CANADA

DEPARTMENT OF MINES AND TECHNICAL SURVEYS

GEOLOGICAL SURVEY OF CANADA

MEMOIR 271

BATTY LAKE MAP-AREA, MANITOBA

BY

D. S. Robertson

EDMOND CLOUTIER, C.M.G., O.A., D.S.P.
QUEEN'S PRINTER AND CONTROLLER OF STATIONERY
OTTAWA, 1953

Price, 75 cents

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PREFACE

Batty Lake map-area lies almost entirely within an easterly trending belt of Precambrian Kisseynew gneisses in west-central Manitoba. To the west, in the adjoining Sherridon map-area, these rocks contained the ore deposits of the Sherritt Gordon mine, and to the south, in the adjacent belt of Amisk and Missi strata, lies one of the most extensively mineralized and productive regions of the province.

In the present report, the author is largely concerned with the petrologic and structural problems of the highly metamorphosed and partly granitized Kisseynew sedimentary rocks, their stratigraphic succession, their relation to associated granitic masses, and their mineralization. An attempt has been made to classify them with respect to their metamorphic grade, and from this to establish their original characteristics and, hence, to trace and use as stratigraphic markers beds that now vary materially from place to place. The conclusions reached on both the internal and external structural relations of these Kisseynew gneisses differ in some significant particulars from those held by other recent workers in this general region, but the petrologic data collected and their application to the economic and other problems of this highly complex Precambrian terrain should find useful employment in future studies, both in this and in other similarly metamorphosed parts of the Canadian Shield.

The report, which covers an area of some 340 square miles, is illustrated by a geologically coloured map on a scale of 1 inch to 1 mile.

GEORGE HANSON,
Chief Geologist, Geological Survey of Canada

OTTAWA, November 25, 1952

Batty Lake Map-Area, Manitoba

CHAPTER I

INTRODUCTION

LOCATION AND ACCESSIBILITY

Batty Lake map-area occupies an area of about 340 square miles of west-central Manitoba between 55° and 55°15′ north latitude and 100°30′ and 101° west longitude. It adjoins Sherridon map-area (6)[1] to the west and Elbow Lake map-area (28) to the south. Geological mapping was carried on as for publication at 1 inch to 1 mile, except locally where more detail was necessary to determine structural or stratigraphic relations.

The area can be reached by air from Sherridon. Travel within it was entirely by canoe, a good water route extending from south of Nokomis and Hutchinson Lakes north through Walton Lake, and thence east to Limestone Point Lake, File River, and Batty and Moody Lakes.

ACKNOWLEDGMENTS

In the field, information and assistance were received from Walter Hanson of Sherridon, Manitoba, and Mr. P. Stewart of International Mining Corporation. Mr. J. M. Baker of International Mining Corporation very kindly supplied drilling data on the Evans Lake property. Student assistants in the field were H. A. Laine, W. Kost, and E. Reid in 1947; R. E. Bishop, J. T. Twiss, D. W. Organ, and A. Sawatsky in 1948; and G. Genik in 1949. Dr. J. M. Harrison of the Geological Survey of Canada directed the early work in the field, and encouraged the writer's interest in many of the problems that are still to be solved.

Most of the laboratory work was carried out in the geological laboratories of Columbia University, and the use of their facilities and the benefits derived from the stimulating atmosphere provided by fellow students and the professorial staff are gratefully acknowledged. The author particularly appreciated the instruction, direction, and friendship of Professor S. J. Shand during the period in which he had the privilege of working under him.

PREVIOUS WORK

Wright (42) visited the west half of the Batty Lake area in 1928, and described the rocks of the Nokomis and Walton Lake basins. In 1931 he described the mineral deposits of the area (44), and traced the Kisseynew rocks eastward and southward to the southeast corner of the area where they pass into the "Wekuskoan" sedimentary rocks described by Alcock (1). Bruce and Matheson (8) described the mineralogy and

[1]Numbers in parentheses are those of references listed in Bibliography at end of this chapter.

petrology of typical Kisseynew rocks from adjacent areas, and briefly discussed their origin, with the aid of chemical analyses. Bateman and Harrison (6) mapped the Sherridon area to the west of the Batty Lake area, and Harrison (16) mapped the File Lake area to the southeast, and has recently (18) supplied a splendid summary of Kisseynew problems.

PHYSICAL FEATURES

The Batty Lake area is typical of this part of the Canadian Shield, being of low relief and hummocky. Lakes cover much of the surface and their shapes in the main are controlled by bedrock structures. High areas commonly contain abundant outcrops, but the lower areas are swampy or are covered by glacial debris. Small sand plains are common in the area, and some of them have sinuous esker-like trends; they are characterized by small, straight pines and spruce and by a lack of underbrush (*See* Plate I A). The northern and eastern lake shores are commonly covered by boulders and sand, bedrock being best exposed on southerly and westerly shores.

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CHAPTER II

GENERAL GEOLOGY

GENERAL STATEMENT

The consolidated rocks of Batty Lake map-area are of Precambrian age and probably Archæan, with the exception of the Palæozoic dolomite on Limestone Point Lake. In 1929 and 1931, Wright (42, 44) related these basement rocks to the Kisseynew rocks of Kisseynew Lake, as described by Bruce (7), and attempted to correlate them with the Amisk rocks in the Amisk-Athapapuskow Lake district. The rocks in the basin of Nokomis and Walton Lakes, which Wright thought to be Amisk, can now be shown to be part of the Kisseynew.

Amisk rocks lie across the south part of the Batty Lake area in fault contact with Kisseynew gneisses to the north, and can be traced southward into the 'greenstones' of Elbow Lake called "Wekuskoan" by Stockwell (34). The Kisseynew rocks can be traced westward through Sherridon map-area (6) to the vicinity of Kississing Lake, and southwestward along Kisseynew Lake, but difficulties arise in attempting to correlate them with rocks in the vicinity of Flin Flon because of doubt as to their stratigraphic position with respect to the Missi sedimentary rocks of that area (36). Southeastward, in File Lake map-area, they grade into the less metamorphosed rocks of the Snow group (16).

Bruce described the Amisk lavas and Kisseynew meta-sedimentary rocks of the Amisk-Athapapuskow area (7) as being older than the Missi. Wright thought that the "Lower Missi" "... may be a less metamorphosed phase of the Kisseynew sedimentary gneiss" (42). In his discussion of the Wekuskoan group, as referring to all rocks older than the Missi, he writes (42, p. 8): "Further detailed work may prove this group to include two or more series of rocks widely separated in age . . .", and (page 15) ". . . on Kisseynew Lake the sediments as represented by the Kisseynew gneisses are conformably above the Amisk volcanics . . .". It is possible that the Kisseynew complex lies conformably above the Amisk series in this area, or that here, as at Nokomis Lake, Kisseynew hornblende gneisses were mistaken for Amisk rocks.

Stockwell, in discussing relationships in the Herb Lake area (34) writes: "Volcanics and underlying sediments have been named the Wekusko group by F. J. Alcock. However, if some of the sediments on the south-eastern limb of the syncline lie unconformably on this group, they probably should be correlated with the Missi series". Armstrong confirms this unconformity (3), but although his "Laguna" rocks may be tentatively correlated with the Missi, they are undoubtedly of Kisseynew type and rest unconformably on Amisk-type rocks.

Bateman and Harrison relate the Kisseynew of Mikanagan Lake map-area to the Missi on the basis of an "unconformable" contact with the Amisk (5), and point out lithological similarities between the Kisseynew and the type Missi of Flin Flon. Kalliokoski, mapping the Weldon Bay area (20), extended his observations to Mikanagan Lake map-area, and has attempted to show that the Kisseynew is separated from the Amisk in this and adjoining areas by a major thrust fault[1]. Mapping by the writer along the Kisseynew-Amisk contact (29) from Weldon Bay to Annabelle Lake in Saskatchewan has appeared to indicate that although there is some late faulting in the Weldon Bay area, the Kisseynew-Amisk contact is normally of a conformable, gradational type. Apparently, there is a tendency for faulting to occur at this contact due to the differing physical characteristics of the Amisk 'greenstones' (hornblende gneiss) and the Kisseynew meta-greywacke, which result in the prominent fault contact along the south border of Batty Lake map-area. The contact farther west, however, becomes progressively less faulted. Across Mikanagan Lake (5) and Flin Flon (36) map-areas, where, in the main, exposures are good, the contact appears gradational lithologically, with little or no variation in metamorphic grade.

Northwest of Annabelle Lake, Missi rocks contain areas of typical Kisseynew biotite-gneiss, with small pink garnets. Missi strata can be, and are, converted to Kisseynew-type gneiss where suitable physico-chemical conditions exist.

In the Batty Lake area, the Amisk rocks are in fault contact with the Kisseynew, and there is a fairly distinct change in lithology across the fault zone. Flaser gneiss and mylonite are produced at the contact.

A lithological subdivision of the Kisseynew rocks was attempted in Sherridon map-area (6). Division on the basis of a distinct change in sedimentation as applied in Batty Lake map-area has proved to be more successful in that it provides both a means of separating two groups of rocks that are now lithologically very similar, and a stratigraphic marker useful in areas of complex structure such as those north of Batty Lake and north of the Sherritt Gordon mine.

These two groups of gneisses appear to correspond to either Harrison's Snow group or to the Snow group plus unclassified rocks (16). No conglomerate or recognizable pebble-beds have been observed by the writer in these rocks, and they are thus unlike typical Missi sediments. Nor are they cut by "dykes of diorite and gabbro" as is the Snow group. Argillaceous material and sparse interbedded volcanic materials have been observed, as have sills of diorite and hornblendite.

