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METAMORPHISM IN THE SNOW LAKE AREA, MANITOBA

E. FROESE
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CONTENTS

1 Abstract/Résumé
1 Introduction
3 General geology
3 Stratigraphy
3 Lithology
3 General statement
4 Amisk Group
5 Missi Group
5 Small mafic intrusions
5 Gneiss domes
5 Intrusive rocks
6 Structural geology
6 General statement
6 Primary features
6 Planar and linear fabrics
6 Folding
6 First phase (F_1)
7 Second phase (F_2)
7 Third deformation
7 Faulting
7 Mineralization
7 Gold deposits
7 Base metal deposits
8 Metamorphism
8 General statement
8 Timing of metamorphism and deformation
8 A reaction grid for pelitic rocks
8 Graphical representation
10 Sequence of reactions
13 Metamorphism of sulphide-bearing rocks
14 Metamorphic conditions
14 Conclusion
14 Acknowledgments
15 References

Tables

4 *1.* Table of formations
10 *2.* Characteristic mineral assemblages
11 *3.* Compositions of minerals from specimen FQ70-198a (chlorite-biotite-staurolite zone)
11 *4.* Compositions of minerals from specimen ST-406-44 (Stall Lake mine)

Figures

2 *1.* Geology of the Flin Flon-Snow Lake region
in pocket *2.* Geology of the Snow Lake area, Manitoba
9 *3.* Reaction grid for pelitic rocks
9 *4.* Minerals represented in the tetrahedron AKFM
12 *5.* Sequence of reactions in the Snow Lake area
13 *6.* The composition of coexisting chlorite, almandine, cummingtonite, and anthophyllite
13 *7.* Mineral assemblages at a grade slightly higher than the biotite-sillimanite isograd, shown on an AFM diagram
14 *8.* Mineral assemblages at a grade slightly higher than the biotite-sillimanite isograd, shown on the biotite composition surface
14 *9.* Phase relations involving staurolite, gahnite, and sphalerite

METAMORPHISM IN THE SNOW LAKE AREA, MANITOBA

Abstract

The Snow Lake area forms the eastern part of the Flin Flon-Snow Lake volcanic-sedimentary belt in the southern Churchill Province. Two successions of supracrustal rocks are recognized. The Amisk Group, composed of metamorphosed volcanic rocks and greywacke with interlayered shale, underlies most of the area. Towards the north, there is a facies change in the Amisk Group from metavolcanic to predominantly metasedimentary rocks. The Missi Group, composed of metamorphosed crossbedded lithic arenite, overlies the Amisk Group with slight erosional unconformity. The rocks of both groups have been affected by two major periods of folding. The emplacement of gneiss domes, accompanied by folding, constitutes a third major structural event. The repetition of a part of the Amisk succession is attributed to a postulated thrust fault predating the second period of folding. A regional metamorphic zonation was developed during the second period of folding, with grade increasing to the north. Four zones are recognized: chlorite-biotite, chlorite-biotite-staurolite, biotite-staurolite-sillimanite, and biotite-sillimanite-almandine. In the last zone, the metasedimentary rocks acquire the character of gneisses and may be regarded as belonging to the Kisseynew Complex. The volcanic-sedimentary belt and the Kisseynew gneisses are separated only by a metamorphic boundary; there is no structural or stratigraphic discontinuity between them. Volcanogenic sulphide deposits, which occur in some horizons of the Amisk Group, have been deformed and metamorphosed with their enclosing rocks.

Résumé

La région de Snow Lake forme la partie orientale de la zone volcano-sédimentaire de Flin Flon-Snow Lake dans le sud de la Province de Churchill. On distingue deux successions de roches supracrustales. Le groupe d'Amisk, formé de roches volcaniques métamorphisées et de grauwackes contenant des intercalations d'argile litée, occupe la majeure partie de la région. Vers le nord, on observe dans le groupe d'Amisk un changement de faciès de roches métavolcaniques à des roches principalement métasédimentaires. Le groupe de Missi, formé d'une arénite lithique à stratification entrecroisée, recouvre le groupe d'Amisk avec une légère discordance due à l'érosion. Les roches de ces deux groupes ont subi deux grandes périodes de plissement. La mise en place des dômes de gneiss, accompagnée de plissements, constitue un troisième épisode de déformation important. On attribue la répétition d'une partie de la succession d'Amisk à une faille chevauchante hypothétique antérieure à la deuxième période de plissement. Pendant cette deuxième période de plissement, le métamorphisme régional a créé plusieurs zones métamorphiques; le degré métamorphique est plus élevé au nord. On distingue quatre zones: chlorite-biotite, chlorite-biotite-staurolite, biotite-staurolite-sillimanite, et biotite-sillimanite-almandine. Dans la dernière, les roches métasédimentaires ont pris un caractère gneissique et peuvent alors être considérées comme appartenant au complexe de Kisseynew. La zone volcano-sédimentaire et les gneiss de Kisseynew sont séparés seulement par une limite métamorphique; il n'y a aucune discontinuité structurale ou stratigraphique entre ces deux ensembles. Les dépôts sulfureux d'origine volcanique qu'on retrouve dans certains horizons du groupe d'Amisk, ont été déformés et métamorphisés en même temps que les roches encaissantes.

INTRODUCTION

The Snow Lake area is located at the eastern end of the Flin Flon-Snow Lake volcanic-sedimentary belt near the southern margin of the Churchill Province (Fig. 1). To the north, this belt is bordered by the Kisseynew Complex of predominantly metasedimentary gneisses and, to the south, it is overlain by Paleozoic strata. The transition from the volcanic-sedimentary belt to the Kisseynew Complex is marked by an increase in metamorphic grade, by an obliteration of primary structures, and by at least some local faults. The controversy regarding the nature of the boundary has been summarized by Harrison (1951a). It hinges on the significance attributed to faulting. Harrison (1951b) connected faults, observed in various localities along the boundary, into a major fault zone which he referred to as the Kisseynew lineament. Robertson (1951), on the other hand, considered the contact to be essentially unfaulted and interpreted the Kisseynew lineament as the trace of a boundary between dissimilar rock types accentuated by local faults. Consequently he thought that the Kisseynew gneisses included at least some rocks which are equivalent to the succession in the volcanic-sedimentary belt.

In the Flin Flon area, Bruce (1918) established the volcanic Amisk Group and the sedimentary Missi Group, terms eventually applied to the whole Flin Flon-Snow Lake belt. Further work (Wright and Stockwell, 1934; Byers and Dahlstrom, 1954) led to the inclusion of some sedimentary rocks in the Amisk Group, a practice which has found general acceptance. In the Batty Lake area, the Kisseynew gneisses were divided into the Nokomis Group and Sherridon Group (Robertson, 1953). In a geological compilation map, Bailes (1971) correlated Nokomis Group with Amisk Group sedimentary rocks and Sherridon Group with Missi Group. This suggestion has been incorporated in Figure 1. The boundary between the Flin Flon-Snow Lake volcanic-sedimentary belt and the Kisseynew Complex is shown coincident with the disappearance of staurolite in muscovite-bearing pelitic rocks (biotite-sillimanite-almandine isograd).

Petrological studies in the Snow Lake area, between Chisel Lake and Osborne Lake, were undertaken to determine the nature of metamorphism along a key segment of the Kisseynew boundary and to investigate the metamorphism of sulphide deposits.

