorly defined grading in thin, poorly sorted, lensy greywacke beds (Plate 12); and coarse-tail grading, of the kind described by Middleton (1967), in beds which have internal Bouma zonation of sedimentary structures (Plates 13 and 14). Beds with internal Bouma zonation were only observed in a sequence of thick greywacke beds 700 m north of Yakymiw Lake. At this locality, scour channels (Plate 13), intraformational rip-up clasts, convolute laminations, current laminations and flame structures (Plate 14) were also observed.

The mudstone, siltstone and very fine sandstone sequences in the Yakymiw Formation probably represent sedimentation of finely comminuted material through normal subaqueous settling, combined with some weak

PLATE 11: Sequence of laminated mudstone and siltstone (bottom) overlain by a metre-thick pebbly greywacke bed with gradual grain gradation, Yakymiw Formation, 750 m northeast of Yakymiw Lake. The bottom few centimetres of a thick pebble-rich greywacke bed is exposed at top of photograph.

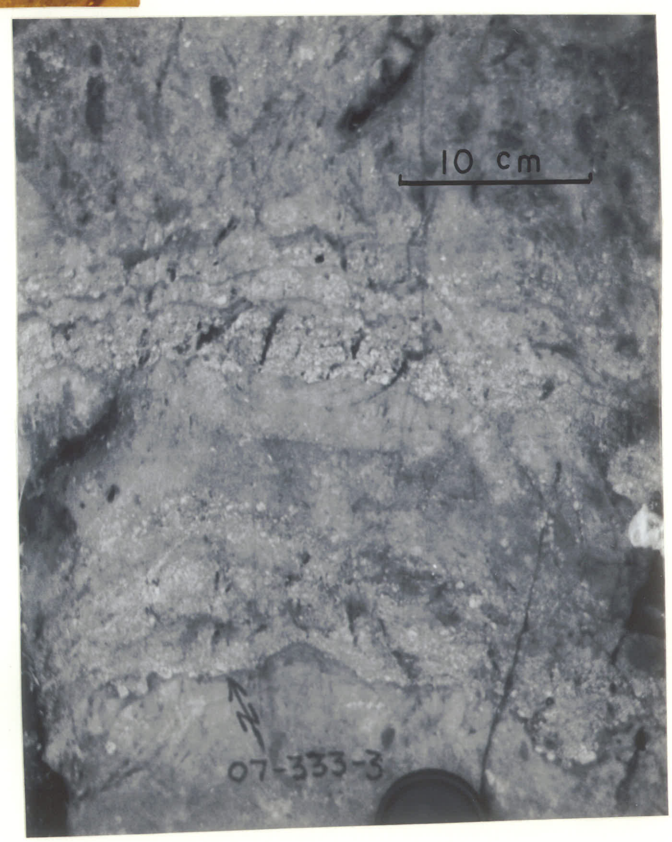


PLATE 12: Irregular lensy thin beds of graded greywacke, Yakymiw Formation, north shore of Yakymiw Lake. Note load-casted scours at base of graded greywacke bed just above camera lens cap.

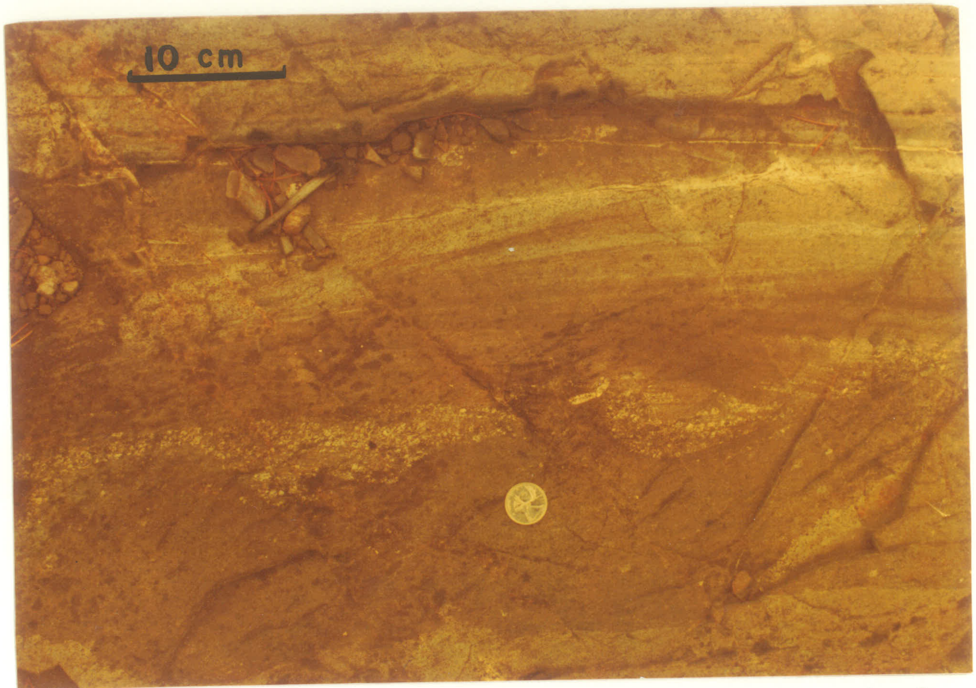


PLATE 13: Series of greywacke and pebbly greywacke beds, Yakymiw Formation, 700 m northeast of Yakymiw Lake. Bed above coin has scour channels at base that are filled by coarse-tail graded pebbly greywacke. This bed grades upward into trough cross-stratified medium sand and subsequently into parallel laminated fine sand (just below top of photo).

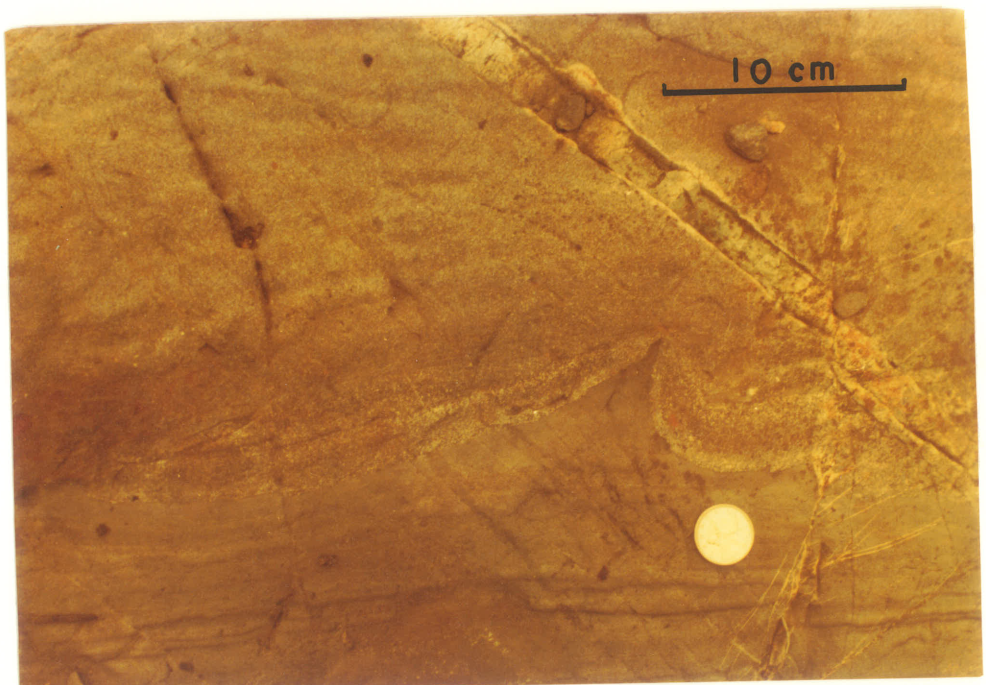


PLATE 14: Laminated siltstone and sandstone beds overlain by thick, graded,coarse-to medium-sand bed (bottom part), Yakymiw Formation, 700 m northeast of Yakymiw Lake. Note coarse-tail grading and flame structure at base of thick greywacke bed.

turbidity current activity that formed the rare thin graded beds. These sequences probably are composed of volcanic detritus, but this could not be determined because of their fine grain size. The relatively quiet sedimentation, represented by these sequences, was periodically interrupted by debris flows which deposited pebbly greywacke beds. The debris flows could have been initiated by: subaerial or subaqueous slumping of pyroclastic detritus from the flanks of a volcano; subaqueous pyroclastic flows; or overloading of the margin of the sedimentary basin by volcanic detritus. The rounding of the detritus (Plates 8, 9, 10 and 11) is not consistent with derivation from subaqueous pyroclastic flows. The extreme immaturity of the detritus, which includes microcline and plagioclase phenocrysts, embayed quartz grains, and weakly cemented fragmental clasts, indicates that there was very limited reworking of the detritus and is consistent with deposition from debris flows formed by slumping of loose pyroclastic debris directly from the volcanic terrain. The limited heterogeneity of clast types in the pebbly greywacke beds is also consistent with this origin. The rounding of detritus in the pebbly greywacke beds indicates that the detritus was probably extremely susceptible to both mechanical and chemical abrasion and was probably composed of volcanic glass.

The Yakymiw Formation occurs at about the same stratigraphic position as the File Lake Formation and is most likely a facies equivalent, as shown in Figure 5a. The sedimentation which produced the mudstone, siltstone and very fine sandstone sequences should be widespread and may be equivalent to similar fine-grained sandstone, siltstone and mudstone sequences that form Unit 13a and occur locally in Unit 13b of the File Lake Formation. The coarser grained, thicker beds in the two formations are quite different. In the Yakymiw Formation they are subaqueous debris flow deposits of extremely immature volcanic detritus whereas in the File Lake Formation they are turbidity current and fluidized flow deposits of more mature, slightly reworked, more hetero-lithologic volcanic debris. This difference could be due to a combination of factors, including: different sediment sources; a local topographic division of the sedimentary basin; and/or channelization of the turbidity currents such that only overbank turbidites and hemipelagic sedimentary deposits could occur in both formations. The Yakymiw Formation is most likely a very local sedimentary facies that was derived from a small local felsic volcanic edifice. It was probably isolated topographically from the more regional turbidity current sedimentation pattern, represented by the File Lake Formation.

4.4 File Lake Formation

4.4.1 General stratigraphy

The File Lake Formation is a 1 km thick succession composed mainly of interbedded greywacke, siltstone and mudstone (Units 13 and 13a) and derived paragneiss and migmatitic gneiss (Units 13b and 13c). Near the top of the formation there is a locally developed 200 to 300 m thick metavolcanic layer (Units 14 and 14a) and a more widespread 50 m thick unit of mudstone, named the Corley Lake member (Unit 15). The File Lake Formation outcrops widely in the File Lake area, in both the Flin Flon and Kisseynew belts, and extends east of the study area, at least as far as Snow Lake and Wekusko Lake (Fig. 3). To the north it can be traced directly into the widespread Nokomis Group paragneisses of the Kisseynew belt.

In most of the area, the File Lake Formation directly overlies, with apparent structural conformity, Amisk Group metavolcanic rocks, but on Woosey Lake, it overlies the Parisian Formation. Nowhere is it in direct contact with the Yakymiw Formation. On File Lake, it is overlain, possibly disconformably, by subgreywacke- and arkose-derived gneisses (Unit 16) of the Missi Group.

The type exposures of the File Lake Formation are due west of Elmes Island on Morton Lake, and on the north tip of the peninsula at the south end of Morton Lake. At these localities, the top of the formation is missing but the rocks are only weakly recrystallized, with greenschist facies mineral assemblages, and contain well preserved primary sedimentary structures and textures. A complete section of the File Lake Formation is exposed along the northwest shore of File Lake, but it is folded and strongly recrystallized to biotite-, garnet-, staurolite-, and sillimanite-bearing paragneisses (Units 13b and 15). Similar high grade metamorphic derivatives are present in the formation at Woosey Lake. Accordingly most of the petrographic and sedimentary structure data come from the Morton Lake area.

On Morton Lake, there is an increase in the sandstone to mudstone ratio and bed thickness from north to south and, in the north part of Morton Lake, from bottom to top of the exposed section. On the northwest shore of File Lake however, the opposite relationship is observed with the sandstone to mudstone ratio and bed thickness decreasing upward. In general, the section on Morton Lake is more sandy and thicker bedded than that on File Lake, but comparisons are difficult because of the stronger metamorphic recrystallization and deformation of the File Lake section.

On Morton Lake, three main bed types have been identified: 1) beds that have partial or complete Bouma sequences (hereafter referred to as Bouma beds); 2) internally homogeneous, massive greywacke and pebbly greywacke beds that lack Bouma sequences, but locally have grading and a thin mudstone or siltstone capping (hereafter referred to as non-Bouma beds); and 3) sequences of laminated mudstone, siltstone and fine sandstone, which locally include thin Bouma A→E beds. The three bed types are interbedded in many exposures. Non-Bouma beds form about 20 percent of the beds on Morton Lake, and range in abundance from 0 to 90 percent. They predominate on the peninsula at the south end of Morton Lake, where the sequence is thick bedded and comprises coarse-grained greywacke and pebbly greywacke, whereas Bouma beds predominate on north Morton Lake, where the sequence is thinner bedded and comprises medium- to fine-grained greywacke, siltstone and mudstone. On north Morton Lake, the proportion of non-Bouma beds increases upwards and near the top of the section they are equal in abundance to Bouma beds. The sequences of laminated mudstone, siltstone and fine sandstone are similar to those which occur in the Yakymiw Formation. They predominate near the base of the section on north Morton Lake (Unit 13a), but elsewhere they are rare. The three bed types cannot be distinguished on File, Loonhead, or Woosey Lakes because internal sedimentary structures by which they are identified have been destroyed by strong recrystallization.

4.4.2 Primary sedimentary structures

Primary sedimentary structures are abundant and well preserved in weakly recrystallized strata on Morton Lake. They have been examined carefully in all exposures and, in addition, their size and distribution have been recorded systematically in several representative stratigraphic sections (Fig. 6; Table 4, p. 66). Parts of two sections, one dominated by non-Bouma and the other by Bouma bed types are shown in Figure 7.

a) Description of primary sedimentary structures

Bedding contacts and thickness

Distinctive well defined bedding is a ubiquitous and striking feature of the greywacke, siltstone and mudstone strata of the File Lake Formation. Bed contacts of Bouma and non-Bouma beds are sharp. They are coarsest at their base and generally grade upwards into finer material (Fig. 7), with the next bed defined by an abrupt coarsening of grain size. Mudstone and siltstone cappings sharply delineate the tops of many Bouma and non-Bouma beds. Bed contacts in sequences of mudstone, siltstone and fine sandstone are well defined, regular and laterally continuous.

Bed contacts vary from flat to highly irregular, with irregularities due to a combination of intraformational erosion and soft-sediment deformation. Scour marks (Plates 15 to 18) are abundant on the top of beds and range in depth from 0.5 to 80 cm, and average 1 to 2 cm. In general, the size of the scour marks is in direct proportion to the thickness of the overlying bed. Mudstone beds overlain by coarse thick greywacke beds have locally been ripped up, leaving irregular truncations (Plate 19), and producing fragments within the greywacke beds (Plates 26 and 31).

Bouma beds average 30 cm in thickness and range from 0.5 to 235 cm (Table 4, p. 66). Grain size varies from silt to granules, but normally

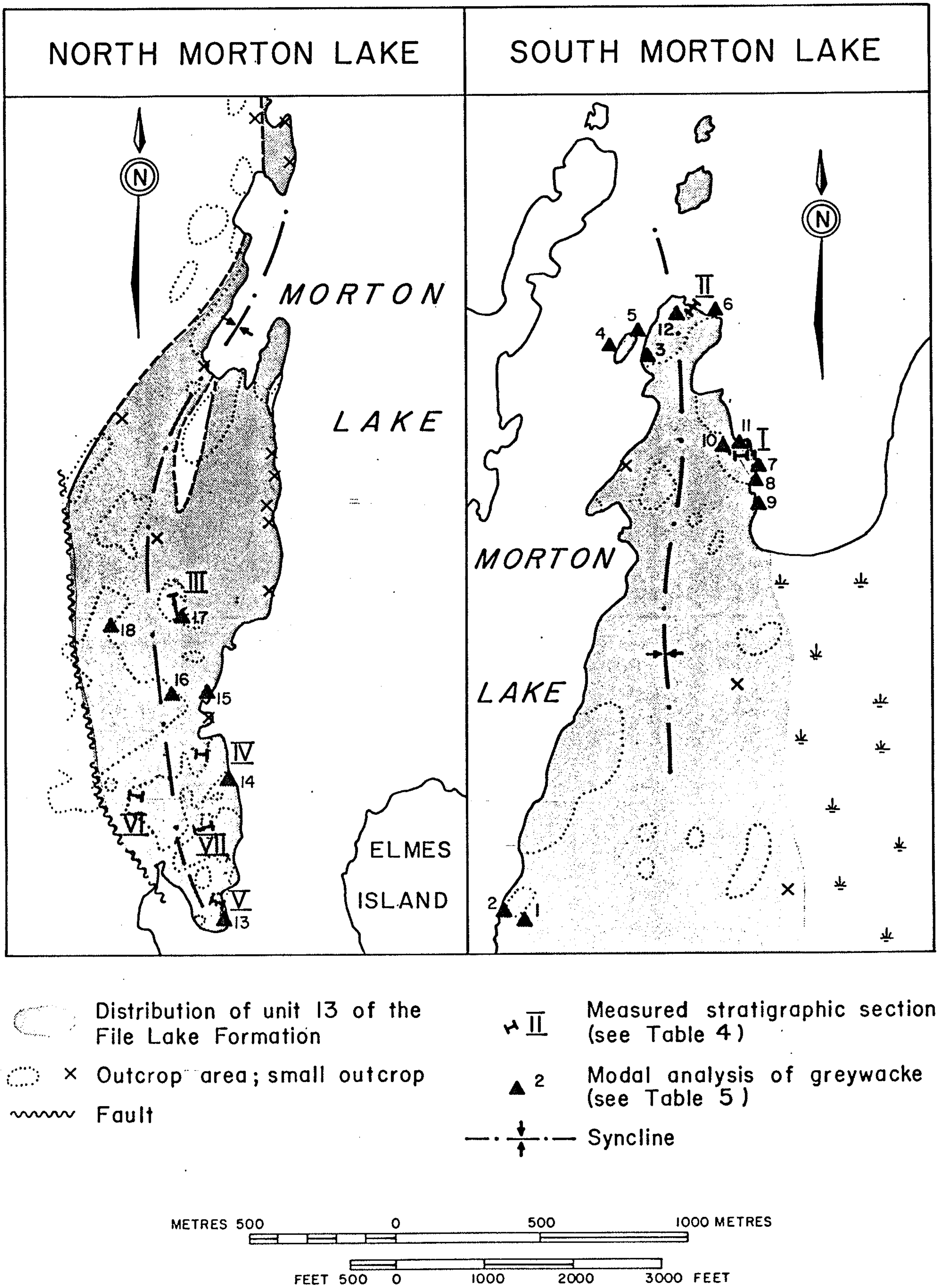
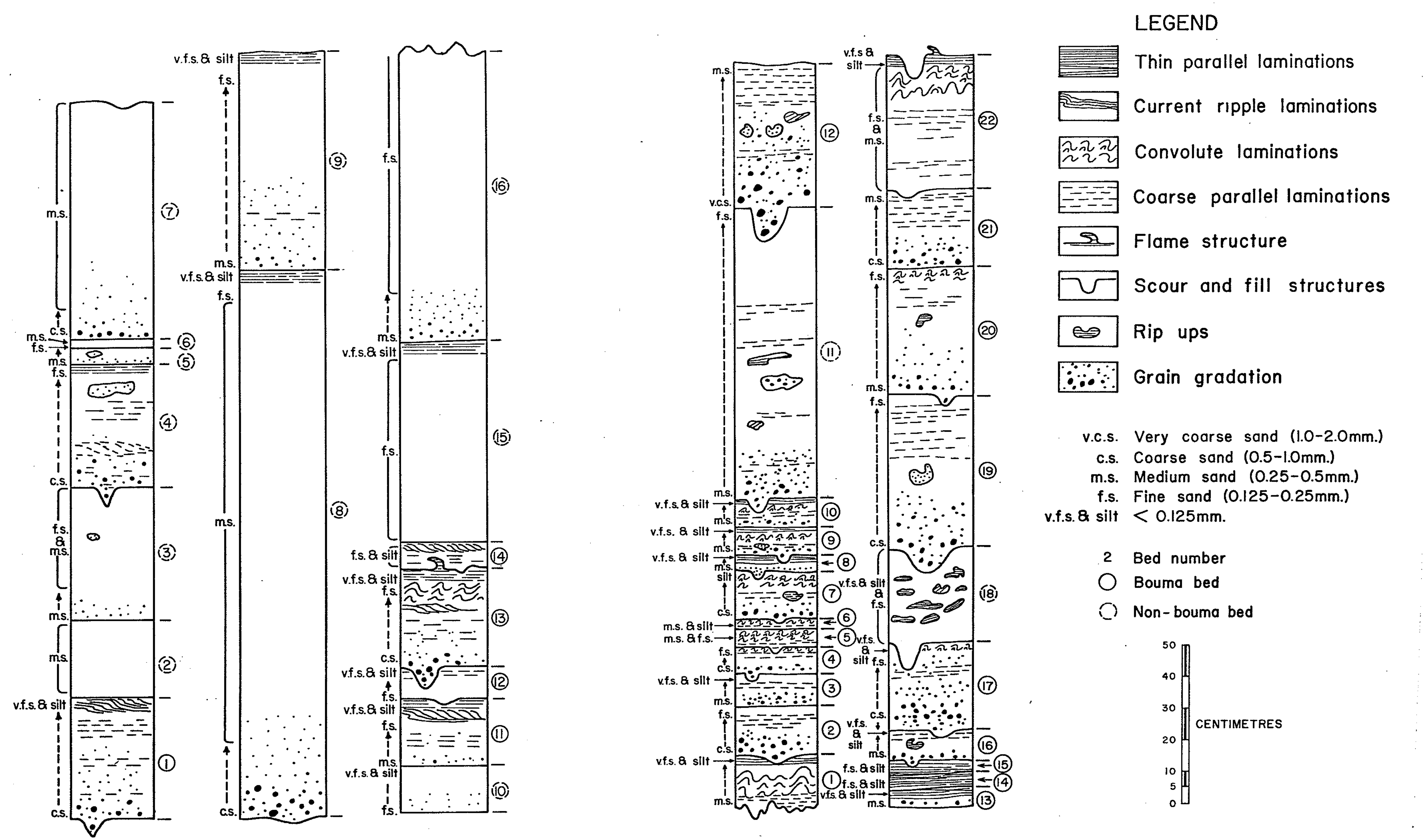


FIGURE 6. Location of measured stratigraphic sections and modally analyzed greywacke and siltstone samples in the File Lake Formation, Morton Lake.



a) Bottom 16 beds of section II, which is composed dominantly of non-Bouma beds.

b) Bottom 22 beds of section III, which is composed dominantly of Bouma beds.

FIGURE 7. Schematic representation of parts of measured stratigraphic sections II and III, File Lake Formation. See Figure 6 for location of sections.

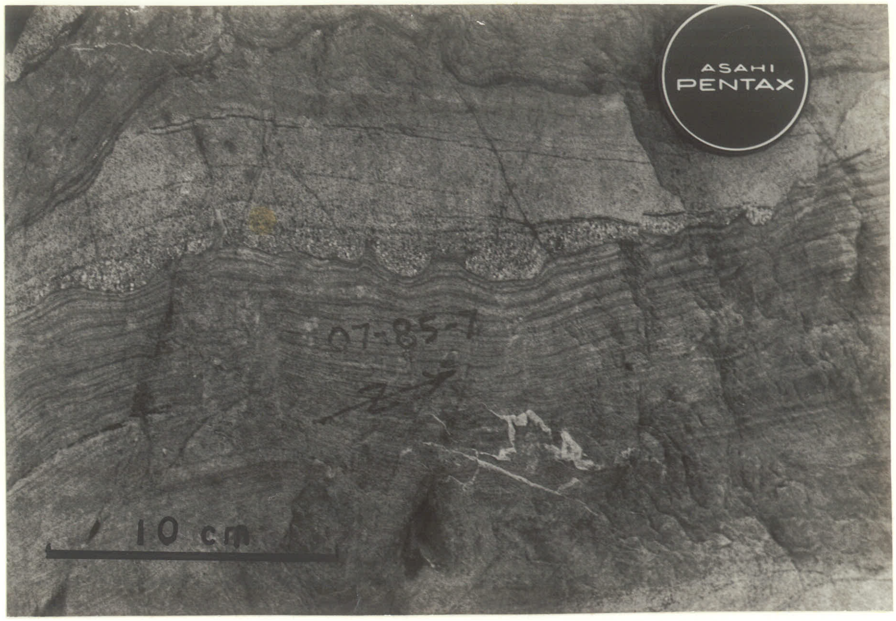


PLATE 15: Parts of three Bouma beds, File Lake Formation, west shore of Morton Lake opposite Elmes Island. Lower bed shows B division; middle bed shows A and B divisions; and upper bed shows B division. Note loaded scour marks filled by coarse-tail graded sandstone at base of middle bed and scour mark at base of upper bed.

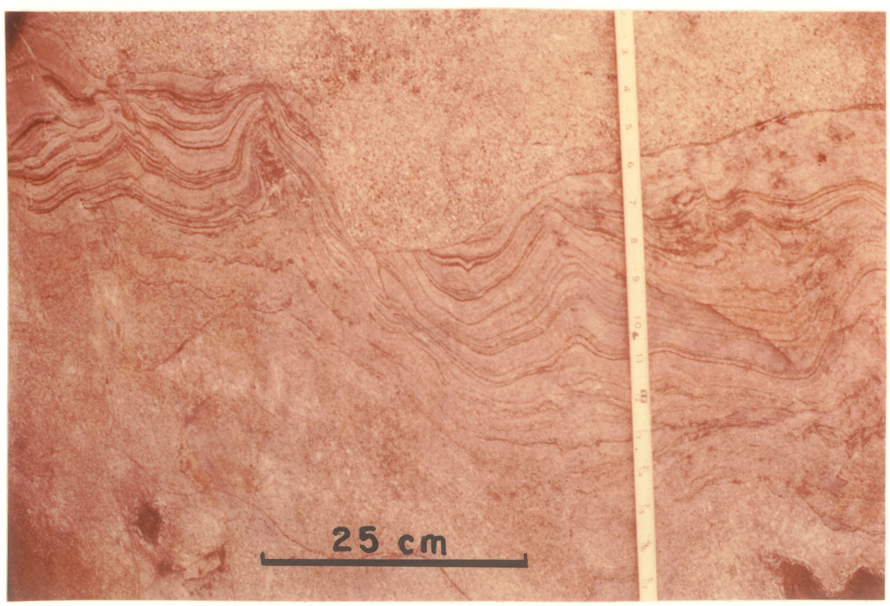


PLATE 16: Parts of two Bouma beds, File Lake Formation, west shore of Morton Lake opposite Elmes Island. Lower bed shows A, B and C divisions. Upper bed shows massive A division with coarse sand-filled scour at base.

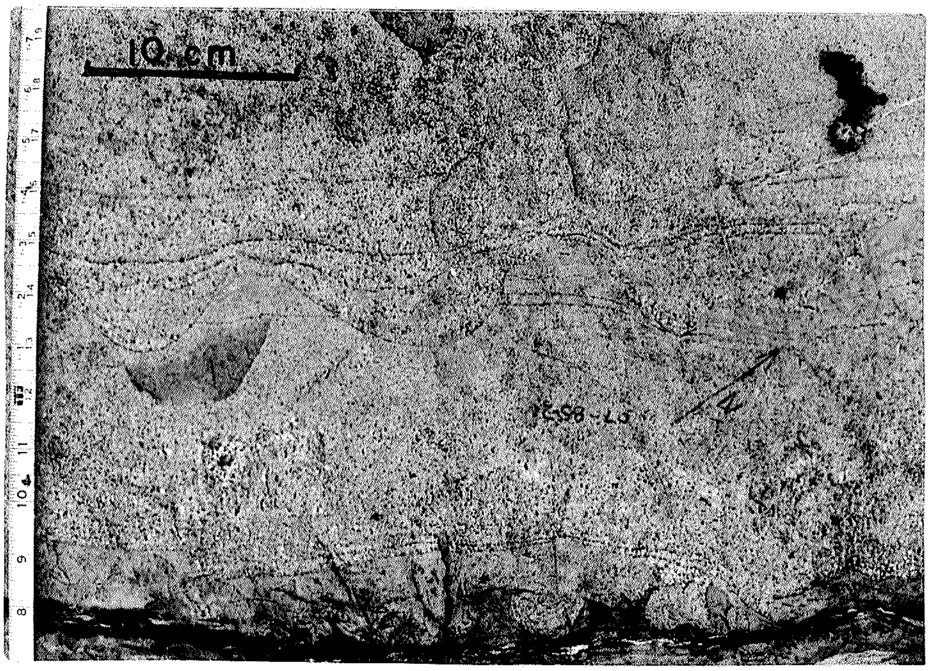


PLATE 17: Series of dish-shaped scour marks (centre of photograph) along contact between two medium to coarse Bouma sandstone beds, File Lake Formation, west shore of Morton Lake opposite Elmes Island. Note gradual grain gradation in A division of bottom bed and parallel laminated B division on it between scours at top. Upper bed begins with B laminated division but includes some overlapping grain gradation.

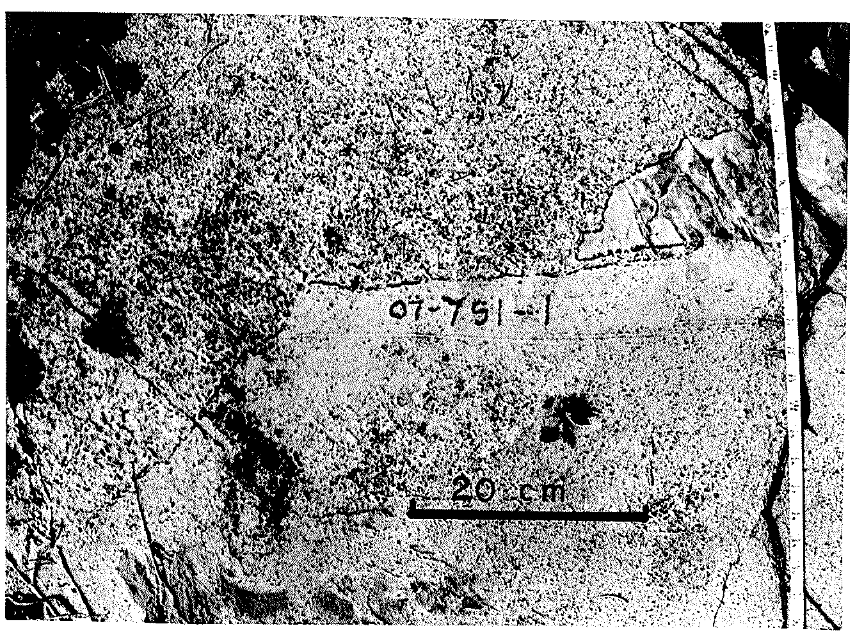


PLATE 18: Part of large scour channel at base of thick coarse non-Bouma graded sandstone bed, File Lake Formation, east shore of peninsula at south end of Morton Lake. Underlying bed is also a non-Bouma sandstone bed.

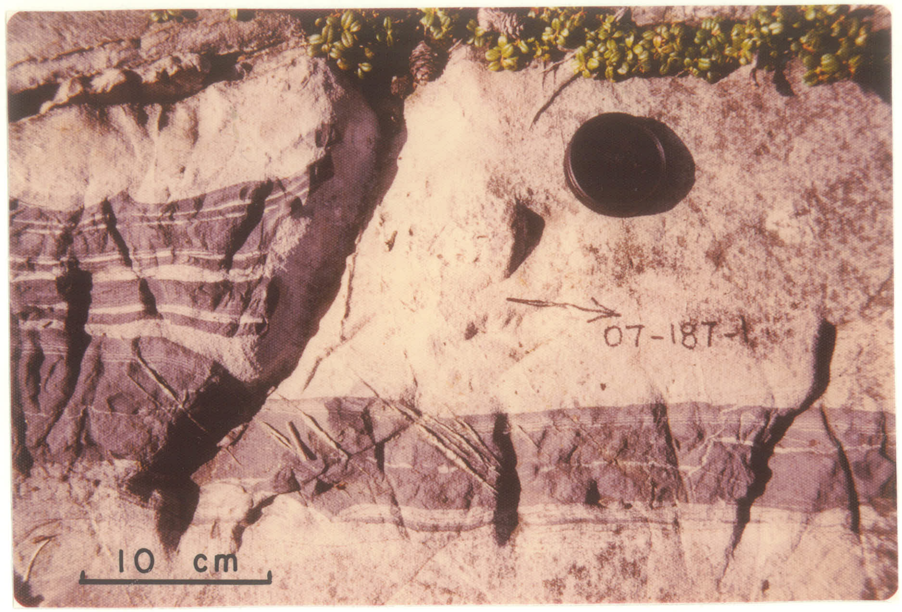


PLATE 19: Truncated beds of mudstone at base of thick coarse non-Bouma massive bed, File Lake Formation, north end of peninsula at south end of Morton Lake.