Two rocks of granitic type were observed: a pink granite that occurs in quantity in the north and that appears to be related to 'soaking' and 'granitization' of the adjacent formations of parts of the area, and a granite in the south, described by Stockwell (34), that does not have 'granitized' rocks at its contacts with the adjacent sedimentary strata.

Pegmatite and aplite are common, the former represented by two types, one of which may be ultimately related to the mobilization of sedimentary material.

The Palæozoic dolomite of Limestone Point Lake is similar to that of exposures near Amisk Lake in Saskatchewan (9), and is probably of Silurian age.

[1]Ed.—A Geological Survey memoir by Kalliokoski on "Weldon Bay Map-area, Manitoba" and a Geological Survey Bulletin, by the same author, on "Structural Interpretations in the Sherridon-Flin Flon Region, Manitoba" (both in press) emphasize this relationship.

TABLE OF FORMATIONS

Age	Group		Lithology
Quaternary			Sands, gravels, boulder deposits
		Unconformity	
Silurian (?)			Mottled, massive to thinly bedded dolomite
		Unconformity	
Archæan and/or Proterozoic			'Northern' granite 'Southern' granite
		Intrusive contact (in part)	
			Diorite and amphibolite
		Intrusive contact	
	Kisseynew gneisses	Sherridon group	Granitized gneisses Quartz-rich, feldspar-biotite gneiss, in part garnetiferous Hornblende-feldspar gneiss, in part garnetiferous Anthophyllite gneiss, in part garnetiferous Limestone-orthoquartzite rocks
		Conformable contact	
		Nokomis group	Granitized gneiss Quartz-plagioclase-biotite gneiss, in part garnetiferous Hornblende-feldspar gneiss, in part garnetiferous
		Fault contact	
Archæan	Amisk series		Andesitic greenstone, pillow lava; interbeds of argillite; in part garnetiferous

AMISK SERIES[1]

DISTRIBUTION AND THICKNESS

Rocks of the Amisk series occur in the south part of the map-area in fault contact with the Kisseynew rocks to the north. Vertically dipping beds, on the southeast limb of a northeasterly plunging anticline in the southwest part of the map-area, give a thickness there of some 2,700 feet of Amisk strata.

PETROLOGY

In other areas (5, 35) the Amisk rocks have been separated into two stratigraphic divisions on a lithological basis. In this map-area, such a division has not been made, because basic hornblende gneiss and chlorite schist are interbedded throughout with argillitic material. In most other areas, too, pyroclastic rocks have been described as abundant, but here they occur in minor amounts only. In the main, the rocks are dark to light green, fine-grained andesites and derived chlorite schists. Medium-grained interbeds of considerable extent carry green hornblende and dull white feldspar. These resemble the diorite near Evans Lake (page 17), and may be either of intrusive origin or altered sedimentary rocks. Fine-grained biotitic argillites, weathering grey to white, are common; they usually occur near the top of the series, but southwest of the narrow lake south of Nokomis Lake they are in contact with the southern granite body at the base of the exposed section. Scattered, small, pinkish garnets occur in the argillites, and small red garnets are sparsely distributed in the hornblende-rich rocks.

Poorly preserved pillow structures were noted in the lavas at the northwest end of the irregular-shaped lake that lies along the southern border of the map-area about 3 miles south of Nokomis Lake, and it seems probable that much of the fine-grained andesitic material is of eruptive origin, although some may be sedimentary.

Argillitic Rocks

The following mineral assemblages were noted in the argillitic rocks: (1) quartz-biotite-hornblende-plagioclase, and (2) quartz-biotite-hornblende-garnet-plagioclase. Under the microscope, thin sections of these rocks exhibit a granoblastic and, in part, finely schistose texture. Quartz is invariably strained, and occurs in fine, occasionally rounded grains. Biotite is dark brown, and the amphibole is actinolitic, with yellow-green to dark greenish blue pleochroism and with an extinction angle of 15 degrees. In the sections that contain garnet, the biotite is lighter in colour and hornblende and biotite less common than normally, suggesting that some of their constituent ions may have gone into the formation of garnet. The garnet is invariably poikiloblastic; apatite is ubiquitous; and magnetite is common. A little hematite was observed in one slide.

[1]Referred to as "Amisk group" on the accompanying geological map, but the term 'series' is now regarded as preferable (18).

Greenstones

The greenstones comprise the following mineral assemblages: (1) hornblende-plagioclase-quartz-epidote; (2) hornblende-plagioclase-quartz-chlorite; and (3) hornblende-plagioclase-quartz-garnet. The rocks are finely schistose, although in the hand specimen they may appear massive. Elongate hornblende grains, with yellowish to greenish pleochroism, form most of the thin sections. Quartz is very common, and the rocks, if eruptive, must have been of dacitic composition originally. Epidote, in small rounded grains, is common, and carbonate occurs in late hackly masses. Chlorite is abundant in a few slides and a minor constituent in most.

KISSEYNEW COMPLEX

STRATIGRAPHY

The first attempt to subdivide the Kisseynew gneisses stratigraphically was made by Bateman and Harrison (6). They divided the complex into three divisions (Table I) on the basis of correlation of the Sherridon group with quartzite at Weldon Bay, and they say "...a section overlying Archæan greenstone resembles in many respects the Sherridon group. The rocks at Weldon Bay, however, are much less metamorphosed and are also strikingly similar to the Missi sediments near Flin Flon...". However, the lack of continuity of structures between Weldon Bay and Sherridon and the difficulties inherent in attempting to correlate between rocks of different metamorphic grade without some continuity, make a correlation of this kind somewhat tenuous.

The Kisseynew gneisses of the Batty Lake area are structurally similar to those of the Sherridon area, and distinctive rock types can be traced continuously from one area into the other. In addition, the rocks of the Batty Lake area are in contact with Archæan rocks in the south, which permits of a more direct stratigraphic zoning than in the Sherridon area.

TABLE I

Correlation between Sherridon and Batty Lake Map-areas

Sherridon area (6)	Equivalent to	Batty Lake area
Post-Sherridon		
Sherridon group	→	Sherridon group
Pre-Sherridon	→	Nokomis group
		(Fault contact)
		Amisk series

Distinctive Sherridon quartzites are found in the Batty Lake area occupying synclinal areas[1] in Nokomis rocks, which are in fault contact with the Archæan Amisk series. The Sherridon group is thus post-Nokomis in age. The Nokomis rocks, however, can be traced into the "post-Sherridon" rocks of Sherridon map-area, where, apparently, the stratigraphy should thus be reversed and the Sherridon structure considered synclinal. The constancy of the Nokomis character of the rocks lying along the Amisk contact has been investigated (29) and is maintained at least as far west as Annabelle Lake in Saskatchewan. Nowhere were Sherridon-like rocks found in contact with the Amisk.

No post-Sherridon sedimentary[2] rocks have been found in the Batty Lake area. It seems probable that the rocks at the centre of the Sherridon structure, formerly regarded as post-Sherridon, are domed Nokomis rocks.

NOKOMIS GROUP

Petrology

The Nokomis group, named from its fine exposures around Nokomis Lake, is composed of two main rock types and their 'granitized' equivalents. The first and most abundant type is a biotite-rich quartz-feldspar gneiss with which the second, a hornblende-rich type, is gradationally interbedded. The rocks are all foliated, but it is commonly difficult to decide where foliation is to be interpreted as relict bedding and where as a metamorphic structure. Gneissosity, where developed, is apparently parallel with the bedding, even around the noses of sharp and overturned folds.

Linear structures comprise elongate clots of grouped individuals or a parallelism of elongated individual grains, the latter being especially common in the hornblende grains of the hornblende-rich gneiss. Slickensides, the result of fault movements, were observed in many parts of the area.

Hornblende Gneisses. Gradationally interbedded with the quartz-rich gneisses are black to dark green hornblende-plagioclase gneisses that occur at varying stratigraphic horizons in the Nokomis sequence. At Evans Lake and among the tightly folded rocks about 3 miles west of File River, in the southeast part of the map-area, the hornblende gneisses invariably occupy high parts of structures and the quartz-biotite gneiss the low parts. If this constancy of position can be established, mapping of structure can be greatly facilitated. This same relationship was noted in the Kississing Lake area by Wright (42), who says (page 14): "The black hornblende and unusual types of gneisses appear to be localized where anticlinal folds are developed, and the synclines are occupied by the grey quartz-mica garnet gneiss".

The rock varies from a dense black to a spotted, black and white gneiss as the feldspar content increases. Foliation is generally well developed, and fine lineation, with elongation of the individual hornblende grains, is

[1]Recent work by Stockwell (35) applied to the Sherridon area by Kalliokoski (personal communication) develops a structural picture, based on the geometrical interpretation of folds, which appears to reverse the writer's stratigraphic sequence. The constancy of the Nokomis-like character of the rocks in contact with the Amisk over a considerable distance and apparent conformity between the Amisk and Kisseynew rocks in the west (29) require further explanation if a reversal of the stratigraphy is to be upheld.

[2]Map-unit 10, granitoid oligoclase-quartz gneiss, which is developed from both the Sherridon and Nokomis rocks during granitization, is not be to confused as a stratigraphic unit later than the Sherridon group.

prominent, especially in areas characterized by numerous folds of small amplitude. Small reddish garnets are not uncommon, but are nowhere more than $\frac{1}{16}$ inch in size.

Southwest of the southern extension of Nokomis Lake, the hornblende gneiss is intensely epidotized; this is also so of the gneiss along the west side of the river arm of Moody Lake, where epidotization appears to be connected with *lit-par-lit* injection.