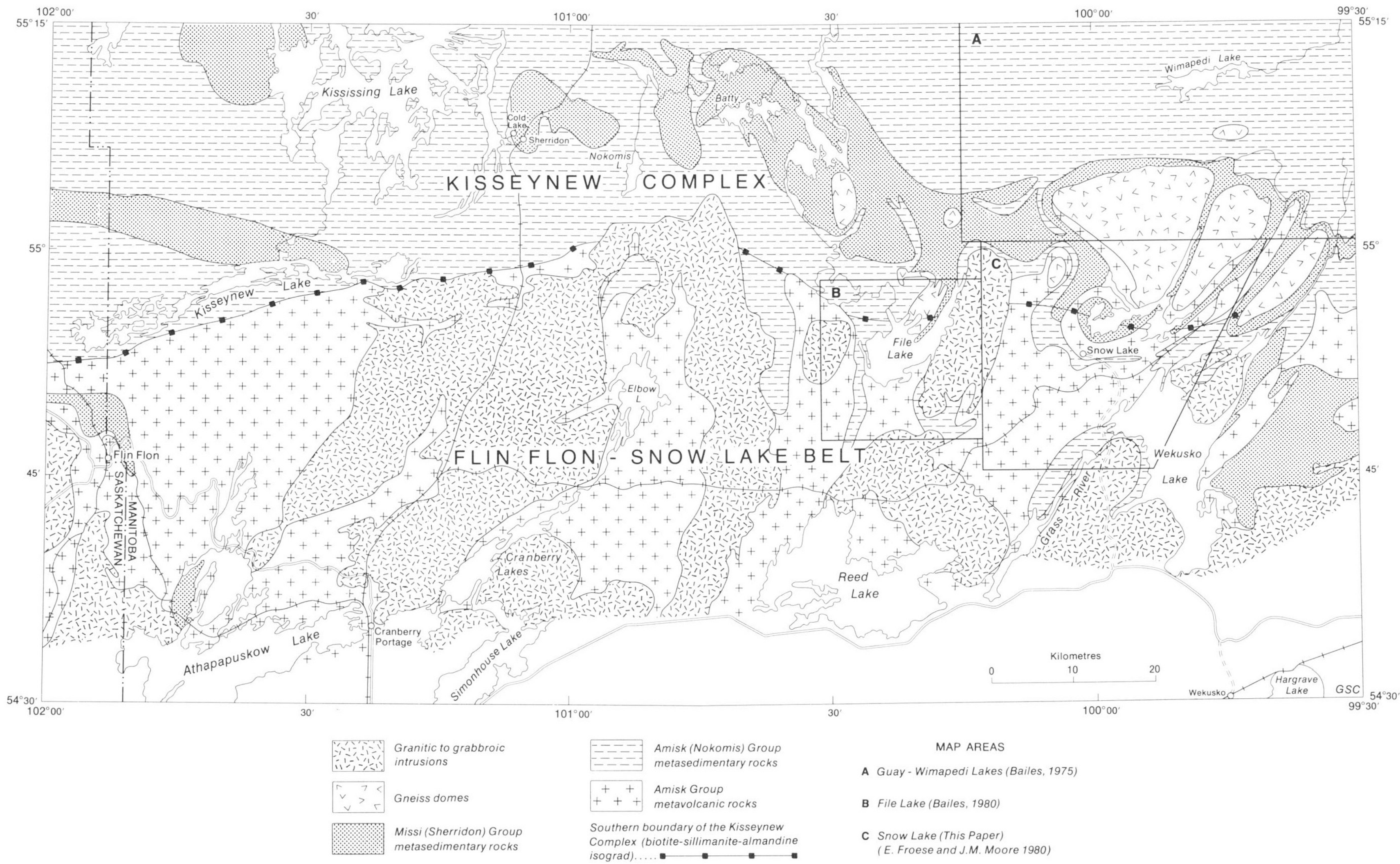

Figure 1. Geology of the Flin Flon-Snow Lake region, modified from Bailes (1971).

The Snow Lake area includes parts of three areas previously mapped on a scale of 1 inch to 1 mile (Armstrong, 1941; Harrison, 1949; Frarey, 1950). Portions of the Snow Lake area have been studied in greater detail (Harrison, 1949; Russell, 1957; Williams, 1966; Hutcheon, 1977). Bailes (1979, 1980) mapped the File Lake area, west of the Snow Lake area, in detail. Various aspects of metamorphism have been presented by Bailes and McRitchie (1978). The File Lake area straddles another segment of the Kisseynew boundary and, in many respects, results obtained there are relevant to the present study. The Guay-Wimapedi Lakes area, north of the Snow Lake area, has also recently been mapped by Bailes (1975). To provide a basis for petrological studies, the area lying between Chisel Lake and Osborne Lake and north of Wekusko Lake was remapped on a scale of 1:50 000 during the summers of 1970 to 1972. A brief summary of this work has been presented by Moore and Froese (1972). The geology of areas adjacent to our mapping has been taken from existing maps. The gap in the quartz-eye tonalite along the railway track has been shown according to maps made available by Falconbridge Nickel Mines Limited. Isograds and metamorphic zones in the Snow Lake area have been discussed previously by Froese and Gasparrini (1975). Hutcheon (1977, 1978, 1979) investigated metamorphic conditions reflected in rocks from two mines (Stall Lake and Anderson Lake). The geology of the area between Chisel Lake and Stall Lake, as well as the geology of mines in this area, has been presented recently by Price (1978).

GENERAL GEOLOGY

Stratigraphy

The metamorphosed supracrustal rocks of the Snow Lake area are derived from three main lithologic types: volcanic rocks, interlayered greywacke-shale, and lithic arenite. The historical development of stratigraphic nomenclature has been reviewed by Harrison (1951a).

Alcock (1920) included all volcanic and sedimentary rock of the Snow Lake area in the Wekusko Group. Harrison (1949), on the other hand, recognized two successions of supracrustal rocks. He included most volcanic rocks in the older Amisk Group and suggested a correlation with volcanic rocks in the Flin Flon region designated as the Amisk series by Bruce (1918). Some sediments interlayered with volcanic rocks were left unclassified. Harrison's younger Snow Group consisted mainly of metasediments showing some similarities to rocks of the Missi series of the Flin Flon region (Bruce, 1918). However, the Snow Group, in contrast to the Missi series, included volcanic rocks and shale and lacked conglomerate. The stratigraphic relationship between the two groups was considered to be obscured by faults along the south shore of Snow Lake. Rocks of both groups were observed to grade into gneisses of the Kisseynew Complex to the north.

In subsequent publications, Harrison (1951a, 1951b) attributed greater significance to faults along the south shore of Snow Lake between rocks of the Amisk and Snow Groups. He considered them to be part of a major fault zone, separating the Amisk and Missi rocks from the Kisseynew gneisses. According to this interpretation, the Snow Group belongs to the Kisseynew Complex and cannot be correlated with the Missi rocks of the Flin Flon region.

Russell (1957) mapped a part of the Snow Lake area and came to some conclusions that departed significantly from those of Harrison (1949). He recognized a distinct unit of siliceous and calcareous rocks, commonly containing disseminated sulphides. These rocks form lenticular stratigraphic units in volcanic rocks and were interpreted as chemical sediments rather than products of secondary replacement along faults, as implied by Harrison (1949, p. 74). Thus the presence of sulphide- and carbonate-bearing rocks along the south shore of Snow Lake was not accepted as evidence of a fault.

In this report all metavolcanic rocks, including those of the former Snow Group, have been assigned to the Amisk Group. Furthermore, sediments of the greywacke-shale affiliation have also been assigned to the Amisk Group. Some of these rocks were part of the Snow Group whereas others belonged to Harrison's (1949) unit of unclassified sedimentary rocks. In most places the sediments of the Amisk Group overlie the volcanic rocks.

The volcanic rocks north of Snow Creek are interpreted as part of a thrust sheet lying on younger rocks. A similar thrust fault had previously been proposed by Russell (1957). Metamorphosed lithic arenite and derived gneisses of the former Snow Group have been assigned to the Missi Group. The Missi Group was deposited on diverse rock units of the Amisk Group, a relationship suggesting an erosional unconformity between them. The present stratigraphic grouping is consistent with common practice in the Flin Flon-Snow Lake belt (Byers and Dahlstrom, 1954; McGlynn, 1959; Bailes, 1971). To the north, rocks of the Amisk and Missi Groups grade into gneisses of the Kisseynew Complex, but even at this higher grade of metamorphism, Bailes (1975) has retained the same stratigraphic divisions. The transition from the volcanic-sedimentary belt to the Kisseynew Complex is marked by an increase in metamorphic grade, by an obliteration of primary structures, and by a facies change in the Amisk Group from volcanic to predominantly sedimentary rocks. The biotite-sillimanite-almandine isograd may be regarded as the boundary.

The Flin Flon-Snow Lake belt has traditionally been interpreted as Archean because of its east-west trend and lithologic similarity to greenstone belts in the Superior Province. However, in view of Rb-Sr isochron studies[1] (Mukherjee et al., 1971; Josse, 1974; Bell et al., 1975) and Pb isotope determinations (Sangster, 1972a, 1978), current opinion favours an Aphebian age of 1700-1800 Ma for the Flin Flon-Snow Lake belt.

Three gneiss domes are present in the area. Bailes (1971) considered them to be remobilized basement. However, further work led Bailes (1975) to conclude that they represent diapirs of recrystallized supracrustal rocks. Rb-Sr whole rock isochron studies (Bell et al., 1975) give the same age for the gneiss domes as for the volcanic rocks, i.e. about 1720 Ma. Thus, it seems that these rocks are not part of an older basement but their origin remains obscure.

Lithology

General Statement

The geology of the area is shown in Figure 2. The subdivision of map units is listed in the Table of Formations (Table 1). The Amisk Group includes metamorphosed volcanic rocks and interlayered sedimentary rocks, becoming dominant near the top of the Amisk Group. Felsic and mafic volcanic rocks are interlayered; their mutual age relations are not clear. A body of quartz-eye tonalite is considered to be a shallow intrusion related to Amisk volcanism. A differentiated mafic intrusion has been included in the Amisk Group, but it is possible that it belongs to the suite of post-Missi intrusions. Metamorphosed crossbedded lithic arenites of the Missi Group were deposited on various rock types of the Amisk Group. A variety of mafic rocks were intruded into rocks of the Amisk and Missi groups. Diapiric uprise of granitoid rocks produced gneiss domes in the northern half of the area. Several intrusions of uniform, nearly massive granodiorite, tonalite, and gabbro are present in the southern part of the area. Masses of pegmatite represent the youngest rocks.

[1] ^{87}Rb decay constant = 1.47×10^{-11} yr^{-1}

Table 1

Table of formations

Age	Formation	Lithology
Aphebian (?)	Intrusive Rocks	12. Pegmatite 11. Granodiorite, foliated or massive, uniform 10. Gabbro, massive, uniform 9. Tonalite, massive
	Intrusive contact	
	Gneiss Domes	8. Pink and light grey granitoid gneisses, well foliated, some layers of amphibolite
	Diapiric emplacement of gneiss domes	
	Missi Group	7. Metamorphosed lithic arenite, uniform composition, crossbedded, some layers of amphibolite
	Inferred unconformity	
	Amisk Group	6. Metamorphosed greywacke and shale, staurolite schist, sillimanite schist, some calc-silicate rocks and marble
		5. Metamorphosed quartz-eye tonalite
		4. Metamorphosed differentiated mafic intrusion: peridotite, gabbro, and diorite
		3. Metamorphosed mafic lavas, mafic pyroclastic and volcaniclastic rocks; minor amounts of felsic fragmental rocks, some layers of amphibolite
		2. Metamorphosed altered volcanic rocks; with rock composition modified to allow the formation of staurolite, kyanite, anthophyllite, and cordierite
		1. Metamorphosed felsic pyroclastic and volcaniclastic rocks, some quartzofeldspathic gneiss; minor amounts of mafic fragmental rocks, some layers of amphibolite

Amisk Group

The felsic volcanic rocks (unit 1) are light grey and typically weather white or buff. In the western part of the Snow Lake area, they are commonly fragmental, thickly bedded and probably of pyroclastic origin. Locally, the felsic rocks are bedded on a scale of 1 to 20 cm. These rocks apparently were transported by water and thus presumably are of volcaniclastic origin. Quartz phenocrysts averaging 3 to 5 mm are common. Felsic volcanic rocks are fine grained, granoblastic, and typically consist of quartz and oligoclase with subordinate biotite and almandine. In some rocks, hornblende is also present. Quartzofeldspathic gneisses around the Pulver gneiss dome (Fig. 2) are thought to be coarsely recrystallized felsic volcanic rocks and have been included in unit 1.