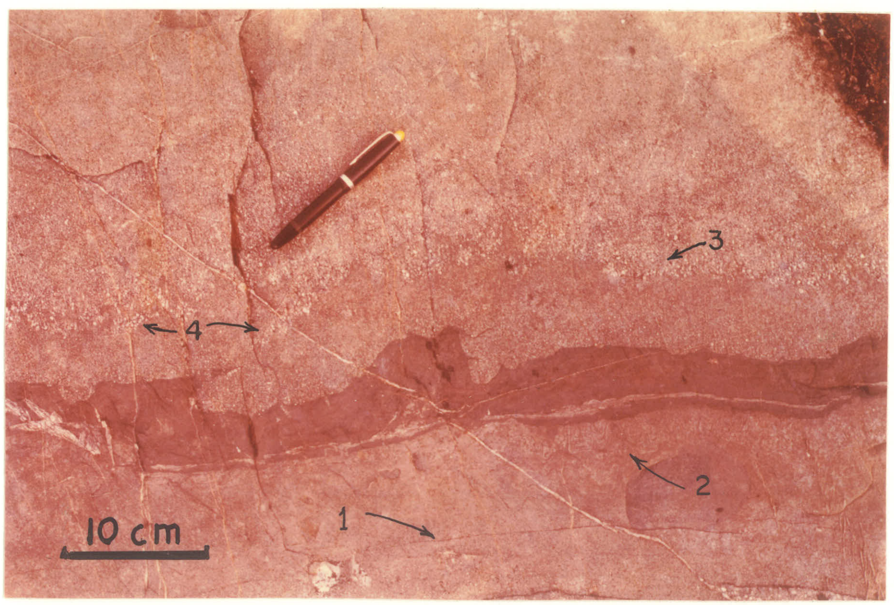


PLATE 20: Three Bouma sandstone beds with the lower bed separated from the upper two by a 6 cm wide unit of black massive mudstone, File Lake Formation, west shore of Morton Lake opposite Elmes Island. Lower Bouma bed shows B (1) and C (2) divisions, the latter containing delicate small convolute laminations under mudstone unit at right of photograph. The upper two Bouma beds comprise two amalgamated A divisions. The upper of these has a coarse-tail graded base (3) followed by more gradual distribution grading. Small detached coarse sand lenses (4) occur below loading areas at the base of uppermost bed.

it is fine to medium sand. The bottom parts of beds are generally graded.

Non-Bouma beds average 90 cm in thickness and range from 5 to 1140 cm (Table 4, p. 66). They are thickest and coarsest on south Morton Lake, where they average 185 cm in thickness and typically are composed of medium to very coarse sand; pebbles are present at the base of some thick graded beds. At the top of the exposed section on north Morton Lake, non-Bouma beds are anomalously thin. They average 35 cm in thickness, range from 5.5 to 105 cm, and are much thinner than associated Bouma beds which are thicker than normal, average 65 cm and range from 11 to 235 cm. The grain size of these non-Bouma beds is generally fine to medium sand.

Internal structures of Bouma beds

Bouma beds are characterized by an internal sequence of sedimentary structures known as the Bouma cycle (Bouma, 1962). The ideal Bouma cycle contains five divisions, A to E, but the Bouma beds on Morton Lake rarely have a complete sequence; commonly one or more of the upper and/or lower divisions, and rarely an internal division is missing (Fig. 7).

The graded division (A) is present in 70 percent of the Bouma beds. The grain size is generally coarse at the base and medium to fine sand at the top. The grain gradation, which characterizes this division, is variable. In many beds it begins as a rapid grain gradation (the coarse-tail grading of Middleton, 1967) in the bottom few centimetres, followed upward by more subtle and gradual grain gradation (the distribution grading of Middleton, 1967) and/or ungraded medium to fine sand (Plates 15 and 20). Also common are A divisions with distribution grading throughout. In a few thick beds, reverse grading is present under large intraformational mudstone clasts, within otherwise normally graded beds. Beds beginning with the A division are generally thicker than beds beginning with other divisions and are most abundant in sections containing many non-Bouma beds (Table 4, p. 66).

The lower parallel laminated division (B) is present in 90 percent of the Bouma beds and typically consists of medium to fine sand. It generally overlaps or is gradational with the underlying A division. The laminations vary from diffuse and locally discontinuous to well defined and regular (Plates 15 and 21). B divisions are most poorly developed and locally missing in thick coarse beds with thick A divisions. Such beds are most common on south Morton Lake associated with non-Bouma beds.

The current ripple laminated or convolute laminated division (C) is present in 70 percent of the Bouma beds and typically consists of fine sand to silt. It is most prominently developed in beds of moderate thickness which either have a thin A division or begin with the B division. It is generally weak or missing in thick beds with thick A divisions. Beds with convolute laminations (Plate 21) are four times as common as those with current ripple laminations (Plate 22). The convolutions comprise a complex series of broad bulbous synclines and sharp crested anticlines. The upper and lower surfaces of the convoluted units are undeformed and this, in conjunction with the presence of current ripple laminations in some convoluted units (Plate 23), indicates that the convolutions were formed by or during action of the current depositing the beds.

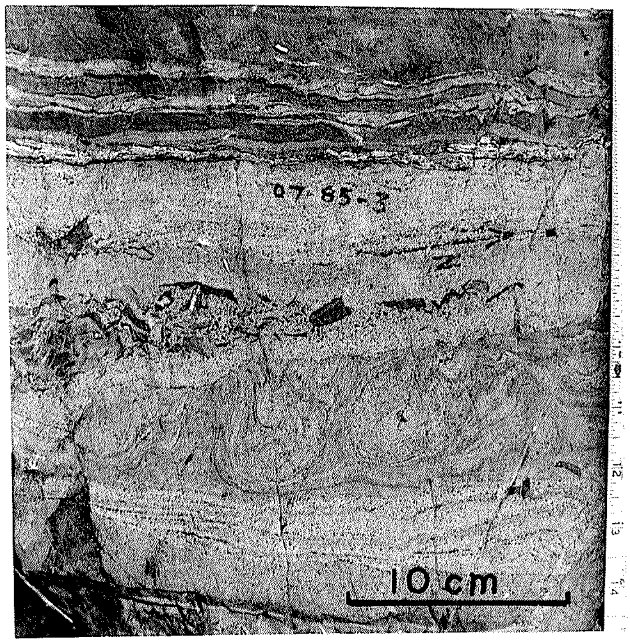


PLATE 21: Series of three Bouma greywacke beds overlain by 6 cm sequence of laminated mudstone and siltstone, File Lake Formation, west shore of Morton Lake, opposite Elmes Island. Bottom Bouma bed consists of a massive A division, a parallel laminated B division, and a convolute laminated C division with bulbous synclines and sharp-crested anticlines. The overlying bed truncates the convolute laminations and contains a zone of angular slabby intraformational mudstone fragments.

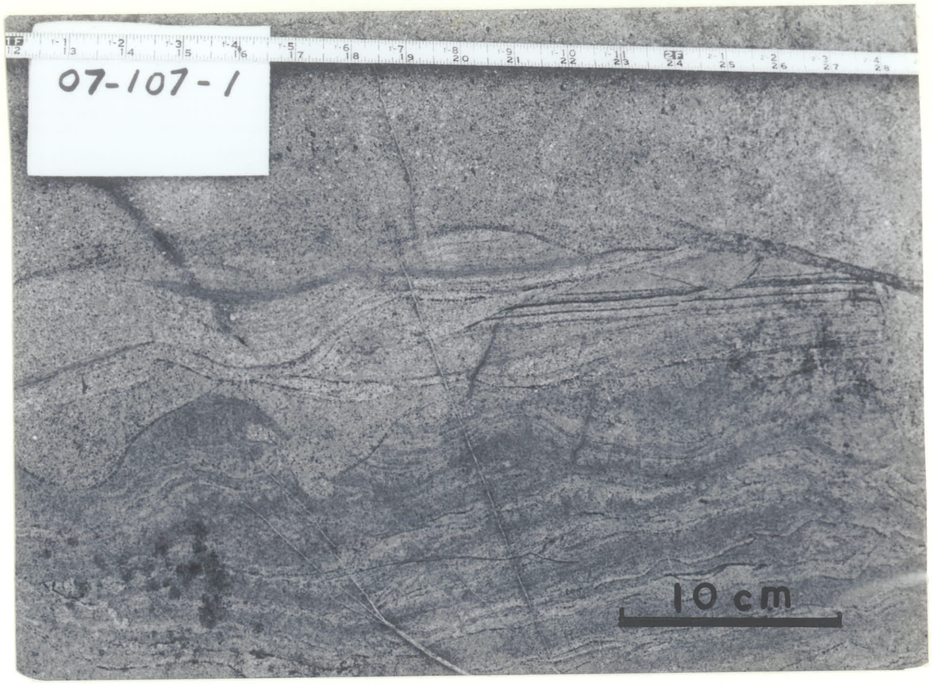


PLATE 22: Sequence of three Bouma beds, 750 m west of Elmes Island. The lower bed shows the upper parallel laminated D division. The middle bed shows divisions B and C. The upper bed shows the lower A division. Note the scour features at the base of the middle bed and also the contained current ripple laminations.

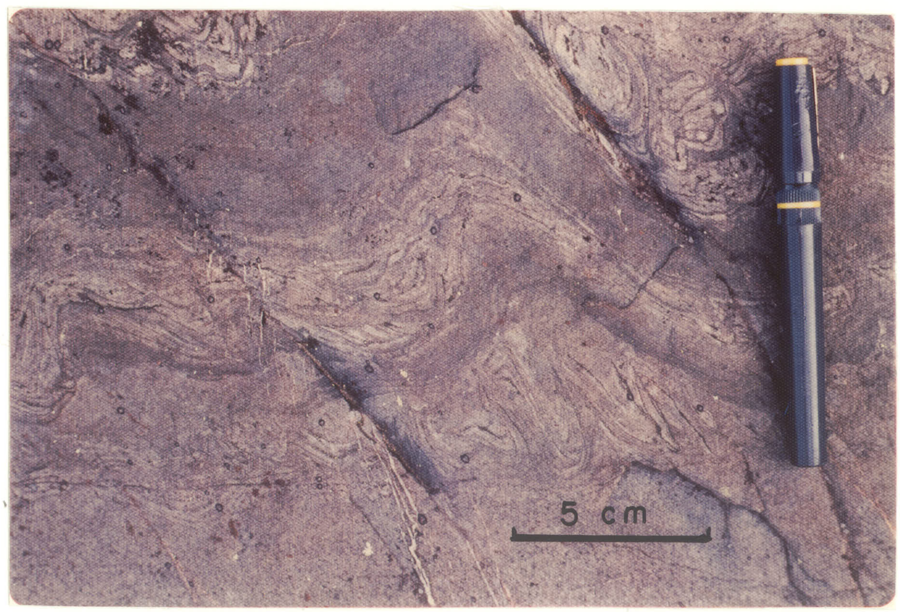


PLATE 23: Combined current ripple laminations and convoluted laminations in C division of Bouma bed 600 m northwest of Elmes Island on west shore of Morton Lake.

The upper parallel laminated division (D) and the pelitic division (E) comprise dark grey to black siltstone and mudstone. They are gradational and generally could not be subdivided. One or both of these divisions is present in 65 percent of the Bouma beds.

Some beds, generally less than 5 cm thick, have a narrow graded fine sand division that passes directly into massive poorly laminated, silty to clayey D E divisions (Plate 24). These beds are similar to the A$\rightarrow$E beds that Walker (1967) considered to be deposits of almost stagnant turbidity currents and, therefore, to be closely related to Bouma D E beds.

Internal structures of non-Bouma beds

Non-Bouma beds are thick greywacke beds that lack the internal zonation of sedimentary structures characteristic of Bouma beds, but which do have a crude regular distribution of structures. Two varieties of non-Bouma beds have been recognized: massive and graded (Fig. 8).

Massive beds (Fig. 8a) locally have scour marks, scour channels, and load and flame structures (Plate 25) at their bases. They also contain rare intraformational mudstone clasts (Plate 26) and locally have thin cappings of fine sand and silt (Plate 25). Their most characteristic feature however, is homogeneity and lack of internal structures. They comprise 15 percent of the observed non-Bouma beds.

Graded beds (Fig. 8b) commonly have scour marks at their base (Plate 18) and always have grading, generally a basal coarse-tail grading which is overlain by either massive sandstone or more gradually graded sandstone that passes upward into massive sandstone. They

PLATE 24: Series of A→E beds, File Lake Formation, west shore of Morton Lake, opposite Elmes Island. Note delicate load casts on top of evenly graded small A→E bed (in centre of photograph). Shale protrusions on loaded bed are overturned to north and indicate this is probably downslope direction. Also note elliptical concretions (at bottom of photograph).

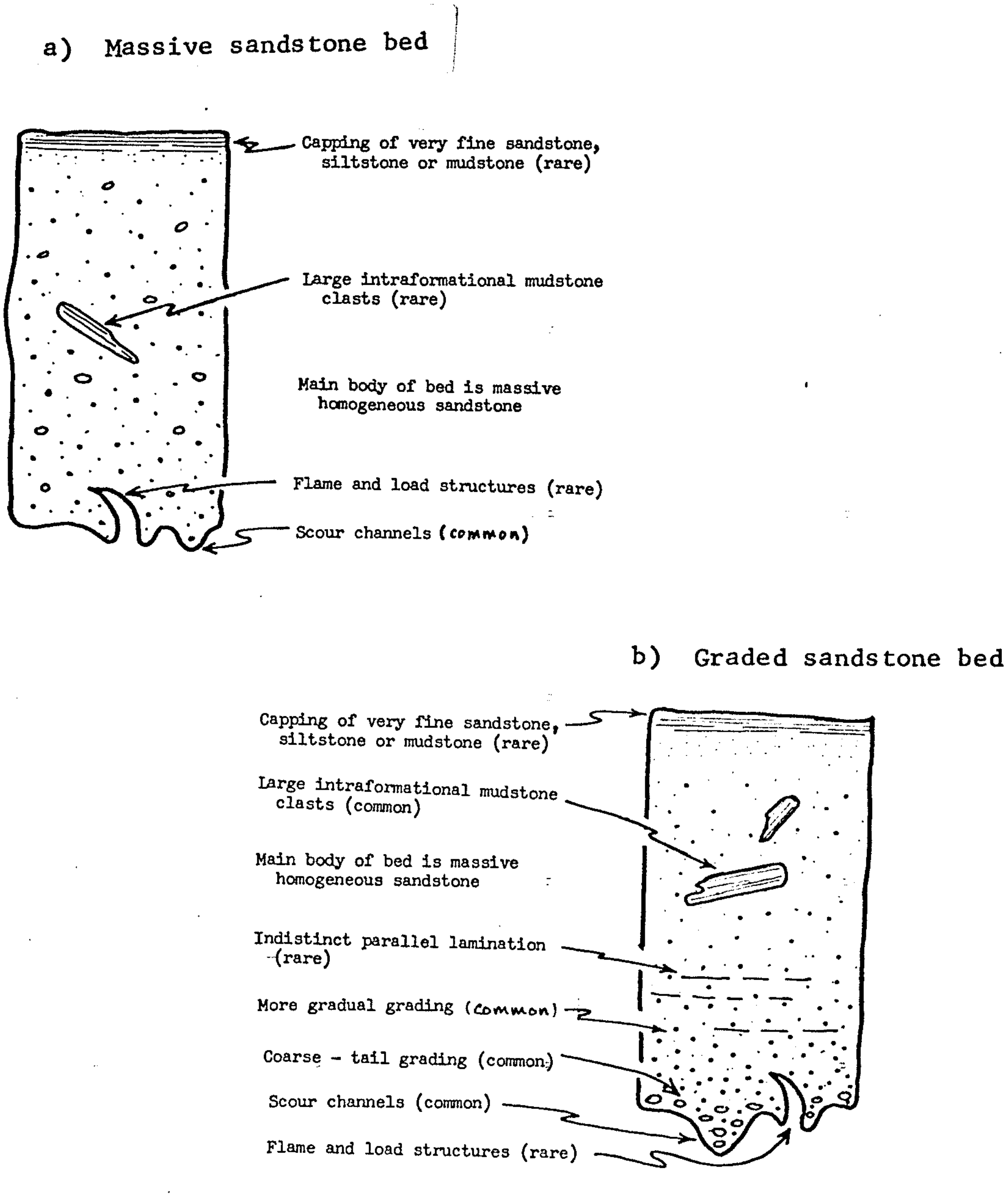


FIGURE 8. Schematic representation of sedimentary structures in typical non-Bouma beds, File Lake Formation.

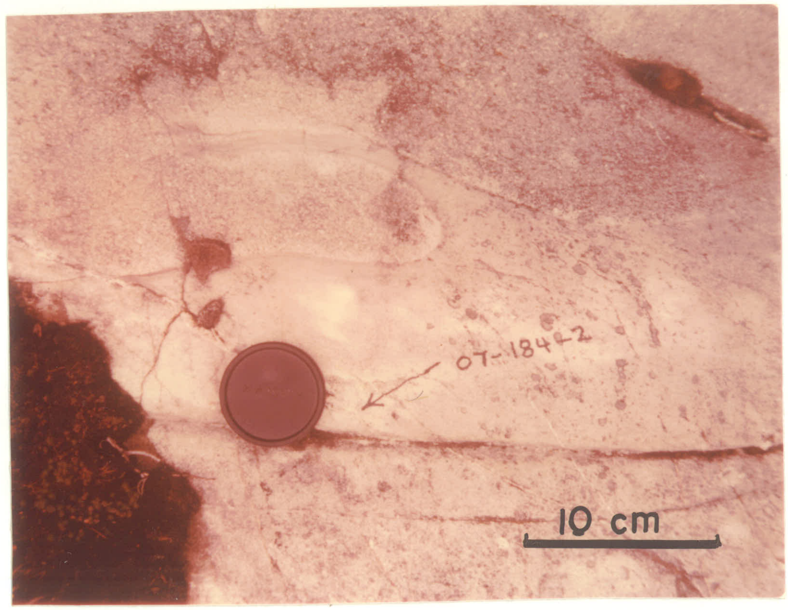


PLATE 25: Two non-Bouma beds, File Lake Formation, west shore of peninsula at south end of Morton Lake. Lower bed has fine sand to silt capping. Upper bed is massive coarse sand with large flame structure at base. The flame structure is overturned to north, down the interpreted paleoslope.

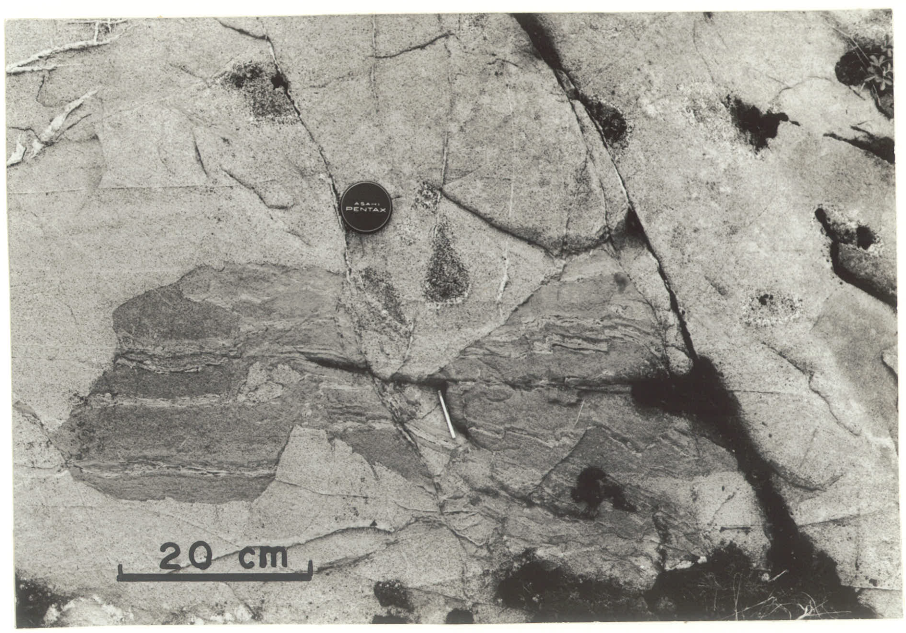


PLATE 26: Part of thick massive non-Bouma coarse sandstone bed, File Lake Formation, north shore of peninsula at south end of Morton Lake. Note large intraformational siltstone rip-up fragment and small black metamorphosed calcareous concretions.

rarely contain poorly developed coarse parallel laminations, like those in Bouma B divisions, and commonly have intraformational mudstone clasts. They locally have narrow cappings of fine sand and silt and rarely have reverse grading in the bottom 1 to 3 cm of some thick beds. The reverse grading is generally overlain by the characteristic normal grading.

In graded beds the thickness of the graded basal zone relative to the bed thickness is variable. Where it is thin, the graded beds are very similar to massive beds. For this reason, it is likely that there is no real break between the two bed types and they are part of a continuum. To some extent, there is also a continuum between graded non-Bouma beds, that contain discontinuous parallel laminations and a capping of fine siltstone, and coarse thick Bouma A B D (E) beds which have a thick A division but lack the C division. However, beds that are difficult to classify as Bouma and non-Bouma are extremely rare. Generally any bed of this type which contained relatively continuous coarse parallel laminations, restricted to a definable zone, was classified as Bouma-type.

Penecontemporaneous deformation structures

Both Bouma and non-Bouma beds contain deformation structures that formed during or immediately after deposition, while the sediment was still soft. These include: gravity induced features such as load structures; gravity movement structures such as slump faults and folds; and liquefaction structures such as sandstone intrusions.

Load structures, that formed when heavier sand sank into lighter fine sand, silt and mud of the underlying bed, are common. They include bulbous sand protrusions into underlying mud or silt beds and narrow flames composed of mud or silt between the sand protrusions (Plates 15 and 24). Rarely the sand protrusions are detached and form sandstone balls (Plate 20). Many of the load structures were probably initiated by scour marks (Plate 16). Small downslope movements of the beds, after formation of the load structures, has bent the tops of many of the flames downslope (Plates 24 and 25). This is one of the few paleoslope criteria in the File Lake Formation, and the overturning suggests a northerly paleoslope.

Slump structures include some discontinuous gravity-induced faults (Plate 27) and some rare large irregular folds (Plate 28). The faults are rarely continuous for more than 10 cm, die out gradually, and generally come in pairs that are concave upwards with a downdropped bed in between. Their penecontemporaneous formation is indicated by undeformed overlying strata. Slump folds are also overlain by undeformed strata. They differ from convolute laminations in that they have bulbous anticlines as well as synclines and generally involve several beds (Plate 28). The slump folds in Plate 28 are concentric and die out at depth.

Sand intrusions (Plates 29 and 30) are rare and include both upward and downward protrusions of sand into thinly laminated mudstone and siltstone layers. Locally they brecciated the intruded beds (Plate 30). They probably formed by escape of water from compacting of sand beds buried beneath cohesive, relatively impermeable clay-rich sediments.

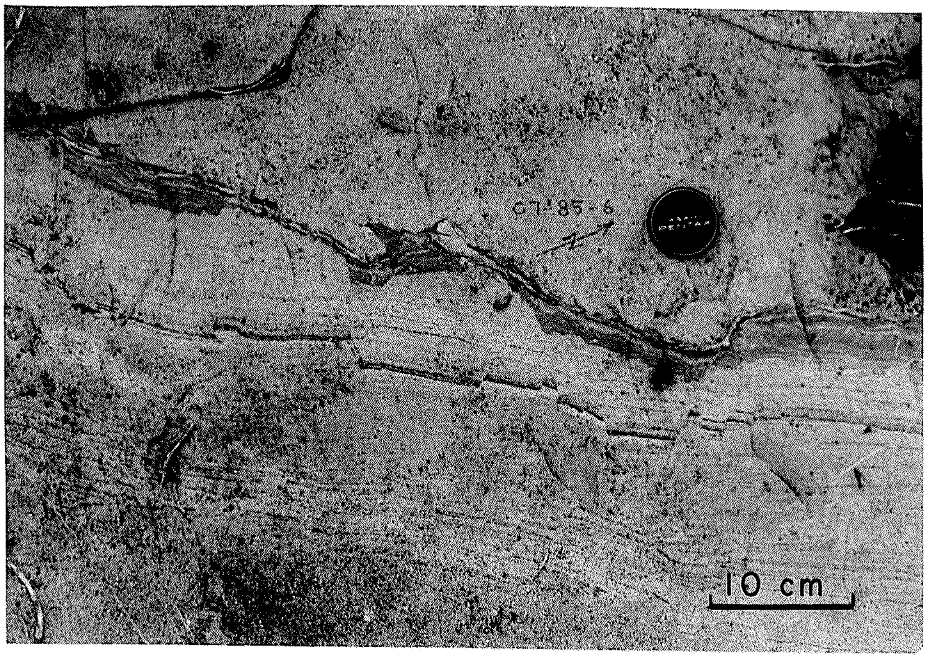


PLATE 27: Two Bouma beds with an intervening layer of black mudstone, File Lake Formation, west shore of Morton Lake opposite Elmes Island. Lower bed comprises upper massive part of A division and a well-laminated B division. The upper bed is an amalgamation of two A divisions. Penecontemporaneous soft sediment gravity slump faults are conspicuous in laminated B division under mudstone bed. The faults bounding downdropped sections are concave upwards. Note also the load structures on top of the dark mudstone bed.

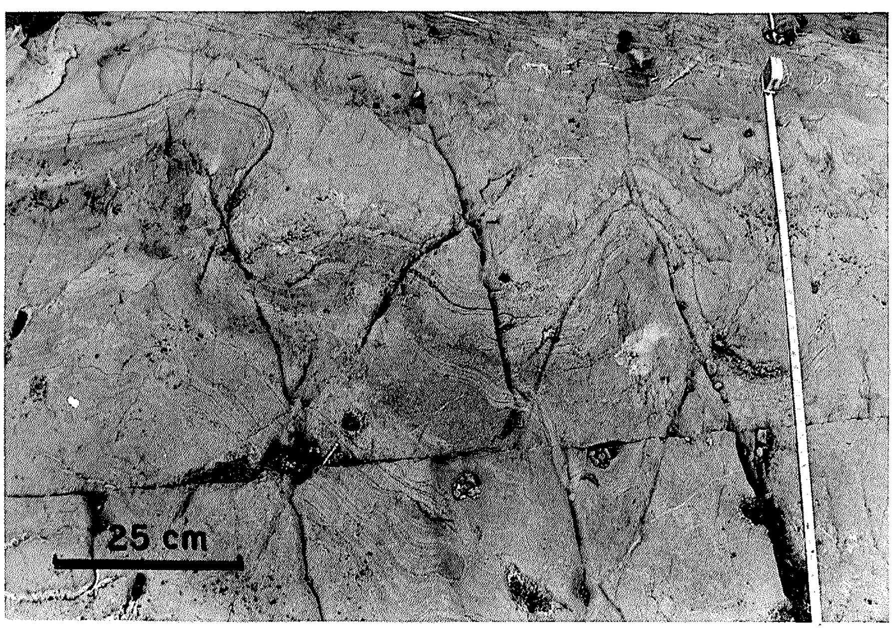


PLATE 28: Large bulbous concentric slump folds, File Lake Formation, west shore of Morton Lake opposite Elmes Island Fold amplitude is approximately 50 cm in centre of photograph and decreases downwards. Folds affect several beds. Note undeformed overlying siltstone beds and black recrystallized carbonate concretions (in bottom part of photograph).

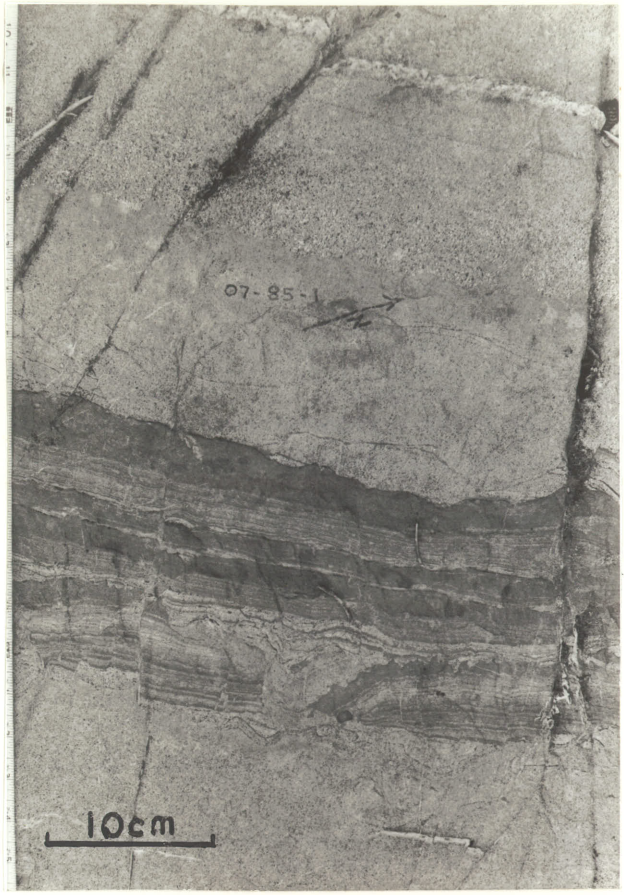


PLATE 29: A series of coarse sandstone Bouma beds and an intervening succession of narrow A→E fine sand and DE mudstone beds, File Lake Formation, west shore of Morton Lake opposite Elmes Island. Note the cone-shaped sand intrusion into thin A→E silt and mudstone beds and the load structures on mudstone bed below sand intrusion (centre bottom of photograph). Note also the two amalgamated A divisions of the Bouma beds in top half of photograph.

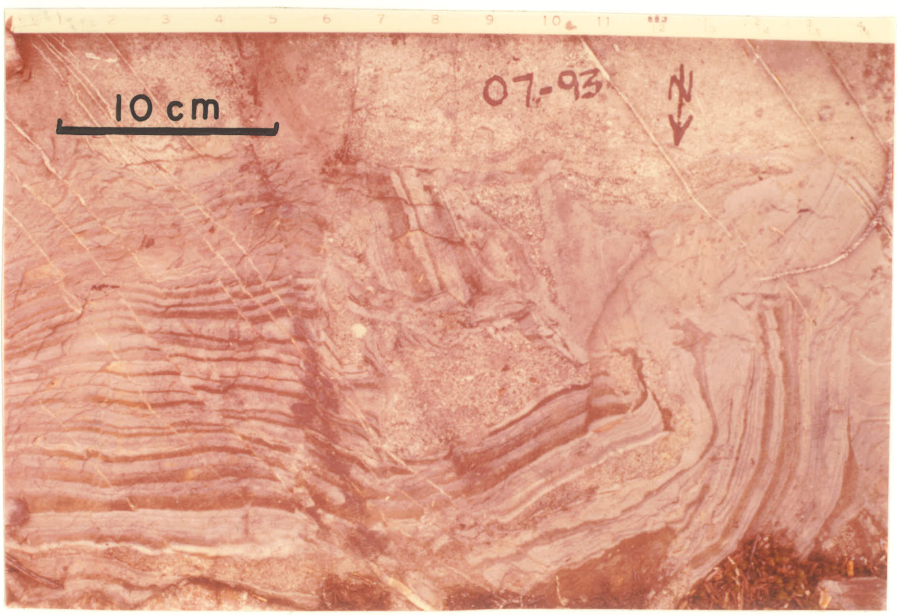


PLATE 30: Irregular intrusions of coarse sand into A→E silt and mudstone beds, File Lake Formation, 1.5 km northwest of Elmes Island. Note rotation and brecciation of A→E silt and mudstone beds by the sand intrusions.

Other structures

Dark coloured, angular to tabular massive to laminated intraformational mudstone fragments (Plate 31) are common in non-Bouma beds and in the A division of Bouma beds. Siltstone and rare sandstone clasts are also present. Most of the fragments are 1 to 3 cm in size, but in thick non-Bouma sandstone beds they are locally more than 20 cm (Plate 26). The fragments occur in about one-third of the beds and generally, but not always, form trains concentrated along a single horizon in the bed (Plate 21). The position of these trains of fragments varies from bed to bed; in Bouma beds they are common at the top of the A division, but in non-Bouma beds they have no preferential position. The fragments probably originated by intraformational erosion and/or slumping. Truncated mudstone beds (Plate 19) are evidence that subsequent subaqueous sediment flows have ripped up parts of partially consolidated mudstone beds and transported them deeper into the sedimentary basin. Rare angular fragments of folded mudstone (Plate 32) suggest that erosion also occurred during slump folding and slump failure higher on the sedimentary slope.

Elliptical 10 to 20 cm long carbonate concretions are common in the coarse parts of thick sandstone beds. They generally occur selectively along a single horizon in a bed (Plate 33), but locally occur randomly (Plates 26 and 28). They are white to dark green and typically weather in positive relief. Bedding planes pass through some of the concretions, indicating that they formed after deposition of the sediment. This is also indicated by the presence of clastic grains, in the carbonate cement of the concretions. During regional metamorphism the carbonate in the concretions has reacted with silicate

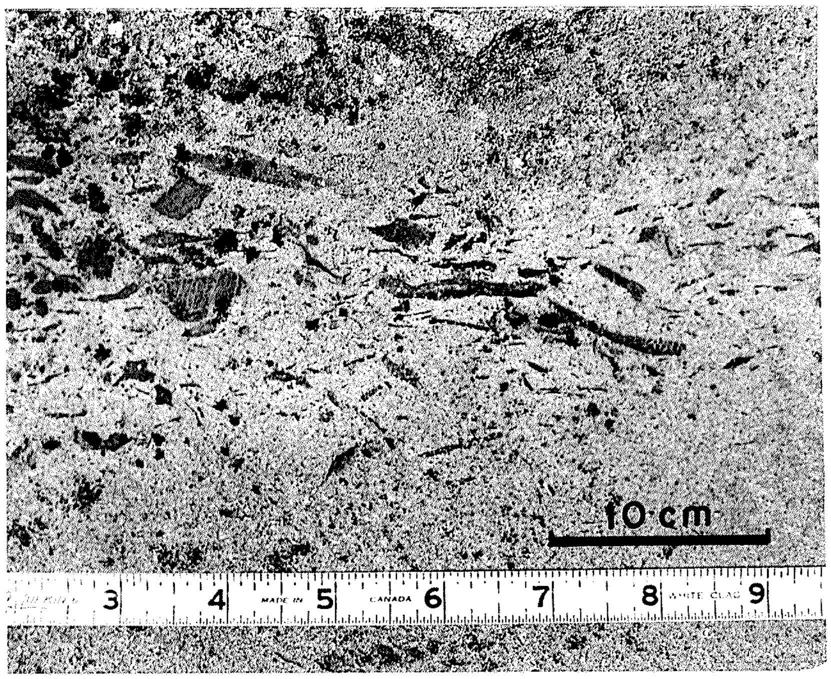


PLATE 31: Angular and tabular dark intraformational mudstone fragments in non-Bouma massive sandstone bed, File Lake Formation, north end of peninsula at south end of Morton Lake.