Along the north border of the map-area, these gneisses are invaded by granitic material, which accompanies 'granitization'. In the outcrop, the hornblende gneisses show the effects of the introduction of feldspathic material much more readily than the quartz-biotite gneisses, but they also remain as recognizable units when the others have reached a granitoid state. The appearance of magnetite is also an indication of 'granitization' processes, as in the quartz-biotite gneisses.

Three diagnostic mineral assemblages have been recognized as characteristic of the Nokomis hornblende gneisses: (1) plagioclase-hornblende-almandine-quartz; (2) plagioclase-hornblende-epidote-almandine-quartz-biotite; and (3) quartz-zoisite-calcite.

The amphibole of these assemblages is a green, actinolitic hornblende; the mineral shows light yellow to green to blue pleochroism, and lies in the foliation planes of the gneiss. Biotite is commonly a minor constituent; it is a brownish green variety, with light yellow to dark brownish green pleochroism. Plagioclase (An_{30-35}) forms large to small grains, both twinned and untwinned. Epidote is in minor amounts, but is widely distributed. Where hydrothermal epidotization has occurred, the mineral is orthorhombic and should be called zoisite. In such cases the rock is commonly a quartz-zoisite rock with no plagioclase or amphibole. Quartz is invariably present, and red garnet (almandine) is common. Calcite, sphene, and apatite have also been noted.

The hornblende gneisses have in the past been considered to be of sedimentary origin and with this the present study concurs. Wright (42) and Bruce and Matheson (8) cite the banded appearance of some varieties, and Wright (42, p. 81) says: "Furthermore the hornblende-bearing gneisses alternate with quartz-mica gneisses of undoubted sedimentary origin without the sharp contacts they should show if they represented recrystallized lava flows or metamorphosed intrusive bodies". The passage from one type to the other is gradational, biotite and hornblende imperceptibly changing place as the dominant dark constituent across a contact zone that may be many yards in width. No pyroxene or olivine was seen, and the mineralogical evidence points toward a slightly calcareous shale as being the progenitor of the hornblende gneiss.

Quartz-plagioclase-biotite Gneiss. This rock type is especially well exposed in the southern third of the area, with higher grade and 'granitized' equivalents in the northern parts. In the outcrop, it appears as a bedded to gneissic, greyish white to brownish rock in which twisted flakes of biotite are commonly prominent. A rounded, pinkish garnet is often a striking constituent. On the east side of the north arm of Hutcheson Lake, the gneiss closely resembles a bedded sedimentary rock, consisting of alternating quartzitic and more feldspathic and biotitic bands 2 to 5 inches wide. These bands are well fractured, with coarse joints both normal to and parallel with the bedding. Similar conditions were encountered northeast of the north end of Nokomis Lake, where clear, angular, detrital quartz grains up to $\frac{1}{16}$ inch in diameter are recognizable. This is the only locality where the original detrital character of the material has not been obliterated by recrystallization. Bateman and Harrison (6) report conglomerates of Sherridon map-area in rocks equivalent to the Nokomis, but none was seen here, with the possible exception of a rock of doubtful character near the Nokomis-Amisk contact at about longitude 101° 53′ in the south part of the area that may well represent stretched pods of fine, *lit-par-lit* material. Biotite-sericite schist occurs here and there, apparently along shear zones that parallel the regional foliation. In much of the northern part of the map-area, as well as in other indicated parts, the sedimentary gneisses have been 'soaked' by later granitic material. An increase in pinkish feldspar, together with coarsening texture and the appearance of considerable magnetite, marks the areas mapped as 'granitized' gneisses, whereas rocks of distinct gneissic character that otherwise resemble granites or tonalites are mapped as granitoid gneisses, which are regarded as sedimentary rocks that have been transformed past the 'granitized' stage into material resembling true igneous rock.

The following six mineral assemblages have been recognized in exposed areas of the quartz-plagioclase-biotite gneiss: (1) plagioclase-biotite-almandine-quartz; (2) plagioclase-biotite-hornblende-almandine-quartz; (3) plagioclase-biotite-microcline-quartz; (4) plagioclase-biotite-cordierite-almandine-quartz; (5) plagioclase-biotite-sillimanite-almandine-quartz; and (6) plagioclase-biotite-sillimanite-cordierite-almandine-quartz.

All textures are those typical of recrystallized rocks, the minerals being intergrown, with serrate borders, and commonly oriented parallel with the foliation. Quartz is invariably the most abundant constituent; it forms clear, intergrown grains, commonly in groups elongated parallel with the foliation, or occurs in small rounded grains enclosed in plagioclase and in garnet. Bruce and Matheson (8), discussing this material in the vicinity of Sherridon, state that most of the quartz shows no strain effects. However, the quartz in the material studied by the writer always shows strain shadows and gives an abnormal biaxial figure, indicating some strain. Plagioclase (An_{21-30}) occurs both twinned and untwinned, and so far as could be determined from observation of the albite-twin lamellæ, the grains have no individual preferred orientation. An etch-stain treatment (14), applied to differentiate the untwinned feldspar from quartz, also showed that orthoclase is not a constituent of these gneisses. Biotite is commonly a brown variety with light yellow to red-brown pleochroism, and forms long, thin flakes oriented parallel with the foliation. Hornblende is stable where the hornblende-rich rock grades into the biotite-rich type. It occurs in subhedral to anhedral, green crystals, with faint yellow-green, green, and blue-green pleochroism. The grains normally lie in the plane of foliation and are commonly well oriented, as in exposures at Evans Lake. Cordierite has not been found in the Nokomis group south of a line through Walton Lake, except at one locality east of Nokomis River. Its appearance is heralded by a coarsening of the rock texture to a coarsely foliate material in which the cordierite lies as blue-mauve, in some instances highly dichroic, veinlets and grains. Normally it carries rounded grains of quartz and plagioclase, and is partly altered to chlorite. It is optically positive and has an optic angle of 88 degrees and refractive indices of 1·535(nα) and 1·542(nγ). Sillimanite occurs sporadically as pasty to shiny white lamellar flakes with a fibrous sheen. It is commonly visible to the naked eye, and in thin sections can be clearly seen forming from biotite; it appears as clear fibrous folia of high index tailing out between other mineral grains or as fine slender needles commonly enclosed in biotite.

Garnet is everywhere visible as small subhedral to anhedral grains. In thin section, the garnets appear as rounded, fractured grains of high relief and light pink colour, and almost always contain rounded quartz and rounded to euhedral plagioclase grains. Rarely, the garnet shows incipient alteration to chlorite. Magnetite occurs generally in small, ragged, interstitial grains. It appears in quantity in the 'granitized' gneisses and with cordierite. It commonly lies along foliation planes, augmenting the general banded appearance, but it is also found in wormy crosscutting blebs. Graphite occurs in quantity, but only near the top of the Nokomis group, where it may form as much as 50 per cent of rusty weathered parts of the gneiss. Under the microscope it is seen to form ragged, torn flakes rimming the edges of other minerals and lying in cracks in them. Although the graphite was undoubtedly mobile late in the metamorphic sequence, its origin from other than organic material seems improbable. Its constancy near the top of the Nokomis group and its absence elsewhere indicate some stratigraphic control; the possibility that it has an organic origin is further suggested by Rankama's recent article (25) proving the presence of organic carbon in Archæan graphite. Apatite, chlorite, and microcline have been noted in small amounts.

The Nokomis quartz-plagioclase-biotite gneisses change composition laterally and vertically, reflecting their original sedimentary characteristics. Variation is chiefly in the amounts of biotite and plagioclase. The rocks lower in the sequence are of coarser grain than those higher up, apparently as a consequence of original deposition rather than metamorphism. The upper part of the sequence is fine grained, and normally has a greasy appearance due to the presence of graphite. This feature is of value in mapping, and can be used as a stratigraphic control.

Table II presents two modal analyses of Nokomis quartz-biotite gneiss as determined from thin sections. No chemical analyses are available, but analyses of similar material are given in Table III.

TABLE II

Percentage Modes of Nokomis Quartz-biotite Gneiss

—	I	II
Quartz	47·3	46·5
Plagioclase (An_{21-30})	25·7	18·8
Biotite	20·6	30·5
Garnet	5·9	Nil
Graphite	Nil	3·8

I. Nokomis quartz-plagioclase-biotite gneiss from north of Limestone Point Lake.

II. Gneiss, as above, northeast of Pamela Lake.

Table III

Analyses of Rocks of Nokomis Quartz-biotite Type

	1	2	3	4	5	6	7
	%	%	%	%	%	%	%
SiO_2	63·84	58·55	64·63	58·90	62·40	61·52	6[illegible]·1
Al_2O_3	20·34	18·95	19·00	21·70	15·20	13·42	15·4
Fe_2O_3	3·34	0·51	1·56	1·20	0·57	1·72	3·4
FeO	3·98	5·16	3·63	5·10	4·71	4·45	3·4
MgO	2·20	2·70	2·49	2·63	3·52	3·39	1·8
MnO	—	—	—	—	—	—	0·2
CaO	0·64	2·70	3·48	1·54	0·59	3·56	2·3
Na_2O	0·95	1·85	1·54	1·39	2·68	3·73	2·6
K_2O	2·42	4·07	1·60	2·41	2·57	2·17	2·2
H_2O+	—	1·37	0·92	1·32	1·56	2·32	—
	1·05						2·1
H_2O	—	0·23	0·20	0·46	0·07	0·06	—
P_2O_5	—	0·17	0·21	0·50	—	—	0·2
CO_2	—	0·60	trace	none	1·30	3·04	—
C	—	2·58	0·64	1·56	—	—	—
TiO_2	0·80	0·53	0·42	0·63	0·50	0·62	0·7
	99·56	99·97	100·32	99·34	99·57	99·92	102·4

1. Sedimentary phase of the Wekusko-Kiski. Wright, J. F.: Geol. Surv., Canada, Sum. Rept. 1930, pt. C. p. 11 (1931).

2. Argillite. Harrison, J. M.: Geol. Surv., Canada, Mem. 250, 1941, Anal. I, p. 26.

3. Staurolite gneiss. As above, Anal. II.

4. Sillimanite gneiss. As above, Anal. III.

5. Archæan greywacke (average of three) from Pettijohn after Grout. G.S.A. Bull., vol. 44, 1929, p. 97.

6. Archæan greywacke (average of three) from Pettijohn after Todd. Ont. Dept. of Mines, Ann. Rept., vol. 37, pt. 2, p. 20.