Some of the felsic volcanic rocks of unit 1 have been altered before regional metamorphism and have been distinguished as unit 2 on the map. This process changed the composition and allowed the formation of schists containing staurolite and kyanite, minerals which normally do not occur in metavolcanic rocks. Typical assemblages include quartz, sodic plagioclase, muscovite, biotite, staurolite, and chlorite. Some magnesium-rich rocks are represented by the assemblage biotite-kyanite-chlorite. Altered rocks near Chisel Lake were mapped as unclassified sedimentary rocks by Harrison (1949) and later as metasedimentary rocks of the Amisk Group by Williams (1966), but he noted the presence of volcanic fragments in some exposures. Similar rocks, including staurolite-kyanite-chlorite schist, near Anderson Lake have been known for some time (Alcock, 1920; Wallace, 1924). In a geological sketch map (Moore and Froese, 1972), all these rocks were included in the Amisk sedimentary rocks. Their petrology near Anderson Lake was studied in detail by Hutcheon (1977) who simply termed them "pelitic". However, following discussions with J.M. Franklin and P. Walford, we accept their interpretation that these are altered volcanic rocks. A similar view has been expressed by Gale and Koo (1977) and Price (1978). In altered rocks not containing muscovite, anthophyllite is common. Garnet-anthophyllite rocks occur around the Squall gneiss dome and near Wolverton Lake; there also is an occurrence north of Snow Creek. In a few places, cordierite is also present. Specific occurrences of staurolite, anthophyllite, cordierite, and kyanite are marked on the map (Fig. 2).

The mafic metavolcanic rocks (unit 3) consist mainly of lavas and pyroclastic rocks. They are dark green to black amphibolites and hornblende schists, typically weathering to greenish grey. They are fine- to medium-grained, granoblastic, lineated or schistose, and contain oligoclase-andesine and hornblende with or without biotite, garnet, and cummingtonite or epidote. Pillows and quartz amygdules are preserved in many mafic lavas. Breccias containing mafic fragments 10 to 15 cm across, in a similar matrix, are common. Some of these are thickly layered (0.2 to 1 m or more) and contain abundant coarse (blastoporphyritic?) hornblende. Some of the mafic rocks are thought to be of volcaniclastic origin. At Chisel Lake they are bedded and show evidence of water transport such as crossbedding, scour channels, flame structure, and graded bedding.

Thin discontinuous interlayers of chemical sediments (<2 m), are found in the metavolcanic rocks. For example, fine grained, pyritic, calcareous, and siliceous rocks are exposed on the south and west shores of Snow Lake, along a horizon outlining the Nor-Acme anticline, and in a narrow area extending from Snow Lake to Osborne Lake, just north of the McLeod Road thrust.

A large intrusion (unit 4) near Chisel Lake is composed of rocks ranging in composition from mafic to ultramafic (Williams, 1966). Rock types are arranged in a concentric pattern from peridotite along the rim to zones of gabbro and diorite towards the centre. Metamorphism has resulted in almost complete destruction of original minerals and textures.

Between Cook Lake and Anderson Lake, there is a slightly discordant body of metamorphosed quartz-eye tonalite (unit 5). This is a fine- to medium-grained, granoblastic rock, consisting mainly of quartz and oligoclase with minor biotite and hornblende. The presence of pale blue quartz megacrysts ("eyes"), 5 to 8 mm, is the characteristic feature of the rock. In view of its massive character, the absence of fragmental texture, and some crosscutting relations to bordering rocks, the tonalite is considered to be a shallow porphyritic intrusion probably related to Amisk volcanism.

Amisk metasedimentary rocks (unit 6) derived from greywacke and shale are interlayered on a scale of 10 to 50 cm. Graded bedding and flame structures are commonly evident in low grade rocks. Some calcareous concretions are present also. The mineralogical composition changes appreciably with metamorphic grade. At the lowest grade observed, the rocks consist of quartz, oligoclase, chlorite, muscovite, and biotite. Almandine and staurolite appear together at about the same grade. At higher grade, chlorite no longer coexists with staurolite, and aluminum silicate (kyanite or sillimanite) is stable in the presence of biotite. Staurolite and sillimanite coexist over a range of metamorphic conditions. At still higher grade, staurolite disappears from muscovite-bearing rocks, leaving almandine, biotite, and sillimanite. Along with these changes in mineral assemblages, the grain size of quartz, plagioclase, and mica increases progressively from fine grained to medium grained, and a metamorphic mineral segregation becomes evident. Staurolite porphyroblasts are as large as 10 cm. In a few places, granoblastic calc-silicate rocks and impure marble are interlayered with greywacke and shale.

Missi Group

The rocks of the Missi Group (unit 7) are a monotonous succession of metamorphosed clastic rocks, which in previous reports have been called arkose (e.g. Harrison, 1949). However, according to unpublished analyses provided by J.M. Franklin, their chemical composition corresponds to that of lithic arenite rather than arkose (Pettijohn et al., 1973, p. 62). For this reason, rocks of the Missi Group are here designated as metamorphosed lithic arenites. They are fine grained, grey, granoblastic rocks which weather pinkish grey, are typically thickly bedded (0.2 to 2 m), and break along parting planes into large slabs. Crossbedding in sets 10 to 20 cm thick is also preserved in many places. The main mineral constituents are quartz, oligoclase, and microcline, accompanied by biotite, muscovite, and almandine. Within 10 to 20 m of the base of the Missi succession, biotite and garnet are concentrated and the rock is laminated. Conglomerate, although characteristic of the Missi Group in the Flin Flon area, is notably lacking in the present map area. A metaconglomerate lens 0.5 m thick, containing rounded pebbles of felsic volcanic clasts, was observed near the base of the Missi succession at the north boundary of the area, northwest of the Squall Lake dome.

In the biotite-sillimanite-almandine zone, quartz-sillimanite nodules typically occur in these rocks. The origin of the nodules remains obscure because no highly aluminous minerals are present in lower grade rocks.

Small Mafic Intrusions

Rocks of the Amisk and Missi groups have been intruded by a variety of mafic rocks. In mineralogical composition, they are mainly similar to mafic volcanic rocks and, therefore, are difficult to distinguish from massive flows. In Amisk rocks, the intrusions may have very irregular shapes, but in Missi rocks they typically form sills, locally with blastoporphyritic plagioclase. At the townsite of Snow Lake, a small dyke of orbicular gabbro is present, characterized by radiating plagioclase crystals up to 10 cm long. Because of the difficulty of accurately mapping the large number of these intrusive bodies, they are not shown as a separate map unit.

Gneiss Domes

Granitoid gneisses (unit 8) compose three domes in the Snow Lake area, the Herblet, Pulver, and Squall, which are localized along antiforms of the F_2 fold system. The foliation in the outer parts of the domes and in the surrounding rocks is parallel to the contact; in the interior portions the foliation patterns are more complex.

The Herblet and Pulver gneiss domes extend north into the adjacent Guay-Wimapedi lakes area, where they have been described by Bailes (1975). The outer layer of the domes, typically 3 to 4 km thick, is composed of fine- to medium-grained pink granitoid gneisses (unit 8a) consisting of quartz, oligoclase, microcline, and biotite with minor amounts of hornblende. The Squall dome consists entirely of pink gneisses, and is probably exposed at a higher level than the other domes. Light grey, medium grained gneisses (unit 8b) consisting of quartz, oligoclase, biotite and hornblende constitute the cores of the domes; the core of the Pulver dome does not extend into the Snow Lake area.

The composition of the gneisses is similar to felsic volcanic rocks or plutonic granodiorite. Thus these rocks may be diapirs of light volcanic rocks, from lower in the succession, or they may be remobilized intrusions.

Intrusive Rocks

Several plutons are present in the western and southern parts of the area. North of Herb Bay an elongate body of tonalite (unit 9) is aligned parallel to the layering in the surrounding schists. South of Herb Bay, the metasediments are intruded by a pluton of massive gabbro (unit 10), a dark grey, medium grained rock consisting of labradorite and hornblende. Massive to slightly foliated granodiorite (unit 11) forms large plutons east of Tramping Lake and south of Herb Bay. These rocks are composed of quartz, oligoclase, microcline, and biotite. Some have a porphyritic texture; microcline crystals up to 3 cm occur in a medium grained groundmass. In contrast to these rocks, the Ham Lake granodiorite also belonging to unit 11, has an equigranular, medium grained texture and is foliated, at least near its margin. Small bodies of pegmatite (unit 12) are abundant in the northern part of the area.

The tonalite of unit 9 and the Ham Lake granodiorite (unit 11) exhibit an F_2 foliation and appear to be emplaced approximately at the time of the second period of deformation. The gabbro of unit 10 and most plutons of unit 11 are massive and postdate the development of the F_2 foliation. Granodiorite (unit 11) is truncated by the Berry Creek fault. Pegmatite (unit 12) occurs mainly in the biotite-sillimanite-almandine zone. Although more than one generation may be present, most dykes appear undeformed and are thus probably the youngest plutonic rocks in the area.