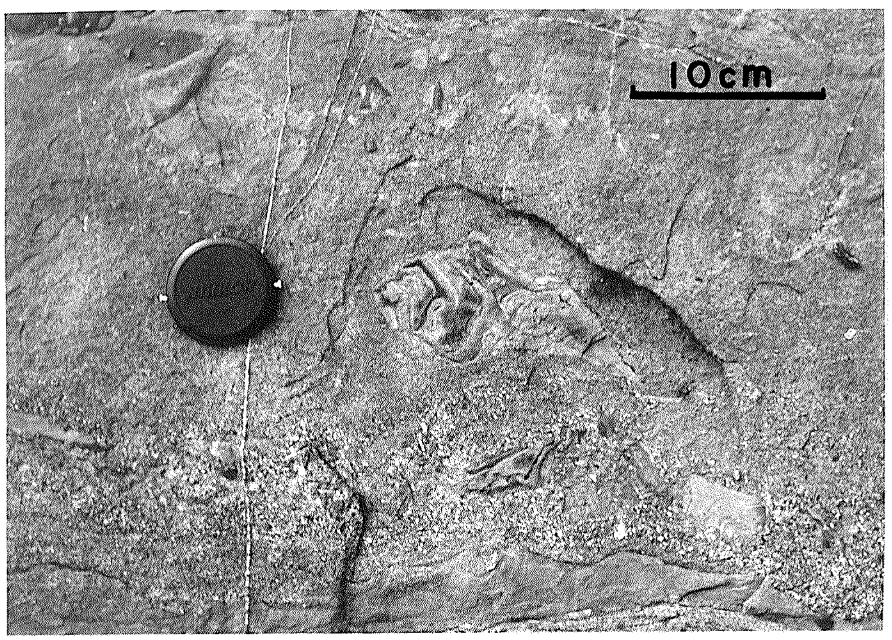


PLATE 32: Coarse-tail graded non-Bouma bed with numerous intraformational mudstone clasts, File Lake Formation, 1 km northwest of Elmes Island. Note angular intraformational clast of folded mudstone.

PLATE 33: Series of four non-Bouma graded beds containing elongate carbonate concretions, File Lake Formation, 600 m west-northwest of Elmes Island. In top bed, the concretions occur in a single horizon, in the coarsest sand, at the base of the bed.

PLATE 34: Metamorphically zoned calc-silicate concretion in strongly recrystallized File Lake Formation greywacke on Woosey Lake.

material, within and adjacent to the concretions, to form calc-silicate mineral assemblages. Acicular green actinolite porphyroblasts are abundant in the concretions on Morton Lake and give them a pseudo-gabbroic texture (Plate 28). In more highly metamorphosed greywacke, on File and Woosey Lakes, the concretions are composed of a mixture of calcic plagioclase, diopside, sphene, epidote, calcic garnet, green hornblende, sphene and calcite, and are concentrically zoned (Plate 34).

b) Distribution and characteristics of bed types in measured sections

The frequency of bed types and primary sedimentary structures in the Morton Lake area has been recorded systematically from seven representative stratigraphic sections located in Figure 6. The percentage of non-Bouma beds and Bouma beds, the latter subdivided by the division which is lowermost in the bed, is shown for each section in Table 4.

Sections I and II are from the peninsula at the south end of Morton Lake (Fig. 6). The positions of these sections relative to the base of the File Lake Formation is not known, because the base is not exposed. These sections are characterized by the predominance of non-Bouma beds, extreme thickness of beds, particularly the non-Bouma beds, and scarcity of Bouma beds which begin with B, C and D (E) divisions. The non-Bouma beds vary widely in thickness, ranging from 5 to 1140 cm. Their grain size also varies widely and although the thickest beds commonly contain the coarsest grains, many of the thin beds have grain sizes comparable to and locally coarser than thick beds. The most characteristic feature of the Bouma beds is the absence of C divisions in many beds. The P_1 index, modified from Walker (1967), for sections

TABLE 6: Frequency of bed-types and their thickness and grain size in measured sections of the File Lake Formation, Morton Lake

Section No.[1]	Thickness of Section (in m)	Bed Nos.	Bed Types (Percent)						Modified P_1 Index[3]	Bed Thickness (in cm)								Average of coarsest grain size of beds (in mm)
			Non-Bouma Beds		Bouma beds beginning with division:			A→E beds		Non Bouma beds				Bouma beds				
			Massive	Graded	A[2]	B	C			Mean	Log Normalized Mean	Thinnest bed	Thickest bed	Mean	Log Normalized Mean	Thinnest bed	Thickest bed	
I	26.900	1-14	0	78	22	0	0	0	100	229.0	62.4	5	1140	55.3	54.1	40.0	66	–
II	23.300	1-26	8	38	35	8	0	11	85	141.1	87.4	5	425	48.0	32.6	9.0	126	.51
III	65.723	1-25	4	12	40	32	8	4	72	44.0	35.5	14.5	88	16.8	12.5	3.0	45	.56
		26-50	4	20	52	12	8	4	82	25.3	18.5	11.5	55	35.0	28.5	8.0	80	.50
		51-75	0	0	52	28	8	12	66					30.1	18.5	3.0	105	.37
		76-100	0	0	30	30	40	0	45					16.0	10.5	1.1	38	.54
		101-125	0	16	56	16	0	12	80	23.0	21.5	11.0	28	29.3	16.3	0.5	99	.65
		126-150	0	4	64	16	0	16	76					40.7	26.4	8.0	138	.40
		150-178	4	4	21	4	3	64	31	23.0	21.9	16.0	30	26.6	22.6	10.0	70	.31
IV	11.330	1-25	4	0	60	28	4	4	78					14.1	11.4	5.4	58	.36
		26-50	0	0	44	40	8	8	64					13.2	10.8	3.0	33	.45
		51-75	0	0	36	32	12	20	52					15.4	12.6	3.0	38	.56
V	35.752	1-25	0	8	80	12	0	0	94	392.0	270.4	109.0	675	31.4	22.7	7.0	124	.67
		26-53	4	4	61	14	17	0	76	520.0	280.0	82.0	958	35.0	17.3	1.2	210	.53
VI	23.360	1-29	0	59	38	0	0	3	97	29.4	25.2	8.0	68	61.0	41.3	13	211	1.23
		30-58	10	28	62	0	0	0	100	28.8	20.0	5.5	68	44.5	36.9	11	113	.77
VII	18.040	1-31	6	62	23	0	3	6	91	44.3	37.3	17.0	105	112.5	90.9	25	235	1.28
I-VII	204.405	435	2.6	19.6	45.6	16	6.5	9.6	76	90.2	39.1	5	1140	30.6	19.0	0.5	235	.61

Note:

[1] Location of section is given in Figure 4.

[2] Does not include A→E beds which are classified separately.

[3] The P_1 index in this table is calculated as follows:

P_1 = % A beds + % non-Bouma beds + ½% B beds.

This differs from the P_1 index of Walker (1967) which was calculated as follows:

P_1 = % A beds -%(A→E beds) + ½% B beds.

This difference is because Walker (1967) either did not have or did not recognize non-Bouma beds and because his beds beginning with the A division included A→E beds whereas in this tabulation the A beds do not include A→E beds.

I and II is high (Table 4) and indicates that most beds in these sections initiated their deposition under high flow velocities. The method used for calculating the P_1 index is given in note 3 (Table 4).

Sections III to VII are from north Morton Lake (Fig. 6) and are in stratigraphic order. Section III is 200 to 300 m above the base of the Formation, and Section VII is at the top of the exposed section, 700 to 800 m above its base. A fault, not shown on the geological map (Fig. 2, in pocket) but shown on Fig. 6, marks the west side of the File Lake Formation on north Morton Lake and locally has removed the lower part of the Formation. Strata underlying Section III are thin-bedded mudstone, siltstone and fine sandstone, which near the base of the Formation are less than 5 cm and commonly less than 2 cm thick. They locally contain graded bedding and ripple current laminations, but due to their fine grain size, these features are poorly preserved and largely destroyed by metamorphic recrystallization. With the exception of Section IV, the grain size and bed thickness increase upward from the base to Section VII. As the beds become thicker and coarser the sedimentary structures are better preserved.

c) Interpretation

The excellent preservation of sedimentary structures in the File Lake Formation on Morton Lake suggests that these strata were not reworked by strong bottom currents. According to Walker (1976), this indicates that they were probably deposited in a deep marine basin below storm wave base.

The Bouma beds contain all the typical features of turbidity current deposits, including: 1) the Bouma zonation of internal primary structures, which Harmes and Fahnestock (1965), Walker (1965) and Middleton and Hampton (1975) have shown to be, in terms of hydraulic flow regimes, the logical consequence of slowing of a turbidity current; 2) intraformational erosion features such as scour marks and intraformation mudstone clasts formed by scouring and erosion of underlying bed by the head of the flow; and 3) soft sediment penecontemporaneous deformation structures resulting from instantaneous burial, loading, and current-induced shearing of water-saturated strata.

The non-Bouma beds are intercalated with and contain many features in common with Bouma beds, including intraformational scour marks, grain gradation and large suspended intraformational mudstone clasts. The main difference between the two bed types is that non-Bouma beds lack traction features, such as parallel laminations and current ripple laminations, that are characteristic of Bouma beds. Several authors, most notably Middleton (1970) and Middleton and Hampton (1973), have suggested that traction features are suppressed in subaqueous, mass-sediment flows that have high grain concentrations because there is a rapid restriction of grain movement and rapid deposition when the flow loses velocity. Thus, the non-Bouma beds may simply represent the deposits of higher density and higher concentration flows that were similar to turbidity currents in many respects, but which deposited their load instantaneously rather than by progressive deposition during a waning turbidity current as in Bouma beds. The common occurrence of coarse-tail grading at the base of both non-Bouma and Bouma beds attests to the high grain concentration of flows depositing these beds, because coarse-tail grading has been demonstrated experimentally (Middleton, 1967) to be characteristic of high concentration flows.

The sequences of laminated mudstone, siltstone and fine sandstone include A→E and Bouma D E beds that were probably deposited by weak, almost stagnant turbidity currents. They also contain many thin massive beds that were probably deposited by hemipelagic settling of finely comminuted material.

The bed types, bed thicknesses, grain sizes and distribution of bed types are comparable to those that have been identified on modern submarine fans. Walker and Mutti (1973) and Walker (1976) contain good descriptions of this sedimentary environment and have integrated available data into a hypothetical submarine fan model (Fig. 9). For example, the thick non-Bouma beds in the File Lake Formation on south Morton Lake are similar to Holocene and late Pleistocene strata described by Nelson and Kulm (1973) from the Cascadia channel of the Astoria fan, Oregon, and to the pebbly sandstone and massive sandstone beds described by Walker (1976), and which he considered to be typical of channels on the upper mid-fan (Fig. 9). Thus, the non-Bouma beds on south Morton Lake could be a channel facies of an Amisk subaqueous fan system.

The upward increase in grain size, bed thickness, and percentage of non-Bouma beds, and the upward decrease in Bouma beds beginning with the B, C, and D divisions, on north Morton Lake, are features characteristic of many submarine fans. According to Walker (1976), these changes are a natural consequence of an aggrading submarine fan and are due to prograding of the fan into its depositional basin, such that coarse-grained, thick-bedded mid-fan deposits build out over earlier finer-grained, thinner bedded outer fan deposits. The lower third of the Formation, below Section III, comprises a mixture of thin fine-grained hemipelagic beds and thin A→E and base truncated Bouma beds. These

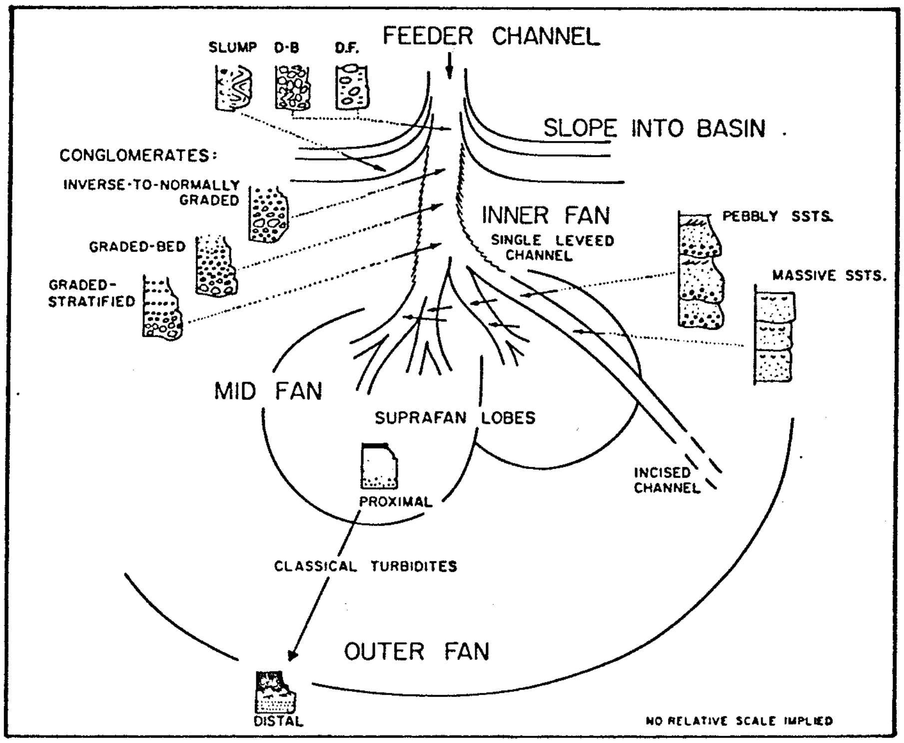


FIGURE 9. Plan view of idealized submarine fan showing anticipated distribution of turbidite and turbidite-associated facies (after Walker, 1976).

strata are similar to those normally associated with the outer fan and which Walker (1976) referred to as distal turbidites (Fig. 9). The middle third of the Formation, between Sections III to V, is composed mainly of Bouma beds, over 50 percent of them beginning with the A division; it also includes a few local non-Bouma beds and averages 20 percent A→E beds (Table 4). These strata are typical of supra-fan lobes of the lower mid-fan and correspond to strata which Walker (1976) referred to as proximal turbidites (Fig. 9). The upper third of the Formation, which includes Sections VI and VII, is composed of coarse-grained thick beds that are a mixture of non-Bouma and Bouma beds (Table 4). These strata are similar to those normally associated with the upper mid-fan and which Walker (1976) referred to as massive sandstone, pebbly sandstone and proximal turbidite beds (Fig. 9).

On the northwest shore of File Lake, across a major antiform from strata on Morton Lake, the File Lake Formation has an upward decrease in bed thickness and grain size and an increase in percentage of mudstone beds, opposite to the upward changes observed on north Morton Lake. This suggests that a different fan may have deposited the File Lake section, possibly one that was slowly abandoned. This could occur if the supply of sediment to File Lake section was from a volcano with decreasing activity. The Morton Lake section may have been fed by a volcano with increasing activity and consequent increase in sediment supply.

4.4.3 Petrography

On Morton Lake, where metamorphic grade is greenschist facies, primary textures are well preserved, particularly in the coarser greywackes. Elsewhere, where metamorphic grades are higher, primary textures have been largely destroyed. Consequently, all petrographic data is from exposures on Morton Lake.

a) Greywacke and siltstone petrography

Detrital modes of 15 greywacke and 3 coarse siltstone samples are given in Table 5. They are composed dominantly of felsic volcanic rock fragments and volcanic quartz and plagioclase crystal fragments, and are lithic and feldspathic greywackes (Fig. 10, after Pettijohn, 1957). They also contain lesser amounts of intermediate to mafic volcanic fragments, chert fragments, translucent microcrystalline rock fragments, opaque and semi-opaque amorphous fragments (probably collophane), felsic granophyric tonalite fragments, and angular intraformational mudstone fragments. The framework grains are surrounded by and commonly supported by a matrix composed of silt- and clay-sized particles that are largely the same composition as the framework grains. The framework grains and matrix are described in Table 6.

Mineralogically, compositionally, and texturally the greywacke and siltstone are immature. This is evident from an abundance of mechanically unstable volcanic rock fragments and by the abundance of plagioclase relative to the mechanically more stable quartz grains. The framework clasts are generally angular to subrounded and poorly sorted (Plate 35), and this in conjunction with the euhedral volcanic shapes of quartz and plagioclase grains (Plates 35a, 36 and 37) indicate limited mechanical abrasion. Some abrasion, in particular chert and felsic granophyre fragments, is indicated by rounding of their margins.

TABLE 5 : Detrital modes[1] of meta-greywacke and meta-siltstone, File Lake Formation, Morton Lake

Column No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Sample No.	F07-179-1	F07-179-2	F07-184-1	F07-185-3	F07-185-4	F07-187-1	F07-189-2B	F07-189-C	F07-190-1A	F07-751-1	F07-751-3	F07-3745-1B	F07 85-2	F07-89-5	F07-90-1	F07-90-1	F07-93-1	F07 402-B
Monocrystalline quartz	0.9	3.1	2.4	6.0	1.5	1.5	5.5	3.9	2.2	6.5	8.5	1.7	2.3	1.4	2.3	1.8	3.5	2.6
Polycrystalline quartz		1.7		2.1			0.2	1.5	0.7	1.0	3.5		0.8		1.3	0.5	4.6	4.3
Plagioclase	18.0	24.2	22.0	9.5	10.8	15.7	13.4	3.9	12.3	6.7	5.3	12.4	1.2	0.4	1.5	2.0	0.9	0.6
Quartz- and plagioclase-phyric felsic volcanic rock fragments	1.3	5.8	4.1	4.2	26.7	0.5	9.1	21.6	5.5	23.0	6.3		5.8		0.3	1.3		
Aphyric felsic volcanic rock fragments	6.7	4.4	12.7	14.5	11.7	3.2	8.9	15.7	23.3	16.4	16.4	5.9	29.5	12.8	20.3	16.8	14.9	13.7
Mafic and intermediate volcanic rock fragments	0.3	1.3	1.2	0.7	2.2		3.6	9.0	0.1	3.6	0.8		4.3		0.1	1.4	6.4	
Chert rock fragments		3.5	1.4	6.1	2.4		2.5	6.8	8.8	8.4	8.1	0.1	4.1	0.4	3.3	2.6	7.4	5.4
Translucent microcrystalline rock fragments		0.2	0.1	0.5		0.1					0.5							0.5
Opaque and semi-opaque amorphous rock fragments				1.3	0.5		0.4	0.3		1.0								
Felsic granophyre fragments		3.3						8.8	1.1	2.5	8.0		0.8		0.5			0.2
Mudstone fragments					8.9		5.9	1.8		0.4				5.6				1.2
Total framework	27.2	47.5	43.9	45.5	64.7	21.0	50.5	73.3	54.0	69.5	57.9	20.1	48.8	20.6	29.6	26.4	37.7	31.2
Plagioclase, quartz and rock fragments less than 0.06 mm	57.4	42.3	46.1	42.0	32.3	55.4	38.5	20.5	31.6	22.1	31.9	67.4	32.3	36.9	43.8	53.0	43.0	53.0
Biotite[2]		9.0		1.4	3.0	12.0	12.0			6.5	5.9	11.7	16.9	32.6	24.8	20.5	17.9	15.7
Actinolite[2]			8.1	0.1				6.0	13.0	1.2	3.9		0.3					
Chlorite[2]	15.1	0.2	0.3			11.6				0.1	0.4		1.7		1.4			
Sericite[2]	0.3	0.2												9.7			0.5	
Calcite		0.8	1.3	11.5					1.4	0.6		0.5						
Opaque minerals			0.3	0.5				0.2				0.3		0.2	0.4	0.1	0.9	0.1
An content plagioclase	38,38,39	37	41	31	34	23,30,32	34,35,36 37,38		40,42,45			37						
Coarsest size graction	1 mm	3-4 mm	1-2 mm	1-2 mm	3-5 mm	1 mm	3-8 mm	3-5 mm	5-7 mm	3-4 mm	2-3 mm	1-2 mm	1-2 mm	1 mm	1-2 mm	1-2 mm	1-2 mm	2-3 mm

Note: 1 Based on an average of 680 points per thin section. Points were 1 mm apart along traverses 1 mm apart. Minimum points counted was 473. Main detrital components are described in Table 6.

2 Biotite, tremolite, chlorite and sericite are metamorphically generated from fine-grained clay-rich matrix.

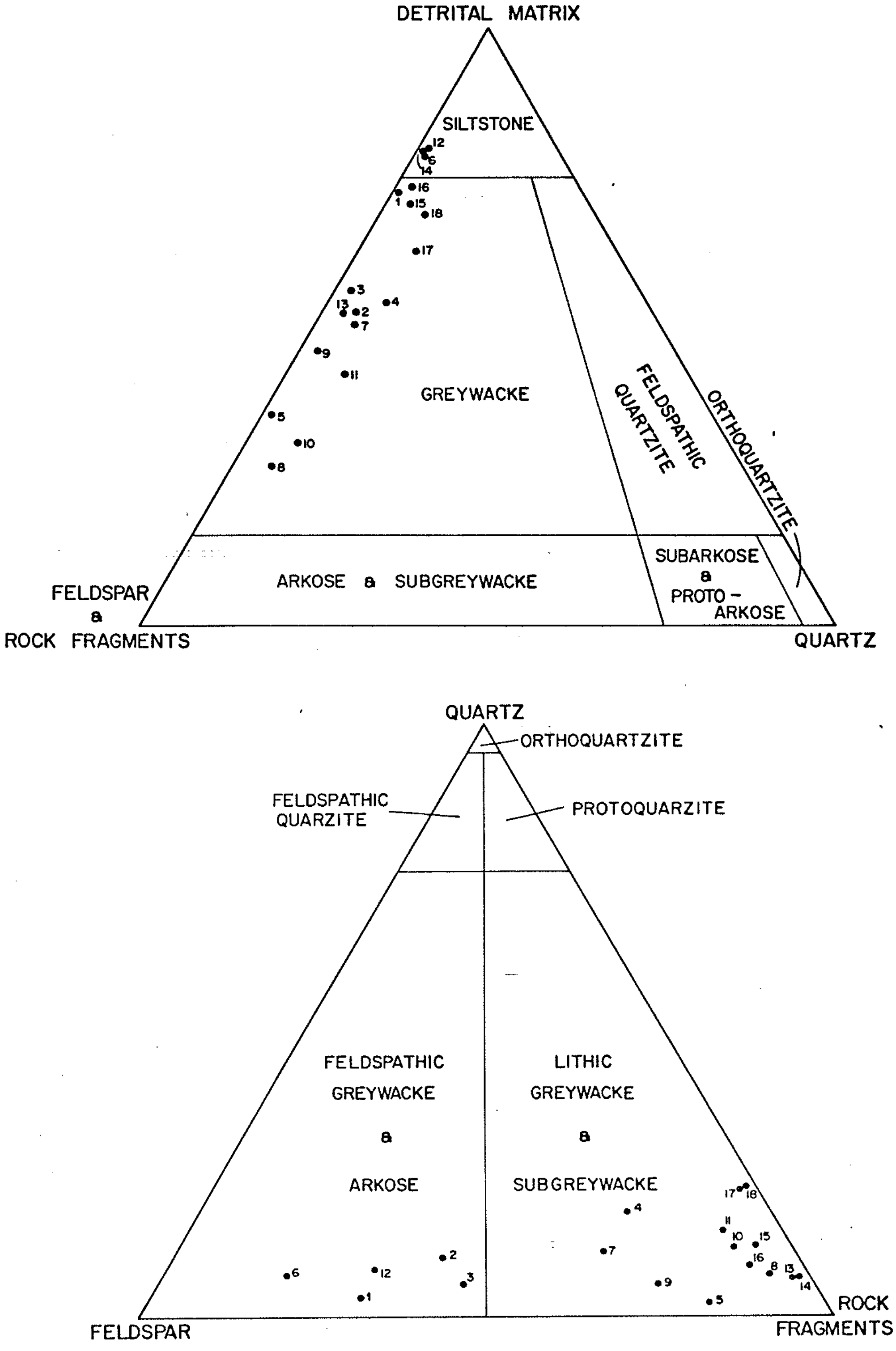


FIGURE 10. Ternary diagram (after Pettijohn, 1957) showing detrital modes of greywackes and siltstones, File Lake Formation, Morton Lake.

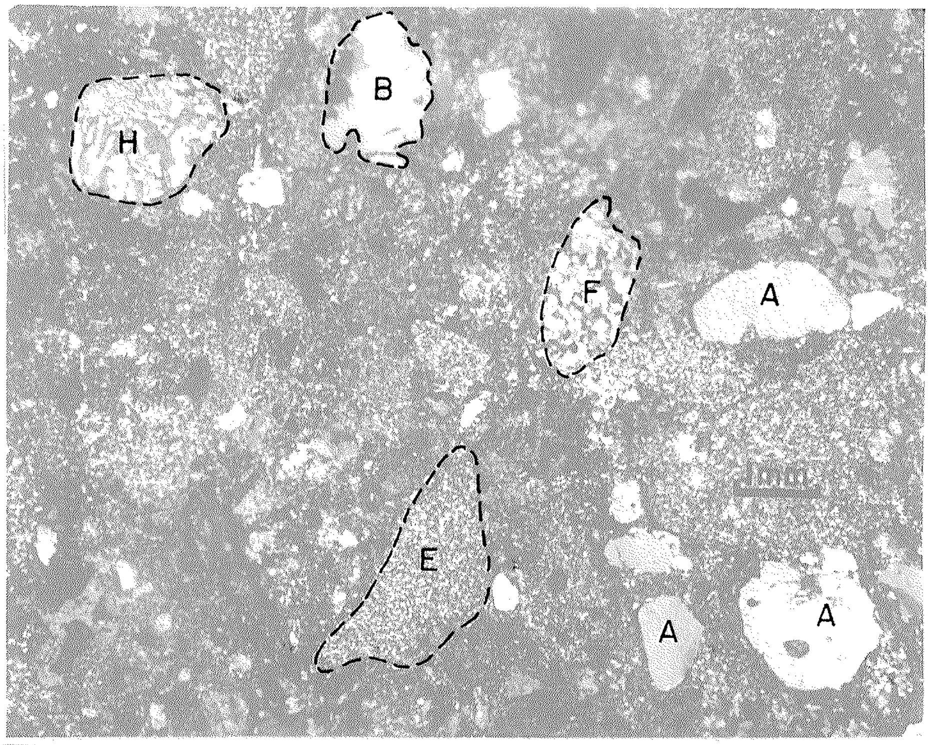
TABLE 6: Description of detrital components in greywackes from File Lake Formation Morton Lake

Monocrystalline quartz:	Large (0.5 to 3 mm) clear single-unit grains; generally round in shape, locally with embayed margins and partial sheaths of microcrystalline felsic material; some have crystal faces; grains typically have undulose extinction due to post-depositional deformation; the shape and local sheaths of microcrystalline felsic material indicate that some, and possibly all, of the grains were originally volcanic phenocrysts.
Polycrystalline quartz:	Large (1 to 3 mm) clear multiple unit grains; generally round in shape, but include subangular varieties; rounded grains locally have embayed margins; internal grain size of clasts varies from 0.3 to 1 mm; clasts have undulose extinction due to post-sedimentation deformation; internal contacts between units in grains are typically lobate-sutured, probably also due to post-sedimentation deformation; polycrystalline quartz similar to that forming framework grains is also present in felsic granophyre rock fragments; embayed margins suggest that some grains were originally volcanic phenocrysts whereas similarity to quartz in felsic granophyre clasts suggest that others were derived from felsic granophyre intrusions.
Plagioclase:	Large (0.3 to 1 mm) clear subhedral to euhedral crystal fragments ranging from An_{23} to An_{45} and averaging An_{35}; generally well twinned with abundant albite and Carlsbad twins and rare pericline twins; locally have oscillatory zoning; high temperature structure present in some grains; identical in size, shape, twinning and composition to plagioclase phenocrysts in felsic and intermediate volcanic rock fragments; the shape, zoning and high temperature structure also indicate that at least some, and probably most, of the grains were originally volcanic phenocrysts; the An contents of the plagioclase crystal fragments suggest a dacitic to andesitic source.

Porphyritic felsic volcanic rock fragments:	Angular to subrounded, but generally subangular clasts; 2 to 8 mm in size; plagioclase- and quartz-phyric; phenocrysts range from 0.3 to 2 mm in size; groundmass is slightly recrystallized, very fine-grained (<0.03 mm) mixture of quartz, plagioclase and 2 to 10 percent tiny secondary crystals of biotite and muscovite; quartz phenocrysts locally have embayed margins; clasts within this group have variable matrix grain size, phenocryst size and abundance, and groundmass mica content.
Aphyric felsic volcanic rock fragments:	Very fine-grained (<0.03 mm) clasts which vary in size from 0.5 to 5 mm; vary from angular to subrounded, but are generally subangular; clasts are composed of recrystallized mixture of plagioclase and quartz with 2 to 10 percent secondary biotite and muscovite; grain size and mica content vary from clast to clast; clasts are interpreted to be largely volcanic because they are identical to the groundmass of the porphyritic felsic volcanic rock fragments.
Mafic and intermediate volcanic rock fragments:	Lenticular, wispy clasts, 0.5 to 2 mm long; comprise recrystallized mixtures of actinolite, biotite, chlorite and lesser amounts of plagioclase and quartz; clasts vary in percentage of mafic minerals; more felsic varieties generally less recrystallized, less flattened, and locally plagioclase-phyric.
Chert fragments:	Fine-grained (0.03 to 0.2 mm) granoblastic-polygonal aggregates of quartz; clast size is variable, but generally is between 0.5 and 1 mm; grain contacts are straight and not sutured; clasts are subangular to rounded, but generally are subrounded.
Translucent high relief microcrystalline rock fragments:	Microcrystalline (<0.03 mm) mixture of colourless to pale yellow chlorite, colourless zoisite and minor quartz and opaque minerals; clasts are subangular and 0.5 to 1 mm in size; possibly altered vitric volcanic fragments.

Opaque and semi-opaque rock fragments:	Clasts are angular and 0.5 to 1.5 mm in size; include pyrite clasts but most are black, do not reflect light and are amorphous; X-ray analysis indicates presence of apatite and suggests clasts are collophane; chemical tests indicate fragments contain phosphorus ; amorphous clasts contain crystals of plagioclase; several intermediate volcanic clasts with plagioclase-bearing black amorphous margins were observed; most clasts are probably collophane and appear to be formed by alteration of volcanic clasts, either in the volcanic environment or during diagenesis.
Felsic granophyre fragments:	Fine- to medium-grained (0.5 to 2 mm) tonalite with graphically intergrown quartz and plagioclase; no mafic or micaceous minerals; vary from subangular to rounded, but generally are subrounded; range from 1 to 4 mm in size; source of clasts probably an unroofed epizonal intrusion, but it could also have been the centre of a felsic dome or ejected from a vent.
Mudstone fragments:	Angular, massive, homogeneous intraformational mudstone and siltstone fragments; 0.5 to 8 mm in size; comprise silt-sized grains of quartz, plagioclase and rock fragments, 10 to 25 percent biotite and minor amounts of chlorite, sericite, actinolite and opaque minerals; layering present in some fragments; fragments vary widely in composition, most notably in their biotite contents; angularity of fragments and similarity to formational mudstone layers indicates they are probably intraformational rip-up clasts.
Detrital matrix:	Fine-grained interstitial material generally less than 0.03 mm but up to 0.06 mm in grain size; dominantly quartz and plagioclase plus some small rock fragments; includes approximately 20 percent biotite and 5 percent combined actinolite, chlorite, sericite, calcite and oxide minerals; biotite, actinolite and, more rarely, chlorite and muscovite form small porphyroblasts 0.1 to 1 mm in size.