7. Average of thirty greywackes compiled by Tyrrell. C. R. Reunion Inter. Pour l'etude Pre-Cambrian, 1933, p. 26.

Wright's description of the rock of sample 1 is comparable to descriptions of Nokomis material, and it seems probable that it was obtained from strata of the same relative age and of very similar composition. Samples 2, 3, and 4 were provided by J. M. Harrison of the Geological Survey of Canada. Reference to his File Lake map (16) indicates that these samples are from material mapped as Nokomis in the adjoining Batty Lake area, and thus have chemical compositions representative of these meta-sedimentary rocks.

Comparison of these analyses with samples 5, 6, and 7 indicate that the original sediment was of greywacke type, a material typical of orogenic belts of deposition, an observation that can also be applied to Bateman and Harrison's account of conglomerates in the Sherridon area. Due to regional metamorphism, discussed in a later part of this report, these sediments have been brought to their present gneissic state, some even to granite-like material.

RELATIONS BETWEEN NOKOMIS AND SHERRIDON GROUPS

The division of the Kisseynew gneisses into two groups is based on the distinct change in sedimentation expressed by the development of limestones and orthoquartzites at their contact. The Nokomis becomes fine grained at the top and contains graphite, which is apparently stratigraphically controlled. Discontinuous limestones and orthoquartzites then appear, displaying relict bedding and apparently grading into the succeeding Sherridon, which is almost everywhere quartz-rich. The Nokomis represents geosynclinal detritus from an actively contributing orogenic land area, which was considerably lower topographically at the end of Nokomis time and which did not again contribute detritus as coarse as that of the Nokomis, at least not until post-Sherridon time. No apparent unconformity exists between the Sherridon and the Nokomis, but the laterally discontinuous character of the lime-rich rocks near the contact might, however, be interpreted as indicating an erosional interval rather than a facies variation, as suggested above.

SHERRIDON GROUP

Petrology

The name "Sherridon group" was introduced by Bateman (4) as a subdivision of the Kisseynew to separate decidely quartz-rich gneisses and interbedded hornblende-rich rocks from the other sedimentary gneisses. The fact that he placed the group below rocks equivalent to the Nokomis does not alter the value of the term as representing a distinctive map-unit, and it is used here to refer to all Kisseynew strata above the Nokomis.

Two main rock types, respectively quartz-rich and hornblende-rich, plus some limestones and an anthophyllite band, comprise the Sherridon group. All are foliated and range from recognizably bedded materials to distinctly gneissose beds with granitoid characteristics. Lineation is commonly well developed, and is indicated by alined clots of dark minerals. These rocks are best exposed across the central part of the map-area, lying in broad, overturned folds of complex character.

Quartz-rich Gneisses. These consist of white to grey weathering gneisses of distinctive character. A texture, emphasized by quartz that weathers out in ridges and by large red-garnet knots, facilitates their recognition in the field. Orthoquartzites at the base of the sequence and at a few higher horizons are of relatively fine grain and weather greyish white. Their best exposures have been observed north of the power-line west of Star Lake and southeast of Walton Lake. They consist of more than 80 per cent quartz, with minor plagioclase feldspar and almost no dark minerals. Recrystallization at all horizons is complete, and no original boundaries or cementing material can be seen. The gneissic bands vary in mineral composition both laterally and vertically, as in the Nokomis gneiss, and so far as observed the mineral assemblages are also the same. The only real difference between the bulk of the Sherridon and the Nokomis is the quartz-rich character of the Sherridon, which results in rough ridgy textures and definite trends towards true quartzite. There also appears to be a small but constant amount of microcline feldspar in the Sherridon as opposed to its rare and patchy occurrence in the Nokomis.

Quartz invariably comprises more than 50 per cent of the rock and may form nearly 90 per cent in the true quartzites. Strain shadows and constant biaxial character indicate some strain. Plagioclase (An_{31-40}) occurs in clear to cloudy grains of serrate and intergrown habit. Biotite is everywhere present except in the orthoquartzites, and is the normal brown variety. Garnet is ubiquitous, and occurs in reddish to red-brown anhedral crystals invariably poikiloblastic and commonly large. Garnet lumps north of Camp Lake, near the east side of the map-area, measured 3 inches across, and crystals 1 inch across and resembling plums in a pudding (*See* Plate I B) are very common. In places the foliation wraps around the garnet crystals, but elsewhere the garnet individuals seem to have grown around the quartz grains that give the rock its foliation, resulting in garnet crystals with bands of quartz running through them. In thin section, the garnets appear as large, fractured crystals growing around rounded remnants of quartz, feldspar, and occasionally biotite. Commonly they are groups of individuals grown together in the plane of the foliation, forming elongate lenses with very irregular boundaries. In some outcrops garnet is the only dark mineral in a feldspathic quartzite, suggesting its formation from the components of the biotite that is normally present. Cordierite and sillimanite occur in coarsely textured lenses in exactly the same way as in the Nokomis group, and with the same physical characteristics. Sillimanite also occurs in thin, filmy, fibrous sheaths on planes that parallel the foliation, with no apparent coarsening of the rock texture; in each occurrence it appears to be connected with slickensiding movements. Magnetite is not common except where 'soaking' has occurred. Chlorite is not uncommon; in outcrops where it does not normally occur it may be found replacing biotite in the immediate vicinity of garnet grains. Hornblende, muscovite, apatite, titanite, and carbonate are occasional mineral constituents.

A mineral assemblage included in the mapping with the quartz-rich gneisses is the plagioclase-diopside-hornblende-epidote assemblage, with biotite and microcline. This rock has a granular appearance in the hand specimen. It lacks pronounced foliation and is flecked with small black biotite flakes and with bright green, glassy, diopside crystals, which give a striking appearance. It is of limited areal extent even though found in numerous places, and it could not be mapped as a continuous band for any distance. The diopside is of greenish hue, twinned in broad bands, and altered to hornblende. The hornblende is green, with yellow-green, dark yellow-green, and blue-green pleochroism, and is optically positive. Biotite is brown, and is pleochroic in light yellow to dark brown colours. Plagioclase and microline occur in equal amounts, with the microcline in wormy rims around other minerals. Quartz occurs in large, clear, intergrown crystals that exhibit peculiar structures resembling original grains within regrowth material. Individual parts of 'original grains' may not be optically continuous, and any variation is faithfully followed by the surrounding material. Epidote is interstitial and definitely rims the plagioclase. Its constant occurrence in this assemblage and its association with plagioclase indicate that a shearing stress was operative to the extent that an anorthite-rich plagioclase was unstable (40, pp. 51, 87). The mineralogical composition indicates that the reason for the epidote is the relatively high lime (CaO) content of this assemblage rather than high stress developed locally.

'Granitization' processes have affected these quartz-rich gneisses even more readily than those of the Nokomis group. Feldspathized and granitoid gneisses are very common, especially in the eastern part of the map-area, and these grade imperceptibly into bodies of plutonic appearance.

Hornblende Gneisses. Hornblende-rich gneisses of both volcanic and sedimentary origin occur in the Sherridon group, the first forming pillows characteristic of their mode of origin and the second grading imperceptibly into the quartz-rich gneisses, thereby indicating their sedimentary affinities.

Metamorphosed pillow lavas are exposed at latitude 55°9′ and longitude 100°10′ just south of a small lake, and Bateman and Harrison (6) report their occurrence east of Sherridon. Dark green in appearance and with euhedral garnets up to $\frac{1}{8}$ inch in diameter, their original pillows are outlined by darker borders caused by a greater proportion of hornblende than in the centres of the pillows, and by concentration of garnet along these borders. The hornblende-plagioclase-biotite-quartz mineral assemblage is diagnostic, and places the material in the staurolite-kyanite sub-facies of the amphibolite facies (40, p. 81). The presence of chlorite and calcite, the former in quantity, indicates a trend towards the albite-epidote facies.

Amphibole occurs in colourless non-pleochroic grains, with an extinction angle of 15 degrees, and also in green grains, with light yellow to dark green to dark yellow pleochroism. Both varieties are in bladed, ragged patches showing broad twins. The colourless variety appears to grade into the green variety, suggesting that the relationship may be one of bleaching of hornblende, with loss of iron to chlorite. Plagioclase (An_{35-38}) occurs in twinned and untwinned grains of slightly brown colour due to alteration. Chlorite occurs in quantity; its chief association is with the colourless amphibole, as noted above. Quartz, biotite, magnetite, and minor calcite are present.

The following modal analysis of a thin section of pillow lava shows an uncommonly large amount of quartz and approximately 30 per cent dark minerals; on a basis of no significant introduction of material, these pillow lavas might originally have been dacites.