Structural Geology

General Statement

The Snow Lake area, like other areas along the southern border of the Kisseynew Complex in general, exhibits an interplay of several deformation patterns (Fig. 2). The interpretation of structural history here presented is based on preserved primary features allowing top determinations, and on superimposed metamorphic fabric elements. The observed features can be accommodated in three proposed structural events:

1. First phase folding F_1. Although several megascopic folds of this generation were mapped in Amisk rocks, only a few outcrop-scale folds of this event were seen. With few exceptions, these folds are isoclinal. This episode is reflected mainly in a prominent schistosity and stratiform foliation subparallel to compositional layering. Although this foliation is also present in Missi rocks, folds of this generation have not been observed at any scale in the Missi Group.
2. Second phase folding F_2. These folds are responsible for the dominant northeasterly structural grain of the area. The earlier stratiform foliation (S_1) is commonly bent around these folds. However, biotite is typically reoriented parallel to the F_2 axial planes.
3. Emplacement of gneiss domes. Diapiric rise was apparently localized by antiforms in the F_2 fold system. These folds in turn were modified by lateral deflection and appression between adjacent gneiss domes.

A major early (syn-F_1?) fault, the McLeod Road thrust, is proposed to account for the distribution of map units north of Snow Lake. The Berry Creek fault is a major tectonic feature west of Wekusko Lake; its extension northeastward is obscure. Other brittle deformation is confined to small fractures and shears throughout the area.

Primary Features

In low grade metasedimentary rocks of the Amisk Group along the shores of Wekusko Lake, graded bedding and flame structures are preserved and can be used to indicate stratigraphic tops. Crossbedding, a very prominent feature in rocks of the Missi Group, also provides excellent top indicators. Pillows were observed in a few outcrops. Volcaniclastic rocks exhibit graded bedding, crossbedding, scour-channels, flames, and intraformational slumping.

Planar and Linear Fabrics

All rocks except the intrusions of units 9-12 display a prominent planar fabric S_1, developed during the early folding F_1; in supracrustal rocks this is nearly parallel to compositional layering. It is expressed by a preferred orientation of minerals (biotite and hornblende), by flattening of fragments and mineral aggregates and, in high grade rocks, by lenticular mineral segregations. During F_2, S_1 mineral segregations and amphibole schistosity were folded; biotite flakes grew in F_2 axial surfaces (S_2).

In general, only one lineation is observed, parallel to F_2 axes, formed by crenulations, mica edges (S_1/S_2 intersection), and elongate clasts and mineral segregations. Locally however, as at Chisel Lake, there is a small deviation (5°-15°) between the elongation direction of fragments and the S_1/S_2 intersection, indicating extension during F_1. Because the greater strain accompanied F_1, except perhaps in high grade rocks, it is possible that at least some elongation features should be assigned to L_1. As their orientation is indistinct from L_2 however, they are labelled L_2 on the map (Fig. 2). In general, fragments and other aggregates are more nearly discoidal than rod-shaped, indicating that flattening strain predominated during F_1.

During rise of the gneiss domes, no new major fabrics were produced. S_2 was crenulated; small folds along dome margins, with steep axes, are either F_3 or reoriented folds of the second generation.

Folding

First Phase (F_1)

Megascopic F_1 folds include the Ghost Lake syncline, Nor-Acme anticline, the Anderson Lake anticline, and several unnamed anticlines and synclines at the north end of Wekusko Lake. The Ghost Lake syncline is an open, upright, northwesterly-trending and plunging fold truncated to the west by the zoned ultramafic-mafic pluton of Chisel Lake. The syncline is established on the basis of primary facing directions in mafic volcaniclastic rocks. The Nor-Acme anticline (after Harrison, 1949) exhibits S_1 foliation parallel to its axial surface, and is truncated on its west limb by the McLeod Road thrust. The nearly isoclinal Anderson Lake anticline (B.D. Simmons, pers. comm., 1975; named by Gale and Koo, 1977) is based on opposed primary facing between Anderson and Stall lakes (including that of metal zoning in the Stall, Anderson and Linda deposits). On the basis of these structures, mafic volcanic units overlie felsic rocks at Ghost Lake but are interlayered with felsic rocks north of Anderson Lake. Two interpretations of the alternation of mafic and felsic rocks in the belt between Stall Lake and Ghost Lake are possible:

1. All of the felsic units underlie mafic rocks, and hence there are several more F_1 axial surfaces which cannot be verified with the available data. Two of these would be synclinal traces passing approximately through Noteme Lake (south of Snow Lake) and Moore Lake (south of Threehouse Lake), lying within mafic units which close out east of Stall Lake. Felsic rocks would occupy intervening anticlines. This interpretation is appealing, as all of the metal deposits would thereby lie on or near a single stratum, tectonically repeated. However, it is not supported by available primary facing directions, which indicate that the entire succession from Stall Lake mine north to Snow Creek faces northward (see also Hutcheon, 1977).
2. Although felsic rocks underlie mafic units at the main sulphide deposits, there are intercalations of mafic rocks between Anderson Lake and Snow Lake. By this interpretation, the Stall, Anderson and Joannie deposits would all lie on one horizon, distinct from that containing the Chisel Lake, Lost Lake, and Ghost Lake deposits.

Second Phase (F_2)

Megascopic, northeast-trending F_2 structures involve both Amisk and Missi groups. The major structures, from northwest to southeast, are (Fig. 2):

- Squall Lake antiform
- McLeod Lake synform (Harrison, 1949)
- West Narrows antiform (Russell, 1957)
- Threehouse synform (Harrison, 1949)
- Southeast Bay antiform (Russell, 1957)
- Whitefish Bay synform (Russell, 1957)
- Herb Bay antiform.

These folds open and die out southward into the Amisk rocks, and are tightened to isoclines and refolded around the gneiss domes. They are best expressed as upright to northwestward-overturned folds in the Missi Group. Although they affect F_1 traces in the Amisk rocks, there is no evidence of F_1 folds in the Missi Group, and the synforms containing Missi rocks are also synclines as demonstrated by primary facing of crossbeds. There are numerous minor F_2 folds on all scales, from crenulations to tens of metres across, particularly in the Missi Group and in micaceous and calcareous rocks close to Amisk-Missi contacts. Schists formed from altered volcanic rocks (unit 2) are intensely crenulated, and sulphide orebodies in them are elongated parallel to F_2 axes (Martin, 1966; Coats et al., 1970).

The F_2 axial surface orientation is marked by a penetrative foliation in the Missi and Amisk metasedimentary rocks, and oriented biotite flakes in the Amisk felsic metavolcanic rocks (mafic rocks do not generally exhibit S_2).

Third Deformation

The Squall and Pulver domes are situated on the crests of the Squall Lake and Southeast Bay antiforms, respectively. An antiformal trace could be drawn in the Herblet dome, approximately north-south through Johnson Lake; it does not correspond to an antiform in the surrounding rocks, however, and must die out abruptly or be truncated near Herblet Lake. Adjacent synforms containing Missi rocks were refolded during dome emplacement; the most prominent example, noted by Harrison (1949), is that of the McLeod Lake synform, folded around an east-striking axial surface trace east of the Squall dome. The synforms tighten to isoclinal or near-isoclinal geometry along about the biotite-sillimanite-almandine isograd, probably as a result of superimposed flattening during the third deformation.

Faulting

The McLeod Road thrust fault, predating or synchronous with F_1, is postulated to extend westward from Osborne Lake to Snow Lake, and thence northward to Angus Bay of Herblet Lake. This feature was named (Russell, 1957) after the winter road from Snow Lake to McLeod Lake. Russell gave different names to several relatively straight segments of the fault, but in this study it is regarded as a folded thrust with an arcuate trace. It is postulated mainly on the basis of truncations of unit 6 east of Snow Lake, of units 1 and 3 on the west limb of the Nor-Acme anticline, and on the existence of two symmetrically-disposed "triple junctions" of units 3, 6, and 7 east and south of McLeod Lake, all of which are not readily accounted for in the absence of a major dislocation. As a consequence of this thrust fault, only one major Amisk volcanic cycle is demonstrated, capped by a greywacke-shale succession. The volcanic rocks north of the fault are repeated. The presence of a fault would also explain the fact that, east of Snow Lake townsite, volcanic rocks of units 1 and 3 with abundant small intrusions lie on metasediments devoid of dykes. The fault is older than the regional metamorphism and has been deformed by F_2 folding and by gneiss dome emplacement. Although it is presumably a low-angle thrust, a direction of movement cannot be ascertained. Such features may be common elsewhere, but escape detection because of the lenticular character of the volcanic stratigraphy.

Minor fractures and shearing along lithologic contacts are common throughout the area. One late fault, the Berry Creek fault, is marked west of Wekusko Lake by a prominent topographic lineament and the development of mylonite in granodiorite. It enters Wekusko Lake at Berry Bay and is obscure farther east, although Collett and Bell (1971) interpreted AFMAG data as suggesting an extension of the Berry Creek fault for some distance northeastward.

Mineralization

Gold Deposits

The Snow Lake area contained one commercial gold deposit, the Nor-Acme mine, which was in production from 1949 to 1958. This deposit has been described in considerable detail by Harrison (1949) and Hogg (1957). Native gold, together with arsenopyrite, pyrite, and pyrrhotite was present in two orebodies, 400 m apart and connected by a mineralized zone of uneconomic grade. Quartz and calcite are common gangue minerals which cement brecciated felsic pyroclastic rocks and form veins and stringers along the contact with overlying mafic pyroclastic rocks. Both orebodies plunged northeast parallel to the regional plunge of F_2 folds. The localization of the ore along a stratigraphic horizon suggests a syngenetic origin, similar to the one proposed by Ridler (1970) for gold deposits in the Kirkland Lake area. According to this interpretation, the quartz and carbonate are viewed as products of chemical sedimentation rather than hydrothermal alteration.