(a)



(b)

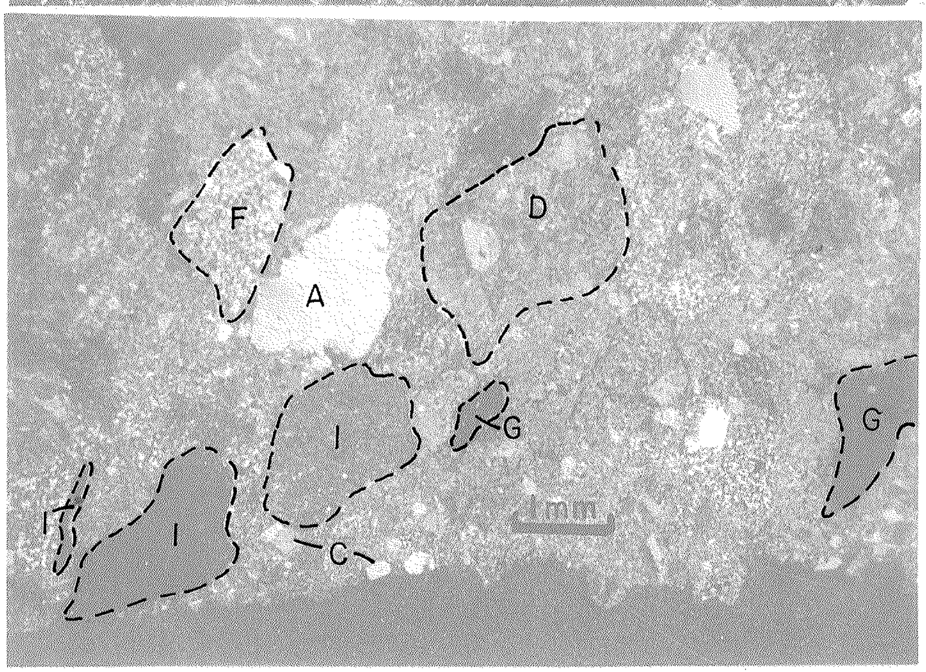


PLATE 35: Photomicrographs (polarized light) of lithic greywacke of the File Lake Formation, south Morton Lake, showing wide variety of fragment types including: A monocrystalline quartz; B polycrystalline quartz; C plagioclase; D plagioclase-phyric felsic volcanic rock fragments; E aphyric felsic volcanic rock fragments; F fine-grained chert rock fragments; G opaque and semi-opaque amorphous fragments; H felsic granophyre fragments; and I mudstone fragments. Note embayed margins on monocrystalline quartz grains in (a) and the load structures at the base of the greywacke bed in (b).

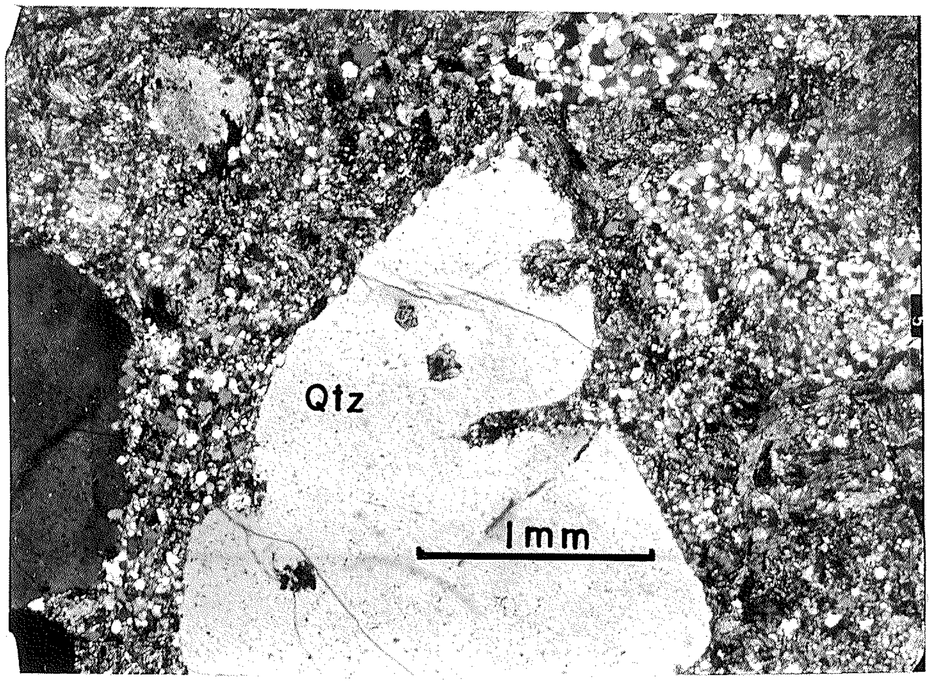


PLATE 36: Photomicrograph (polarized light) of embayed quartz grain in lithic greywacke from the File Lake Formation, south Morton Lake.

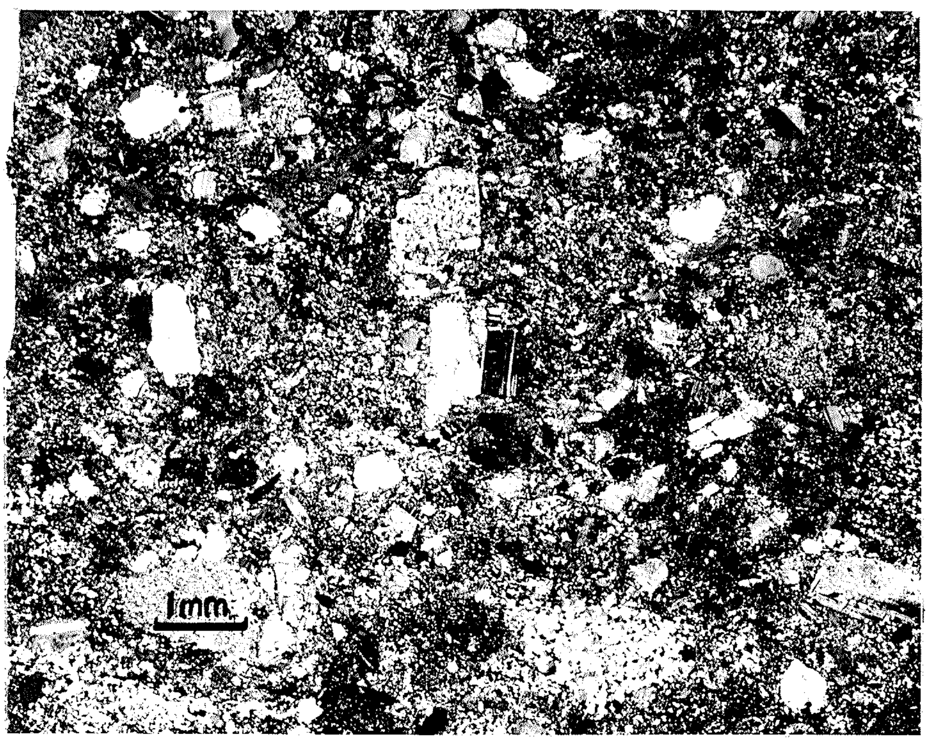


PLATE 37: Photomicrograph (polarized light) of feldspathic greywacke from the File Lake Formation, south Morton Lake. Note abundant fragments of well-twinned plagioclase (An_{41}).

The matrix is probably largely detrital in origin, because it consists mainly of silt-sized quartz, plagioclase and rock fragments. The biotite, however, was formed during metamorphic recrystallization, probably from clay minerals. Actinolite prophyroblasts and metamorphically recrystallized calcite in the matrix suggests that there was probably some original carbonate cement.

The average of framework clast types, recalculated to 100 percent, in 18 modally analyzed greywacke and siltstone samples is given in Table 7. With the exception of intraformational mudstone, they are all either obviously volcanic or can be interpreted to be volcanic in derivation. For example, many of the monocrystalline and a few of the polycrystalline quartz grains have resorbed margins and are locally subhedral, features characteristic of volcanic quartz; and some plagioclase grains have subhedral shape, oscillatory zoning and high temperature structure, features characteristic of volcanic plagioclase. Chert is a common sediment in volcanic successions and the felsic granophyre clasts could be from high level subvolcanic intrusions, centres of felsic extrusive domes or volcanic vent ejecta. The amorphous collophane clasts could be altered clastic material around a fumerole. No metamorphic or obviously deep-seated plutonic fragments were noted in the File Lake Formation on Morton Lake.

b) Mudstone petrography

Mudstones have a grain size less than 0.06 mm and are partially recrystallized with small porphyroblasts of biotite, sericitic muscovite, chlorite and actinolite. Detrital components in the matrix include small felsic rock fragments and grains of quartz and

TABLE 7: Average of framework clast types recalculated to 100 percent in 18 greywackes, File Lake Formation, Morton Lake

Monocrystalline quartz	7.5%
Polycrystalline quartz	2.8%
Plagioclase	23.7%
Porphyritic felsic volcanic rock fragments	11.2%
Aphyric felsic volcanic rock fragments	35.5%
Mafic to intermediate volcanic rock fragments	4.6%
Fine-grained chert rock fragments	8.4%
Translucent microcrystalline rock fragments	0.3%
Opaque and semi-opaque cryptocrystalline rock fragments	0.3%
Felsic granophyre clasts	2.2%
Mudstone clasts	3.5%

plagioclase. The biotite, sericitic muscovite, chlorite and actinolite probably were derived from clay minerals and carbonate cement. Detrital modes of the mudstones were not determined, but their composition is probably similar to that of associated siltstone and greywacke samples, except for their higher content of mica and mafic minerals.

4.4.4 Major element geochemistry

Nine greywacke samples and fourteen mudstone samples have been analyzed for major elements (Tables 8 and 9). They include relatively unrecrystallized samples (Unit 13) from Morton Lake, and strongly recrystallized samples (Unit 13b) from File and Woosey Lakes. There does not appear to be any significant chemical differences between the highly recrystallized samples and weakly recrystallized equivalents. The apparent difference in chemistry of highly and weakly recrystallized mudstones in Table 8 is probably due to higher silt- contents in the higher grade samples.

The greywacke samples (Table 8) have typical greywacke major element chemistry, including excess Na_2O over K_2O (Fig. 11) and, relative to other sandstones, high Al_2O_3, MgO and total iron contents. They plot in the greywacke field on a log-log plot of SiO_2 / Al_2O_3 versus Na_2O / K_2O (Fig. 12). They show a wide range in composition, which largely reflects variation in plagioclase to rock fragment ratio and in abundance of clay minerals. In Table 8, analyses in columns 3 to 8 are listed, as closely as possible, in order from finest to coarsest grained. These samples show an increase in SiO_2 content and a partial decrease in Al_2O_3, total iron, MgO and TiO_2 contents with increasing grain size. The decrease in Al_2O_3, total iron, MgO and TiO_2 is probably due to a

TABLE 8: Chemical analysis[1,2] of meta-greywackes from the File Lake Formation

UNIT NO.[3]	1	2	3	4	5	6	7	8	9
	13					13b			
SiO_2	63.3	63.4	62.6	62.95	64.85	67.0	67.55	68.15	71.35
Al_2O_3	14.25	15.5	17.0	16.8	15.5	16.65	15.55	13.35	13.10
Fe_2O_3	1.83	0.62	0.30	1.04	1.08	1.07	1.11	0.82	0.53
FeO	6.96	5.40	7.00	6.10	5.97	5.30	4.29	6.71	5.23
MgO	4.17	2.98	3.21	2.82	2.61	2.04	2.35	1.90	1.86
CaO	1.98	4.02	3.58	3.20	3.57	1.25	3.20	0.40	2.39
Na_2O	1.78	3.06	2.77	2.78	3.15	1.78	2.80	4.27	2.49
K_2O	2.29	0.54	1.15	1.80	0.98	2.24	1.14	2.05	1.65
TiO_2	0.85	0.51	0.56	0.54	0.48	0.48	0.32	0.41	0.42
P_2O_5	0.13	0.31	0.15	0.18	0.18	0.14	0.15	0.09	0.16
MnO	0.08	0.08	0.07	0.08	0.13	0.07	0.07	0.12	0.05
$H_2O\pm$	2.56	2.62	1.39	1.72	1.30	1.66	1.66	0.60	0.99
CO_2	0.17	0.75	0.27	0.20	0.34	0.40	0.05	0.34	0.11
S									
TOTAL	100.35	99.8	100.05	100.02	100.15	100.1	100.25	99.3	100.33
Total Fe as Fe_2O_3	9.49	6.56	8.00	7.75	7.65	6.90	5.83	8.20	6.28

1 Weakly recrystallized silt-rich lithic meta-greywacke (F07-90-1); see Table 5, column 15, for modal analysis).

2 Weakly recrystallized feldspathic meta-greywacke (F07-184-1; see Table 5, column 3, for modal analysis).

3 Biotite-garnet-bearing, fine-grained meta-greywacke (F07-30-2).

4 Garnet-biotite-bearing meta-greywacke (F07-08-1).

5 Garnet-hornblende-biotite-bearing, fine-grained meta-greywacke (F07-01-2).

6 Garnet-muscovite-sillimanite-staurolite-bearing, interlayered meta-siltstone and meta-greywacke (F07-762-1).

7 Garnet-chlorite-biotite-bearing, medium-grained meta-greywacke (F07-738-1).

8 Garnet-biotite-bearing meta-greywacke (F07-1798-1).

9 Garnet-biotite-bearing, medium- to coarse-grained meta-greywacke (F07-705-2).

[1] Chemical analyses by Analytical Laboratory of Manitoba Mineral Resources Division

[2] Sample sites are located on geological map (Fig.2, in pocket)

[3] Unit number corresponds to those on geological map (Fig.2, in pocket)

TABLE 9: Chemical analysis[1,2] of meta-mudstones from the File Lake Formation

UNIT NO.[3]	1	2	3	4	5	6	7
		13				13b	
SiO_2	57.3	58.5	59.6	60.9	58.5	59.35	59.1
Al_2O_3	17.1	17.5	17.4	16.0	20.4	21.1	19.6
Fe_2O_3	2.10	1.30	1.15	1.36	2.64	2.65	2.73
FeO	7.99	6.94	6.79	7.32	4.74	4.58	4.06
MgO	4.22	3.79	3.66	3.85	2.86	2.69	2.89
CaO	0.95	1.55	1.43	2.37	1.40	1.20	1.95
Na_2O	1.39	2.45	2.23	1.97	1.75	1.68	1.83
K_2O	3.57	2.78	3.28	2.34	3.72	2.87	2.73
TiO_2	0.77	0.77	0.82	0.82	0.54	0.58	0.58
P_2O_5	0.18	0.09	0.09	0.70	0.14	0.15	0.22
MnO	0.05	0.05	0.05	0.05	0.05	0.05	0.06
$H_2O\pm$	3.89	2.92	2.45	2.40	2.25	2.05	2.36
CO_2	0.18	0.13	0.15	0.38	0.10	0.08	0.2
S		0.25	0.17		0.05	0.03	
GRAPHITIC CARBON[4]		0.25	0.25		*	*	*
TOTAL	99.6	99.4	99.56	100.45	99.15	99.1	98.35
Total Fe as Fe_2O_3	10.89	9.01	8.70	9.41	7.85	7.68	7.20

UNIT NO.	8	9	10	11	12	13	14
				13b			
SiO_2	63.1	63.95	64.6	65.4	58.55	64.63	58.90
Al_2O_3	17.8	19.55	17.95	15.75	18.95	19.00	21.70
Fe_2O_3	1.15	0.98	1.12	1.07	0.51	1.56	1.20
FeO	4.53	4.40	4.88	4.27	5.61	3.63	5.10
MgO	2.55	2.32	2.65	2.22	4.07	2.49	2.63
CaO	2.17	1.27	1.50	6.03	2.70	3.48	1.54
Na_2O	2.72	1.65	1.93	1.39	1.85	1.54	1.39
K_2O	3.02	2.06	2.72	1.50	4.07	1.60	2.41
TiO_2	0.49	0.80	0.54	0.43	0.53	0.42	0.63
P_2O_5	0.18	0.12	0.18	0.18	0.17	0.21	0.50
MnO	0.05	0.03	0.04	0.09			
$H_2O\pm$	2.02	1.71	1.86	1.35	1.60	1.12	1.78
CO_2	0.15	0.3	0.40	0.20	0.60	tr	0.00
GRAPHITIC CARBON[4]		*			2.58	0.64	1.56
TOTAL	99.95	99.15	100.35	99.9	99.97	100.32	99.34
Total Fe as Fe_2O_3	6.13	5.82	6.49	5.77	6.57	5.55	6.81

1 Weakly recrystallized meta-mudstone (F07-89-5) with scattered sand-sized lithic particles (see Table 5, column 14, for modal analysis).

2 Weakly recrystallized meta-mudstone (04-74-M2, unpublished analysis from W.D. McRitchie).

3 Weakly recrystallized meta-mudstone (07-74-M1, unpublished analysis from W.D. McRitchie).

4 Weakly recrystallized meta-mudstone (F07-89-3).

5 Staurolite-muscovite-biotite-bearing laminated meta-mudstone (F07-3278-1) (contains pseudomorphs of andalusite replaced by muscovite + staurolite + quartz).

6 Sillimanite-andalusite-staurolite-muscovite-biotite-bearing mudstone hornfels (F07-3379-1).

7 Garnet-muscovite-staurolite-biotite-bearing meta-mudstone (F07-30-1).

8 Staurolite-muscovite-garnet-biotite-bearing meta-mudstone (F07-31-1).

9 Sillimanite-staurolite-biotite-bearing meta-mudstone (F07-632-1).

10 Sillimanite-staurolite-muscovite-biotite-bearing meta-mudstone (F07-757-1).

11 Garnet-hornblende-biotite-bearing meta-mudstone (F07-943-2).

12 Garnetiferous argillite (Harrison, 1949, I, p.26).

13 Staurolite schist (Harrison, 1949, II, p.26).

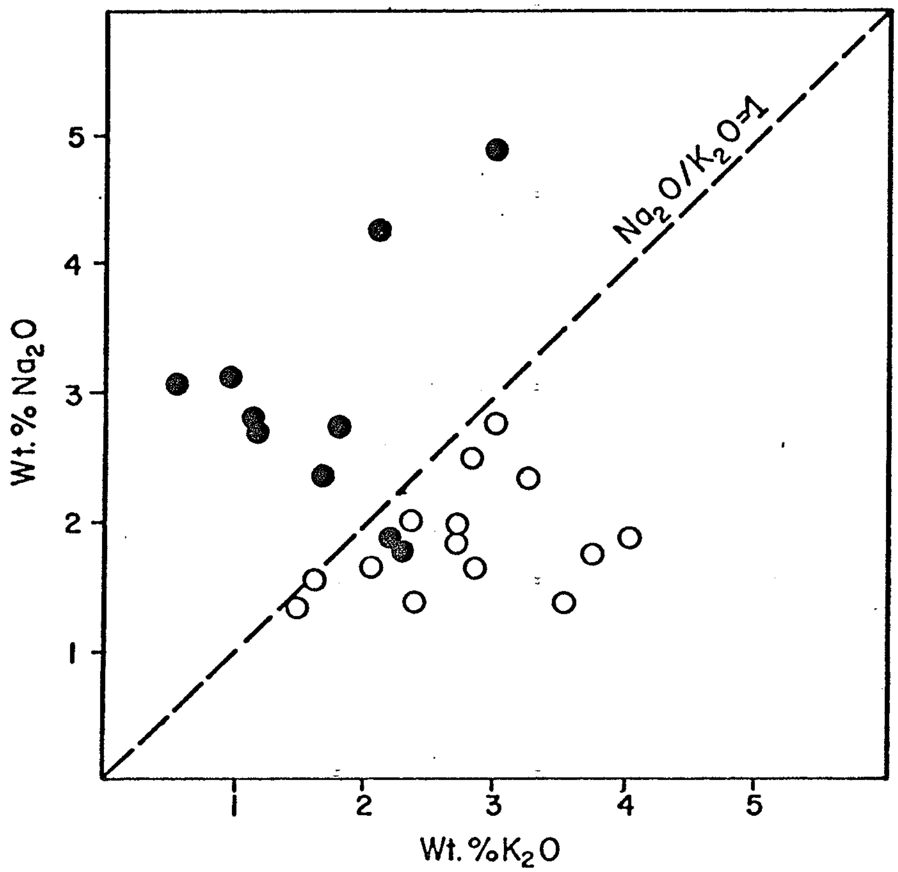
14 Sillimanite-staurolite schist (Harrison, 1949, III, p.26).

[1] Chemical analyses by Analytical Laboratory of Manitoba Mineral Resources Division.

[2] Sample sites are located on geological map (Fig. 2, in pocket).

[3] Unit number corresponds to those on geological map (Fig. 2, in pocket).

[4] Samples with asterick have graphitic carbon in undissolved residue.



● Greywacke and metagreywacke, File Lake Formation.

O Mudstone and metamudstone, File Lake Formation.

FIGURE 11 : K_2O versus Na_2O diagram (after Pettijohn, 1963), metasedimentary rocks of the File Lake Formation.

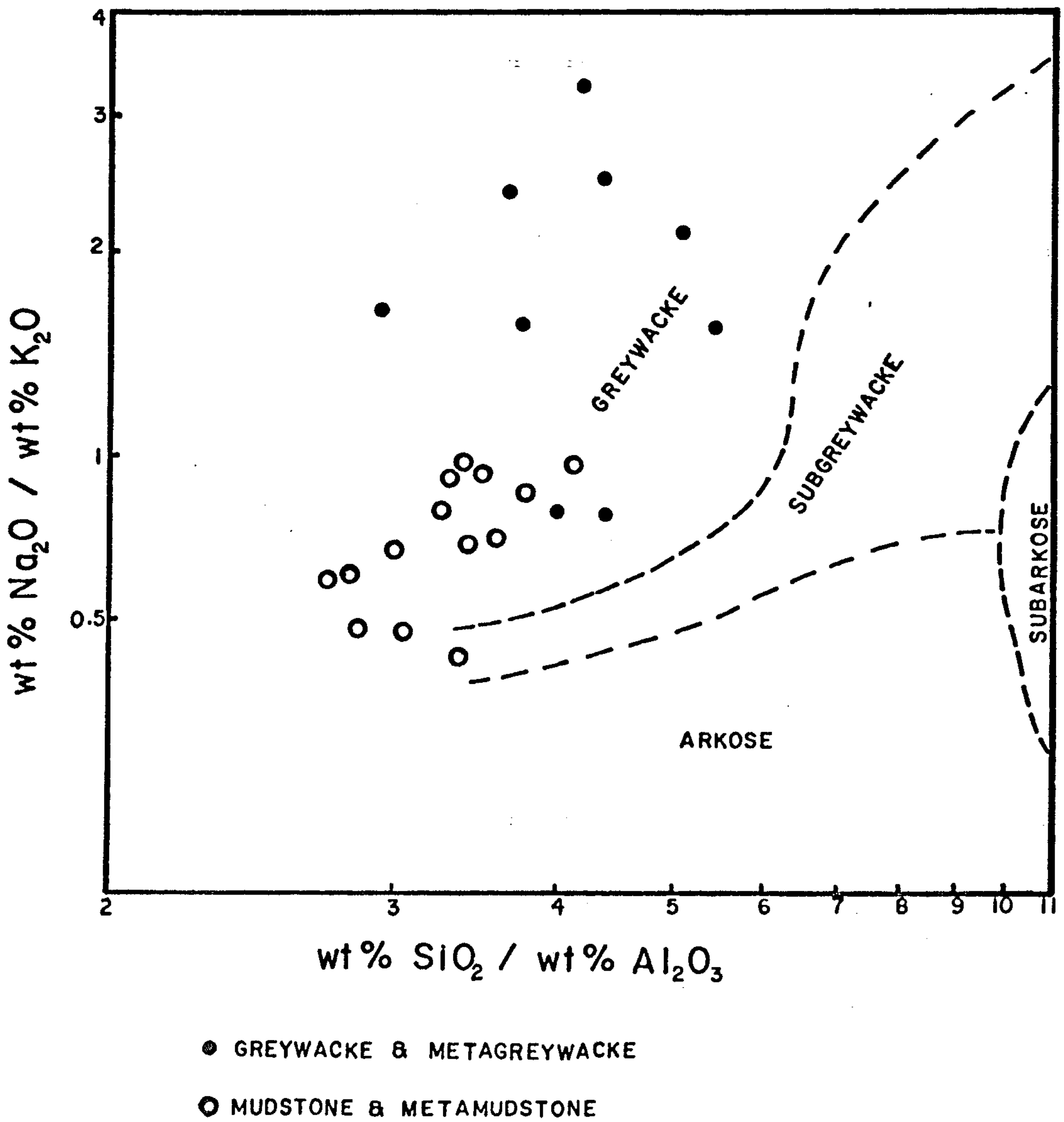


FIGURE 12: Log (SiO_2/Al_2O_3) vs log (Na_2O/K_2O) diagram (after Pettijohn et al, 1972) for meta-sedimentary rocks of the File Lake Formation.

decrease in clay-rich matrix. The decrease in Al_2O_3 content does not represent a decrease in plagioclase content because there is no parallel decrease in Na_2O contents and in Na_2O / K_2O ratios.

The mudstone samples (Table 9), have typical mudstone chemistry, including $K_2O > Na_2O$ (Fig. 10). Relative to greywacke samples, they have lower SiO_2, CaO and Na_2O and higher Al_2O_3, total iron, MgO, TiO_2 and K_2O contents. This probably reflects lower quartz and plagioclase and higher clay contents in the mudstone.

The average composition of File Lake Formation greywackes and mudstones is very similar to other suites of Precambrian greywackes and mudstones (Table 10). Relative to Phanerozoic mudstones, the Precambrian varieties have low CaO and CO_2 contents, which largely reflects their lower content of organic fossil detritus. In addition, both Precambrian mudstone and greywacke have lower H_2O contents and Fe_2O_3 / FeO ratios than do Phanerozoic varieties, due to higher grade metamorphism and consequent loss of water from clay minerals and reduction of Fe_2O_3 to FeO. For this reason, meaningful comparisons between the early Precambrian and Phanerozoic analyses can only be made volatile- and carbonate-free (bracketed analyses, Table 10), with the FeO and Fe_2O_3 values totalled. Comparisons made this way indicate that the early Precambrian greywackes (columns 1 to 3) and mudstones (columns 5 and 6) have lower SiO_2 contents and higher Al_2O_3, total iron, MgO, CaO and Na_2O contents than Phanaerozoic greywackes (Column 4) and platformal mudstones (column 7); but Phanerozoic geosynclinal mudstones (Column 8) are very similar to early Precambrian mudstones. These differences, rather than reflecting a secular variation in chemistry of greywackes and mudstones, more likely reflect the immaturity, rapid deposition and

TABLE 10: Chemical composition[1] of average metagreywacke and metamudstone of the File Lake Formation compared to typical early Precambrian and Phanerozoic greywackes and mudstones

	GREYWACKE				MUDSTONE			
	1	2	3	4	5	6	7	8
SiO_2	65.7 (67.2)	67.47	63.66 (66.9)	66.7 (70.7)	60.9 (62.5)	57.80 (59.87)	56.2 (64.1)	53.4 (61.9)
Al_2O_3	15.3 (15.6)	15.76	14.85 (15.6)	13.5 (14.3)	18.6 (19.1)	18.37 (19.0)	15.1 (17.2)	16.4 (19.0)
Fe_2O_3	0.93 (6.86)	6.10	1.01 (5.97)	1.6 (5.4)	1.54 (7.38)	1.67 (8.16)	3.4 (6.5)	3.4 (7.1)
FeO	5.78		4.67	3.5	5.64	6.21	2.3	2.8
MgO	2.66 (2.72)	1.70	2.99 (3.14)	2.1 (2.2)	3.06 (3.14)	3.93 (4.07)	2.1 (2.4)	2.4 (2.8)
CaO	2.62 (2.38)	1.98	2.63 (1.20)	2.5 (1.4)	2.11 (1.96)	1.89 (1.78)	4.4 (1.3)	5.8 (1.7)
Na_2O	2.92 (2.99)	3.20	3.14 (3.30)	2.9 (3.1)	1.84 (1.89)	2.19 (2.27)	1.1 (1.3)	1.1 (1.3)
K_2O	1.54 (1.57)	2.59	2.30 (2.42)	2.0 (2.1)	2.76 (2.83)	3.26 (3.38)	2.6 (3.0)	2.7 (3.1)
TiO_2	0.51 (0.52)	0.49	0.57 (0.60)	0.6 (0.6)	0.66 (0.68)	0.70 (0.72)	0.8 (0.9)	0.7 (0.8)
P_2O_5	0.19 (0.19)		0.14 (0.15)	0.2 (0.2)	0.22 (0.23)	0.19 (0.20)	0.1 (0.1)	0.2 (0.2)
MnO	0.08 (0.08)	0.09	0.11 (0.12)	0.1 (0.1)	0.05 (0.05)	0.09 (0.09)	0.1 (0.1)	0.1 (0.1)
H_2O ±	1.61		2.17	3.0	2.09	3.11	5.0	4.5
CO_2	0.29		1.49	1.2	0.20	0.17	3.3	4.3
SO_3				0.3			0.8	0.8
C				0.1 (0.1)			0.2 (0.2)	0.2 (0.2)
TOTAL:	100.21	99.38	99.73	100.3	99.67	99.99	100.5	100.8

1. Average of 9 greywackes, File Lake Formation
2. Average of 7 early Precambrian volcaniclastic greywackes (Shegelski, 1976)
3. Average of 20 early Precambrian greywackes (Henderson, 1975)
4. Average of 61 analyses of greywacke (mainly Phanerozoic, but includes 13 early Precambrian greywackes) (Pettijohn, 1963)
5. Average of 14 mudstones, File Lake Formation
6. Average of 20 early Precambrian slates (Henderson, 1975)
7. Average of 4030 Mesozoic and Cenozoic mudrocks (290 analyses) from Russian platform (Ronov et. al., 1966)
8. Average of 11, 151 mudrocks (455 analyses) from the Great Caucasus geosyncline (Ronov et. al., 1966)

[1] Chemical compositions in brackets have been recalculated volatile-free to 100 percent after CaO equivalent to the weight percent of CO_2 has been removed. This has been done to delete the effects of volatiles and carbonate[2] (cement and organic fossil remains).

volcanic environments which characterize the early Precambiran sediments. For example, their lower SiO_2 and higher Al_2O_3, Na_2O and CaO (CaO in calcite excluded) contents probably reflects abundant discrete volcanic plagioclase crystals and plagioclase-bearing rock fragments. Their higher MgO and FeO contents also probably reflects their volcanic provenance and rapid deposition. This is because volcanic rock fragments contain MgO and FeO whereas quartz and plagioclase, which are typically abundant in non-volcanic sediments, do not. The rapid deposition prevents chemical leaching of the MgO and FeO from the volcanic rock fragments. The similarity of Phanerozoic geosynclinal mudstones to Precambrian mudstones is a consequence of their similar immaturity and rapid deposition, and probably also reflects increased volcanogenic character of mudstones in Phanerozoic geosynclinal environments.

4.4.5 Provenance

Almost all framework clasts in greywacke samples are volcanic, and over two-thirds are of felsic volcanic detritus. Thus, the most probable source area for the File Lake Formation was a felsic volcanic terrain. The absence of obvious metamorphic, plutonic or sedimentary rock fragments, except for intraformation clasts, suggests that the source area did not include cratonized land areas.

The greywackes are poorly sorted and texturally immature. This is, in part, a consequence of their deposition by turbidity currents. However, the poor rounding of all clasts, both rock and crystal fragments, and the chemical immaturity of samples, shown by their low SiO_2 / Al_2O_3 ratios, indicate that detritus in the greywackes had undergone limited chemical decomposition, mechanical abrasion, transportation and sorting prior to resedimentation by turbidity currents. Thus, the source area was probably nearby and was undergoing active and rapid erosion. These features suggest that the greywackes were derived from largely unconsolidated pyroclastic deposits rather than an older extinct volcano which would require dissection by stream activity and cause abrasion of clasts. The large volume of sediment, the general coarseness of detritus and its deposition by mass sediment gravity flows all indicate that the source volcanic terrain was being built up as it was being eroded. They also indicate that the source area was largely subaerial.

Paleocurrent and paleoslope data are virtually absent in the File Lake Formation because basal sole marks are concealed by metamorphic welding of bed contacts. On Morton Lake,current ripple laminations and bent flame structures indicate a northerly dipping paleoslope and/or paleocurrent direction. However, this is only an approximation because the three dimensional form of these structures was not observed.

In summary, the predominance of felsic volcanic framework clasts, the textural immaturity and the limited paleocurrent data in the File Lake Formation all indicate that it was derived by rapid subaerial erosion of loose pyroclastic detritus from a large, predominantly felsic stratovolcano (or stratovolcanoes) that was to the south in the Flin Flon belt.

4.5 Depositional Environment of Amisk Group Metasedimentary Rocks

The Amisk Group metasedimentary rocks overlie a thick predominantly mafic sequence of metavolcanic flows that were erupted in a moderate to shallow water environment. The sediments are composed predominantly of texturally immature felsic volcanic detritus and were deposited by catastrophic subaqueous downslope movement of sediment-charged density currents. They locally contain hemipelagic mudstone, siltstone and fine sandstone deposits. The excellent preservation of sedimentary structures in the sediments indicates that they were not reworked by strong bottom currents and were probably deposited in deep water below storm wave base.

Debris flow deposits, comprising the Parisian and Yakymiw Formation, are restricted to the volcanic terrain of the Flin Flon belt and were probably deposited close to the margin of the Amisk sedimentary basin. Turbidity current and fluidized sediment flow deposits comprising the File Lake Formation are widespread and contain bed types and distributions of bed types which indicate that they are part of a subaqueous fan system that was transporting volcanic detritus from the Flin Flon belt into the Kisseynew belt.

Several features indicate that the sedimentary rocks were derived from contemporaneous upslope Amisk volcanoes rather than an older dissected volcanic terrain. These include direct input of the pebbly greywackes of the Yakymiw Formation from their volcanic source without any evidence of reworking; intercalation of thin layers of volcanic rocks in the Parisian and File Lake Formations; absence of plutonic or metamorphic rocks which would be expected from a deeply dissected volcanic terrain; and only slight rounding of detritus which favours derivation from largely unconsolidated pyroclastic deposits rather than stream dissection of an older volcanic terrain with consequent abrasion of clasts.

The wide variety of volcanic clast lithologies in the Parisian and File Lake Formations indicates a subaerial source area because such mixtures of detritus generally require subaerial transport to form. Slight rounding of the detritus and scattered clasts of epizonal, probably subvolcanic intrusions also indicate a subaerial source area. A subaerial derivation for the Amisk sedimentary deposits is also implied by their thickness and extensiveness, because the quantity of detritus is too great to be derived from a subaqueous source.