	Per cent
Plagioclase (An_{35-38})	48·7
Amphibole	20·5
Quartz	20·2
Chlorite	5·6
Other minerals	5·0

Sedimentary Hornblende Gneiss. Interbedded with the quartz-rich gneisses are considerable bodies of black to grey hornblende gneisses. In part, these grade into the other sedimentary rocks by decrease in hornblende content, but in other instances their contacts are relatively sharp, and the field relations do not indicate whether they are derivatives of sedimentary or of igneous material—thin lava flows and the like. Their relative thinness and great areal extent at a constant stratigraphic level suggest a sedimentary derivation, a suggestion that is strengthened by the lack of any variation between their minerals and those of undoubted sedimentary materials.

Bruce and Matheson (8) give the following analysis of a hornblende-rich rock from Sherridon, which they consider to be an altered sedimentary rock:

Analysis	
SiO_2	57·48
Al_2O_3	15·22
Fe_2O_3	2·19
FeO	9·83
MgO	4·54
CaO	6·85
MnO	0·35
Na_2O	undet.
K_2O	undet.
	96·46

Approximate Mode	Per cent
Plagioclase (andesine)	51
Amphibole	26
Garnet	11
Magnetite	3
Quartz	9

Chemical evidence in this case does not demand a sedimentary origin, but together with the field evidence appears to suggest a ferruginous shale as the material from which the gneiss developed.

The following are modal analyses of two etched specimens of Sherridon hornblende gneiss:

—	1	2
	Per cent	Per cent
Plagioclase (An_{33-42})	17·8	30·7
Hornblende	52·6	25·7
Quartz	27·8	27·0
Garnet	2·0	14·5
Biotite	trace	—
Magnetite and chlorite	—	3·5
	99·8	101·2

1. Hornblende gneiss from west of Elken Lake.
2. Hornblende gneiss from west of Wapu Lake.

In the field, these gneisses display good foliation and commonly fine lineation—elongation of clots of hornblende or of individual grains. Small, red garnets are commonly present, and are occasionally circled by a white collar or rim of feldspar and quartz. Checkerboard-like patterns of white feldspar and black hornblende are not uncommon, and may be connected with the formation of rimmed garnet (*See* pages 36, 37). A variety mapped as sedimentary hornblende gneiss occurs east of Nokomis River; this is a well-banded rock, with alternating light and dark layers giving a bedded appearance. Glassy lamellæ of clear quartz, many with a reddish dusty tinge, are common.

The following assemblages have been noted: (1) plagioclase-hornblende-almandine-biotite-quartz; (2) plagioclase-hornblende-epidote-biotite-quartz; and (3) plagioclase-hornblende-almandine-quartz.

The plagioclase (An_{33-42}) is medium grained and anhedral. Hornblende is commonly green, with light yellow-green to dark yellow-green, to dark green, or yellow to dark green to blue-green pleochroism, and with an extinction angle of 20±3 degrees. Prisms lie commonly within the plane of the foliation and occasionally are oriented within it. Quartz ranges in amount from a minor constituent to as much as 30 per cent of the rock. In the sedimentary gneiss, the glassy quartz lenses show what appear to be regrowths around rounded to elliptical cores. Garnets are common as small, rounded and larger poikiloblastic grains, or in elongate blebs (*See* Plate II A). Rounded quartz and plagioclase grains are enclosed and oriented within the garnet, but in lines at angles of 10 to 25 degrees with the foliation. In some instances the garnet shows other evidence of rotation, such as snowballing. In a few cases the garnet appears to be preferentially replacing feldspar in the vicinity of quartz-feldspar material. Chlorite occasionally replaces hornblende as a normal product of retrograde metamorphism, and replaces hornblende and biotite in the vicinity of garnet in areas where chlorite is not normally present. This latter occurrence is probably a step in garnet formation, small flakes and fibres of the chlorite being found only between garnet and adjacent hornblende and biotite. It has been suggested (15, p. 355) that chlorite forms in this latter case as a result of the formation of garnet, it being a more flexible mineral than hornblende or biotite and stable under the stresses set up by garnet growth. Biotite, epidote, and magnetite occur sporadically, the magnetite definitely of late origin. Zircon, sphene, and carbonate have also been noted.

The Sherridon group is in large part 'granitized' and granitoid to the east, and there hornblende is ubiquitous. This may be due to a mineralogical shift to the minerals stable under the prevailing metamorphic conditions, or to a different bulk composition of the sediment to the east, which favours only hornblende formation. As biotite is stable in granitoid areas to the west the latter explanation seems the more probable.

Anthophyllite Band. A band of anthophyllite-rich rock has been traced from east to west in the map-area and, although not mentioned by Bateman and Harrison (6), has been seen at several localities in the Sherridon area. It varies in width from 50 to 100 feet and occupies a relatively constant stratigraphic position 500 to 800 feet above the base of the Sherridon group. It has not been identified in highly 'granitized' areas, possibly due to loss of its distinctive character through metamorphic alteration.

In the western half of the map-area, the anthophyllite-rich rock is composed mainly of yellowish brown anthophyllite in large radiating crystals, some of which are 4 inches long. Garnet is an occasional constituent, and a little of quartz and biotite are generally present. Farther east, cordierite makes its appearance in quantity, accompanied by magnetite-spinel intergrowths, and the anthophyllite occurs in smaller radiating groups of dark brown crystals. So far as observed, the anthophyllite blades do not lie in the plane of foliation. Biotite is plentiful.

Characteristic mineral assemblages in the anthophyllite band are: (1) anthophyllite-cummingtonite-biotite; (2) anthophyllite-biotite-almandine; (3) anthophyllite-cordierite-biotite; and (4) anthophyllite-cordierite-biotite-almandine; all include minor quartz and plagioclase.

In the western part of the anthophyllite band, the anthophyllite occurs in long brownish pink bladed crystals of radiating habit, optically negative, with pink to yellow-brown to yellowish pleochroism, an optic angle of 75 degrees, and low indices of refraction ($\alpha = 1 \cdot 651$; β and $\gamma = 1 \cdot 656$), indicating the aluminous variety gedrite. In the eastern half of the map-area, the anthophyllite is similarly bladed, but of grey-green colour with brownish green to yellow to brownish yellow pleochroism. It, too, is optically negative; has an optic angle of 75 degrees; and is also the variety gedrite, but with slightly higher indices of refraction indicating a higher iron content than in the anthophyllite farther west. It is invariably poikiloblastic.

The analyses in the following table (Table IV) confirm the conclusions reached on optical grounds that the anthophyllite of the anthophyllite band is the variety gedrite, and that it has a higher iron (Fe) content to the east than in the west. This and the appearance of quantities of magnetite in the east seem to confirm the introduction of iron. The relatively minor change in magnesium (Mg) could hardly account for the production of the quantities of cordierite found in the eastern part of the band, although it is possible that some magnesium produced by change of composition of the anthophyllite has contributed. In this regard it is of interest that the Mg:Al decrease in the anthophyllite is in the ratio of 2:5 as it should be in the composition of pure magnesium cordierite. Bulk analyses of the rock would be of definite interest.

TABLE IV

Analyses of Anthophyllite

—	1		2		3
	E	W	E	W	
SiO_2	44·03	45·32	21·39	21·19	+0·20
Al_2O_3	19·06	22·74	10·50	12·04	−1·54
FeO	19·77	14·15	15·97	11·00	+4·97
CaO	1·30	1·11	0·96	0·793	+0·17
MgO	15·20	16·90	9·53	10·20	−0·67
TiO_2	0·47	0·25	0·364	0·19	+0·17

1. Analyses by R. J. C. Fabry of the Geological Survey of Canada. Total iron (Fe) expressed as FeO; 'E' is anthophyllite from Star Lake; 'W' is anthophyllite north of the lake 2 miles north of the west end of Batty Lake.
2. Analyses calculated to atomic proportions against constant oxygen.
3. Difference in atomic proportions between west and east, with west (W) as the standard.

A clear monoclinic amphibole (cummingtonite?)[1] was observed in minor amounts to the west, and indicates an assemblage not at equilibrium, as two minerals containing the same components are not stable together at equilibrium. Cordierite is poikiloblastic, with quartz inclusions, and it is commonly polysynthetically twinned. It is blue, dichroic to pale grey, and optically positive, with an optic angle of 87 degrees and indices

[1]Colourless, $Z \wedge c = 5°$, $2V = 72°$. In this case FeO and MgO can substitute for one another in any amounts and thus are considered as one component. In cases such as cordierite and almandine, substitution of FeO for MgO is limited (?), and when the $\frac{FeO}{MgO}$ ratio passes a certain limit the components must be considered separately and an "extra" phase is possible, i.e., cordierite and almandine can coexist at certain $\frac{FeO}{MgO}$ ratios even though both contain the same components, FeO and MgO.

of refraction of 1·537 and 1·547. Analysis (page 32) shows this to be an iron-rich variety. Magnetite and green spinel are intergrown in the cordierite-rich rocks and are of apparently late origin, appearing in fractures in the cordierite and quartz as well as in misshapen blebs and masses. Chlorite rims the spinel-magnetite in the cordierite, and was observed in small amounts in most slides. Garnet is common in large poikiloblastic grains, and carries quartz inclusions along oriented planes. Other mineral constituents are biotite, quartz, plagioclase, zircon, and epidote.