Base Metal Deposits

The Snow Lake area contains six producing copper-zinc mines (the year production started is given in brackets) and several undeveloped or partially developed deposits:

- Chisel Lake (1960)
- Stall Lake (1963)
- Osborne Lake (1968)
- Anderson Lake (1970)
- Ghost Lake (1972)
- Lost Lake (1979)
- Joannie (undeveloped)
- Rod (mined from 1962 to 1964)
- Linda (undeveloped)
- Ram (undeveloped)

These deposits, as well as showings of minor sulphide mineralization, are shown on the geological map (Fig. 2).

In the area south of Snow Creek, copper-zinc mineralization is found chiefly in felsic pyroclastic rocks, near the contact with overlying mafic volcanic rocks. The following structural and stratigraphic controls may be distinguished:

1. Ghost Lake syncline. The Chisel Lake, Lost Lake, and Ghost Lake deposits occur on its southern edge. The mineralized horizon is thought to extend to the northwest of Ghost Lake (Gale and Koo, 1977).

2. Anderson Lake anticline. The Joannie, Anderson Lake, Stall Lake, Rod, Linda and Ram deposits occur around the crest. Some showings are present along its possible extension west of Edwards Lake. Altered volcanic rocks occur west of Chisel Lake.

In the McLeod Road thrust sheet, mineralization occurs along one main stratigraphic horizon connecting the Osborne Lake mine and several showings just north of the thrust fault. Southeast of Osborne Lake, a lead-zinc showing is present, apparently on a different stratigraphic horizon (Wright, 1931).

Around the gneiss domes, felsic volcanic rocks of the Amisk Group are exposed. These felsic rocks are altered and mineralized in many places. The Wim deposit occurs north of Wolverton Lake in the Guay-Wimapedi lakes area north of the Snow Lake area (Bailes, 1975) and minerals indicative of alteration (cordierite and anthophyllite) are found near Wolverton Lake. Similarly, the Bee deposit in the Guay-Wimapedi area occurs in felsic rocks surrounding the Pulver dome. Garnet-anthophyllite rocks are present surrounding the Squall dome but mineralization has not yet been found there.

The copper-zinc deposits are now generally considered to be of volcanogenic origin (Sangster, 1972b). Subsequent to their formation, they were deformed and metamorphosed. The Chisel Lake mine has been described in detail by Williams (1966) and structural aspects have been studied by Martin (1966). The individual ore lenses have been flattened subparallel to the layering in the surrounding rocks and display isoclinal F_1 folds. These in turn are refolded by F_2 folds and elongated parallel to the plunge of F_2 folds. The Rod deposit has been studied in detail by Coats et al. (1970). This orebody consists of two lenses flattened in the S_1 foliation of the surrounding rocks and plunging parallel to crenulation lineation developed during F_2 folding. Coats et al. (1970) presented excellent descriptions of various deformation textures. Of particular interest is the preferred orientation of pyrrhotite and chalcopyrite. A brief description of the Anderson Lake mine is given by Price (1978). The orebody is an elongated lens, flattened parallel to the S_1 foliation and plunging parallel to the L_2 lineation.

Disseminations of nickeliferous pyrrhotite in gabbro are present on Rice Island (Wright, 1931). Similar showings also occur in the large gabbro body south of Herb Bay (Wright, 1931) and on Eureka Island in Wekusko Lake (Russell, 1957). The two localities shown south of Herb Bay are taken from Armstrong (1941).

The Kisseynew terrane has, to date, yielded only a few base metal deposits (notably the Sherritt Gordon mine). However, the continuation of suitable host rocks into the Kisseynew Complex and the presence of a few base metal occurrences (Wim, Osborne Lake) indicate that the scarcity probably is not due to metamorphism and deformation. More likely it is the northward facies change of the Amisk Group, to a dominantly metasedimentary character which accounts for the relatively few prospects in the Kisseynew Complex.

METAMORPHISM

General Statement

The Snow Lake area and the File Lake area to the west contain rocks which record the metamorphic transition from the low grade volcanic-sedimentary Flin Flon-Snow Lake belt northward to the Kisseynew Complex (Fig. 1). In both areas, abundant exposures and the presence of pelitic rocks permit mapping metamorphic zones. The metamorphic zonation was first established by Harrison (1949). In comparing these zones to the classic Barrovian sequence he noted some significant differences: a very narrow garnet zone, a relatively broad staurolite zone, and the absence of a kyanite zone. This was a very noteworthy observation because it predates the recognition that the sequence of metamorphic zones differs significantly from area to area, reflecting different pressures of metamorphism. In this study, we examined the zones in muscovite-bearing pelitic rocks in greater detail and, following Winkler (1979), regard them as definitive of metamorphic grade. The definition of metamorphic grade in terms of a reaction grid in muscovite-bearing rocks is discussed in more detail by Ermanovics and Froese (1978). Reactions in K_2O-poor rocks, not containing muscovite, have been related to those in muscovite-bearing rocks. The sulphide deposits in the Snow Lake area have been subjected to the same regional metamorphism as their surrounding rocks and their response to metamorphism is also considered here. A discussion of the metamorphism in the File Lake area has been presented by Bailes and McRitchie (1978) and Bailes (1979, 1980). It is apparent from their study that the Snow Lake area and File Lake area have many metamorphic features in common.

Timing of Metamorphism and Deformation

S_1 foliation survives throughout the map area, marked by preferred orientation of hornblende, mica, and mineral aggregates. Porphyroblastic minerals such as staurolite and garnet have overgrown this fabric and have been, in part, rotated during and after growth. Folding of S_1 by F_2 has led to various degrees of reorientation of minerals parallel to S_2. Minerals involved in F_2 structures are unstrained. Isograds transect F_2 axial surface traces. From these observations, it is evident that metamorphism began during F_1, continued through F_2, and reached peak conditions after most of the F_2 deformation had occurred. At least in the north of the area, recrystallization continued at high grade during dome emplacement. Coarse sheaves of anthophyllite, for example, are unstrained in rocks immediately flanking the Squall and Herblet domes.

A Reaction Grid for Pelitic Rocks

A reaction grid for pelitic rocks shown in Figure 3, has been used to interpret the isograd reactions recognized in the Snow Lake area. The grid is based on the assumption that the activity of water is a smooth function of pressure and temperature. The three invariant points involving muscovite were taken from Hess (1969). The same invariant points are shown by Kepezhinskas and Khlestov (1977), in each case with one reaction observed in rocks without muscovite. These three reactions are part of a petrogenetic grid presented by Korikovsky (1970) for K_2O-poor rocks. The grid shown in Figure 3 is a modification of a grid developed by D.M. Carmichael (pers. comm., 1978) including reactions in K_2O-rich and K_2O-poor rocks. He also provided estimates of pressure and temperature based on a critical evaluation of experimental calibrations and involving the assumption that the activity of water is unity (i.e. water pressure is equal to total pressure).

Graphical Representation

A wide range of compositions in pelitic and mafic rocks can be represented in a four-component system defined as follows (Froese, 1969):

$$A = Al_2O_3 - (Na_2O + CaO + K_2O)$$

$$K = K_2O \cdot Al_2O_3$$

$$F = FeO - (Fe_2O_3 + TiO_2)$$

$$M = MgO$$

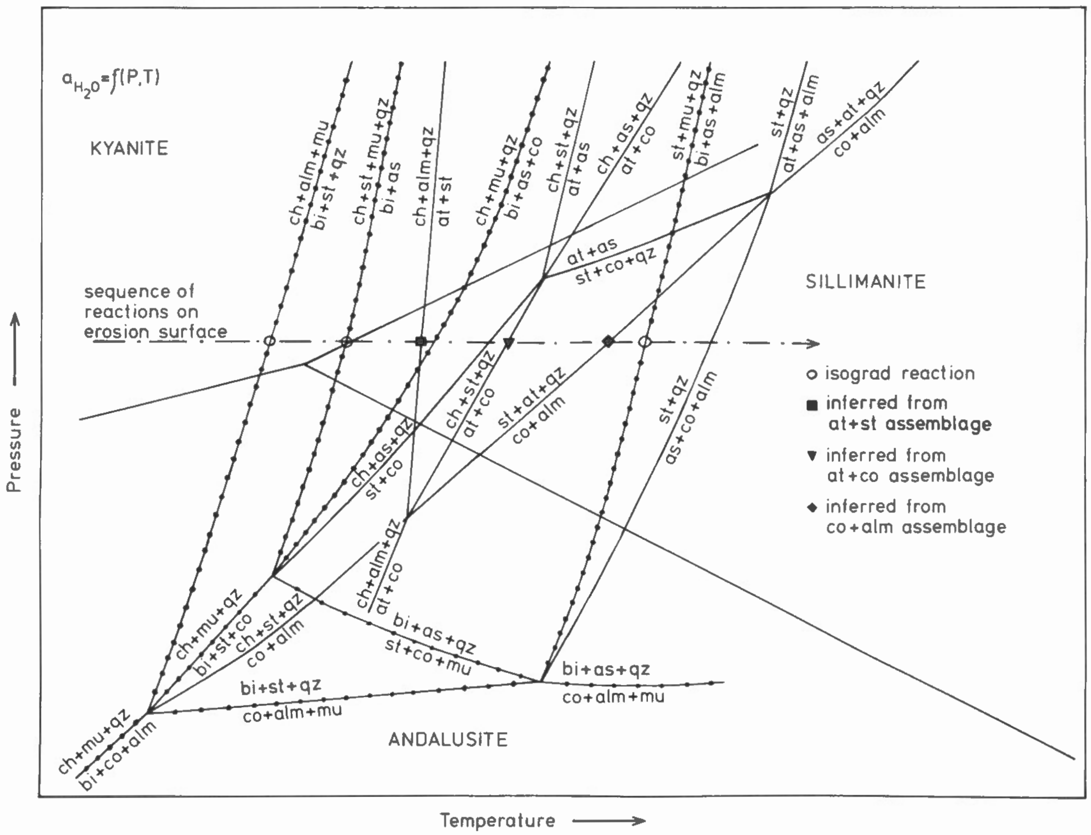

Figure 3. Reaction grid for pelitic rocks, modified from Hess (1969) and Carmichael (pers. comm., 1978). Dotted boundaries are reactions involving muscovite. Key to mineral abbreviations:

qz	*— quartz*	*as*	*— aluminum silicate*
mu	*— muscovite*	*st*	*— staurolite*
bi	*— biotite*	*alm*	*— almandine*
ch	*— chlorite*	*co*	*— cordierite*
		at	*— anthophyllite*