The predominance of immature felsic volcanic detritus in the Amisk sediments and the subaerial derivation of this detritus from contemporaneous loose Amisk pyroclastic deposits suggest that at least one major emergent felsic stratovolcano was constructed south of the study area late in the evolution of the Flin Flon belt. Subaerial stratovolcanoes are inherently unstable because they are dominantly fragmental and because newly erupted material near their top causes unstable slopes (Ayres, 1978). Thus, subaerial debris flows, rain, stream activity and shoreline wave erosion probably transported the detritus from the stratovolcano and deposited a surrounding subaqueous epiclastic apron. The Amisk metasedimentary rocks of the File Lake area are deposits that formed by downslope subaqueous mass sediment density flows transporting detritus from this epiclastic apron towards the Kisseynew belt.

4.6 Stratigraphic Character of the Boundary between the Flin Flon and Kisseynew Belts

The File Lake Formation can be traced directly into the Nokomis Group, a widespread sequence of more recrystallized paragneisses that comprises the largest and lowermost stratigraphic formation of the Kisseynew sedimentary gneiss belt. Thus, by analogy, the felsic volcanoes of the Flin Flon belt were the main source of Nokomis Group sediments. The delivery system which transported volcanic detritus from the Flin Flon belt to the Kisseynew belt was probably a series of coalesced subaqueous fans extending out from major felsic strato-volcanoes along the axis of the Flin Flon belt. According to this interpretation, a large quantity of felsic volcanic detritus was eroded from the Flin Flon belt and redeposited in the Nokomis Group. In fact the quantity of felsic volcanic detritus in Nokomis Group paragneisses probably far exceeds the volume of felsic metavolcanic rocks presently exposed in the Flin Flon volcanic belt.

A close link between volcanism and sedimentation is not unique to the Flin Flon and Kisseynew belts. Similar relationships have been documented by Ayres (1969), Ojakangas (1972), Dimroth et al (1975) Pirie and Mackasey (1978) in early Precambrian volcanic and sedimentary belt pairs in the southern part of the Superior Province in Ontario and Quebec. These volcanic and sedimentary belt pairs are identical in most respects to the Flin Flon and Kisseynew belts. For example, the major episode of sediment infilling in the sedimentary belts is turbiditic and consists largely of reworked felsic volcanic detritus. In addition, all the sedimentary belts have been highly recrystallized and migmatized, while the adjacent volcanic belts were metamorphosed at lower grades.

Modern analogues of the Precambrian paired volcanic and sedimentary belts are volcanic island arcs and their marginal sedimentary basins. A characteristic feature which modern volcanic arcs share with early Precambrian volcanic belts is redeposition of volcanic detritus in adjacent basins by subaqueous, mass-sediment, density flows (Dickinson, 1968, 1974; Mitchell, 1970; Moore, 1973; Ballance,1974). Dickinson (1968, 1974) has estimated that reworked volcanic detritus from stratovolcano clusters in Fiji was at least 100 percent greater in volume than the flows and breccias of the volcanoes. This agrees with the interpretation made in this study that the Nokomis Group paragneisses of the Kisseynew belt contain more Amisk felsic volcanic detritus than do the volcanic centres now exposed in the Flin Flon belt.

5. METAMORPHIC REACTIONS AND ZONES IN THE FILE LAKE FORMATION ACROSS THE BOUNDARY BETWEEN THE FLIN FLON AND KISSEYNEW BELTS

5.1 General Statement

In the File Lake area, middle greenschist facies File Lake Formation strata can be traced directly from the Flin Flon belt into highly recrystallized migmatitic upper almandine-amphibolite facies Nokomis Group paragneisses in the Kisseynew belt. The gradual, but relatively rapid metamorphic transition indicates that the apparent jump in grade described by earlier workers between the Flin Flon and Kisseynew belts is not due to a fault, but rather is a steep metamorphic gradient imposed on a stratigraphically continuous supracrustal succession.

The steep metamorphic gradient is part of a regional increase in metamorphic grade from the margins to the centre of the Kisseynew belt (Fig. 13) and is a characteristic feature elsewhere of the boundary between the Kisseynew and Flin Flon belts. Many other Precambrian sedimentary belts, particularly those with associated volcanic belts, such as the English River and Quetico belts of northwestern Ontario (Thurston and Breaks, 1978; Pirie and Mackasey, 1978), also have steep metamorphic gradients at their margins with highest grade mineral assemblages in their centres. Thus high grade metamorphism may be an intrinsic feature of the tectonic development of many Precambrian sedimentary basins.

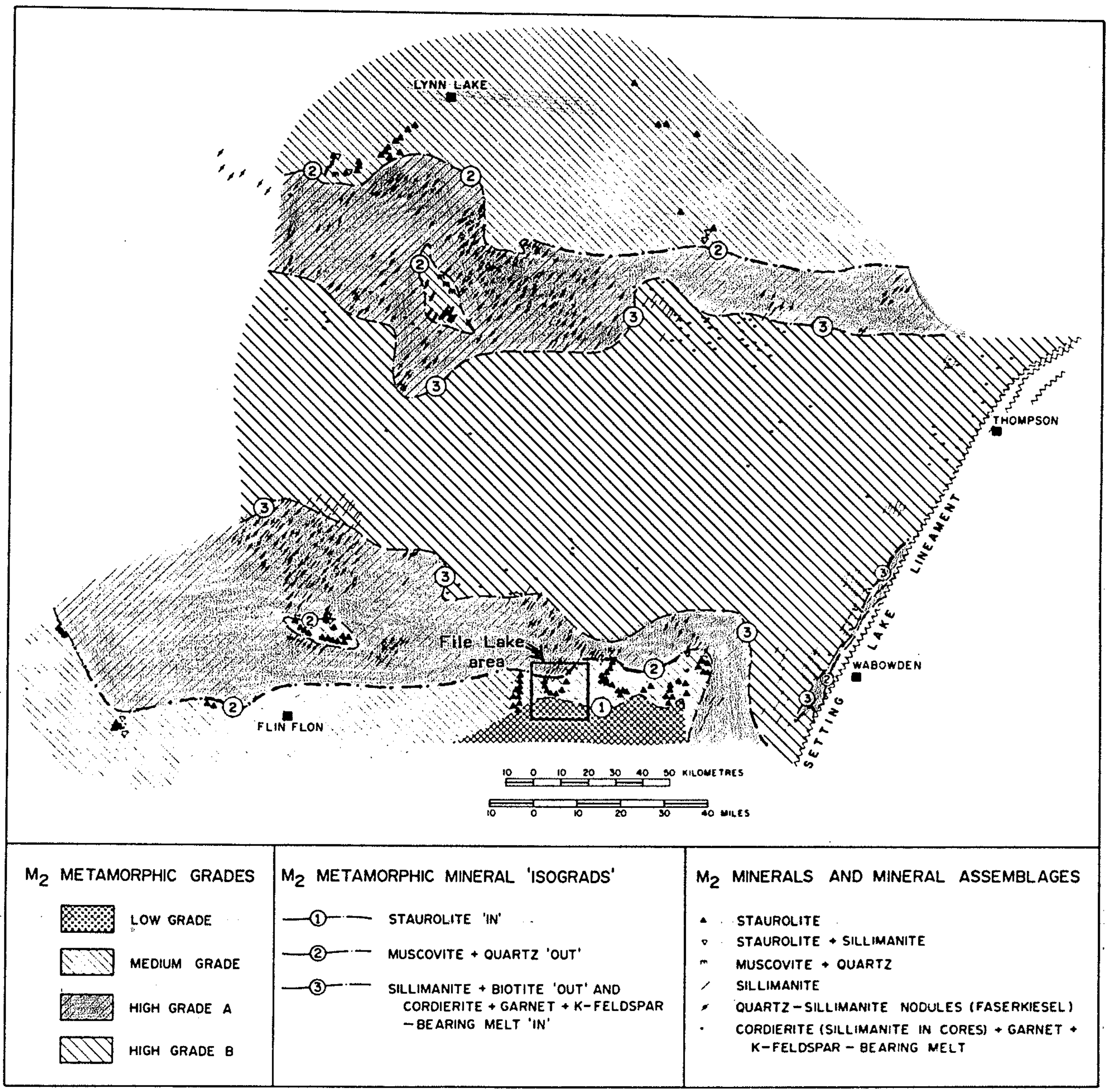


FIGURE 13. Regional metamorphic zonation of critical minerals and mineral assemblages in the Kisseynew sedimentary gneiss belt (from Bailes and McRitchie, 1978).

Metamorphic reactions in the File Lake Formation, across the boundary between the Flin Flon and Kisseynew belts, indicate a temperature gradient on the erosion surface of 21^{o}C/km. This gradient is too high to be explained solely by selective uplift of more deeply buried and more highly metamorphosed rocks in the sedimentary belt. Rather, they indicate that there was probably a lateral increase in metamorphic temperatures across the boundary and that the heat flow in the Kisseynew belt was higher than in the adjacent Flin Flon belt.

Stable metamorphic mineral assemblages are readily identified in the File Lake Formation because it has been affected by only one high grade metamorphic event and assemblages are relatively well preserved and have not been modified by later deformation and retrogressive metamorphism. Winkler (1976) has recommended that "only minerals in contact...be regarded as an assemblage of co-existing minerals, i.e. a paragenesis". In this study, however, co-existing mineral assemblages in a single thin section have been treated as a stable paragenesis, whether or not the individual minerals are in direct contact. This wider approach is used because several studies, including this one, have demonstrated that metamorphic reactions proceed by cation exchange and therefore stable minerals do not have to be, and usually are not, in contact (see Carmichael, 1969, and Foster, 1977).

5.2 Metamorphic Zones and Isograd Reactions

5.2.1 Introduction

Specific metamorphic reactions have been used to delineate metamorphic zones in the File Lake Formation, in the manner described by Thompson (1957) and Carmichael (1970), and used previously, in the adjacent Snow Lake area, by Froese and Gasparrini (1975). Four discontinuous reactions and two continuous reactions have been identified for muscovite-bearing rocks; and six discontinuous and two continuous reactions have been identified for muscovite-free rocks (Table 11). Discontinuous reactions in muscovite-bearing rocks were used to define five mineralogical zones in the File Lake Formation (Fig. 14), with each zone named after its most characteristic assemblage:

1) chlorite-biotite zone;
2) staurolite-biotite zone;
3) sillimanite-biotite zone;
4) sillimanite-garnet-biotite zone; and,
5) K-feldspar (melt)-sillimanite zone.

The discontinuous reactions which define the zone boundaries are isograd surfaces; they have been named as follows:

staurolite-biotite isograd (reaction (2))

sillimanite-biotite isograd (reaction (6))

sillimanite-garnet-biotite isograd (reaction (12))

K-feldspar (melt)-sillimanite isograd (reaction (14))

These reactions are typical of the transition from greenschist to upper almandine-amphibolite facies grade in many metamorphic belts (Guidotti, 1970, 1974; Carmichael, 1970). The first three isograd reactions, (2), (6) and (12), control, respectively, the first appearance of staurolite, the first appearance of sillimanite, and the decomposition of staurolite in muscovite-bearing rocks. The K-feldspar (melt)-sillimanite isograd reaction (14) is a combination of the following two reactions:

TABLE 11: Discontinuous and continuous metamorphic reactions[1] identified in File Lake Formation, File Lake area

(1)	chlorite + plagioclase + quartz ⇌ hornblende + garnet + H_2O	D[2]
(2)	chlorite + muscovite + garnet ⇌ staurolite + biotite + quartz + H_2O	DM
(3)	chlorite + muscovite ⇌ staurolite + biotite + quartz + H_2O	CM
(4)	chlorite + garnet + hornblende + quartz ⇌ cummingtonite + plagioclase + H_2O	D
(5)[3]	chlorite + garnet + cummingtonite ⇌ anthophyllite + quartz + H_2O	D
(6)	chlorite + muscovite + staurolite + quartz ⇌ sillimanite + biotite + H_2O	DM
(7)	chlorite + sillimanite + quartz ⇌ staurolite + cordierite + H_2O	D
(8)	chlorite + staurolite + quartz ⇌ cordierite + garnet + H_2O	D
(9)	muscovite + staurolite + quartz ⇌ sillimanite + biotite + H_2O	CM
(10)	chlorite + staurolite + quartz ⇌ cordierite + H_2O	C
(11)	staurolite + quartz ⇌ cordierite + garnet + H_2O	C
(12)	muscovite + staurolite + quartz ⇌ sillimanite + garnet + biotite + H_2O	DM
(13)	staurolite + quartz ⇌ cordierite + garnet + sillimanite + H_2O	D
(14)	muscovite + plagioclase + quartz + H_2O ⇌ melt + sillimanite	DM

Note: [1] Reactions listed in order from lowest to highest grade. They are based on observed mineral assemblage changes and were delineated by method introduced by Thompson (1957).

[2] Letters indicate type of reaction, as follows:

D – discontinuous, muscovite-free rocks
C – continuous, muscovite-free rocks
DM – discontinuous, muscovite-bearing rocks
CM – continuous, muscovite-bearing rocks

[3] Position of this reaction based on mineral assemblages observed in the adjacent Snow Lake area by Froese and Moore (1978). Mineral assemblages defining this reaction were not observed in the File Lake area until higher metamorphic grade due to lack of rocks of appropriate composition.

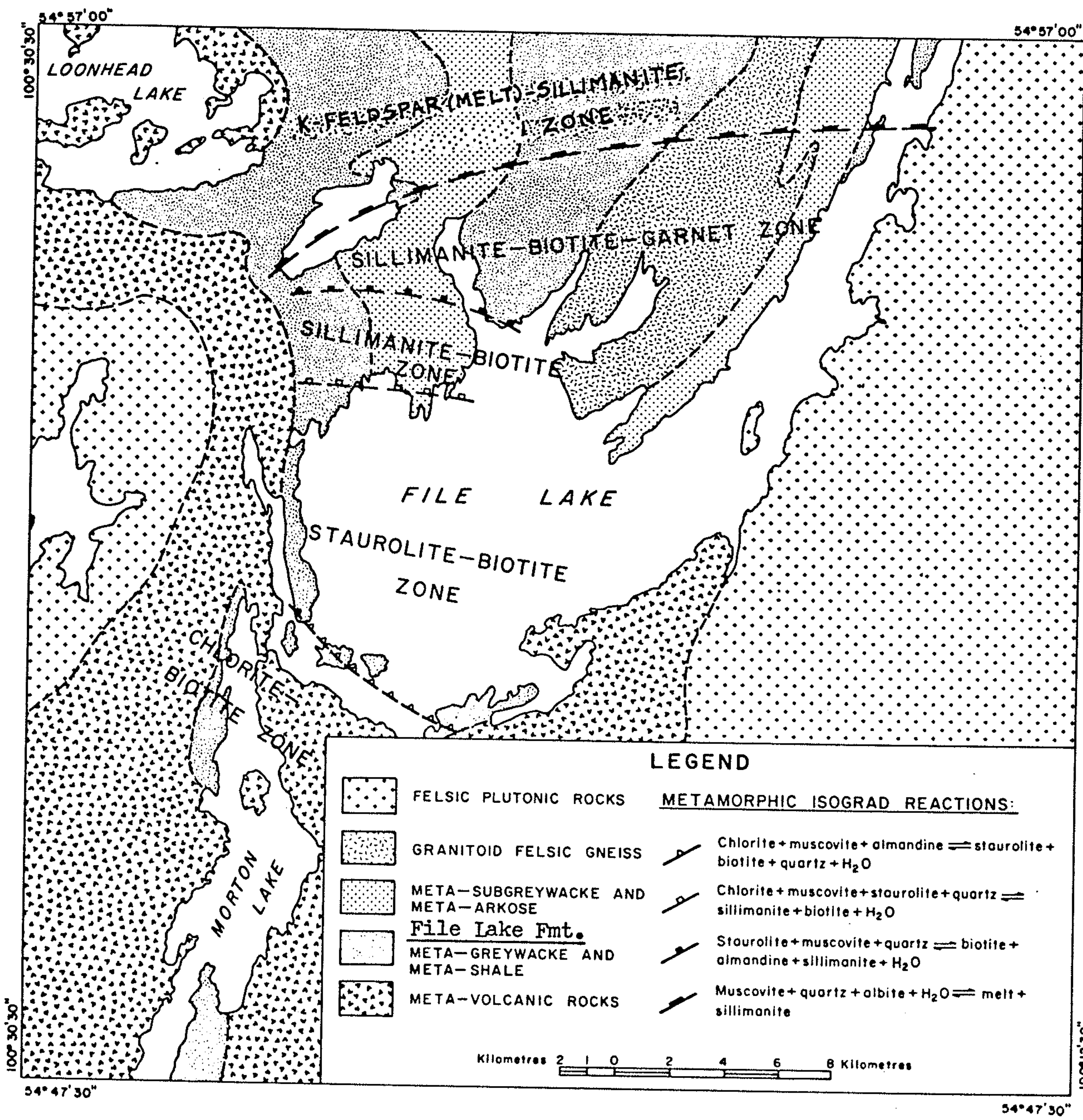


FIGURE 14. Disposition of metamorphic zones and isograd reactions in the File Lake Formation, File Lake area.

$$\text{muscovite} + \text{plagioclase} + \text{quartz} \rightleftharpoons \text{K-Na-feldspar} + Al_2SiO_5 + H_2O; \text{ and} \quad (15)$$

$$\text{K-Na-feldspar} + \text{plagioclase} + \text{quartz} + H_2O \rightleftharpoons \text{melt} \quad (16)$$

It leads to partial melting and migmatization of pelitic and semi-pelitic rocks (see Winkler, 1976, p. 84 and p. 309).

5.2.2 Chlorite-biotite zone

Rocks of the chlorite-biotite zone on Morton Lake are weakly recrystallized and contain middle to upper greenschist facies metamorphic mineral assemblages. Primary sedimentary structures and textures are well preserved and have been discussed previously.

Typical mineral assemblages in K_2O-rich, muscovite-bearing rocks are shown in Figure 15, a modified Thompson AFM projection through muscovite, quartz and plagioclase of constant composition. Typical mineral assemblages of K_2O-poor muscovite-free rocks are shown in Figure 16, an A*FM projection after Froese (1969) through quartz and plagioclase of constant composition. In K_2O-poor rocks, biotite is the only K_2O-bearing mineral and it is compatible with all mineral assemblages shown in A*FM projections.

Near the upper boundary of the chlorite-biotite zone, muscovite-free rocks contain garnet (Fig. 17). This is probably due to the discontinuous reaction

$$\text{chlorite} + \text{plagioclase} + \text{quartz} \rightleftharpoons \text{hornblende} + \text{garnet} + H_2O \quad (1)$$

which shifts the chlorite-hornblende-garnet mineral compatibility triangle to more magnesian compositions. Garnet was not observed in muscovite-bearing assemblages in the upper part of the chlorite-biotite

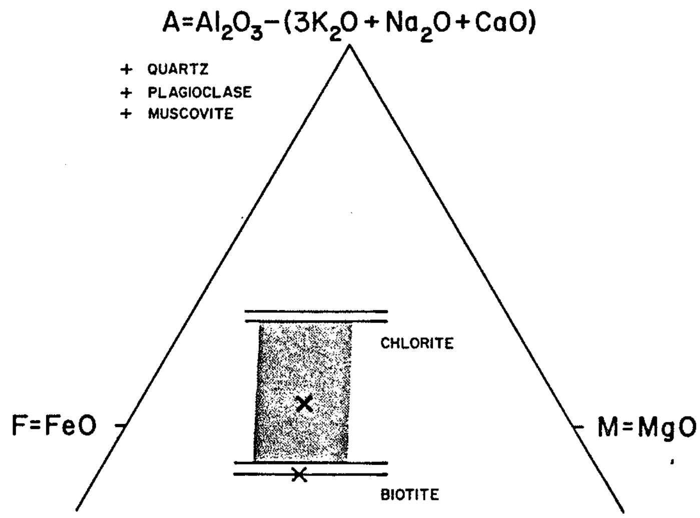


FIGURE 15. Schematic Thompson AFM projection through muscovite, quartz and plagioclase of constant composition of observed muscovite-bearing assemblages (shown by X) in the chlorite-biotite zone, File Lake area.

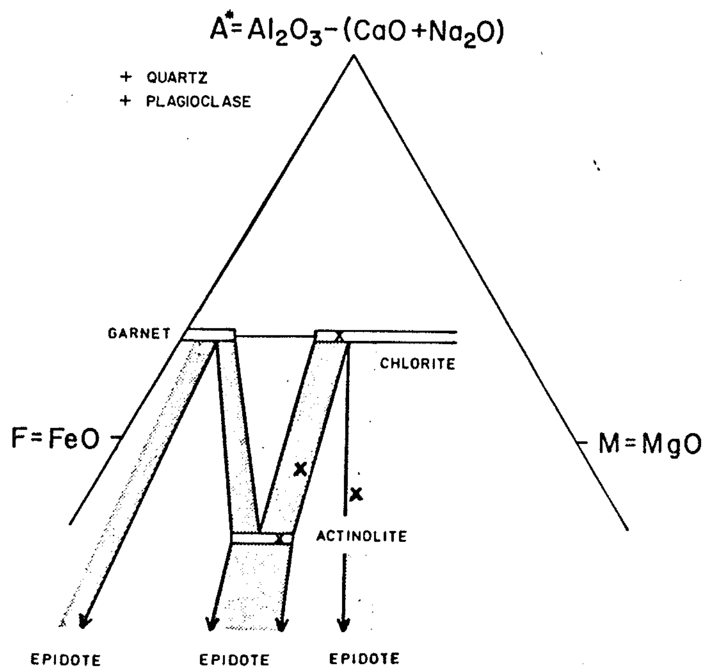


FIGURE 16. Schematic A*FM projection through quartz and plagioclase of constant composition (after Froese, 1969) of observed muscovite-free assemblages (shown by X) in the lower chlorite-biotite zone, File Lake area. Biotite is present in observed assemblages.

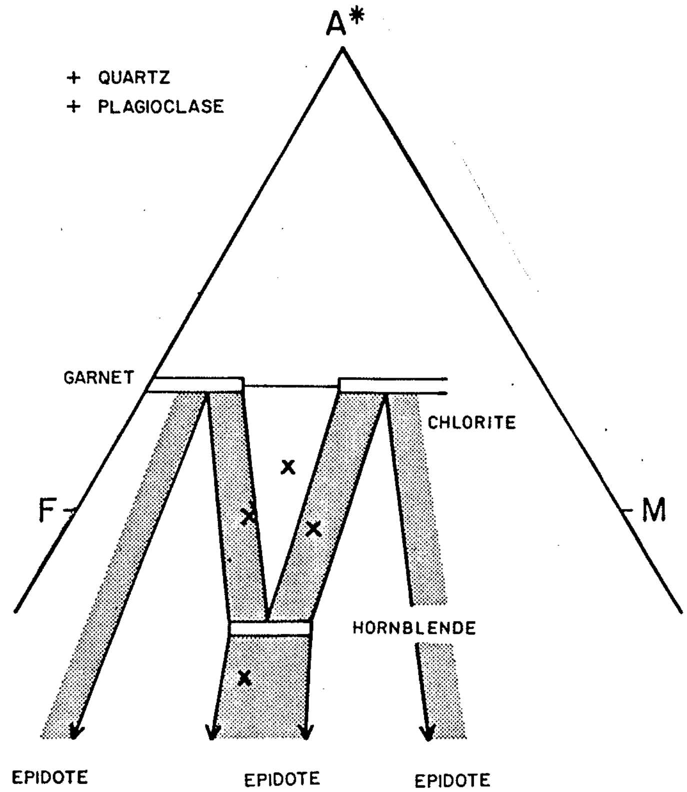


FIGURE 17. Schematic A*FM projection of observed muscovite-free assemblages (shown by X) in the upper chlorite-biotite zone, File Lake area. Biotite is present in observed assemblages.

zone, probably because of a lack of muscovite-bearing rocks of appropriate composition.

5.2.3 Staurolite-biotite zone

The staurolite-biotite zone is separated from the chlorite-biotite zone by the discontinuous staurolite-biotite isograd reaction

$$\text{chlorite} + \text{muscovite} + \text{garnet} \rightleftharpoons \text{staurolite} + \text{biotite} + \text{quartz} + H_2O \text{ (Fig. 18)} \qquad (2)$$

This reaction, rather than the higher grade continuous reaction

$$\text{chlorite} + \text{muscovite} \rightleftharpoons \text{staurolite} + \text{biotite} + \text{quartz} + H_2O \qquad (3)$$

is considered to control the appearance of staurolite, since garnet co-exists with staurolite in most rocks of the lower staurolite-biotite zone. Assemblages which indicate that reaction (2) has been exceeded are: garnet-muscovite-staurolite-biotite-quartz (Fig. 19); chlorite-muscovite-staurolite-biotite-quartz (Fig. 19); and garnet-chlorite-staurolite-biotite-quartz (Fig. 20).

Within the staurolite-biotite zone the following changes are observed with increase in metamorphic grade:

1) an increase in the abundance and grain size of staurolite, which changes from small poikiloblastic crystals to large inclusion-free idioblastic euhedral crystals (Plate 38); and
2) an increase in range of rock compositions which contain staurolite. In the low grade part of the staurolite-biotite zone, staurolite occurs only in metamudstone, but at higher grades it also occurs in metasiltstone and metagreywacke.

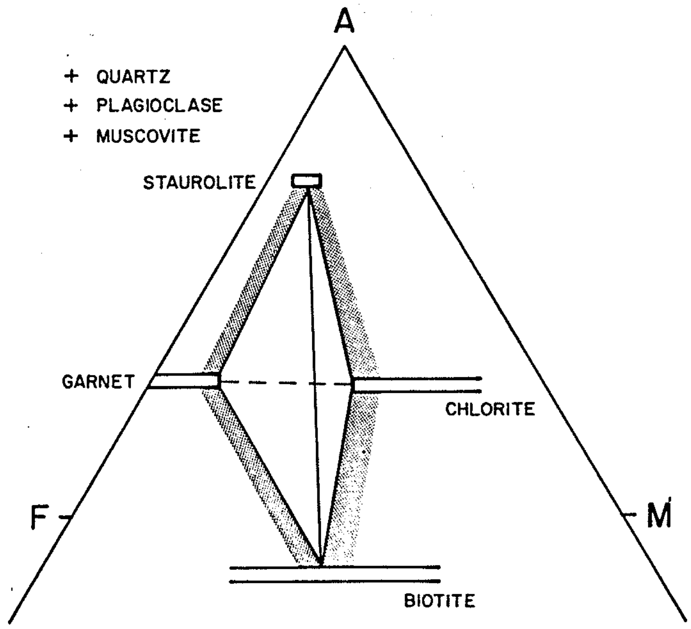


FIGURE 18. The discontinuous reaction at the staurolite-biotite isograd, represented on a schematic Thompson AFM projection. Dashed tie line is broken by staurolite-biotite isograd reaction, represented by solid line.

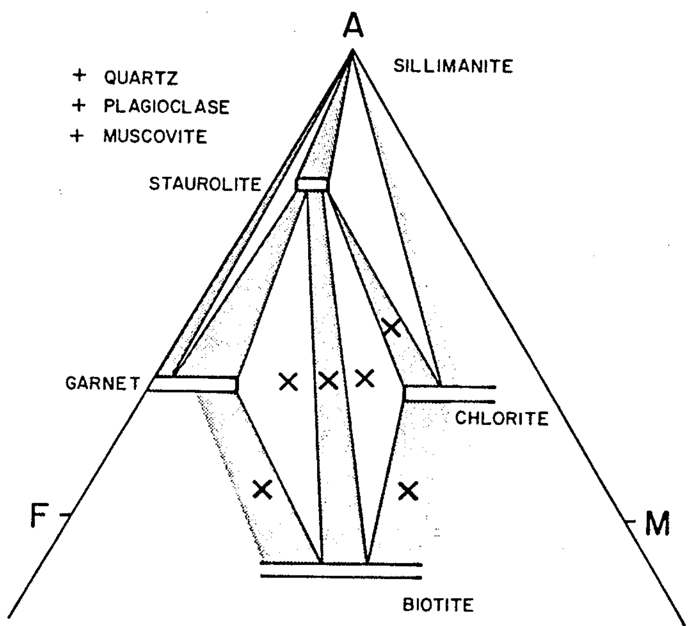


FIGURE 19. Schematic Thompson AFM projection of observed muscovite-bearing assemblages (shown by X) in the staurolite-biotite zone, File Lake area.

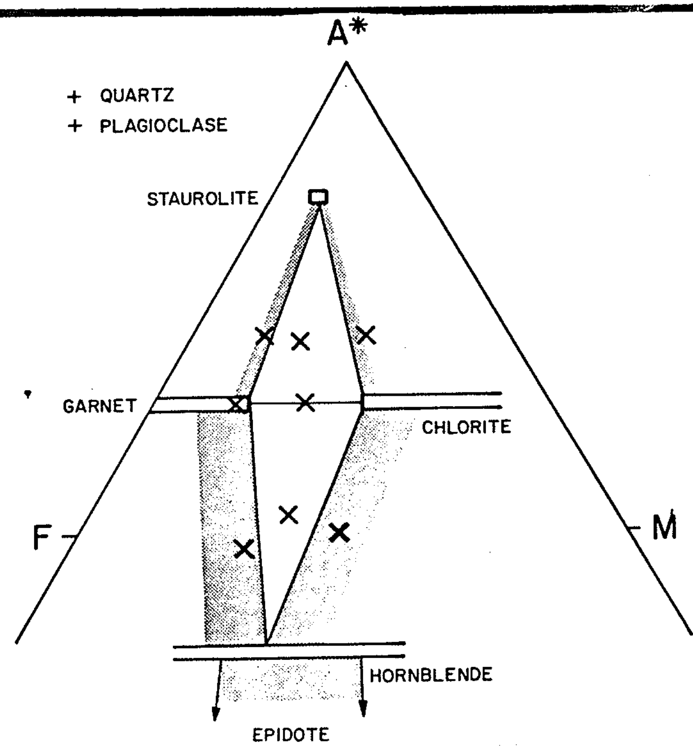


FIGURE 20. Schematic A*FM projection of observed muscovite-free assemblages (shown by X) in the lower staurolite-biotite zone, File Lake area. Biotite is present in observed assemblages.

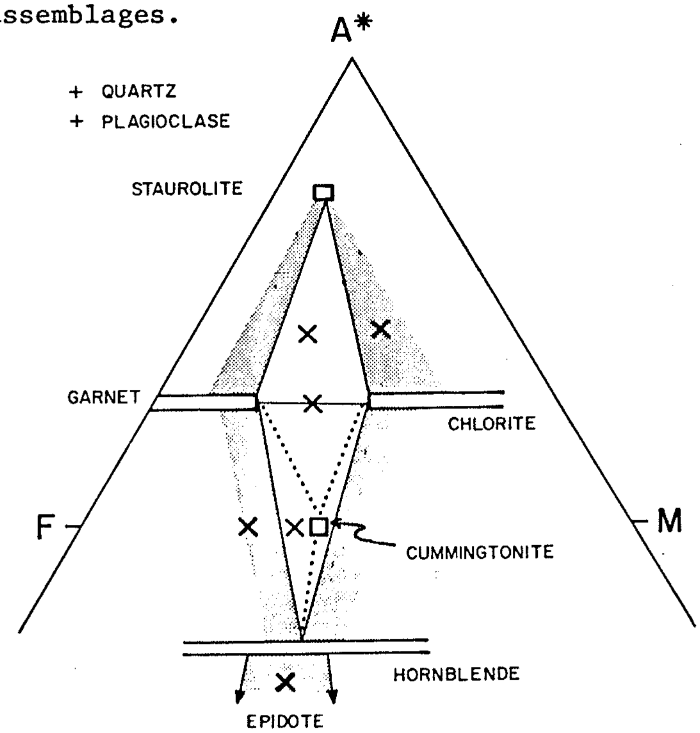


FIGURE 21. Schematic A*FM projection depicting discontinuous reaction responsible for the first appearance of cummingtonite in muscovite-free rocks of the staurolite-biotite zone, File Lake area. Observed assemblages stable above reaction are shown by X. Biotite is present in observed assemblages. Dotted lines are new tie lines established by discontinuous reaction forming cummingtonite.

PLATE 38: Photomicrograph (polarized light) of large euhedral staurolite porphyroblasts (ST) in muscovite-bearing pelitic schist, upper part of staurolite-biotite zone, File Lake Formation.

These two features are probably due to continuous reaction (3) which, as pointed out by Carmichael (1970), causes the staurolite-biotite-chlorite mineral compatibility triangle to migrate towards more magnesian compositions. This reaction forms staurolite and biotite at the expense of chlorite and muscovite, and causes depletion of the bank of tie lines between chlorite and staurolite and between chlorite and biotite while increasing those between staurolite and biotite (compare Figs. 18 and 19). Thus the compositional field of staurolite-bearing rocks is enlarged.

In muscovite-free rocks the following discontinuous reaction probably occurred about midway between the lower and upper boundaries of the staurolite-biotite zone:

$$\text{chlorite} + \text{garnet} + \text{hornblende} + \text{quartz} \rightleftharpoons \text{cummingtonite} + \text{plagioclase} + H_2O \qquad (4)$$

Mineral assemblages in muscovite-free rocks below this discontinuous reaction, are shown in Figure 20. The topology of the reaction, and the assemblages occurring above it, are shown in Figure 21. Based on data from the Snow Lake area (Froese and Moore, 1978), the discontinuous reaction

$$\text{chlorite} + \text{garnet} + \text{cummingtonite} \rightleftharpoons \text{anthophyllite} + \text{quartz} + H_2O \qquad (5)$$

probably occurred in the staurolite-biotite zone. However, anthophyllite-bearing assemblages are not observed in the File Lake Formation until much higher grade, because of absence of rocks of appropriate composition in the lower grade areas.