Rocks of this type have been described from numerous areas, but theories regarding their origin fall into only two main classes, those suggesting development by metasomatic alteration of sedimentary or volcanic rocks (10, 23, 39) and those indicating an origin by contamination of basic eruptive material by aluminous sediment (24, 33). In the present instance the wide distribution of the anthophyllite band at a constant stratigraphic position indicates its sedimentary antecedents. Although introduction of iron and magnesium is not megascopically obvious in the western part of the area, the appearance of cordierite and wormy, magnetite-spinel intergrowths suggests it in the east. Also, it is shown elsewhere in this report that introduction of magnetite is a part of 'granitization', and here we have further evidence that iron, and probably in this case iron-magnesium, played a part in the development of the Kisseynew rocks.

The character of the mineral assemblages in the anthophyllite band suggests iron-magnesium metasomatism of an aluminium-rich sediment or tuff, with the latter possibility favoured by the wide lateral development and apparent continuity of the band. A normal sediment in these types of rocks would probably be less continuous, nor would it offer such a permeable medium for ascending solutions as this band seems to have done. A blanket of tuffaceous material is possible, in so far as there is evidence of volcanic activity in this and adjoining areas, and a tuff band would in all probability supply the requisite constant width and path of ingress for solutions.

The increase in iron content of the anthophyllite to the east, along with the appearance of cordierite and magnetite, suggests two possibilities: (a) introduction of magnesium and iron in certain areas to the point where MgO and FeO had to be considered as separate components (*See* footnote, p. 19). The gedrite became slightly more iron rich; iron-rich cordierite appeared; and magnetite formed where an excess of iron was introduced; and (b) magnesium metasomatism preceded iron metasomatism, or the solutions became progressively more iron rich and, with advent of preponderant iron, magnetite-spinel was formed.

Limestones. Beds of impure, crystalline limestone are observed at the Nokomis-Sherridon contact in disconnected patches across the map-area. Limestones also occur in the Sherridon area north of Sherlett Lake. These beds weather white to greyish brown and with granular ridged surfaces. The occurrence of rounded, dark green diopside crystals on the fresh surface is a distinctive feature. The relation of these limestones to the surrounding gneisses is well displayed west of Nokomis River, where they appear to grade by increase in quartz content and discontinuous variation in dark minerals into the quartz-rich gneisses.

Surprisingly few references[1] to these limestone beds have been made in the literature, a paper by Wright (43) being the major contribution. Noting their occurrence in the vicinity of Sherridon, he states that they are intercalated with quartzites and with hornblende gneisses. A few days spent around the Sherridon vicinity during this investigation suggest that material mapped by Bateman (4) in the vicinity of Sherridon as his map-unit 2 is in large part altered limestone. The following mineral assemblages were noted: (1) hornblende-tremolite-quartz-calcite; (2) diopside-tremolite-quartz-calcite; (3) diopside-hornblende-quartz-calcite; and (4) diopside-hornblende-quartz-calcite-biotite-microcline. The last two also contain plagioclase, epidote, and scapolite, and are characteristic of the eastern part of the area where the metamorphic grade seems slightly higher than in the west.

Quartz and calcite are everywhere stable, both varying considerably in quantity. The quartz invariably displays strain shadows and biaxial figures, and the calcite occurs in granoblastic intergrowths and in stringers and blebs, indicating late mobility. Peculiar, wormy, late calcite intergrowths in quartz were observed in one slide. Diopside occurs in greenish, rounded grains, commonly twinned, with many altered to an actinolitic amphibole. The hornblende is green, with faint greenish yellow to green to blue-green pleochroism and with an extinction angle of 12 degrees. Tremolite occurs in colourless elongate blades, with fibres extinguishing at an angle of 20 degrees; in one slide it appeared to be later than the diopside. Clinozoisite with typical anomalous, blue and yellow birefringence colours, commonly replaces plagioclase and calcite. Scapolite, in fibrous, colourless grains of high birefringence is common in the eastern part of the area. Sphene, apatite, and plagioclase occur in minor amounts, and a few potash-rich assemblages, with biotite and microcline, were observed.

Although calcite has undoubtedly been mobile late in the metamorphic sequence in some instances, it seems improbable, on the basis of field evidence and general petrographic character, that the rocks could be other than altered limestone beds. Their constant association with the Nokomis-Sherridon contact zone is of stratigraphic interest, as discussed earlier, and their relation to structural determinations and ore localization in the Batty Lake area are of definite significance. The relation of the Sherritt Gordon deposits to these altered limestones has, apparently, been overlooked by earlier workers, although Wright (43) suggests that the limestones may have importance in ore localization. Mapping in adjoining areas now shows that many small prospects worked in the past are located along this same stratigraphic horizon, and it has been possible to subdivide the ore deposits of the area into classes (page 45), one group of which is obviously related to this lime-rich band.

RELATIONS BETWEEN THE KISSEYNEW AND THE AMISK

The Amisk series abuts the Nokomis group across the base of the western part of the map-area, but the contact is covered with glacial debris for most of its length. South of the roughly quadrilateral lake in the southwest corner of the map-area, the Amisk presents a north-facing scarp 200

[1]Since these rocks were first studied by the author, an excellent résumé of their characteristics has appeared (18) in which Harrison lists two Masters theses that describe the rocks.

feet high, which disappears in the sand plain immediately to the east. Farther east this contact curves north of a many-bayed lake, where large exposures of Nokomis rock show considerable contortion. Shearing has been active in these rocks, and augen and flaser gneiss have been developed. Drag-folds indicate that the Nokomis moved downward and to the east relative to the Amisk. The Amisk rocks are also dragged and otherwise deformed.

The structural trends in the Kisseynew gneisses are not the same as those in the Amisk series, and a similar situation in other areas has elicited the hypothesis that the Kisseynew-Amisk contact is along a thrust fault, with the Kisseynew thrust southward over the Amisk (17, 20).

Wright (42) believed that on Kisseynew Lake, the Kisseynew strata lay conformably above the Amisk. Bateman studied the contact in the Mikanagan Lake area (5) and concluded that it probably represents an erosional unconformity, with the younger Kisseynew gneisses the equivalent of the Missi series of the Flin Flon map-area. Studies of the lineament as far west as Annabelle Lake in Saskatchewan (29) indicate that, in the western areas at least, the contact is conformable.

In the Batty Lake area, the Kisseynew and the Amisk are in fault contact wherever the contact has been recognized. Elucidation of their true relationships for the entire length of their contact requires further study.

GRANITES AND 'GRANITIZATION'

Gneissic, granite-like bodies occur in the Batty Lake area as bodies of batholithic size, as stock-like and sill-like bodies, and as pegmatite bodies. Viewed in air photographs, the larger bodies exhibit complex to broadly sweeping folds resembling those of sedimentary formations, but in the outcrop they are granodiorites, tonalites, and granites compositionally, with well-defined foliation and grading imperceptibly across this foliation into rocks that are apparently of sedimentary origin.

Two bodies of batholithic size occur in this region, one along the northern margin of the map-area, which most of the granite bodies of the map-area resemble, and a whitish 'granite' (7, 42) in the south. The white 'granite' varies greatly in petrographic character. It appears to be roughly zoned, an exterior zone of foliate, porphyritic albite-oligoclase tonalite, with white euhedral plagioclase crystals (An_{10-17}), surrounding an inner zone of granite or granite porphyry with phenocrysts of albite and quartz. The outer zone carries considerable biotite and only a very little pink feldspar (orthoclase), whereas the inner zone contains considerable orthoclase. In a few places hornblende predominates over biotite.

The foliated outer zone and the presence of hornblende-rich patches are the only suggestion that this southern 'granite' has reacted with the surrounding meta-sediments and greenstones. Otherwise, the 'granite' contacts are relatively sharp, being marked by *lit-par-lit* injections and little, if any, evidence of 'granitization'. This is in marked contrast with most of the smaller granitic bodies north of the south border of the map-area.

The batholithic rock to the north of the map-area, which is represented by sills and the stock around Hutchinson Lake, is a pink, gneissic granite, with biotite, elongate pink microcline crystals, and magnetite. It grades imperceptibly south into granitoid gneisses and 'granitized' gneisses. In a few places the gneiss looks enough like the granite to be mapped as such, and here and there migmatitic material is found in masses of dominantly sedimentary origin.

The sills and stocks of the map-area are evidently more closely related to this northern granite than to the southern one, as they resemble the northern mass both in their contact relations with surrounding sedimentary rocks and in their content of microcline rather than orthoclase.

Are these granitic masses the results of intrusion of magma or of soaking of sedimentary strata by solutions from depth? Field relations indicate that, in the main, the latter is the case. Only two masses of distinctly intrusive character were found that dome the surrounding sedimentary rocks, and these, which lie just to the east of the centre of Nokomis Lake, are very small. In most instances the centre of a stock-like mass has a homogeneous, swirly appearance, and passes outward through highly gneissic, pink to white material into bedded sedimentary rock without the slightest apparent break. It appears that soaking and infiltration by solutions from below results in the feldspathization of the sedimentary material, the swirly interiors suggesting that the central parts of the bodies so formed were mobile if not truly fluid.

All thin sections of the stock west of Nokomis Lake are very smiliar, showing quartz, plagioclase (An_{10-18}), microcline, biotite, muscovite, and minor zircon and magnetite. Modal analyses give:

	Per cent
Quartz	31·8
Plagioclase (An_{10-18})	25·6
Microcline	37·7
Biotite	4·9

GRANITOID AND 'GRANITIZED' GNEISSES

It is believed that action of solutions from depth has facilitated recrystallization in the sedimentary rocks and added feldspar material. The 'granitized' gneisses are recognized by their increase in feldspar content, normally oligoclase (An_{15-22}); microcline is rare, any pink feldspar present being generally oligoclase. The granitoid gneisses comprise a white variety with little microcline, and a pink type with considerable microcline but less than in the granites. The following is a modal analysis of this latter type:

	Per cent
Quartz	39·4
Plagioclase (An_{15-20})	28·0
Microcline	28·0
Biotite	4·6

Magnetite is common in the granitoid and granitized gneisses, occurring along and accentuating the foliation planes.