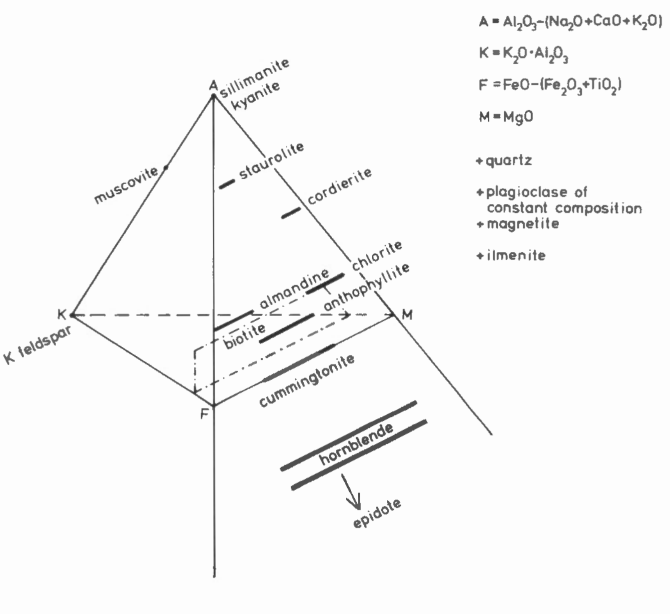

Figure 4. Minerals represented in the tetrahedron AKFM.

In defining the components, the oxides are expressed as molecular proportions. Then the four components are normalized to 100%. This system may be regarded as a projection through quartz, plagioclase of constant composition, magnetite, and ilmenite (Fig. 4). Magnetite is absent from many rocks, in particular from those containing graphite. In these rocks, the ferromagnesian minerals have a low content of Fe_2O_3. Therefore, an assumed projection through magnetite is of little consequence.

A planar representation of phase relations in muscovite-bearing rocks can be achieved by projecting through muscovite (Thompson, 1957). However, since many rocks in the Snow Lake area do not contain muscovite, this method is not applicable. Biotite is present in nearly all rocks of interest. Thus all four-phase assemblages in the AKFM tetrahedron are represented by subtetrahedra having one apex on the biotite composition surface. Similarly, three-phase assemblages subtend a line and two-phase assemblages an area on the biotite composition surface. Consequently, a subdivision of the biotite composition surface may be used to portray mineral compatibilities (Froese, 1969, 1972, 1978). Because the content of component K is nearly constant in biotites, the variation in composition is adequately represented by the relative amounts of components A, F, and M. Due to the small amount of component A, it is best to choose co-ordinates M/(F+M) and A/(F+M); this allows an exaggeration of the A/(F+M) axis.

Table 2

Characteristic mineral assemblages

	qtz	plag	mu	ch	bi	st	ky	si	alm	at	cum	hb	cor
chlorite-biotite zone	x	x	x	x	x								
chlorite-biotite-staurolite zone	x	x	x	x	x	x			x				
	x	x	x	x	x	x							
	x	x		x	x				x				
	x	x		x	x				x		x		
	x	x		x	x				x	x	x		
	x	x		x	x						x	x	
	x	x			x				x		x	x	
	x	x			x				x			x	
biotite-staurolite sillimanite zone	x	x	x	x	x	x		x	x				
	x	x	x		x	x		x	x				
	x	x	x		x	x			x				
	x		x	x	x	x	x						
	x		x	x	x		x						
	x	x		x	x	x				x			
	x	x			x	x				x			x
biotite-sillimanite-almandine zone	x	x	x		x			x	x				
	x	x			x	x		x	x				
	x	x			x				x	x			x

Sequence of Reactions

Characteristic mineral assemblages are listed in Table 2 and some of these are plotted on Figure 2.

The presence of pelitic rocks makes it possible to map three isograds (Froese and Gasparrini, 1975) based on the following reactions:

chlorite + almandine + muscovite

$\rightleftharpoons$ biotite + staurolite + quartz + H_2O

chlorite + staurolite + muscovite + quartz

$\rightleftharpoons$ biotite + Al silicate + H_2O

staurolite + muscovite + quartz

$\rightleftharpoons$ biotite + Al silicate + almandine + H_2O

These isograds (Fig. 2) mark the boundaries between four metamorphic zones: chlorite-biotite; chlorite-biotite-staurolite; biotite-staurolite-sillimanite; and biotite-sillimanite-almandine. Each zone is named after a characteristic assemblage. In the two zones marked by the presence of staurolite, almandine commonly is associated with the three-phase assemblage. Presumably it is stabilized by manganese, which is a significant constituent (Tables 3 and 4). In many assemblages, there is considerable difficulty in deciding whether chlorite is a compatible mineral. It commonly occurs as well developed blades, both parallel to the S_2 foliation and grown across it. In the chlorite-biotite-staurolite zone, chlorite was interpreted as part of the prograde assemblage. In the biotite-staurolite-sillimanite zone, chlorite persists in biotite-staurolite-sillimanite-muscovite assemblages. The isograd has been drawn on the basis of the appearance of sillimanite and/or kyanite. The isograd assemblage probably is stable over a temperature range but, in rocks far above this isograd, chlorite is regarded as a secondary mineral. Almandine, probably stabilized by MnO, is commonly present in biotite-staurolite-sillimanite assemblages. Thus the biotite-sillimanite-almandine isograd was based on the disappearance of staurolite in the presence of muscovite. The isograd reactions are part of the petrogenetic grid shown in Figure 3. The erosion surface trace of metamorphic conditions in the Snow Lake area is represented in the petrogenetic grid at a pressure somewhat greater than that of the triple point of the aluminum silicates. The sequence of reactions along this trace through the grid, including the isograd reactions, is shown diagrammatically by changes in topology in the subdivisions of the biotite composition surface (Fig. 5). The biotite composition surface is terminated along bevelled edges from which tie lines run to muscovite.

In addition to the grid reactions, two other reactions, leading to the formation of cummingtonite and anthophyllite, are shown in Figure 5. Due to restrictions in bulk composition, not all reactions shown in Figure 5 can be documented. However, the available assemblages listed in Table 2 are consistent with the inferred sequence of reactions.

Mineral assemblages considered to be stable in the chlorite-biotite zone are shown in the upper left-hand corner of Figure 5. The chlorite-biotite zone has been examined only on the northwest shoreline of Webusko Lake in metasedimentary rocks characterized by the assemblage biotite-muscovite-chlorite. Other assemblages shown are those expected to be stable in low grade metamorphism (Winkler, 1979). Reaction (1) in Figure 5 marks the biotite-staurolite isograd and lower boundary of the chlorite-biotite-staurolite zone. At slightly higher grade, cummingtonite

Table 3

Compositions of minerals from specimen FQ70-198a (chlorite-biotite-staurolite zone)

	biotite	chlorite	anthophyllite	cummingtonite	almandine
SiO_2	36.09	25.12	40.85	51.81	39.96
TiO_2	1.55	0.15	0.20	0.07	0.07
Al_2O_3	17.24	20.71	17.14	1.60	20.47
FeO	23.32	29.70	30.67	31.98	36.22
MnO	—	0.10	0.71	0.49	2.93
MgO	9.49	12.60	7.71	12.79	2.47
CaO	0.01	—	0.14	0.08	1.02
Na_2O	0.22	—	1.69	0.01	0.04
K_2O	8.68	0.08	—	0.02	—
Total	96.60	88.46	99.11	98.85	100.18

Total iron expressed as FeO.

Mineral assemblage: quartz, plagioclase An_{10}, chlorite, biotite, almandine, cummingtonite, anthophyllite, ilmenite.

Electron microprobe analyses by M. Bonardi, Mineralogy Section, Geological Survey of Canada.

should be stabilized because it is a common mineral in medium grade rocks (Winkler, 1979). For this reason reaction (2) in Figure 5 has been inferred:

chlorite + almandine + hornblende + quartz

$\rightleftharpoons$ plagioclase + cummingtonite + H_2O

In the middle of the chlorite-biotite-staurolite zone, the assemblage chlorite-almandine-cummingtonite-anthophyllite has been observed. Based on chemical analyses (Table 3), the composition of these minerals has been plotted in the AFM system, as previously defined (Fig. 6). Their relative composition suggests reaction (3) in Figure 5:

chlorite + almandine + cummingtonite

$\rightleftharpoons$ anthophyllite + quartz + H_2O

Because of the presence of manganese in almandine, this reaction will be somewhat dependent on composition.