5.2.4 Sillimanite-biotite zone

The lower boundary of the sillimanite-biotite zone is defined by the discontinuous sillimanite-biotite isograd reaction

chlorite + muscovite + staurolite + quartz $\rightleftharpoons$ sillimanite + biotite + H_2O (Fig. 22) (6)

Assemblages which indicate that this reaction has been exceeded are muscovite-sillimanite-biotite-quartz and staurolite-muscovite-sillimanite-biotite-quartz (Fig. 23). The muscovite-free assemblage staurolite-chlorite-sillimanite-biotite-quartz should ideally occur in rocks above reaction (6), but it was not observed. The absence of this assemblage is probably due to consumption of chlorite or sillimanite by the discontinuous reaction

chlorite + sillimanite + quartz $\rightleftharpoons$ staurolite + cordierite + H_2O (Fig. 24) (7)

which is indicated to have occurred just above the sillimanite-biotite isograd by the muscovite-free assemblage staurolite-cordierite-chlorite-biotite-quartz (Fig. 24). At slightly higher grades, but still in the lower part of the sillimanite-biotite zone, the discontinuous reaction

chlorite + staurolite + quartz $\rightleftharpoons$ cordierite + garnet + H_2O (8)

is inferred to have occurred in muscovite-free rocks by the assemblage staurolite-garnet-cordierite-chlorite-biotite-quartz (Fig. 25). It is possible that garnet could have been stabilized as an extra phase in this assemblage by either MnO or CaO, in which case it would not indicate that reaction (8) went to completion. However, an electron microprobe analysis of garnet in this assemblage (F07-3776-10A, Table 12) indicates

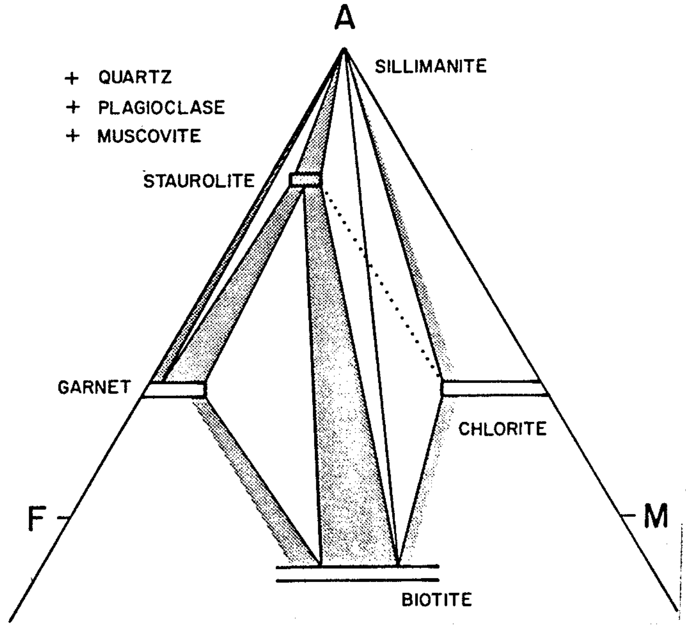


FIGURE 22. The discontinuous reaction at the sillimanite-biotite isograd, represented on a schematic Thompson AFM projection. Dotted tie line is broken by sillimanite-biotite isograd reaction, represented by solid line.

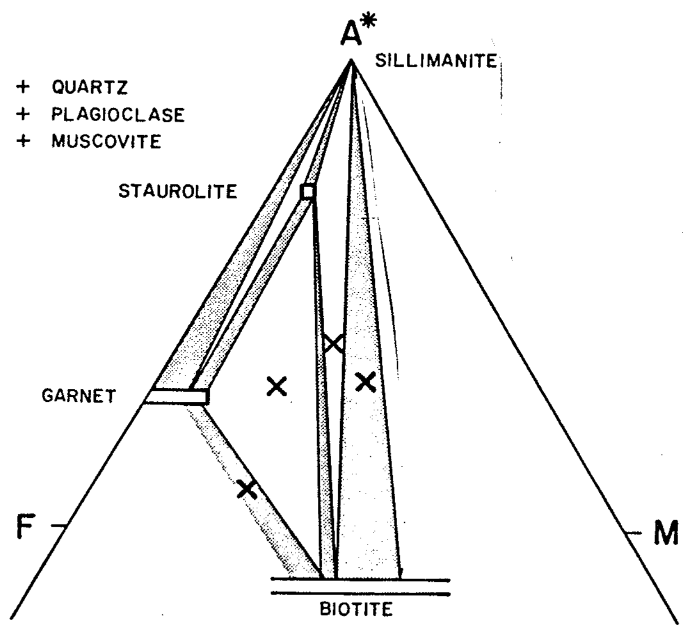


FIGURE 23. Schematic Thompson AFM projection of observed muscovite-bearing assemblages (shown by X) in the sillimanite-biotite zone, File Lake area.

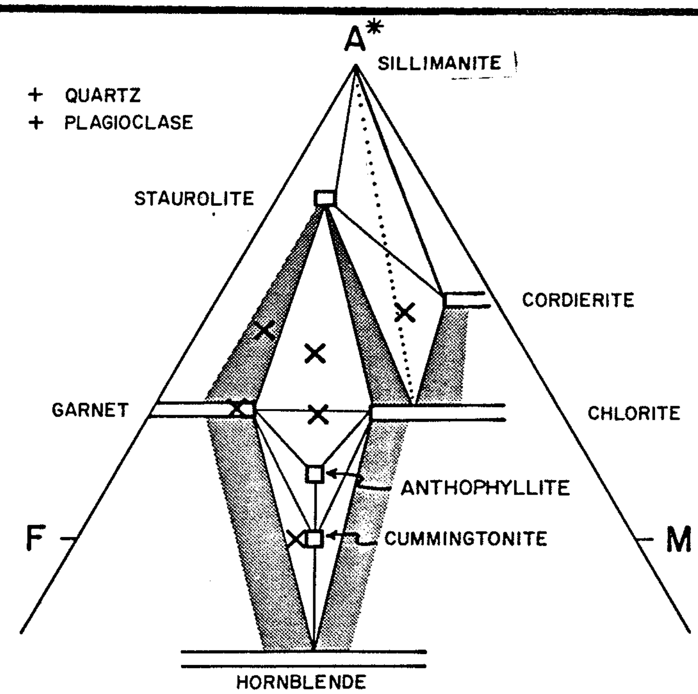


FIGURE 24. Schematic A*FM projection depicting discontinuous reaction inferred to be responsible for first appearance of staurolite + cordierite assemblages in muscovite-free rocks of the lower sillimanite-biotite zone, File Lake area. All observed assemblages stable above reaction (shown by X) contain biotite. Dotted tie line is broken by discontinuous reaction forming staurolite + cordierite assemblages.

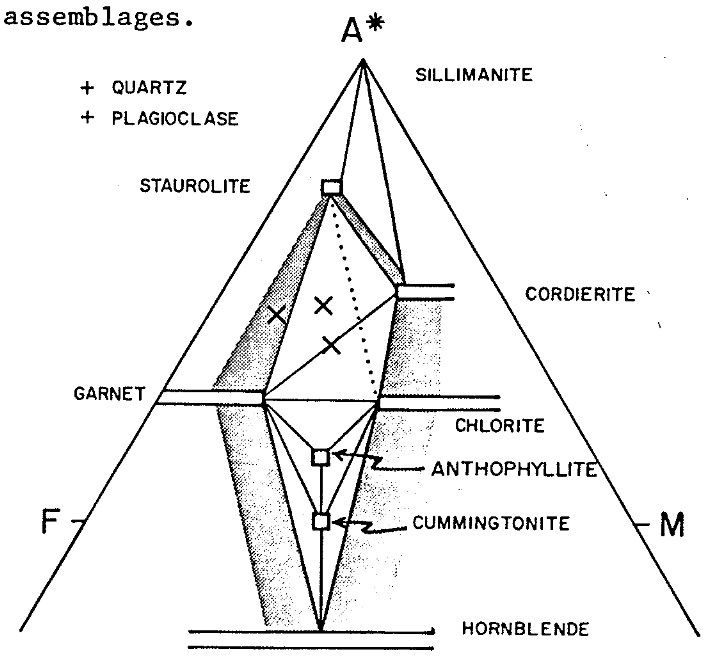


FIGURE 25. Schematic A*FM projection depicting discontinuous reaction responsible for first appearance of cordierite + garnet assemblages in muscovite-free rocks of the lower sillimanite-biotite zone, File Lake area. All observed assemblages stable above reaction (shown by X) contain biotite. Dotted tie line is broken by discontinuous reaction forming cordierite + garnet assemblages.

TABLE 12: Chemical composition[1,2] of garnet in assemblage defining reaction (8) compared to MnO-stabilized garnet. Both are from sillimanite-biotite zone, File Lake area.

		SiO_2	TiO_2	Al_2O_3	Cr_2O_3	FeO	MnO	MgO	CaO	Na_2O
Garnet in assemblage defining reaction (8)[3]	(centre)	37.45	0.04	20.45	0.06	35.60	0.36	4.29	1.63	0.20
	(edge)	37.15	0.07	20.47	0.09	36.17	0.21	3.95	1.33	0.00
MnO stabilized garnet[4]		36.86	0.04	20.49	0.06	35.87	2.83	2.65	1.35	0.04

1 Analyses by George Plant, G.S.C., Ottawa using a Kevex lithium-drifted solid state detector for energy dispersive analysis attached to a MAC electron microprobe. Operating conditions were: 20 kv accelerating voltage, specimen current 0.01 nano amps measured on biotite, 40 seconds counting time, focused beam.

2 Analyses are average of three to four grains of mineral in each rock specimen.

3 Sample number F07-3776-10A, a garnet-, staurolite-, cordierite-, chlorite-, biotite-, quartz-, plagioclase-, ilmenite-bearing paragneiss.

4 Sample number F07-2086-1B, a garnet (MnO stabilized)-staurolite-, muscovite-, biotite-, quartz-, plagioclase-, chlorite (retrograde)-bearing paragneiss.

that the garnet is neither MnO or CaO stabilized; the presence of plagioclase also indicates the garnet is not CaO stabilized. Reaction (8) is particularly significant because it indicates a slightly lower pressure path of metamorphism in the File Lake area than in the adjacent Snow Lake area where Froese and Moore (1978) have documented somewhat higher pressure reactions involving anthophyllite (see Fig. 34, page 134).

Within the sillimanite-biotite zone the following changes are observed with increasing metamorphic grade:

1) gradual depletion of staurolite and its progressive replacement by other minerals;
2) gradual increase in sillimanite, which occurs as fibrolitic knots, and a coincident loss of staurolite-chlorite and groundmass muscovite; and
3) gradual increase in cordierite in very aluminous, but muscovite-free rocks.

The following three continuous reactions are inferred to be responsible for these features:

$$\text{muscovite} + \text{staurolite} + \text{quartz} \rightleftharpoons \text{sillimanite} + \text{biotite} + H_2O \quad (9)$$

$$\text{chlorite} + \text{staurolite} + \text{quartz} \rightleftharpoons \text{cordierite} + H_2O\text{; and} \quad (10)$$

$$\text{staurolite} + \text{quartz} \rightleftharpoons \text{cordierite} + \text{garnet} + H_2O \quad (11)$$

Reaction (9) follows the discontinuous sillimanite-biotite isograd reaction (6), and, as pointed out by Carmichael (1970), causes the staurolite-sillimanite-biotite mineral compatibility triangle to shift to more iron-rich compositions (compare Figs. 22 and 23). Reaction (10) causes the staurolite-chlorite-cordierite mineral compatibility triangle to move towards more iron-rich compositions (compare Figs. 24 and

25), decreases the bank of tie lines between staurolite and chlorite, and eventually leads to discontinuous reaction (8), when the last staurolite-chlorite tie line is broken (Fig. 24). Reaction (11) follows discontinuous reaction (8) and ultimately leads to discontinuous reaction (13) in the sillimanite-garnet-biotite zone.

5.2.5 Sillimanite-garnet-biotite zone

The lower boundary of the sillimanite-garnet-biotite zone is defined by the discontinuous sillimanite-garnet-biotite isograd reaction

$$\text{muscovite} + \text{staurolite} + \text{quartz} \rightleftharpoons \text{sillimanite} + \text{garnet} + \text{biotite} + H_2O \text{ (Fig. 26)} \qquad (12)$$

Assemblages which indicate that this reaction has been exceeded are muscovite-sillimanite-biotite-garnet-quartz (Fig. 26) and staurolite-sillimanite-biotite-garnet-quartz (Fig. 27).

In muscovite-free rocks staurolite persists about 0.5 km beyond the sillimanite-garnet-biotite isograd until it is decomposed by the discontinuous reaction

$$\text{staurolite} + \text{quartz} \rightleftharpoons \text{cordierite} + \text{garnet} + \text{sillimanite} + H_2O \text{ (Fig. 28)} \qquad (13)$$

Sillimanite was formed for the first time in many muscovite-free pelitic and semi-pelitic rocks due to breaking of tie lines from staurolite to cordierite and staurolite to garnet by reaction (13).

Anthophyllite-bearing assemblages are present in muscovite-free rocks of the sillimanite-garnet-biotite zone (Figs. 27 and 28) due to the presence of rocks of appropriate composition. Anthophyllite was not found in lower grade rocks, where it should be stable, due to

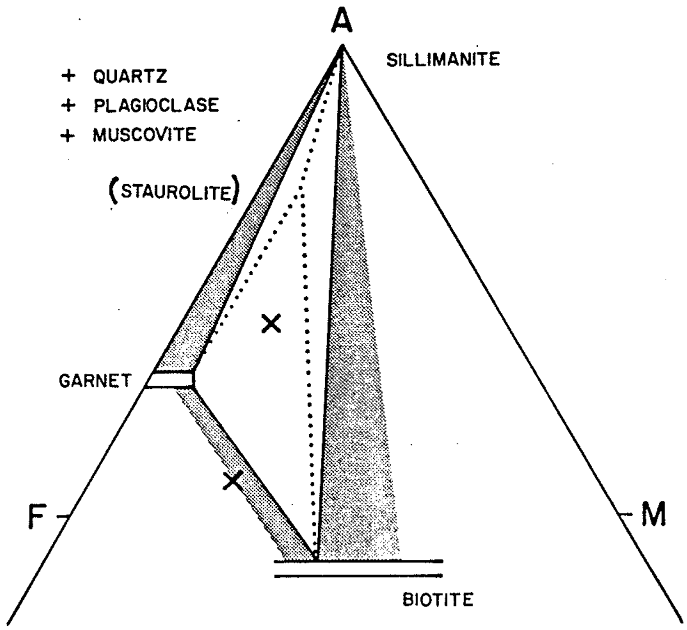


FIGURE 26. Discontinuous reaction at the sillimanite-garnet-biotite isograd, represented on a schematic Thompson AFM projection. Observed assemblages above reaction shown by X. Dotted tie lines are broken by sillimanite-garnet-biotite isograd reaction.

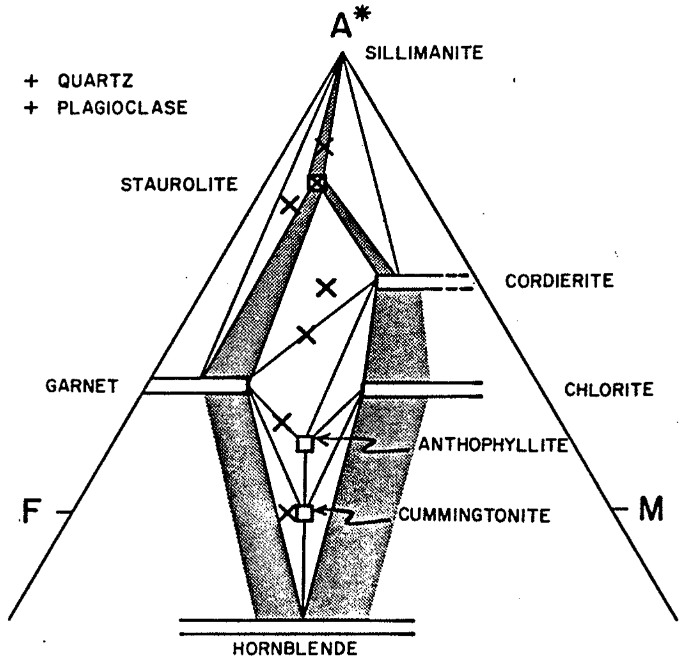


FIGURE 27. Schematic A*FM projection of observed muscovite-free assemblages (shown by X) in the lower sillimanite-garnet-biotite zone, File Lake area. All observed assemblages contain biotite.

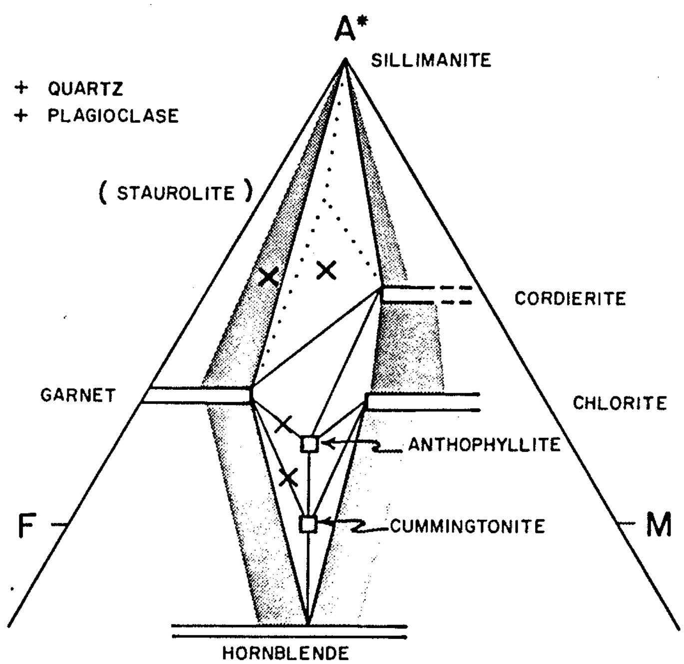


FIGURE 28. Schematic A*FM projection depicting discontinuous reaction responsible for breakdown of staurolite in muscovite-free rocks. All observed assemblages stable above reaction shown by X. Biotite is present in observed assemblages. Dotted lines are tie lines broken by discontinuous reaction decomposing staurolite.

absence of rocks of appropriate composition.

5.2.6 K-feldspar (melt)-sillimanite zone

Rocks of the K-feldspar (melt)-sillimanite zone are characterized by disappearance of muscovite, prominent veining by white tonalite and granodiorite, decrease in sillimanite content, and coarse recrystallization (0.1 to 1.0 mm grain size compared to 0.01 to 0.02 mm in the chlorite-biotite zone, Plate 39).

The disappearance of muscovite and the coincident appearance of small sills and veins of tonalite and granodiorite suggest that the lower boundary of this zone is defined by the reaction:

$$\text{muscovite} + \text{plagioclase} + \text{quartz} + H_2O \rightleftharpoons \text{melt} + \text{sillimanite} \quad (14)$$

According to Winkler (1976) this reaction only occurs in rocks under conditions of moderate to high pressure and is a combination of the muscovite decomposition reaction (15) and the granite melting reaction (16):

$$\text{muscovite} + \text{plagioclase} + \text{quartz} \rightleftharpoons \text{K-Na-feldspar} + Al_2SiO_5 \quad (15)$$

$$\text{K-Na-feldspar} + \text{plagioclase} + \text{quartz} + H_2O \rightleftharpoons \text{melt} \quad (16)$$

The observed depletion of sillimanite, however, is at odds with reaction (14) which predicts that sillimanite should be produced rather than depleted. This could have been caused by parallel consumption of alumina by other, as yet undetermined, reactions, possibly involving Fe and Mg and producing aluminous minerals such as biotite or garnet, both of which are common in the tonalite and granodiorite.

(a)

(b)

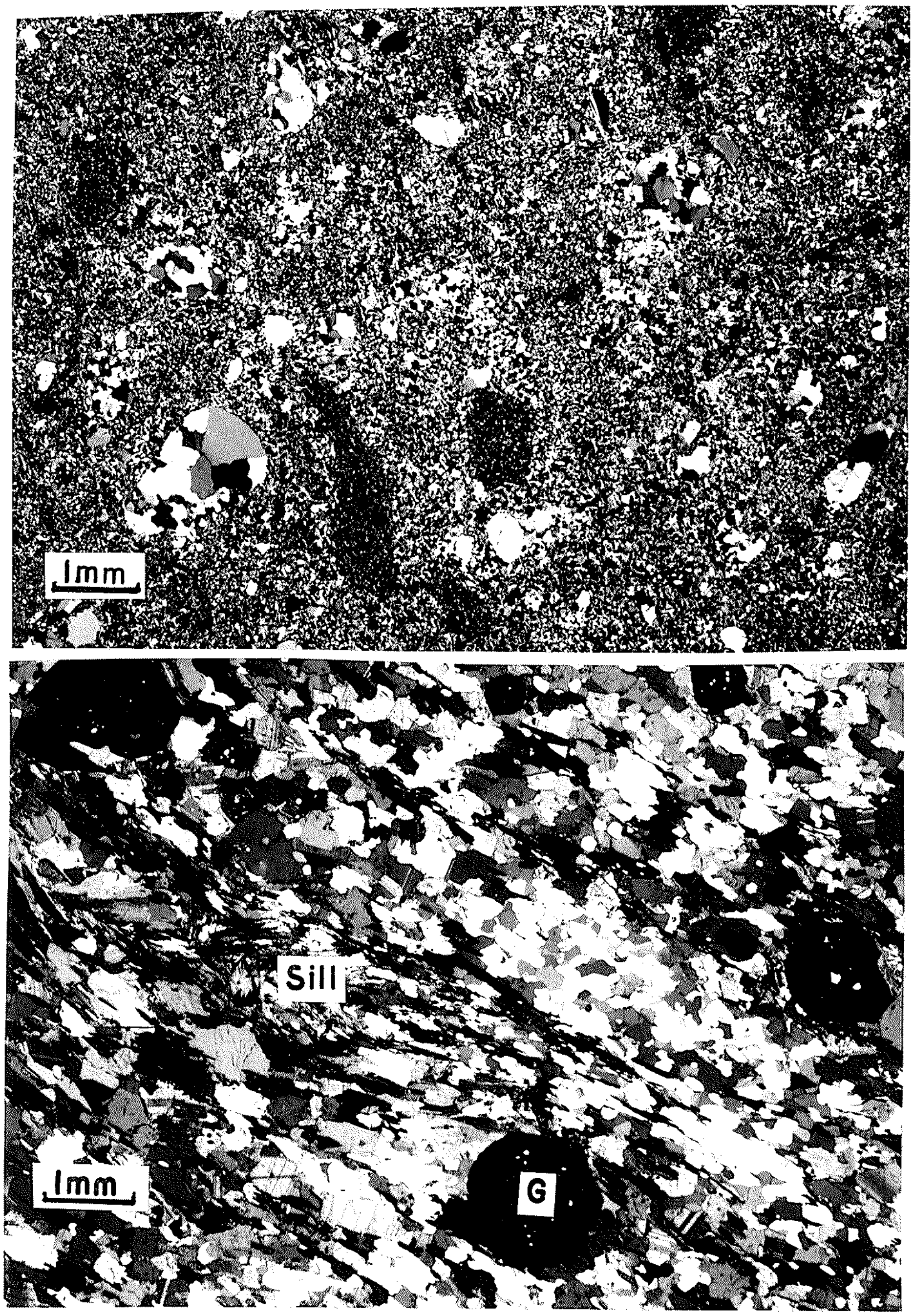


PLATE 39: Photomicrographs (polarized light) comparing grain size of (a) weakly recrystallized lithic greywacke from the chlorite-biotite zone and (b) coarsely recrystallized metagreywacke from the K feldspar (melt)-sillimanite zone of the File Lake Formation. Note trails of fibrolitic sillimanite (SIL) and garnet porphyroblasts (G) in coarsely recrystallized metagreywacke.

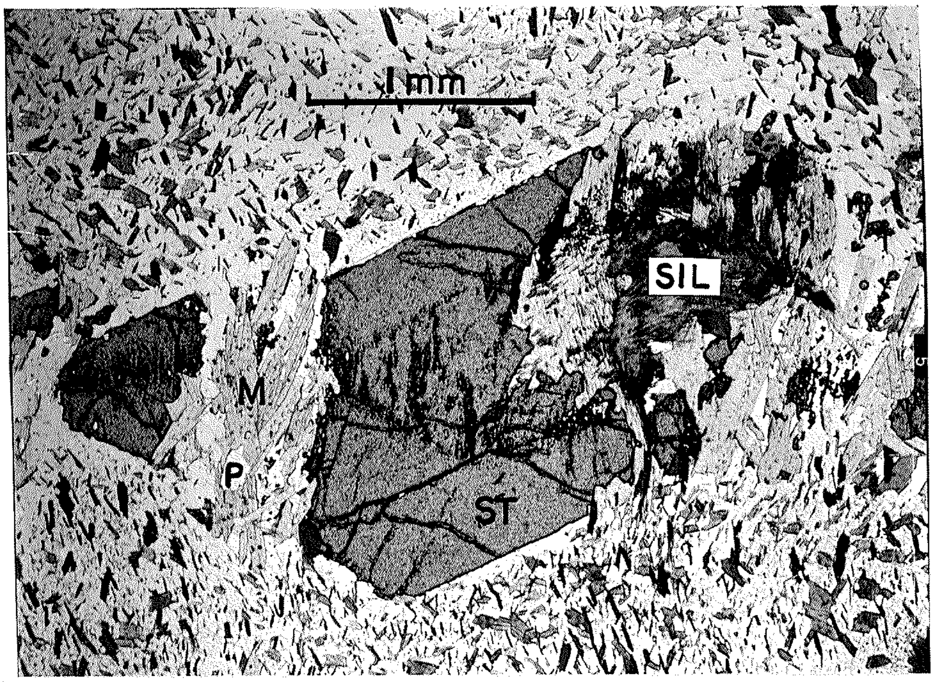
An anatectic derivation for the tonalite and granodiorite is strongly suggested by its occurrence only in sedimentary rocks of the File Lake Formation and only in those above the K-feldspar (melt)-sillimanite isograd. This holds for both small veins and sills, that occur ubiquitously, and large sheeted sill and dyke complexes, shown as Unit 27 on the geological map (Fig. 2, in pocket). Melting did not occur at lower grades because the sedimentary rocks of the File Lake Formation contain no K-feldspar and it is the K-feldspar-producing muscovite decomposition reaction (15) which permits the granite melting reaction (16) to occur.

5.3 Textures in Pelitic Gneisses and Their Bearing on the Mechanism of Prograde Metamorphic Reactions

One of the problems with isograd reactions based on discontinuities in topology of Thompson AFM projections is that microscopic textures do not always agree with the topologically deduced reactions (Turner and Verhoogen, 1960, p. 460; Chinner, 1961; Carmichael, 1969). In the pelitic gneisses of the File Lake area, particularly in the sillimanite-biotite zone, textures that do not agree with predicted reactions include:

1) replacement of staurolite by prograde muscovite (Plate 40a);
2) replacement of staurolite by prograde plagioclase (Plates 40b and 41);
3) the occurrence of sillimanite in fibrolitic knots isolated from other aluminous minerals (Plate 42; Fig. 29); and
4) garnet porphyroblasts with rims of quartz.

(a)



(b)

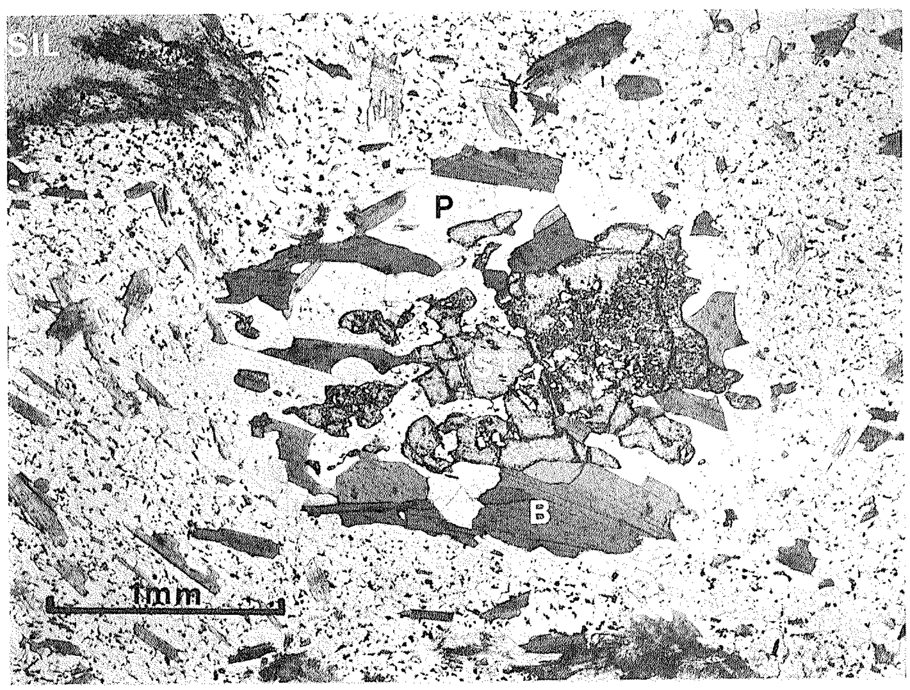


PLATE 40: Photomicrographs (plain light) of corroded porphyroblasts of staurolite (ST) in muscovite-bearing pelitic gneiss, sillimanite-biotite zone, File Lake Formation. In (a) staurolite is partially replaced by a mixture of muscovite (M), fibrolitic sillimanite (SIL), plagioclase (P), and minor biotite (B). In (b) staurolite is partially replaced by a mixture of plagioclase (P) and biotite (B).

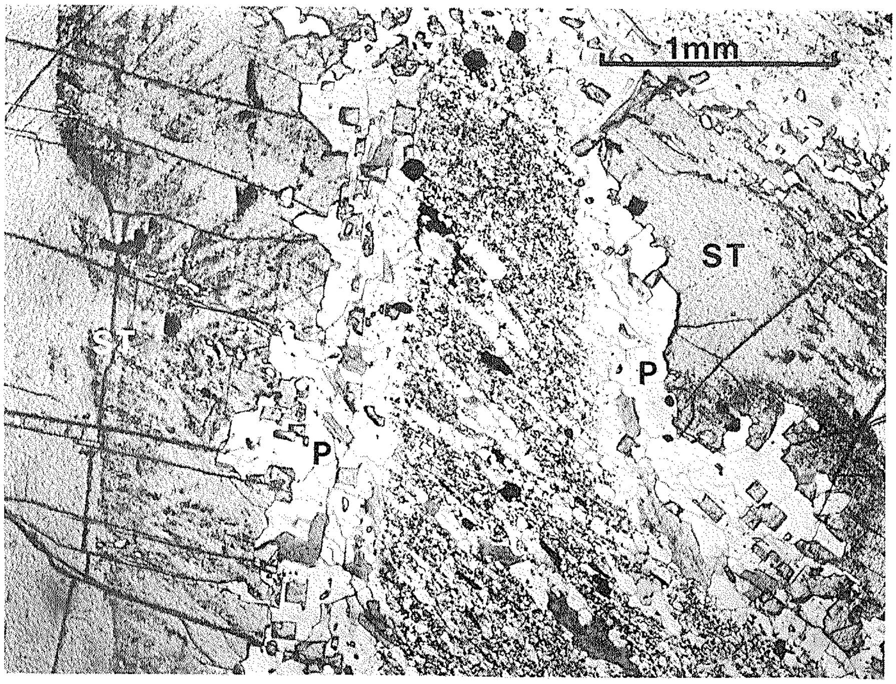


PLATE 41: Photomicrograph (plain light) of staurolite porphyroblasts (ST) partially replaced by plagioclase (P) in a muscovite-free pelitic gneiss, sillimanite-biotite zone, Corley Lake member, File Lake Formation.

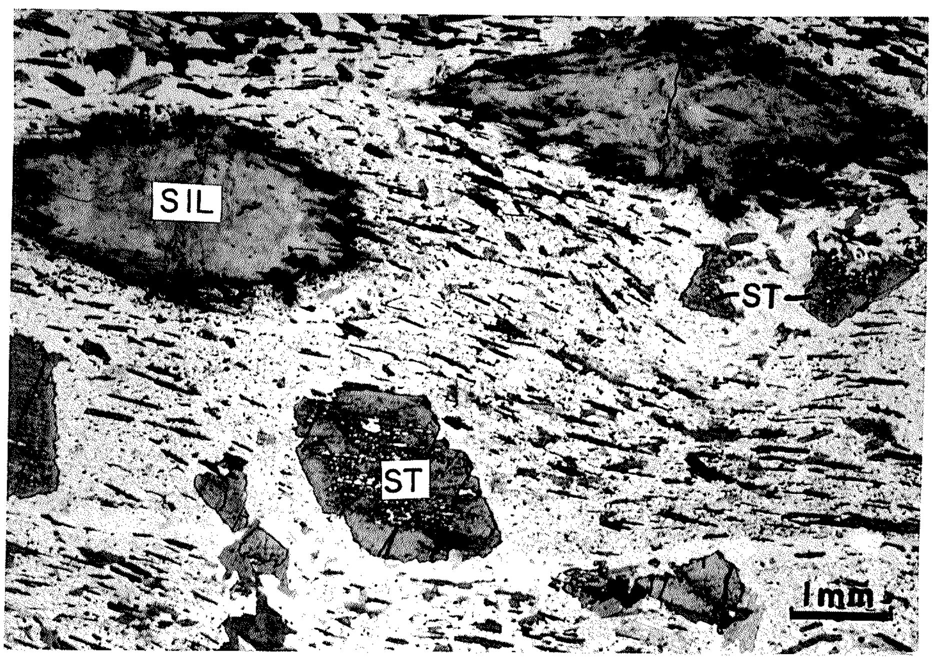


PLATE 42: Photomicrograph (plain light) of nodular aggregates of sillimanite (SIL) and corroded porphyroblasts of staurolite (ST) in muscovite-bearing pelitic gneiss, sillimanite-biotite zone, File Lake Formation. Sillimanite nodules are surrounded by a rim of disseminated magnetite (dark material).