Injected hornblende gneisses occur south of Elken Lake, along the Sherridon granitoid gneiss boundary, and just west of the long arm of Moody Lake. The hornblende gneiss is altered with difficulty to materials of granitic character; the injected material segregates in lenses, forming migmatites rather than a uniformly 'granitized' rock. Elongate lenses of hornblende-rich gneiss in otherwise granitoid gneiss also indicate the resistance to change offered by the hornblende gneisses.

It is concluded that 'granitization' commences with the development of albite-oligoclase in the sedimentary rocks, producing rocks mapped as 'granitized' gneisses, and continues with the later formation of microcline to form bodies of granitoid gneiss that may, in some instances, have become mobile. Recrystallization, facilitated by solutions from below and the temperature increase concomitant with rising solutions, undoubtedly played a major role in the production of these bodies. As many of them are tonalites or granodiorites in composition, precise petrographic study may help in differentiating them from true intrusive rocks that, in this region, are truly granites. The white plagioclase pegmatites, described below, may represent mobile sedimentary material. They are certainly genetically different from the normal potash-rich pegmatites and seem mineralogically related to the white granitoid gneisses.

PEGMATITES, APLITES, AND QUARTZ VEINS

The pegmatites in the area mapped are of two main types, pink and white, the former carrying considerable microcline and microperthite and the other predominantly plagioclase (An_{10-15}). Graphic pegmatites of the pink type are not uncommon, but they appear to be restricted to areas of granitoid gneiss or granite. Tourmaline is found replacing plagioclase in a large pegmatite-like body east of Nokomis Lake, the replacement proceeding from plagioclase to biotite to tourmaline. Green microcline (amazonite) is found near Sherridon and west of Wood Lake, apparently associated with mineralization. Cordierite, as described later, has been found in quartz-rich pegmatites.

East of the long lake south of Nokomis Lake, aplite dykes are very common and, indeed, are scattered throughout the area. They both cut and are cut by pegmatite bodies and are, apparently, connected with the pink pegmatite type. Quartz veins up to 3 or 4 inches wide and tens of feet in length are common, many of them within pegmatite bodies.

DIORITE AND HORNBLENDITE

Rocks of dioritic appearance have been mapped in the Amisk series and in the Nokomis group from east to west in the map-area. A black, very coarse-grained amphibolite has been observed at Moody Lake, and near Elken Lake is an altered rock of similar character containing considerable pyrite.

The diorites are characteristically dark greenish, medium- to coarse-grained, equigranular rocks, homogeneous to foliate or even schistose at their borders. On weathered surfaces their plagioclase feldspar has a dull, flat appearance, with a greenish hue, and the hornblende, the other major constituent, commonly occurs in dark green, lumpy, etched grains. These rocks occur as lenticular to elongate bodies commonly up to one-quarter mile in width, everywhere paralleling the foliation.

The grain size of the dioritic rocks is variable, with in most instances medium-sized hornblende grains lying in a mass of smaller plagioclase crystals. Quartz is a negligible constituent. In schistose bands the hornblende flakes may be slightly twisted, and textural relations suggest that movement and either crystallization or recrystallization went actively hand in hand. The plagioclase of the diorite in the Amisk series is invariably finely twinned, strained, fractured, and partly granulated, and epidote invariably occurs as a metamorphic alteration product of the plagioclase. The schistose borders of these bodies and the equigranular, in some cases swirled, interiors suggest intrusion during or probably just after a major period of folding.

The following mineral assemblages are characteristic of these dioritic rocks: (1) hornblende-augite-plagioclase (An_{57-60}); (2) hornblende-plagioclase (An_{57-60}); and (3) hornblende-epidote-plagioclase (An_{16-50}).

Hornblende is the principal dark mineral and is normally green, with pale yellow to green to bluish green pleochroism. Commonly it is poikilitic, enclosing relict pyroxene, epidote, rounded feldspar, and other hornblende grains. A pale variety, with otherwise similar optical properties, occurs in schistose zones. Augite occurs as clear, corroded remnants enclosed in the hornblende. Plagioclase grains are small, and do not interlock. Twinned and untwinned varieties occur, and in some slides the grains can be seen to be strained and broken. Epidote is pleochroic yellow to greenish, in grains of subhedral to anhedral form; it is especially common in schistose zones, where it tends to be euhedral. Small, rounded to elliptical grains of sphene are common.

The hornblendite of Moody Lake occupies the area immediately north of the granite point and is surrounded by lake and swamp so that its contact relations with other rocks were not observed. It is a coarse- to medium-grained rock, with dark green hornblende crystals up to one-half inch in length forming most of the megascopically visible material. Foliation is indistinct, being visible over large surfaces but completely lacking in fine detail. A modal analysis gave the following mineralogical composition:

	Per cent
Augite	9
Hornblende	88
Epidote, Sphene	3

The hornblendite in a small area at the southwest corner of Elken Lake is a light greenish rock of coarse grain similar to the above, without obvious foliation and with considerable pyrite, which is probably associated with its alteration. In thin section it is apparent that the colour of the rock is due to its high degree of saussuritization.

Augite occurs in both rocks in clear remnants poikilitically enclosed in hornblende. In the Elken Lake rock it is highly fractured and altered. The presence of the pyroxene as an early mineral makes probable an eruptive origin for this rock type. Hornblende forms large sheaf-like grains, pleochroic from yellow to dark yellow-green to green-blue. Sphene was observed and sericite and calcite are abundant in the Elken Lake rock, and epidote occurs in interstitial grains and in abundant wormy patches.

The following mineral assemblages were observed in the hornblendite: (1) augite-hornblende-epidote and (2) augite-hornblende-epidote-plagioclase. As in the case of the diorite, these assemblages indicate a rock of slightly higher grade than that of the other rocks of the area. This might be expected if intrusion of hornblendite and diorite took place during the latter stages of metamorphism (*See* page 29).

In a few localities, Nokomis hornblende gneisses, as described earlier, were found to grade into diorite, and the possibility that some rocks mapped as intrusive diorite are in reality more highly altered hornblende gneisses should not be overlooked.

CHAPTER III

METAMORPHISM

MINERAL ASSEMBLAGES

As a result of regional metamorphism, the rocks of the Batty Lake area are represented by mineral assemblages characteristic of the amphibolite facies[1] together with great volumes of 'granite-like' material. Table V lists the rock types and indicates the characteristic assemblages and sub-facies.

Most of the rocks of the area fall into the staurolite-kyanite sub-facies (40), and the pronounced structural overturning, slickensiding, and excellent foliation and lineation support the tenet that this sub-facies is characteristic of assemblages formed under high pressure and shearing stress. Sporadic occurrences of assemblages characteristic of other sub-facies are not unusual, however, and when considered on the basis of occurrence and of genesis they support the genetic implications of the sub-facies classification proposed by Turner and others.

GENESIS OF CERTAIN ROCK TYPES

QUARTZ-RICH GNEISSES

These are, for the most part, in the staurolite-kyanite sub-facies, but small areas of mineral assemblages, such as are shown in Table V, are in the cordierite-anthophyllite or sillimanite-almandine sub-facies. Areas of the former are characterized by abnormally coarse texture and rough foliation. Ascending solutions apparently acted locally to reduce shearing stresses, thus permitting formation of the low-stress cordierite-anthophyllite sub-facies. Although almandine garnet is not a typical representative of these assemblages in other regions, a high ratio of iron to magnesium and limited substitution of iron for magnesium permits cordierite and almandine to exist together (40, p. 79, and footnote, p. 19). The high iron content of the cordierite (*See* analysis Table VI, p. 30) indicates that this condition does exist here. The recent description of an iron-cordierite (27) indicates the possibility of extensive substitution in the iron-magnesium cordierites, and suggests that past discussions in the literature, based on limited substitution, may not be applicable under certain conditions. Complete substitution, as in the olivines, may even be a possibility.

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[1]The idea of metamorphic facies and later of mineral facies was developed by Eskola as a result of his work on Finnish rocks (10). A more recent discussion of metamorphic principles by Turner (40) contains a complete exposition of the subject and is followed in this study of the rocks of the Batty Lake area.

A metamorphic facies includes rocks of any chemical composition that have reached chemical equilibrium during metamorphism under a given set of physical conditions. For a given metamorphic facies, the mineral assemblage that develops in a rock of given chemical composition is constant, and represents a certain degree, rank, or 'grade' of metamorphism. In any one area, then, containing rocks of varying chemical composition that all attain to the same metamorphic 'grade', mineral assemblages will develop that are characteristic of the varying compositions of the rocks at that 'grade'. These assemblages are termed 'isograde'.

A mineral facies includes rocks of any origin that have reached chemical equilibrium under similar physical conditions. In so far as the physical conditions of metamorphism can be similar to those of igneous activity, assemblages in igneous rocks can exist that are 'isograde' with assemblages of metamorphic rocks (*See* footnote, p. 30).

An individual metamorphic facies includes rocks developed over relatively broad variations in pressure and temperature, and it has been shown feasible to subdivide the facies into 'sub-facies' that include rocks developed over rather narrow ranges of pressure and temperature change. Thus the 'amphibolite facies', which embraces, in the main, the products of medium- and high-grade regional metamorphism, can be divided into four sub-facies, namely, the cordierite-anthophyllite, staurolite-kyanite, sillimanite-almandine, and diopside-almandine-hornblende sub-facies.