The assemblage chlorite-staurolite-kyanite (sillimanite) — biotite-muscovite is common in rocks from the Anderson Lake and Stall Lake deposits. This assemblage represents the biotite-aluminum silicate isograd (reaction (4) in Fig. 5) and lower boundary of the biotite-staurolite-sillimanite zone. Furthermore, Hutcheon (1977) reported the assemblage chlorite-anthophyllite-staurolite from the Stall Lake deposit suggesting reaction (5) of Figure 5:

chlorite + almandine + quartz

$\rightleftharpoons$ anthophyllite + staurolite + H_2O

Reaction (6) in Figure 5 has not been documented in rocks from the Snow Lake area, but from the reaction grid (Fig. 3) it is expected to occur in the lower biotite-staurolite-sillimanite zone.

Table 4

Compositions of minerals from specimen ST-406-44 (Stall Lake mine)

	chlorite	almandine	staurolite	gahnite
SiO_2	26.16	37.65	27.09	—
TiO_2	0.12	0.06	0.47	—
Al_2O_3	21.90	20.14	51.59	57.75
FeO	21.09	32.46	11.59	11.74
MnO	0.10	4.05	0.28	—
MgO	19.23	4.02	2.19	3.63
CaO	—	1.19	—	—
Na_2O	—	—	—	—
K_2O	—	—	—	—
ZnO	—	—	4.91	26.33
Total	88.60	99.57	98.12	99.45

Total iron expressed as FeO.

Mineral assemblage: quartz, chlorite, almandine, staurolite, gahnite, magnetite, pyrite, pyrrhotite, sphalerite, chalcopyrite, ilmenite.

Electron microprobe analyses by M. Bonardi, Mineralogy Section, Geological Survey of Canada.

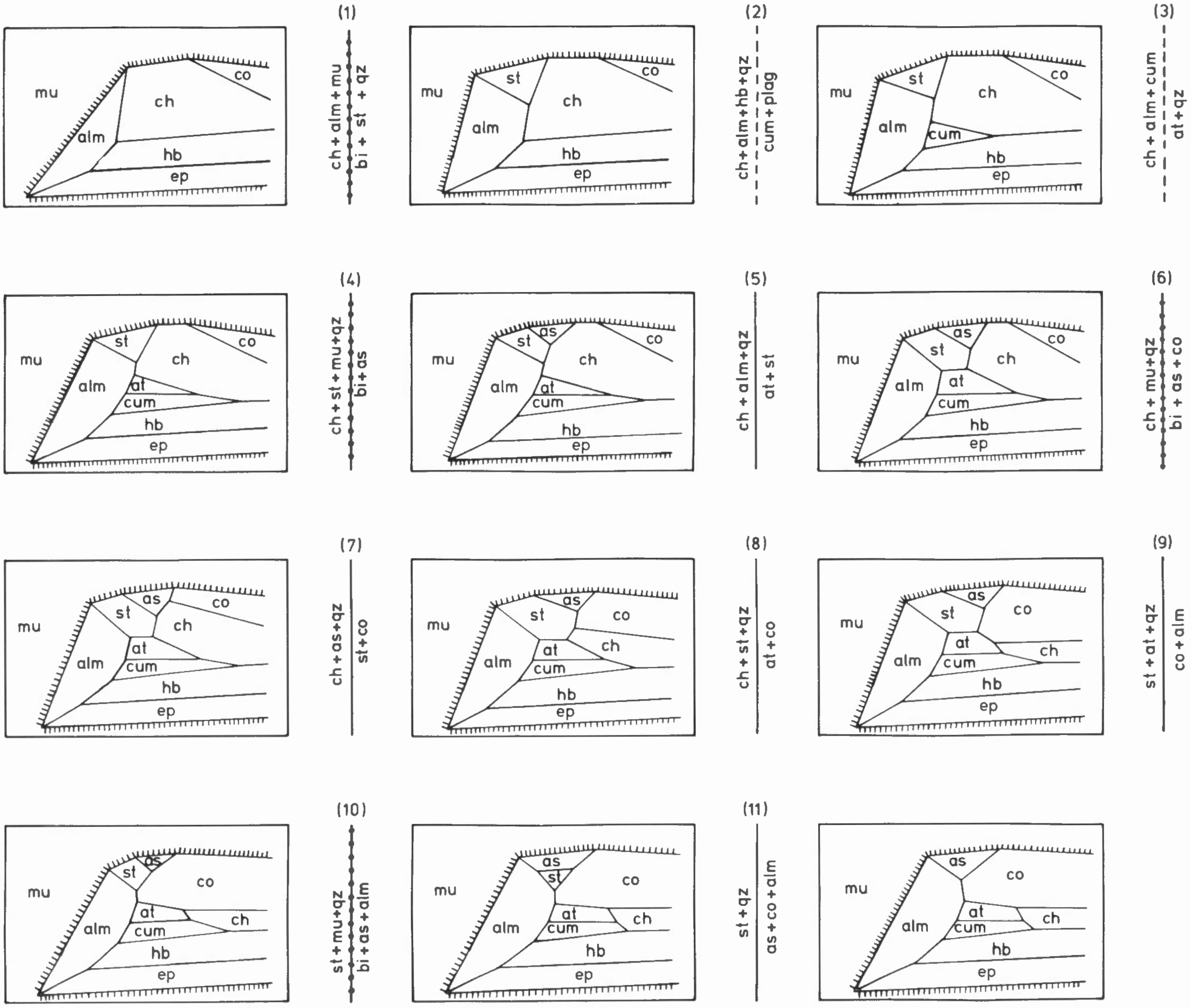

Figure 5. Sequence of reactions in the Snow Lake area. Vertical axis = A/(F+M); horizontal axis M/(F+M). Key to mineral abbreviations.

qz – quartz	*ch – chlorite*	*at – anthophyllite*
mu – muscovite	*as – aluminum silicate*	*cum – cummingtonite*
plag – plagioclase	*st – staurolite*	*hb – hornblende*
bi – biotite	*alm – almandine*	*ep – epidote*
	co – cordierite	

The assemblage staurolite-cordierite-chlorite in the lower biotite-staurolite-sillimanite zone of the File Lake area (Bailes and McRitchie, 1978) indicates reaction (7) in Figure 5:

chlorite + sillimanite + quartz

$\leftrightharpoons$ staurolite + cordierite + H_2O

In the Snow Lake area, the assemblage staurolite-anthophyllite-cordierite suggests that reaction (8) in Figure 5 has gone to completion:

chlorite + staurolite + quartz

$\leftrightharpoons$ anthophyllite + cordierite + H_2O

Within the biotite-sillimanite-almandine zone, the assemblage cordierite-anthophyllite-almandine is an indication that reaction (9) of Figure 5 has occurred, probably in the upper biotite-staurolite-sillimanite zone:

staurolite + anthophyllite + quartz

$\leftrightharpoons$ cordierite + almandine + H_2O

Reaction (10) in Figure 5 represents the biotite-sillimanite-almandine isograd and lower boundary of the biotite-sillimanite-almandine zone. Reaction (11) in Figure 5 has not been documented in the Snow Lake area, because small staurolite crystals persist in muscovite-free rocks to the northern limit of the area. The staurolite grains commonly occur within plagioclase and probably are armoured relics.

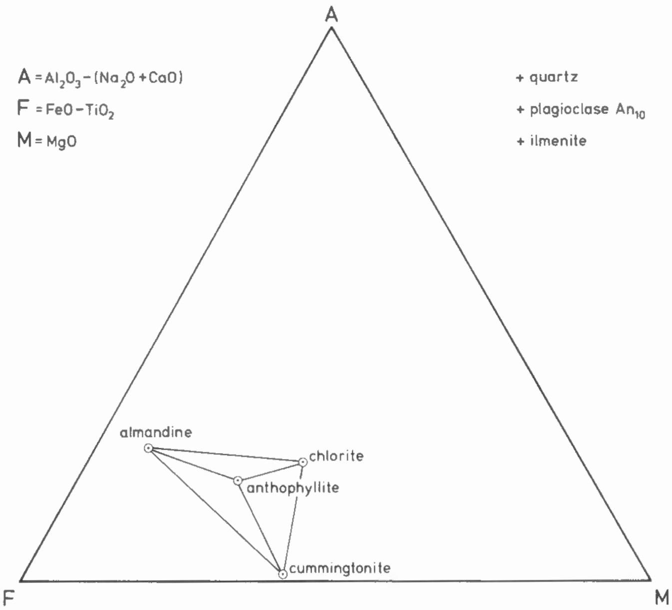

Figure 6. The composition of coexisting chlorite, almandine, cummingtonite, and anthophyllite.

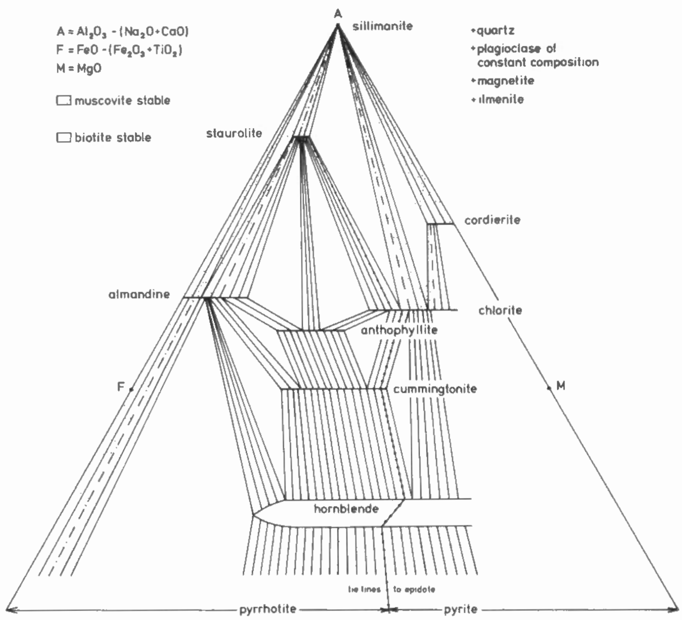

Figure 7. Mineral assemblages at a grade slightly higher than the biotite-sillimanite isograd, shown on an AFM diagram.