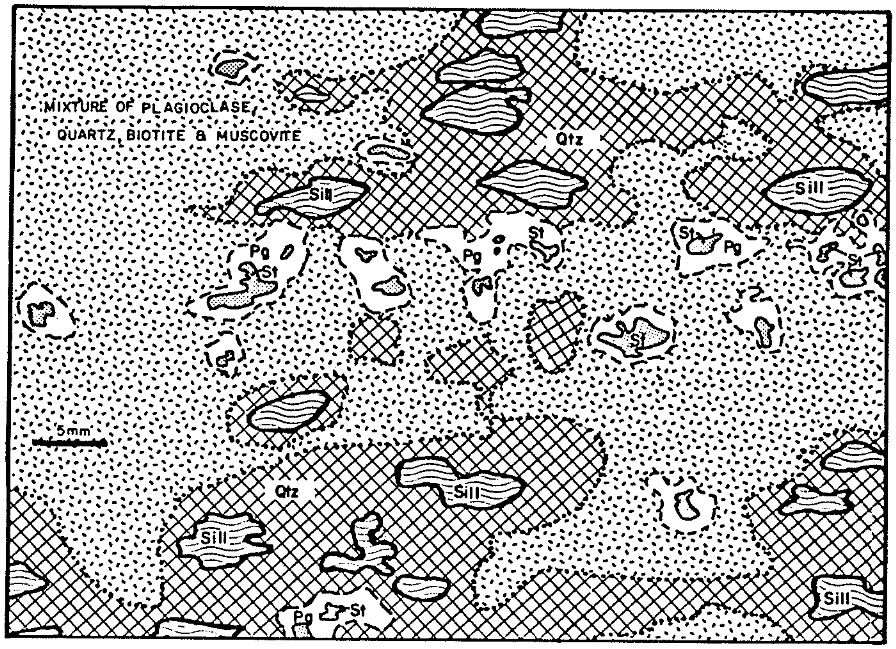


FIGURE 29. Nodules of fibrolitic sillimanite (Sill) surrounded by quartz-rich domains (Qtz) and corroded porphyroblasts of staurolite (St) surrounded by plagioclase-rich domains (Pg). Muscovite-bearing metamudstone from the File Lake Formation, sillimanite-biotite zone.

These textures can be shown to be consistent with the topologically determined reactions, discussed previously, but their reaction mechanism is more complicated than a simple direct transformation from reactants to products. The textures appear to be the result of diffusion-controlled cation exchange reactions (see Carmichael, 1969; Foster, 1977).

5.3.1 Description of textures

Prograde muscovite rimming and replacing staurolite first occurs in muscovite-bearing rocks just above the sillimanite-biotite isograd and occurs in these rocks throughout the sillimanite-biotite zone until staurolite is finally consumed at the sillimanite-garnet-biotite isograd. The replacement of staurolite by muscovite is generally accompanied by the formation of large crystals of biotite, coarse plagioclase aggregates, and, in one sample, sillimanite (Plate 40a). The muscovite content of the rock actually decreases with increasing temperature because matrix muscovite is consumed by production of sillimanite and biotite faster than the formation of new prograde muscovite replacing staurolite. The new muscovite is not a retrograde mineral overprinting staurolite because its first appearance coincides with the sillimanite-biotite isograd and no overprinting of staurolite by muscovite was observed below this isograd. Similar replacement of staurolite by prograde muscovite has been described by Guidotti (1968).

Prograde aggregates of plagioclase rimming and replacing staurolite first occur just above, and appear to be related to, the sillimanite-biotite isograd. This phenomenon occurs in both muscovite-bearing rocks (Plate 40b; Fig. 29) and muscovite-free rocks (Plate 41), throughout the sillimanite-biotite zone, and into the sillimanite-garnet-biotite zone in muscovite-free rocks, until staurolite is consumed. It is most pronounced in muscovite-free rocks, particularly those containing cordierite. It begins as a minor corrosion of the periphery of the staurolite grains (Plate 41) and ends as complete replacement of staurolite. In muscovite-bearing rocks, the plagioclase is generally accompanied by both muscovite and biotite, but in muscovite-free rocks, it occurs alone (Plate 41) or with biotite.

Sillimanite nodules, 3 to 7 mm in size, are characteristic of muscovite- and staurolite-bearing pelitic gneisses of the sillimanite-biotite zone. They comprise aggregates of fibrolitic sillimanite, enveloped by quartz-rich domains, and are isolated from other aluminous minerals (Plates 40b and 42; Fig. 29).

Garnet porphyroblasts with narrow rims of quartz occur in muscovite-free rocks in high grade parts of the sillimanite-biotite zone. They are most prominent in rocks with large porphyroblasts of cordierite and corroded crystals of staurolite.

5.3.2 Interpretation of textures

a) Introduction

Carmichael (1969) suggested that prograde reactions in metamorphosed pelitic rocks proceed by local cation exchange reactions. He assumed that aluminum remained immobile and demonstrated that a set of cation exchange reactions, whem summed over a thin section, can yield a net reaction which is equivalent to a topological change of an AFM diagram. The textures in pelitic rocks of the sillimanite-biotite zone of the File Lake area support this cation exchange mechanism, although they indicate that aluminum diffuses over very short distances and thus is not entirely immobile as assumed by Carmichael (1969).

Textures resulting from cation exchange reactions have been and probably still are being misinterpreted by many geologists. Two of the most common misinterpretations, pointed out by Carmichael (1969), are:

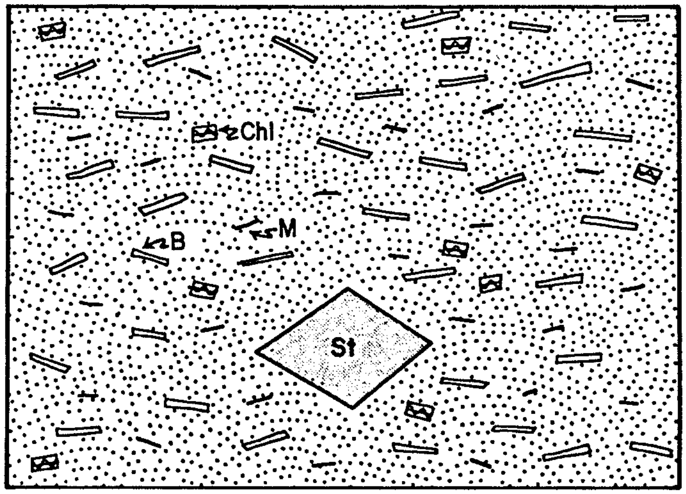
1) the misinterpretation that many replacement phenomena such as muscovite and/or plagioclase overgrowing staurolite are retrogressive features whereas, in fact, they are caused by cation exchange reactions; and
2) the misinterpretation that these textures were produced by a complicated series of metamorphic events, rather than a single event if the cation exchange reactions are properly identified.

Recognition of textures resulting from cation exchange processes was important for correct identification of metamorphic reactions and metamorphic events in the File Lake area.

b) Muscovite-bearing rocks

Typical textures and mineral assemblages of a muscovite-bearing pelitic gneiss from below and above the sillimanite-biotite isograd are compared in Figure 30. Below the isograd, staurolite occurs as well-formed euhedral porphyroblasts (Plate 38). Above the isograd, the staurolite porphyroblasts are corroded and replaced by a mixture of plagioclase, biotite and muscovite; and aggregates of sillimanite, enveloped by a quartz-rich zone, occur where previously there was a mixture of plagioclase, quartz, biotite, muscovite, and chlorite (Plates 40b and 42; Fig. 29). Less obvious, but also important, is the absence of chlorite and the reduced amount of muscovite in pelitic gneisses above the sillimanite-biotite isograd.

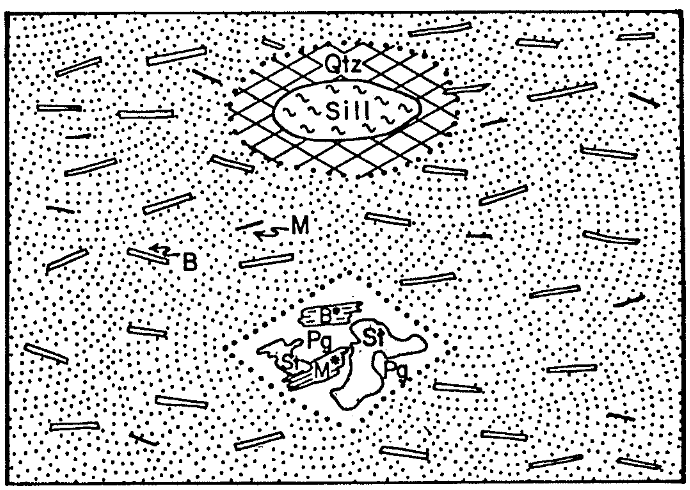
(a)



chlorite + muscovite + staurolite + quartz =

sillimanite + biotite + H_2O

(b)



M	= muscovite in matrix	St	= staurolite
M*	= new muscovite plates	Sill	= sillimanite
B	= biotite in matrix	Dotted area	= mixture of quartz + plagioclase
B*	= new biotite plates		
Chl	= chlorite		
Pg	= plagioclase	Qtz	= quartz

FIGURE 30. Typical textures and mineralogy of a muscovite-bearing pelitic gneiss below (a) and above (b) the sillimanite-biotite isograd reaction, File Lake area.

The textures depicted in Figure 30b are due to cation exchanges which occurred during the sillimanite-biotite isograd reaction

$$\text{chlorite} + \text{muscovite} + \text{staurolite} + \text{quartz} \rightleftharpoons \text{sillimanite} + \text{biotite} + H_2O \quad (6)$$

and the subsequent continuous reaction

$$\text{muscovite} + \text{staurolite} + \text{quartz} \rightleftharpoons \text{sillimanite} + \text{biotite} + H_2O \quad (9)$$

The main cation exchanges for reactions (6) and (9) are depicted in Figure 31. They allow staurolite to break down to sillimanite without being in physical contact and without the need for transporting relatively immobile aluminum between the two. For the sillimanite domain, this is accomplished by the cation exchange reaction

$$\text{plagioclase (in matrix)} \rightleftharpoons \text{sillimanite} + \text{quartz} + Ca^{+} + Na^{+} \quad (17)$$

whereby aluminum necessary for sillimanite is derived by breakdown of matrix plagioclase, followed by slight migration of the aluminum into a concentrated core of sillimanite surrounded by a quartz-enriched (or plagioclase-depleted) domain (Figs. 30 and 31). The Na^{+} and Ca^{+} released by reaction (17), along with K^{+} and Na^{+} cations released by breakdown of matrix muscovite, migrate to the staurolite domain where they contribute to the following cation exchange reaction (approximate):

$$\text{staurolite} + \text{quartz (in matrix)} + Na^{+} + Ca^{+} + K^{+} \rightleftharpoons \text{plagioclase} + \text{muscovite} + \text{biotite} \quad (18)$$

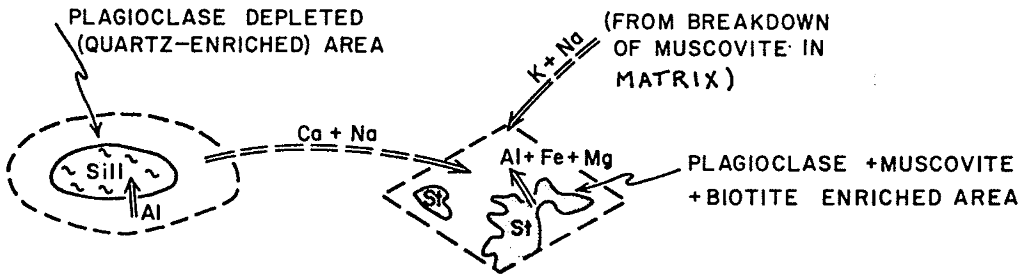


FIGURE 31. Main cation exchanges forming plagioclase-depleted areas around sillimanite knots and plagioclase-enriched areas around, and replacing, staurolite in a muscovite-bearing pelitic gneiss of the sillimanite-biotite zone (see Figure 30).

Reaction (18) permits plagioclase, muscovite and biotite to absorb aluminum, magnesium, iron and silica released by the breakdown of staurolite, plus Ca^+ and Na^+ cations released from the sillimanite domain, K^+ and Na^+ cations released from matrix muscovite, and SiO_2 released from surrounding grains of matrix quartz.

c) Muscovite-free rocks

Typical textures and mineral assemblages of a muscovite-free pelitic gneiss from below and above the discontinuous reaction

$$\text{chlorite + staurolite + quartz} \rightleftharpoons \text{cordierite + garnet} + H_2O \quad (8)$$

are compared in Figure 32. Reaction (8) occurs near the bottom of the sillimanite-biotite zone and is responsible, along with the related continuous reaction

$$\text{staurolite + quartz} \rightleftharpoons \text{cordierite + garnet} + H_2O \qquad (11)$$

for most of the decomposition of staurolite in muscovite-free rocks of the sillimanite-biotite zone. Below reaction (8), staurolite occurs as well-formed, slightly corroded euhedral porphyroblasts. Above reaction (8), the staurolite porphyroblasts are corroded and replaced by plagioclase (Plate 41); large sieved porphyroblasts of cordierite (Plate 43), containing numerous inclusions of quartz and biotite, occur where previously there was a mixture of matrix plagioclase, quartz, biotite and chlorite; and garnet porphyroblasts have rims of granular quartz.

The textures depicted in Figure 32b are due to cation exchanges which occurred during reactions (8) and (11). The main cation exchanges for the staurolite, cordierite and garnet domains, respectively,

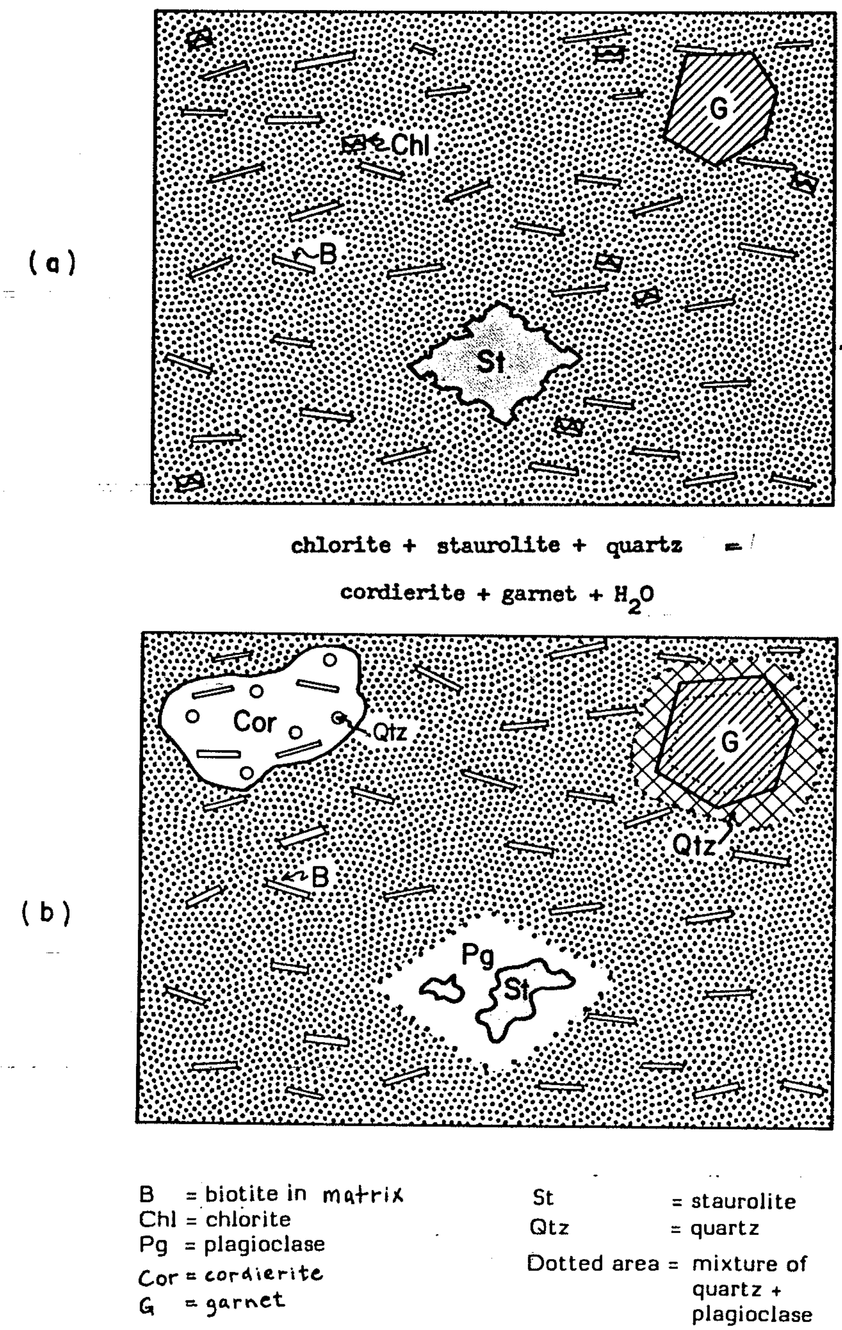


FIGURE 32: Typical textures and mineralogy of a muscovite-free pelitic gneiss (a) below and (b) above discontinuous reaction (8), sillimanite-biotite zone.

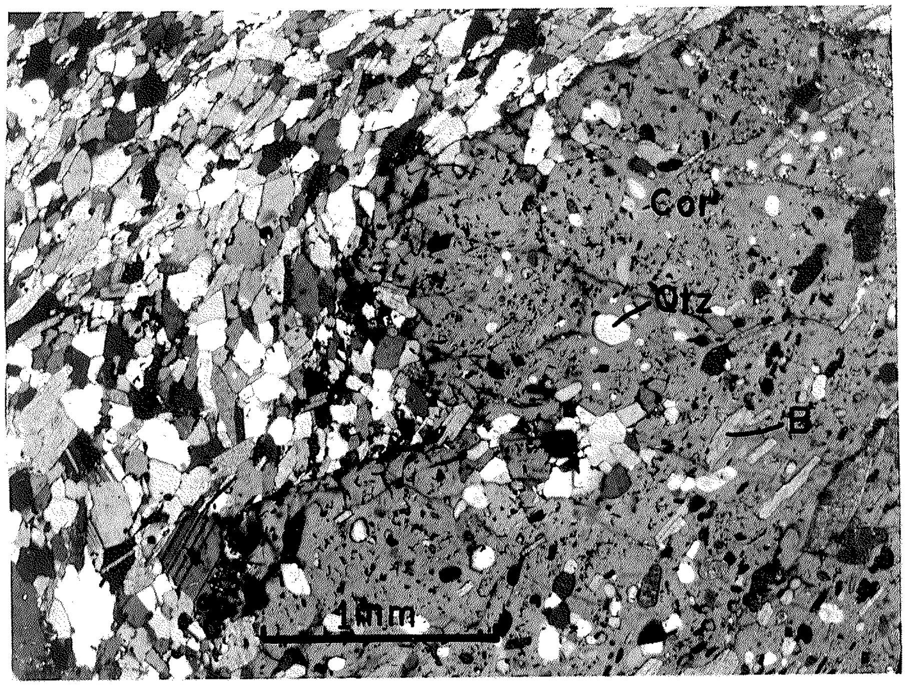


PLATE 43: Photomicrograph (polarized light) of poikiolitic cordierite porphyroblast (Cor) with inclusions of quartz (Qtz) and biotite (B). Muscovite-free metamudstone from the Corley Lake member of the File Lake Formation, sillimanite-garnet-biotite zone.

are (Fig. 33):

$$\text{staurolite + quartz (in matrix)} + Na^{+} + Ca^{+} \rightleftharpoons \text{plagioclase} + Fe^{+} + Mg^{+}; \tag{19}$$

$$\text{plagioclase (in matrix)} + Mg^{+} + Fe^{+} \rightleftharpoons \text{cordierite + quartz} + Na^{+} + Ca^{+}; \text{ and} \tag{20}$$

$$\text{plagioclase (in matrix)} + Fe^{+} + Mg^{+} \rightleftharpoons \text{garnet + quartz} + Na^{+} + Ca^{+} \tag{21}$$

Like the cation exchange reactions (17) and (18) in muscovite-bearing rocks, these reactions allow aluminum to remain relatively immobile and use matrix plagioclase and matrix quartz, respectively, as a source and a sink for needed or unneeded aluminum.

5.4 Inferred P-T Conditions of Metamorphism

Considerable data is available today on metamorphic reactions and the chemical composition of metamorphic minerals in pelitic schists. This information makes it possible to establish chemographic relations and construct petrogenetic grids using techniques developed by Schreinemakers (1965) and summarized by Zen (1966). A calibrated petrographic grid has been constructed by Carmichael (personal communication, 1978) using a combination of experimental and field data. The discontinuous metamorphic reactions observed on the erosion surfaces in the File Lake area (this study) and in the Snow Lake area (Froese and Moore, 1978) are shown on a slightly modified version of Carmichael's petrogenetic grid (Fig. 34). Reactions involving hornblende and cummingtonite are not shown.

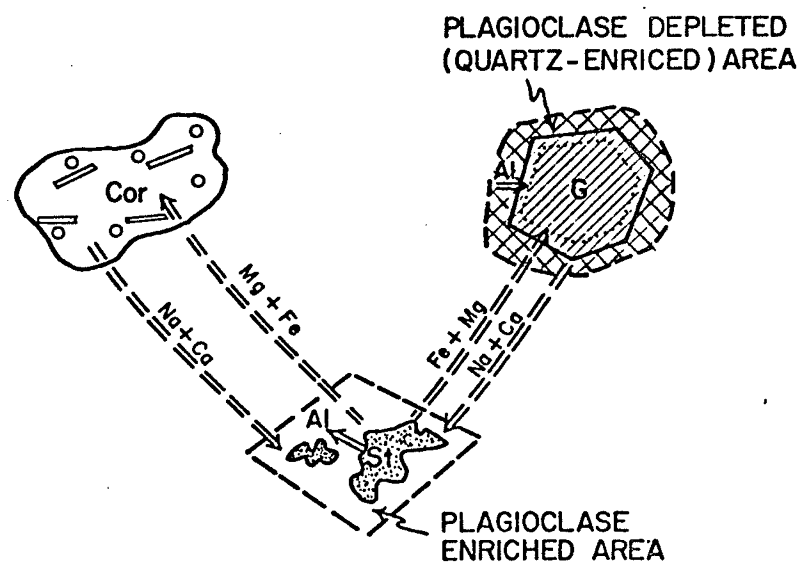


FIGURE 33 : Main cation exchanges in a muscovite-free pelitic gneiss, sillimanite-biotite zone.

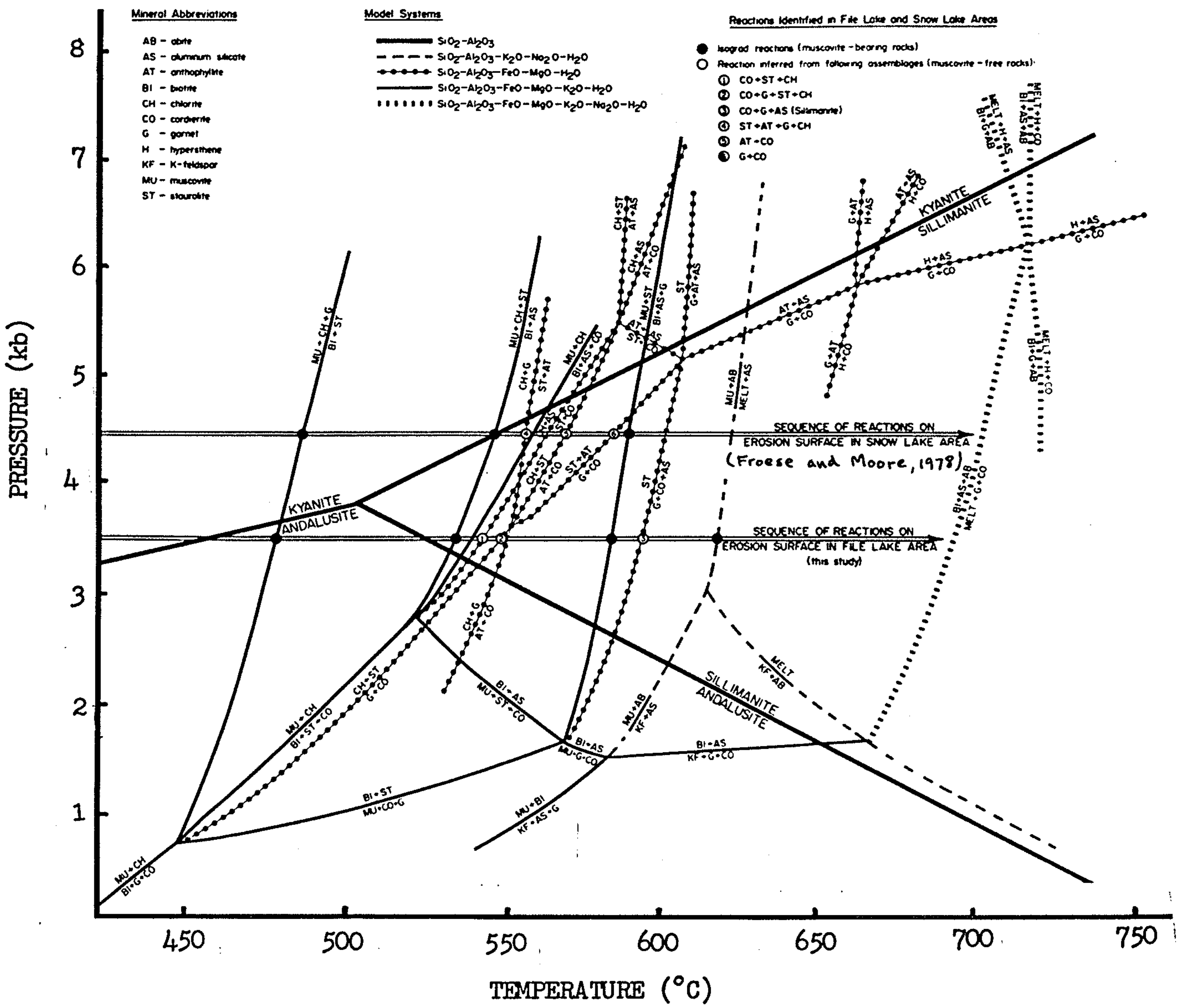


FIGURE 34: Calibrated petrogenetic grid from Hess (1969) and Carmichael (personal communication, 1978) showing metamorphic reactions identified in Amisk Group metasedimentary rocks of the File Lake and Snow Lake areas.

The metamorphic reactions on the File Lake erosion surface indicate metamorphic temperatures ranged from 400 to 500^{o}C in the chlorite-biotite zone to about 625 to 675^{o}C in the K-feldspar (melt)-sillimanite zone. The pressure, based on formation of sillimanite by the reaction

$$\text{chlorite + muscovite + staurolite + quartz} \rightleftharpoons \text{aluminum silicate + biotite + } H_2O,$$

is inferred to have been above 3.3 kb, but below 3.7 kb because the reaction

$$\text{chlorite + staurolite + quartz} \rightleftharpoons \text{cordierite + garnet + } H_2O \quad (8)$$

is intersected. These pressure and temperature values are only approximate because the locations of the reaction curves in Figure 34 are not known precisely and are effected by such parameters as μ_{H_2O}, μ_{O_2} and mineral compositions, in addition to P and T.

The sequence of reactions identified in the Snow Lake area (Froese and Moore, 1978) indicates that slightly higher pressures prevailed than in the File Lake area. The pressure was probably close to 4.5 kb because both kyanite and sillimanite were formed by the reaction

$$\text{chlorite + muscovite + staurolite + quartz} \rightleftharpoons \text{aluminum silicate + biotite + } H_2O$$

Metamorphic pressures estimated from sphalerite compositions in Snow Lake ore deposits (Bristol, 1974; Scott, 1976) are in the 6 to 8.5 kb range. However, these pressures may be due to low temperature re-equilibration of sphalerite during conversion of adjacent hexagonal pyrrhotite to monoclinic pyrrhotite; this feature has been observed in sphalerites from the Ruttan Lake Mine (C.C. Bristol, personal communication, 1978).

The 3.5 kb and 4.5 kb pressures at the sillimanite-biotite isograd ($550^{\circ}C$) in the File Lake and Snow Lake areas indicate depths of burial of 12.25 km and 15.75 km, respectively, assuming an average rock density of 2.85 (3.5 km = 1 kb). The geothermal gradients indicated by these depths of burial are $45^{\circ}C/km$ at File Lake and $35^{\circ}C/km$ at Snow Lake.

The temperature increase on the erosion surface in the File Lake area is $150^{\circ}C$ from the staurolite-biotite to the K-feldspar (melt)-sillimanite isograd, a distance of 7 km. This is a gradient of $21^{\circ}C/km$.

5.5 Metamorphic Character of the Boundary Between the Flin Flon and Kisseynew Belts

The metamorphic isograd reactions and zones identified in the File Lake Formation are part of a steep metamorphic gradient which is regionally coincident with the boundary between the Flin Flon and Kisseynew belts. In detail, however, the metamorphic gradient locally cuts across the boundary (Fig. 14) and was imposed late in the tectonic history of the Flin Flon and Kisseynew belts.

The metamorphic gradient could reflect late updoming of more deeply buried and hence more highly metamorphosed strata in the Kisseynew belt. However, such extensive updoming is unlikely because the metamorphic gradient of $21^{\circ}C/km$ in the File Lake area is too steep. If it was due solely to differences in depth of burial, strata in the central part of the File Lake area would have to be tilted about 45° to the south, and this amount of uplift is not consistent with the structural history of the area (Bailes, 1978).

The metamorphic gradient could reflect higher heat flow in the Kisseynew belt than in the Flin Flon belt. The different geothermal gradients in the File Lake and Snow Lake areas, 45°C/km and 35°C/km, respectively, indicate that significant heat flow differences did exist, favouring this interpretation.

Higher heat flow in the Kisseynew belt than in the Flin Flon belt could have resulted from several mechanisms: 1) concentration of lithophile and radiogenic elements in the Kisseynew belt and higher heat flow from their radioactive decay; 2) rising flow in a mantle convective cell under the Kisseynew belt; or 3) higher thermal conductivity of sedimentary rocks relative to volcanic rocks. Differences in ability of sedimentary and volcanic rocks to conduct heat could have occurred if heat consumed by metamorphic reactions was greater in volcanic than in sedimentary rocks (L. Ayres, personal communication, 1978). Lower ability to conduct heat would mean that volcanic rocks of the Flin Flon belt could have acted as an insulator preventing upward movement of heat. This mechanism could explain why Precambrian volcanic belts are invariably much lower grade than associated sedimentary belts, and does not require special tectonic conditions for development of this difference.

6. SUMMARY AND CONCLUSIONS

Weakly recrystallized Amisk Group metasedimentary rocks of the File Lake Formation can be traced from the Flin Flon belt into highly recrystallized migmatitic Nokomis Group equivalents in the Kisseynew belt. This refutes the widely held view that the contact between the two belts is a major fault zone. Metamorphic reactions identified in Amisk Group metasedimentary rocks indicate a steep metamorphic gradient of $21^{\circ}C/km$ at 3.5 kb across the boundary between the two belts.

The Amisk Group sedimentary rocks overlie a thick sequence of subalkaline mafic volcanic flows that were erupted in a moderate to shallow water environment, probably from a major shield volcano. The sediments are composed predominantly of felsic volcanic detritus and were deposited mainly by turbidity currents, fluidized sediment flows, and debris flows. The debris flow deposits, comprising the Parisian and Yakymiw Formations, are local in extent and restricted to the volcanic terrain of the Flin Flon belt. The turbidity current and fluidized sediment flow deposits comprising the File Lake Formation are widespread and are part of a subaqueous fan system that has been traced into the adjacent Kisseynew sedimentary basin.

The Parisian and File Lake Formations contain a wide variety of volcanic clast lithologies. Such mixing requires subaerial transport. Slight rounding of the detritus and scattered clasts of epizonal, probably subvolcanic intrusions are consistent with portions of the source area being subaerial. In the Yakymiw Formation, extreme immaturity, limited clast type variations, and negligible rounding of detritus indicate direct input of these sediments from a localized volcanic source, possibly as debris flows of unconsolidated pyroclastic material down the flank of a volcano.

Several features indicate that the Amisk Group sedimentary rocks were derived from contemporaneous upslope Amisk volcanoes rather than an older dissected volcanic terrain. These include the direct input of the pebbly greywackes of the Yakymiw Formation from their volcanic source without any evidence of reworking; local although limited intercalation of volcanic strata in the Parisian and File Lake Formations; absence of plutonic or metamorphic clasts which would be expected from an older deeply dissected volcanic terrain; and only slight rounding of detritus which favours derivation from largely unconsolidated pyroclastic deposits rather than by stream dissection of an older volcanic terrain with consequent abrasion of clasts.