At a grade of metamorphism represented by the biotite-sillimanite-almandine isograd, quartz-sillimanite nodules appear in Missi sediments. The origin of the nodules remains obscure, because the low-grade equivalents of the rocks do not contain highly aluminous minerals. Near the northern boundary of the Snow Lake area, beginning of anatexis leads to the disappearance of muscovite (Bailes, 1975).

Metamorphism of Sulphide-bearing Rocks

In metamorphosed sulphide-bearing rocks, the sulphide, silicate, and oxide minerals constitute a metamorphic mineral assemblage. Therefore, a regular relationship among all minerals is to be expected if equilibration was achieved during metamorphism. Phase relations among sulphide and silicate minerals may be examined by plotting coexisting silicate minerals in the AFM system as previously defined and examining their relations to sulphide minerals. In general, pyrite will coexist with magnesium-rich minerals and pyrrhotite with iron-rich minerals and a pyrite-pyrrhotite boundary will run across the AFM diagram (Froese, 1969, 1971, 1977). At constant pressure, temperature, and water activity, and in the presence of quartz, plagioclase of constant composition, magnetite, and ilmenite, the pyrite-pyrrhotite boundary should be fixed. However, such perfect regularity is not usually observed and, in most instances, pyrite, together with pyrrhotite, appears to coexist with relatively iron-rich minerals. Since pyrite is generally stabilized with respect to pyrrhotite at lower temperatures, the possibility of producing pyrite by re-equilibration during quenching must be considered.

The Anderson Lake and Stall Lake mines occur practically at the biotite-sillimanite isograd, or at slightly higher grade as indicated by the occurrence of anthophyllite + staurolite. The appropriate mineral assemblages at this grade are shown in Figure 7. The introduction of K_2O as another component to the system AFM will, in general, give rise to one additional phase. Accordingly, fields of stability of biotite and muscovite have been indicated. Hutcheon (1979) studied sulphide-silicate assemblages from the two mines. The isograd assemblage muscovite-chlorite-biotite-staurolite-kyanite (sillimanite) is common and usually associated with pyrite and pyrrhotite. In Figure 7, the pyrite-pyrrhotite boundary has been shown just inside the stability field of biotite-staurolite-sillimanite and extended diagrammatically to mafic compositions.

Zinc, like iron, is an element which enters into sulphide, oxide, and silicate minerals. Thus zinc may be an important constituent in staurolite (Hutcheon, 1979) and gahnite is a common mineral in metamorphosed sulphide deposits. In the Snow Lake area, gahnite has been reported from the Chisel Lake mine (Williams, 1966) and from the Stall Lake mine (Hutcheon, 1977). It is, therefore, of some interest to introduce ZnO to the system AFM. Theoretically there should be a sphalerite-gahnite boundary similar to the pyrite-pyrrhotite boundary. This boundary should be in the pyrrhotite field allowing for the coexistence of pyrrhotite and sphalerite. Mineral assemblages and the pyrite-pyrrhotite boundary shown in Figure 7 can also be portrayed on the biotite composition surface (Fig. 8). In Figure 8 also a schematic gahnite-sphalerite boundary is shown within the pyrrhotite field.

In the absence of ZnO component, staurolite from three-phase assemblages on the AFM diagram has a fixed composition (Fig. 7). Staurolite contains very little Fe_2O_3 and TiO_2 and the component F is practically equal to FeO. In Figure 9, the composition of staurolite from three-phase assemblages would plot along the line FeO - MgO. Now ZnS is introduced as an additional component. The component ZnO is equivalent to FeO + ZnS - FeS; in the presence of pyrrhotite of fixed composition, ZnO plots midway between FeO and ZnS. Gahnite and staurolite compositions (Table 4) now can be represented in terms of FeO, ZnS, and MgO. It is apparent that the composition of staurolite from three-phase assemblages in the AFM diagram again becomes fixed when coexisting with a zinc-bearing mineral, either gahnite or sphalerite. It is also seen that gahnite coexists with iron-rich minerals and sphalerite with magnesium-rich minerals.

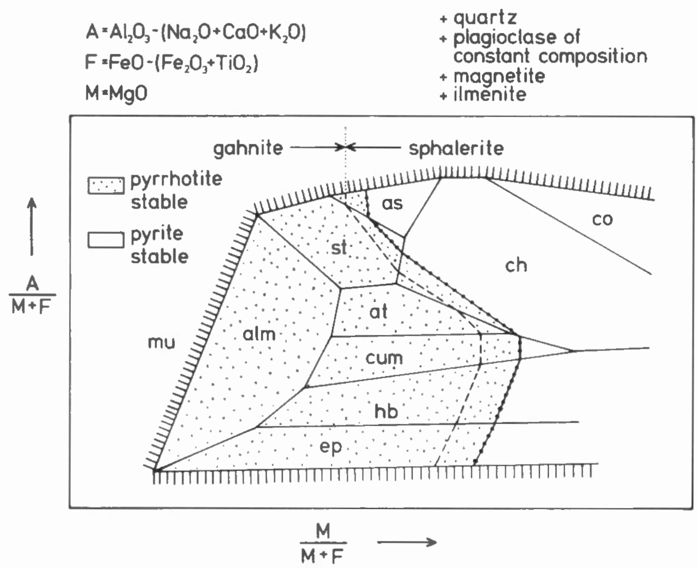

Figure 8. Mineral assemblages at a grade slightly higher than the biotite-sillimanite isograd, shown on the biotite composition surface. For mineral abbreviations see Figure 5.

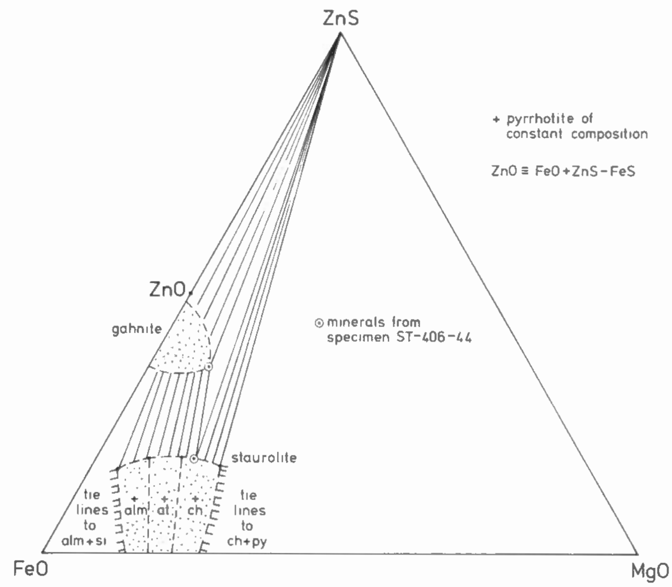

Figure 9. Phase relations involving staurolite, gahnite and sphalerite.

Metamorphic Conditions

The trace of metamorphic conditions on the erosion surface in the Snow Lake area is represented by a line on the reaction grid just above the triple point of the aluminum silicates. On this basis, Froese and Gasparrini (1975) estimated the pressure during metamorphism to have been 5-6 kb*. Recently the triple point of Holdaway (1971) is gaining favour in petrological discussions. According to this triple point, the pressure of metamorphism in the Snow Lake area could have been as low as 4 kb. The sphalerite geobarometer has been applied to sulphide deposits in the Snow Lake area (Bristol, 1974; Scott, 1976; Hutcheon, 1978). The distribution of sphalerite compositions is bimodal, with maxima at 13.4 and 11.4 mole % FeS (Bristol, 1974). These compositions correspond to pressures of 6.0 and 8.5 kb. In view of recent work on ores of the Ruttan mine (Bristol, 1979) the low-iron sphalerites could be interpreted as products of quenching at relatively low temperatures. This could account for the anomalously high pressures indicated by sphalerite geobarometry.

The temperature indicated by the isograd reactions depends on the water activity. If the activity is unity, medium-grade metamorphism (i.e. from the biotite-staurolite isograd to the beginning of anatexis) at 5 kb covers the temperature range of about 550°C-650°C (Winkler, 1979). With the present information, it is not possible to determine temperature and water activity separately.

CONCLUSION

The Snow Lake area is part of a metamorphosed volcanic-sedimentary belt which, according to radiometric dating, accumulated during Aphebian time (Bell et al., 1975). The volcanic rocks of the Amisk Group range in composition from basalt to dacite and the associated metasediments appear to have been largely deposited by turbidity currents. Rocks of the Amisk Group are overlain, with apparent erosional unconformity by shallow-water arenaceous meta-sedimentary rocks of the Missi Group.

Towards the north, the Amisk Group exhibits a facies change, becoming essentially a sedimentary succession. A similar facies change was observed by Bailes (1979, 1980) in the adjacent File Lake area. However, there is no structural discontinuity between the volcanic-sedimentary belt and the Kisseynew Complex. A metamorphic zonation developed at the time of a second period of folding. The metamorphic zones transect the F_2 fold axes. Metamorphic conditions of the present erosion surface can be represented by a flat P-T curve at a pressure somewhat higher than that of the aluminum silicate triple point.

Volcanogenic sulphide deposits and associated alteration zones of the Snow Lake area have been metamorphosed to the same grade as the surrounding rocks. Although the deposits are highly deformed and in many instances segmented into lenses, they have not been dispersed by metamorphism. Thus the scarcity of mineral deposits in the Kisseynew Complex, rather than being a reflection of high metamorphic grade, probably results from the rare development of a favourable volcanic environment.

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* 1 kb = 10^5 kPa (kilo Pascal)

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