Major felsic stratovolcanoes must have been constructed late in the evolution of the volcanic belt and become emergent over large areas. Loose pyroclastic detritus from these felsic stratovolcanoes was eroded by subaerial mass wasting, rain, stream activity and wave action. This material was then transported by subaqueous, mass-sediment flows into adjacent inter-volcanic deep water basins. Some of the detritus entered submarine fan systems and was transported away from the volcanic belt into the Kisseynew sedimentary basin.

The Amisk sedimentary rocks of the File Lake area are probably only part of a series of coalesced subaqueous fans extending out from the Flin Flon belt into the Kisseynew belt. If this interpretation is correct, a large quantity of felsic and, probably also intermediate, volcanic detritus has been shed from Amisk volcanoes into the Nokomis

Group of the Kisseynew belt. This close association between volcanism in the Flin Flon belt and sedimentation in the adjacent Kisseynew belt is a common phenomenon in many Precambrian volcanic and sedimentary belt pairs.

From the Flin Flon into the Kisseynew belts, several prograde metamorphic reactions which define a temperature gradient of $21^{\circ}C/km$ at 3.5 kb have been identified in the File Lake Formation. This gradual, but relatively rapid metamorphic transition indicates that the apparent jump in grade described by earlier workers between the Flin Flon and Kisseynew belts is not due to a fault, but rather is a steep metamorphic gradient imposed on a stratigraphically continuous supracrustal succession. At lowest grades the File Lake Formation contains middle greenschist facies mineral assemblages formed at 400 to $500^{\circ}C$. At highest grades it contains upper almandine-amphibolite facies mineral assemblages formed at 625 to $675^{\circ}C$. The high grade varieties are migmatitic paragneisses which are identical to Nokomis Group paragneisses of the Kisseynew belt.

Textures in strongly recrystallized paragneisses indicate that the prograde metamorphic reactions proceeded by local diffusion-controlled cation exchange reactions. The textures resulting from the cation exchange reactions include replacement of staurolite by prograde muscovite and plagioclase; fibrolitic knots of sillimanite isolated from other aluminous minerals, and garnet porphyroblasts with rims of quartz. Recognition of these textures as products of cation exchange processes was necessary for correct identification of metamorphic isograd reactions.

The $21^{\circ}C/km$ gradient along the erosion surface from the Flin Flon into the Kisseynew belt is too steep to be due solely to updoming of more deeply buried and more highly metamorphosed strata of the Kisseynew belt. It was probably due to higher heat flow in the Kisseynew belt than in the Flin Flon belt. Higher heat flow in the Kisseynew belt than in the Flin Flon belt may have been caused by as simple a difference as higher thermal conductivity of sedimentary rocks relative to volcanic rocks. Lower ability to conduct heat would mean that volcanic rocks could have acted as an insulator preventing upward movement of heat. This mechanism could explain why Precambrian volcanic belts are invariably much lower grade than associated sedimentary belts, and does not require special tectonic conditions for development of this difference.

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APPENDIX:

MAIN FEATURES OF SUPRACRUSTAL ROCK UNITS

(FIGURE 2)

TABLE A-1 : MAIN FEATURES OF AMISK VOLCANIC ROCKS (UNITS 1 TO 8)[1]

Unit No.	Rock type	Weathering characteristics	Colour of fresh surface	Primary structures and textures	Grain size and fabric	Mineralogy	Comments
1	basalt and andesite flows, minor dacite	dark green; large outcrops with low relief	dark green	mainly massive flows; pillows present but not common; aphyric to locally porphyritic; locally contains monolithic fragmental rocks	fine grained; massive, except northern exposures which are weakly foliated	rocks recrystallized, minerals metamorphic; mixture of plagioclase and light green amphibole, plus minor oxide and accessory minerals	grade of metamorphism increases towards the north and towards the Norris pluton, consequently rocks from northern exposures are most intensely recrystallized
1a	mafic metavolcanic gneiss	dark to medium green, with light green layers with rusty tinges	dark to light green	irregular layering, probably primary but may be tectonic or metamorphic	fine grained; moderately to strongly foliated	rocks recrystallized, minerals metamorphic; mixture of plagioclase and medium to dark green amphibole; pyralspite garnet porphyroblasts common; colourless amphibole (cummingtonite?) and red brown biotite common	may be a recrystallized layered mafic volcanic ash deposit or, alternatively, may be derived from rocks of unit 1 by metamorphic and tectonic processes
2, 2a 2b	rhyolite and dacite flows, tuff and breccia	white to light blue green; large outcrops with moderate relief; blue quartz phenocrysts in relief on outcrop surface are common	light grey to light blue green	layering ubiquitous, defined by individual flows and by tuffaceous units; phenocrysts of quartz and plagioclase common; monolithic fragments common, particularly in rocks exposed on Storozuk Lake; vesicles and amygdules moderately common; margins of some flows strongly scoriaceous; pillows observed at one locality (Dickstone minesite)	fine grained; rocks from southern exposures are massive while those further north typically are strongly foliated; fragments, amygdules, and vesicles are tectonically deformed with steep-plunging long axes	rocks recrystallized, mainly composed of metamorphic minerals; consist mainly of mixture of quartz and plagioclase; phenocrysts of quartz and plagioclase (An_{2-9}) common in rocks from southern exposures; pyralspite garnet, pale green amphibole and biotite common as porphyroblasts in rocks north of Yakymiw Lake (caused by contact metamorphism by Norris Lake pluton)	rocks of unit 2 comprise a dome shaped deposit with up to 1500 metres of original relief; rocks from most northerly exposures are more intensely recrystallized
3	basalt and andesite flows	dark green; large outcrops with low relief	dark green	mainly massive and pillowed flows; pillows have thin selvages and are often zoned internally; epidotized cores to pillows are common; pillow breccias occur locally	fine grained; rocks from southern exposures are massive while those further north are strongly foliated	rocks recrystallized, minerals metamorphic; mixture of light to medium green amphibole and plagioclase, plus minor oxide and accessory minerals	in section east of Storozuk Lake rocks become slightly less mafic stratigraphically upwards (from west to east); many of the rocks east-southeast of Josland Lake contain numerous large stubby porphyroblasts of green amphibole giving them pseudo-gabbroic textures
3a	basalt and andesite breccia	dark green	dark green	includes both monolithic and heterolithic breccias; most breccias are monolithic; heterolithic breccias include rare felsic fragments; plagioclase phenocrysts common	fine grained; fragments are tectonically deformed with steep-plunging long axes	as above	many of the rocks east-southeast of Storozuk Lake contain prominent stubby porphyroblasts of green amphibole giving them pseudo-gabbroic textures
3b	felsic tuff and flows	white to light green, locally with rusty discolouration	white to light green	mainly tuffaceous; pillows rare, but present; plagioclase (andesine) phenocrysts common in horizon on east shore of Josland Lake; layering well developed in tuffaceous varieties	fine grained; moderately foliated; between gabbro sills west of Ducharme Bay rocks have bleached, baked appearance	rocks recrystallized, minerals metamorphic; mixture of plagioclase, quartz, green amphibole and red brown biotite; rocks in layer on east shore of Josland Lake are rich in calcite and may be calcareous tuffs	stratigraphic affinity of thin layers of this rock unit not known, they may be genetically related to larger masses of felsic volcanic strata, such as those exposed on Storozuk Lake or on Elmes Island
3c	mafic metavolcanic gneiss	dark green	dark green	pillows present, but rare and poorly preserved	fine grained, approaching medium grain size; moderately foliated (gneissic); characterized by sugary granular texture	rocks recrystallized, minerals metamorphic; mixture of plagioclase, dark green amphibole and accessory oxide minerals; diopside and garnet present rarely	high grade metamorphic derivatives of rocks of unit 3; lack of garnet in these mafic metavolcanic gneisses is believed to be due to composition of parent volcanic strata
3d	felsic metavolcanic gneiss	light grey with buff and orange hues; large outcrops with moderate relief	light grey	massive, homogeneous, nonlaminated; portions porphyritic	fine grained; weakly foliated (gneissic)	rocks recrystallized, minerals metamorphic; mixture of plagioclase, quartz, green amphibole, biotite and rare garnet	parent rock probably dacitic and andesitic in composition
4, 4a	dacite flows [4]; meta-dacite [4a]	white, large outcrops with moderate relief	light grey	mainly massive flows; autoclastic (explosion) breccias present locally; quartz and plagioclase phenocrysts present, but not prominent; amygdules present locally; pillows noted at two localities	very fine grained; massive; fragments tectonically deformed with steep-plunging long axes	mixture of very fine-grained plagioclase and quartz, which also occur rarely as phenocrysts; biotite, chlorite, muscovite and disseminated sulphides and graphite present in small amounts; rocks from northeastern shore of island (unit 4a) characterized by numerous large (1-3 mm) porphyroblasts of green amphibole	autoclastic breccias with a 'shattered porcelain' appearance occur at several localities, they are believed to be caused by internal gas explosions after flows solidified
5, 5b	basalt and andesite flows [5]; basalt and andesite breccia [5b]	dark green; large outcrops with low relief	dark green	mainly massive and pillowed flows; pillows have thin selvages, many have epidotized cores; pillow breccias common as interlayers in flow sequences; heterolithic breccias common in unit 5b; plagioclase phenocrysts common in rocks of unit 5b; narrow ash horizons present rarely; columnar cooling joints present in some massive flows	fine grained; massive to moderately foliated; strongly foliated on west shore of Woosey Lake and south shore of File Lake	rock recrystallized, minerals metamorphic; consist mainly of mixture of plagioclase and green amphibole; accessory minerals include iron oxides, biotite, chlorite and epidote; rocks within 0.3 km of the Reed Lake pluton show significant increases in grain size and degree of recrystallization	during field mapping many exposures between Butler and Fussey Lakes were noted to have very rubbly weathering surfaces, samples from many of these outcrops subsequently have been identified as hyaloclastic breccias; rocks of unit 5 and 5b on strike with fragmental dacites of unit 6 tend to be porphyritic, typically fragmental and generally slightly less mafic than normal
5a	porphyritic basalt and andesite flows	light to medium green	light to medium green	massive; contain prominent flow aligned laths of plagioclase; some plagioclase crystals exhibit excellent igneous zonation; carbonate and quartz filled vesicles present locally	fine grained groundmass with 2-25 mm phenocrysts of plagioclase; plagioclase microlites common in groundmass	rocks recrystallized (some very strongly) by Reed Lake pluton, minerals metamorphic except for plagioclase phenocrysts (An_{48-62}); groundmass is mixture of plagioclase, brown biotite, green hornblende and minor epidote; carbonate vesicles recrystallized with following mineralogy typical from core to rim: calcite → calcium garnet → diopside → mixture of epidote, plagioclase and sphene	unit draped around and recrystallized by Reed Lake pluton (unit 22)
5c	mafic metavolcanic gneiss	dark green; large outcrops with moderate to high relief	dark green	massive, homogeneous; pillows present, but rare and poorly preserved	fine-grained, approaching medium grain size; moderately foliated (gneissic); characterized by sugary granular texture	rocks recrystallized, minerals metamorphic; mixture of plagioclase, dark green amphibole and accessory oxide minerals; diopside and garnet present rarely	high grade metamorphic derivatives of rocks of unit 5; lack of garnet in these mafic metavolcanic rocks is believed to be due to composition of parent volcanic rocks; rocks of unit 5c identical to and, possibly, stratigraphically equivalent to rocks of unit 3c
6	dacite breccia	white to light green, locally with slight rusty staining		heterolithic breccias common; plagioclase present as phenocrysts	fine grained; weakly to moderately foliated		boundaries of this unit difficult to define because of intermixing of a wide variety of lithologies, including mafic flows
7, 7a	garnetiferous fragmental porphyritic mafic metavolcanic gneiss [7]; garnetiferous mafic metavolcanic gneiss [7a]	dark green, large outcrops with low relief	dark green	heterolithic breccias ubiquitous in unit 7, fragments vary from andesite to rhyolite, generally less mafic than matrix, average size of fragments is 2-6 cm (in horizontal plane); both fragments and host rocks	fine grained; massive to weakly foliated	rocks recrystallized, minerals metamorphic; composed chiefly of plagioclase and green amphibole, with lesser amounts of quartz and red brown biotite; pyralspite garnet porphyroblasts common;	rocks of unit 7a generally are non-porphyritic and nonfragmental; this may be due to destruction of these textures by metamorphism adjacent to the Woosey pluton but more likely it is due to lack of them in the parent volcanic rock

						(cummingtonite?) and red brown biotite common	
2, 2a 2b	rhyolite and dacite flows, tuff and breccia	white to light blue green; large outcrops with moderate relief; blue quartz phenocrysts in relief on outcrop surface are common	light grey to light blue green	layering ubiquitous, defined by individual flows and by tuffaceous units; phenocrysts of quartz and plagioclase common; monolithic fragments common, particularly in rocks exposed on Storozuk Lake; vesicles and amygdules moderately common; margins of some flows strongly scoriaceous; pillows observed at one locality (Dickstone minesite)	fine grained; rocks from southern exposures are massive while those further north typically are strongly foliated; fragments, amygdules, and vesicles are tectonically deformed with steep-plunging long axes	rocks recrystallized, mainly composed of metamorphic minerals; consist mainly of mixture of quartz and plagioclase; phenocrysts of quartz and plagioclase (An_{2-9}) common in rocks from southern exposures; pyralspite garnet, pale green amphibole and biotite common as porphyroblasts in rocks north of Yakymiw Lake (caused by contact metamorphism by Norris Lake pluton)	rocks of unit 2 comprise a dome shaped deposit with up to 1500 metres of original relief; rocks from most northerly exposures are more intensly recrystallized
3	basalt and andesite flows	dark green; large outcrops with low relief	dark green	mainly massive and pillowed flows; pillows have thin selvages and are often zoned internally; epidotized cores to pillows are common; pillow breccias occur locally	fine grained; rocks from southern exposures are massive while those further north are strongly foliated	rocks recrystallized, minerals metamorphic; mixture of light to medium green amphibole and plagioclase, plus minor oxide and accessory minerals	in section east of Storozuk Lake rocks become slightly less mafic stratigraphically upwards (from west to east); many of the rocks east-southeast of Josland Lake contain numerous large stubby porphyroblasts of green amphibole giving them pseudo-gabbroic textures
3a	basalt and andesite breccia	dark green	dark green	includes both monolithic and heterolithic breccias; most breccias are monolithic; heterolithic breccias include rare felsic fragments; plagioclase phenocrysts common	fine grained; fragments are tectonically deformed with steep-plunging long axes	as above	many of the rocks east-southeast of Storozuk Lake contain prominent stubby porphyroblasts of green amphibole giving them pseudo-gabbroic textures
3b	felsic tuff and flows	white to light green, locally with rusty discolouration	white to light green	mainly tuffaceous; pillows rare, but present; plagioclase (andesine) phenocrysts common in horizon on east shore of Josland Lake; layering well developed in tuffaceous varieties	fine grained; moderately foliated; between gabbro sills west of Ducharme Bay rocks have bleached, baked appearance	rocks recrystallized, minerals metamorphic; mixture of plagioclase, quartz, green amphibole and red brown biotite; rocks in layer on east shore of Josland Lake are rich in calcite and may be calcareous tuffs	stratigraphic affinity of thin layers of this rock unit not known, they may be genetically related to larger masses of felsic volcanic strata, such as those exposed on Storozuk Lake or on Elmes Island
3c	mafic metavolcanic gneiss	dark green	dark green	pillows present, but rare and poorly preserved	fine grained, approaching medium grain size; moderately foliated (gneissic); characterized by sugary granular texture	rocks recrystallized, minerals metamorphic; mixture of plagioclase, dark green amphibole and accessory oxide minerals; diopside and garnet present rarely	high grade metamorphic derivatives of rocks of unit 3; lack of garnet in these mafic metavolcanic gneisses is believed to be due to composition of parent volcanic strata
3d	felsic metavolcanic gneiss	light grey with buff and orange hues; large outcrops with moderate relief	light grey	massive, homogeneous, nonlaminated; portions porphyritic	fine grained; weakly foliated (gneissic)	rocks recrystallized, minerals metamorphic; mixture of plagioclase, quartz, green amphibole, biotite and rare garnet	parent rock probably dacitic and andesitic in composition
4, 4a	dacite flows [4]; meta-dacite [4a]	white, large outcrops with moderate relief	light grey	mainly massive flows; autoclastic (explosion) breccias present locally; quartz and plagioclase phenocrysts present, but not prominent; amygdules present locally; pillows noted at two localities	very fine grained; massive; fragments tectonically deformed with steep-plunging long axes	mixture of very fine-grained plagioclase and quartz, which also occur rarely as phenocrysts; biotite, chlorite, muscovite and disseminated sulphides and graphite present in small amounts; rocks from north-eastern shore of island (unit 4a) characterized by numerous large (1-3 mm) porphyroblasts of green amphibole	autoclastic breccias with a 'shattered porcelain' appearance occur at several localities, they are believed to be caused by internal gas explosions after flows solidified
5, 5b	basalt and andesite flows [5]; basalt and andesite breccia [5b]	dark green; large outcrops with low relief	dark green	mainly massive and pillowed flows; pillows have thin selvages, many have epidotized cores; pillow breccias common as interlayers in flow sequences; heterolithic breccias common in unit 5b; plagioclase phenocrysts common in rocks of unit 5b; narrow ash horizons present rarely; columnar cooling joints present in some massive flows	fine grained; massive to moderately foliated; strongly foliated on west shore of Woosey Lake and south shore of File Lake	rock recrystallized, minerals metamorphic; consist mainly of mixture of plagioclase and green amphibole; accessory minerals include iron oxides, biotite, chlorite and epidote; rocks within 0.3 km of the Reed Lake pluton show significant increases in grain size and degree of recrystallization	during field mapping many exposures between Butler and Fussey Lakes were noted to have very rubbly weathering surfaces, samples from many of these outcrops subsequently have been identified as hyaloclastic breccias; rocks of unit 5 and 5b on strike with fragmental dacites of unit 6 tend to be porphyritic, typically fragmental and generally slightly less mafic than normal
5a	porphyritic basalt and andesite flows	light to medium green	light to medium green	massive; contain prominent flow aligned laths of plagioclase; some plagioclase crystals exhibit excellent igneous zonation; carbonate and quartz filled vesicles present locally	fine grained groundmass with 2-25 mm phenocrysts of plagioclase; plagioclase microlites common in groundmass	rocks recrystallized (some very strongly) by Reed Lake pluton, minerals metamorphic except for plagioclase phenocrysts (An_{48-62}); groundmass is mixture of plagioclase, brown biotite, green hornblende and minor epidote; carbonate vesicles recrystallized with following mineralogy typical from core to rim: calcite → calcium garnet → diopside → mixture of epidote, plagioclase and sphene	unit draped around and recrystallized by Reed Lake pluton (unit 22)
5c	mafic metavolcanic gneiss	dark green; large outcrops with moderate to high relief	dark green	massive, homogeneous; pillows present, but rare and poorly preserved	fine-grained, approaching medium grain size; moderately foliated (gneissic); characterized by sugary granular texture	rocks recrystallized, minerals metamorphic; mixture of plagioclase, dark green amphibole and accessory oxide minerals; diopside and garnet present rarely	high grade metamorphic derivatives of rocks of unit 5; lack of garnet in these mafic metavolcanic rocks is believed to be due to composition of parent volcanic rocks; rocks of unit 5c identical to and, possibly, stratigraphically equivalent to rocks of unit 3c
6	dacite breccia	white to light green, locally with slight rusty staining		heterolithic breccias common; plagioclase present as phenocrysts	fine grained; weakly to moderately foliated		boundaries of this unit difficult to define because of intermixing of a wide variety of lithologies, including mafic flows
7, 7a	garnetiferous fragmental porphyritic mafic metavolcanic gneiss [7]; garnetiferous mafic metavolcanic gneiss [7a]	dark green, large outcrops with low relief	dark green	heterolithic breccias ubiquitous in unit 7, fragments vary from andesite to rhyolite, generally less mafic than matrix, average size of fragments is 2-6 cm (in horizontal plane); both fragments and host rocks are strongly porphyritic; pillows and amygdules occur rarely	fine grained; massive to weakly foliated	rocks recrystallized, minerals metamorphic; composed chiefly of plagioclase and green amphibole, with lesser amounts of quartz and red brown biotite; pyralspite garnet porphyroblasts common; oxide minerals, chlorite and zoisite occur in small amounts	rocks of unit 7a generally are non-porphyritic and non-fragmental; this may be due to destruction of these textures by metamorphism adjacent to the Woosey pluton but more likely it is due to lack of them in the parent volcanic rock
8	garnetiferous felsic metavolcanic gneiss	light grey to greyish white, locally with slight rusty staining; outcrops small and poorly exposed	light grey	generally massive, but locally contains diffuse fragments and poorly defined layering; feldspar phenocrysts common	fine grained; weakly to moderately foliated	rocks recrystallized, minerals metamorphic; composed chiefly of quartz and plagioclase, with lesser amounts of acicular pale green amphibole, green biotite and disseminated pyrite; pyralspite garnet present as porphyroblasts	

[1] Units 14 and 14a not included. See Table A-3.

TABLE A-2a: GENERAL CHARACTERISTICS AND MEGASCOPIC FEATURES OF AMISK INTRUSIVE ROCKS (UNITS 9 AND 10)

Unit No.	Rock type	Style of intrusion	Contacts	Homo-geneity	Assimi-lation	Inclusions	Megacrysts	Weathering characteristics	Colour of fresh surface	Comments
9	diorite	pre-kinematic; irregular bodies; likely epizonal, possibly sub-volcanic	intrusive, sharp	homogeneous	absent	absent	absent	dark green, iron oxide staining common; outcrops large with moderate relief	dark green	columnar cooling joints only primary structure noted; east of Morton Lake, some intrusions mapped as unit 9 may comprise rocks of unit 18(1)
10	quartz feldspar tonalite porphyry	pre-kinematic; irregular stocks and dykes; likely epizonal, possibly sub-volcanic	intrusive, sharp	homogeneous	absent	absent	abundant phenocrysts of quartz and plagio-clase	white, with minor iron staining; outcrops large with moderate re-lief	light grey	quartz phenocrysts are a translucent blue colour

TABLE A-2b : MICROSCOPIC FEATURES OF AMISK INTRUSIVE ROCKS (UNITS 9 AND 10)

Unit No.	Rock type	Texture		Total mafic mineral content	Mafic minerals		Felsic minerals			Accessory Minerals	An content plagio-clase
		Primary	Secondary		Primary	Secondary	Quartz	Potash feldspar	Plagioclase		
9	diorite	fine to medium grain-ed	fine to medium grained grano-blastic poly-gonal; portions weakly foliated	40-60%		poikilitic blue green amphibole	absent	absent	40-60%; occurs as very fine grained recrystallized granoblastic poly-gonal masses, locally including small amounts of zoizite	sphene, iron-titanium oxide minerals, chlorite, zoi-zite and cal-cite	
10	quartz-feldspar tonalite porphyry	strongly por-phyritic; very fine grained groundmass; phenocrysts 2-10 mm in size	variable, generally minor recrystalliza-tion, portions weakly foliated	10%		1-5% red brown biotite, defines a weak folia-tion in places	in matrix and as pheno-crysts, the latter have strongly embayed boundaries; phenocrysts typically strained, fractured and, in northern exposures, re-crystallized	absent	50-60%; occurs in matrix as subhedral phenocrysts; some phenocrysts are: i) weakly zoned; ii) strained, fractured and, in northern exposures, recrystallized; and iii) partially re-placed by zoizite	pyrite, apatite, and sphene; muscovite, epi-dote, tourmaline, pyralspite garnet present in minor amounts as small porphyroblasts	38-41

TABLE A-3 : MAIN FEATURES OF AMISK SEDIMENTARY ROCKS (UNITS 11 TO 15)[1]

Unit No.	Rock type	Weathering characteristics	Colour of fresh surface	Grain size and fabric	Mineralogy Mine	Character of bedding	Primary structures and textures	Comments
11	polymictic volcaniclastic paraconglomerate	light to medium grey; outcrops on shore of Woosey Lake show strong differential weathering with fragments showing positive relief	light grey	fine grained; weakly to moderately foliated; fragments are tectonically deformed with steep plunging long axes	rocks recrystallized, minerals metamorphic; composed chiefly of quartz and plagioclase with lesser amounts of red brown biotite, garnet and green amphibole	lacks layering at all scales except for some rare, thick diffuse 'beds' defined by slight variation in clast sizes and clast to matrix ratios	conglomerate throughout with fragments which vary widely in composition, size and degree of roundness (most are felsic volcanic, subangular to subround, and pebble sized)	composed of volcanic detritus; probably deposited by subaqueous debris flows
12	laminated sandstone, siltstone and mudstone interbedded with pebbly volcaniclastic sandstone	light to dark grey, weak iron staining common; small outcrops with low relief	light to medium grey	variable, depending upon bed and degree of metamorphism; generally weakly foliated siltstones; local pebble bearing horizons	not significantly recrystallized, small porphyroblasts of acicular pale green amphibole common	bedding in tuffaceous sandstone, siltstone and mudstones is thin, continuous and parallel sided; bedding in pebbly sandstone beds is thick, lensoid, commonly irregular and graded	except for bedding, all other structures and textures are rare; the following have been observed in pebbly sandstone beds: - scour and fill channels - intraformational 'rip-up' fragments - flame structures - current laminations - graded bedding - convolute laminations Slump structures and ironstone concretions have been observed in laminated sandstone, siltstone and mudstone sequences	extremely immature sediments with strong volcanic affinities; pebbly volcanic sandstone beds were probably deposited by gravity-driven subaqueous mass-sediment flows; type exposures located 750 m northwest of Yakymiw Lake
13	lithic greywacke, feldspathic greywacke, siltstone and mudstone	light to dark grey, mudstones have weak iron staining; moderate to large outcrops with low relief	light to dark grey	variable, depending upon bed and degree of metamorphism; generally weakly foliated sandstone sized material	not significantly recrystallized, small metamorphic crystals of chlorite, sericite and biotite present in detrital matrix	bedding is repetitive, generally parallel sided and varies from thin to thick; graded bedding and scouring common; Bouma zonation of internal primary sedimentary structures is common	primary structural features of turbidity current deposits ubiquitous, these include (in order of abundance) - graded bedding - internal parallel laminations - scour and fill channels - intraformation 'rip-up' fragments - convolute laminations - load casts - flame structures - calcareous concretions - current laminations	- two main bed types observed in unit 13: 1) Bouma beds with Bouma zonation of primary sedimentary structures, and 2) non-Bouma beds of massive sandstone and graded massive sandstone; - type exposure of sequence dominated by Bouma beds located on west shore of Morton Lake opposite Elmes Island; - type exposure of sequence dominated by non-Bouma beds located on peninsular at south end of Morton Lake
13a	metasiltstone	light to medium grey; small outcrops with low relief	light to medium grey	fine grained; massive to weakly foliated	recrystallized and characterized by prominent acicular porphyroblasts of green amphibole and small crystals of brown biotite	indistinct, poorly defined, many exposures massive	none, except for bedding and, in one locality, graded bedding and delicate current laminations	relationship to strata of unit 13 uncertain, may be either basal to strata of unit 13 and/or a lateral facies equivalent
13b	File Lake area garnet biotite gneiss ± staurolite ± sillimanite ± anthophyllite	light to medium grey; moderate to large outcrops with very low relief	light to medium grey	fine grained; granoblastic polygonal; prominent porphyroblasts of aluminosilicate minerals; moderately to strongly foliated (schistose)	completely recrystallized, minerals metamorphic; mixture of garnet + biotite + quartz + andesine ± staurolite ± sillimanite ± anthophyllite; sillimanite restricted to rocks north of File Lake	same as unit 13	same as unit 13, but rarely preserved (except in outcrops on south shore of File Lake); graded bedding common, even in highly metamorphosed rocks	zonal distribution of staurolite and sillimanite porphyroblasts define south to north increase in regional metamorphic grade; strata of unit 13b are high grade metamorphic derivatives of rocks of unit 13
13b	Woosey Lake area garnet biotite gneiss ± staurolite ± chlorite	light to medium grey; moderate to large outcrops with very low relief	light to medium grey	fine grained; granoblastic polygonal; prominent porphyroblasts of aluminosilicate minerals; weakly to moderately foliated (schostose)	completely recrystallized, minerals metamorphic; mixture of garnet + biotite + quartz + andesine ± staurolite; sillimanite present but restricted to rocks directly adjacent to the Reed Lake pluton; andalusite present but almost always replaced by mixture of sericite, staurolite and quartz	same as unit 13	graded bedding and calcareous nodules common	metamorphic minerals probably a combination of regional metamorphism and of contact metamorphism by felsic plutons (in particular by the Reed Lake pluton)
13c	garnet biotite lit-par-lit gneiss	light to medium grey, locally with a brown hue; medium sized outcrops with low relief	light to medium grey	same as unit 13b except slightly coarser grained and foliation becomes gneissic; characterized by sills of white granitic mobilizate	same as unit 13b except staurolite and muscovite no longer present (above their limit of stability); sillimanite, although stable, not as prominent as in rocks of unit 13b	common, but only most pronounced bedding preserved	none, except for bedding	granitic mobilizate which occurs in rocks of unit 13c is interpreted to be a product of partial anatexis of the paragneiss
14	mafic metavolcanic gneiss	dark green, strong iron staining locally; medium sized outcrops with moderate relief	dark green	fine to medium grained; granoblastic polygonal; moderately to strongly foliated (gneissic)	completely recrystallized, minerals metamorphic; mixture of plagioclase and green poikilitic hornblende; porphyroblasts of diopside and garnet	layering common, but may be metamorphic	strongly tectonized pillow structures(?) observed in one locality	some felsic gneisses, in very minor amounts occur near top of unit
14a	felsic metavolcanic gneiss	white to light grey	white to light grey	fine to medium grained; granoblastic polygonal; commonly contains megacrysts of quartz (phenocrysts?); strongly foliated (gneissic)	completely recrystallized, minerals metamorphic; mixture of plagioclase, quartz, microcline, minor red brown biotite and trace amounts of oxide minerals, sphene and apatite; porphyroblasts of pyralspite garnet	indistinct layering present locally, many exposures massive	megacrysts of quartz may be phenocrysts	parent rock for these gneisses uncertain; probably felsic volcanic strata, but may also be related to the meta-tonalites of unit 18(3)a, which they resemble; includes some 'interlayered' mafic gneisses
15	meta-pelite with large garnet porphyroblasts	medium to dark grey; outcrops form long linear ridges with moderate relief	medium to dark grey	fine to medium-grained; granoblastic polygonal; characterized by numerous euhedral 5-10 mm porphyroblasts of deep purple pyralspite garnet; strongly foliated (schistose)	completely recrystallized, minerals metamorphic; mixture of plagioclase, quartz and red brown biotite, the latter defines a foliation; large porphyroblasts of garnet, poikilitic cordierite and red brown biotite common; fibrolitic sillimanite clots common in rocks exposed north of Corley Lake; staurolite porphyroblasts present, but not particularly common (do not occur in rocks north of Corley Lake)	delicately laminated; beds very thin compared to those of strata of unit 13b		contact of rocks of units 15 and 13b are rapidly gradational; unit 15 characterized by its homogeniety and distinctive porphyroblasts of garnet and, in thin section, of cordierite; first appearance of sillimanite is 2 km north of its first appearance in rocks of unit 13b

[1] Includes metavolcanic rocks of units 14 and 14a

TABLE A-4 : MAIN FEATURES OF MISSI SEDIMENTARY ROCKS (UNITS 16 AND 17)

Unit No. [1]	Rock type	Weathering characteristics	Colour of fresh surface	Grain size and fabric	Mineralogy	Character of bedding	Primary structures and textures	Comments
16(1)	quartz-plagioclase biotite paragneiss ± garnet ± sillimanite	light grey to white; large outcrops with moderate relief	light grey	fine to medium grained; granoblastic polygonal; strongly foliated	completely recrystallized, minerals metamorphic; mainly quartz and andesine, plus minor amounts of red brown biotite and muscovite; porphyroblasts of pyralspite garnet and small clots of fibrolitic sillimanite common; rare staurolite; magnetite and apatite common accessory minerals	parallel sided, defined by subtle changes in mineralogy, texture, colour and/or composition; finely laminated, the laminations defined by concentrations of biotite and, more rarely, magnetite	cross lamination	rocks, particularly at base of unit, highly variable and include some varieties which contain staurolite porphyroblasts; rocks of unit 16(1) tend to be more quartz-rich than those of either 16(2) or 16(3); locally contain small green calc-silicate layers
16(2)	plagioclase-quartz-biotite paragneiss ± microcline	white to light grey; large outcrops with moderate relief	light grey	as above	completely recrystallized mixture of andesine, quartz, red brown biotite and, in small amounts, microcline and muscovite; quartz-sillimanite nodules common in rocks east of Corley Lake; magnetite and apatite common accessory minerals	as above, except rocks not generally finely laminated	rare cross lamination	
16(3)	plagioclase-quartz-microcline-biotite paragneiss	buff to light grey, pink hues common; large outcrops with moderate relief	buff to light grey	as above, portions with a granitoid texture	as above, except microcline a prominent component	bedding rarely well preserved, generally thick homogeneous	rare cross lamination	many rocks of this unit are gradational into those of unit 17
17	granoblastic microcline-rich paragneiss	buff to pink; large outcrops with moderate relief	buff	fine to medium grained; granoblastic polygonal (granitoid); gneissic	as above, except microcline very prominent	bedding rarely preserved		rocks of unit 17 east of Gates Lake have strong iron staining and contain green amphibole porphyroblasts; portions of unit 17 closely resemble rocks of unit 25

[1] In places unit 16 is more strongly recrystallized and cannot be subdivided into 16(1), 16(2) and 16(3). Unsubdivided 16(1) contains a combination of features described for the various subunits.