TABLE V

Mineral Assemblages of the Metamorphic Rocks

Rock type	Assemblage	Sub-facies
Quartz-rich gneiss	Plagioclase-biotite-almandine-quartz	Staurolite-kyanite
	Plagioclase-biotite-hornblende-almandine-quartz	Staurolite-kyanite
	Plagioclase-biotite-cordierite-almandine-quartz	Cordierite-anthophyllite
	Plagioclase-biotite-sillimanite-almandine-quartz	Sillimanite-almandine
	Plagioclase-biotite-sillimanite-almandine-cordierite-quartz	Transition between cordierite-anthophyllite and sillimanite-almandine
Nokomis hornblende gneiss	Zoisite-calcite-quartz	Staurolite-kyanite
	Plagioclase-hornblende-almandine-quartz	Staurolite-kyanite
	Plagioclase-hornblende-epidote-almandine-quartz	Staurolite-kyanite
Diorite	Hornblende-augite-plagioclase-quartz	Diopside-almandine-hornblende
	Hornblende-plagioclase-quartz	Diopside-almandine-hornblende
	Hornblende-epidote-plagioclase-quartz	Diopside-almandine-hornblende
Hornblendite	Hornblende-augite-epidote	Diopside-almandine-hornblende
	Hornblende-augite-plagioclase-epidote	Diopside-almandine-hornblende
Sherridon hornblende gneiss	Plagioclase-hornblende-almandine-biotite-quartz	Staurolite-kyanite
	Plagioclase-hornblende-epidote-biotite-quartz	Staurolite-kyanite
	Plagioclase-hornblende-almandine-quartz-chlorite	Staurolite-kyanite
Anthophyllite band	Anthophyllite-biotite-plagioclase-almandine-quartz	Cordierite-anthophyllite
	Anthophyllite-biotite-cordierite-plagioclase-quartz	Cordierite-anthophyllite
	Anthophyllite-biotite-cordierite-almandine-plagioclase-quartz	Cordierite-anthophyllite
Limestones	Hornblende-tremolite-quartz-calcite } ±epidote, scapolite	Staurolite-kyanite
	Diopside-tremolite-quartz-calcite } ±epidote, scapolite	Staurolite-kyanite
	Diopside-tremolite-quartz-calcite-biotite-microcline } ±epidote, scapolite	Staurolite-kyanite

Sillimanite-bearing assemblages occur in two ways, both characteristic of the sillimanite-almandine sub-facies considered by some to characterize areas of high differential pressure. The presence of sillimanite with cordierite indicates a transition from the cordierite-anthophyllite to the sillimanite-almandine sub-facies. Biotite, which can co-exist with cordierite, becomes converted to sillimanite, losing its potash and basic oxides. No apparent evidence of pressure increase is found, however, the rock being as coarse grained and as roughly foliate as ever. Solutions later than those causing the formation of the cordierite, but probably of the same sequence and source, caused the formation of sillimanite; they may well have been hotter, as they were introduced later in the metamorphic sequence while the metamorphic grade was increasing. Sillimanite also occurs after biotite in flat blades lying in the plane of finely foliated and apparently sheared rocks. A solvent must have been present to remove the biotite constituents necessary in the biotite-sillimanite transformation, but shearing was apparently active.

HORNBLENDE GNEISSES

The sedimentary hornblende gneisses have assemblages characteristic of the staurolite-kyanite sub-facies. The hornblende is actinolite. Occasional epidote indicates that the available lime was greater than that necessary to form a stable plagioclase. No analyses are available to show whether the composition of the gneiss varies significantly in these cases, or whether stress difference is the important factor. Probably both operate. The presence of chlorite, although normally indicating retrogressive metamorphism, apparently does not always do so; its occurrence after hornblende and biotite at garnet boundaries seems to be a step in garnet formation, although other interpretations have been offered (*See* page 37). The lack of chlorite, except at these boundaries, and its undoubted relation to the hornblende and the biotite are significant.

Pillow lavas are also represented in the staurolite-kyanite sub-facies. Abundant chlorite indicates a trend towards the albite-epidote amphibolite facies although a plagioclase (An_{35-38}) is still apparently stable.

DIORITE AND HORNBLENDITE

The diorite and hornblendite represent a higher grade than the surrounding rocks, being of the diopside-almandine-hornblende sub-facies. This is what might be expected if, as the field evidence suggests, they were intruded late in the metamorphic sequence. Material from depth would be of higher grade than material being metamorphosed, and equilibrium with the surrounding rock would not necessarily be attained[1]. The concentration of epidote in sheared border areas, with plagioclase of lower anorthite content than in other parts of the body (*See* mineral assemblage, p. 25) is interesting, indicating again the instability of anorthite-rich plagioclase under high shearing stress.

ANTHOPHYLLITE BAND

Mineral assemblages of the anthophyllite band are characteristic of the cordierite-anthophyllite sub-facies. The presence of a little cummingtonite to the west and its complete absence in the east indicate that metamorphism reached a higher grade in the east, or was maintained over a longer period, so that equilibrium between the mineral phases formed from the component oxides of the rock was attained. In so far as the metamorphic grade is in part dependent on the conditions attendant on the passage of solutions from depth through the rock it is probable that both higher grade metamorphism and a longer period of infiltration prevailed. This is indicated in the discussion of the development of the band. Incipient alteration of cordierite to chlorite indicates the presence of late solutions under conditions of lower grade, or may be due in part to weathering.

LIMESTONES

The mineral assemblages in the metamorphosed limestones are of the amphibolite facies, and all are silica-rich, with quartz and calcite coexistent. Turner (40) indicates that wollastonite is stable only in the upper temperature ranges of the cordierite-anthophyllite sub-facies, being prevented from forming in the other sub-facies by high pressure. The components of wollastonite are present in the form of free quartz and calcite, and the metamorphic grade, as indicated by surrounding rocks, is of sufficient intensity to permit the 'Goldschmidt reaction'[2]. Wollastonite does not appear, possibly for the reason indicated above, and it seems probable that

[1]'Grade' is, herein, a term indicating the relative physical-chemical conditions under which certain minerals, or mineral groups, exist (*See* footnote, p. 27). If a basic igneous rock intrudes a sedimentary series the minerals existing in stable fashion within it are stable at much higher 'grade' than the minerals stable in the sediment. Indeed, the basic body tends to produce 'high-grade' minerals in the sediment at its contact by reorganizing the chemical constituents of the minerals already there. If the igneous body were able to remain liquid down to temperatures at which the sediments exist, that is, if the minerals forming from the igneous body were able to change compositionally from pyroxenes to amphiboles, etc., so as always to be in equilibrium with their environment and to exist in stable fashion upon final crystallization, the intruding body and the surrounding sediments would be existing at the same 'grade'. This, of course, never happens, as the igneous body cools too quickly for its minerals to reach equilibrium. They exist, therefore, in meta-stable fashion.

A few minerals—and augite, with which we are herein concerned, is one—are both generated during metamorphism and upon the crystallization of 'basic magma'. It is assumed that in both cases appearance of augite indicates a certain 'grade' that can be common to both rocks.

Augite in the diorite is existing (as, of course, are all the minerals) in a meta-stable condition, prevented from changing to something stable by the low temperature and lack of fluid that would catalyze a change. If the diorite had intruded the sediments before the onset of regional metamorphism, the 'grade' of all the rocks would have been raised to, and maintained at, temperatures and pressures such that the augite would have completely disappeared (altering to hornblende) and a mineral assemblage stable under the conditions of regional metamorphism would have developed. The mineral assemblage stable under those conditions would be of 'grade' somewhat lower than that represented by the present mineral assemblage of the diorite and equivalent to that of the surrounding sediment.

[2]$CaCO_3 + SiO_2 = CaSiO_3 + CO_2$
(Calcite + silica = wollastonite + carbon dioxide)
This reaction, investigated at different temperatures and pressures by Goldschmidt, has become known as the 'Goldschmidt reaction'. As CO_2 is one of the products of reaction with rising temperature, it is obvious that pressure has an effect on the temperature of reaction.

It is of interest to note that considerable scapolite, which is carbonate-bearing, is formed in these rocks, and that CO_2 is released during the formation of scapolite in the same manner as, but in somewhat less amounts than, in the formation of wollastonite.

we can consider these assemblages as of the staurolite-kyanite sub-facies, as are the surrounding rocks, rather than of the lower part of the cordierite-anthophyllite sub-facies.

The assemblages with tremolite are stable in the west, around the northern end of Sherlett Lake near Sherridon and east of Nokomis River, whereas the diopside-rich assemblages with scapolite characterize the east. This may be another indication of slightly higher grade metamorphism to the east.

GENESIS OF CERTAIN METAMORPHIC MINERALS

The relationships displayed by some of the metamorphic minerals in the map-area give indications as to their mode of origin.

MAGNETITE

Magnetite is a widespread constituent of the granitic rocks and pegmatites of the Batty Lake area, being very prominent in instances where it lies within, and emphasizes, the gneissosity of the former or forms masses and blebs up to 4 inches in diameter in the latter. A microscopically recognizable amount also commonly occurs in the meta-sedimentary rocks, but the mineral appears in quantity only in those that are considered 'granitized' or 'granitoid'. In the 'granitized' gneisses, increase in feldspar content and occurrence of considerable magnetite go hand in hand. The appearance of cordierite in the quartz-rich gneisses is accompanied by wormy blebs and lenticles of magnetite. This is also true of the appearance of cordierite in the anthophyllite gneiss in the eastern part of the map-area. In the 'granitized' hornblende gneiss, lenticular blebs of magnetite up to ¼ inch in length and surrounded by feldspar are not uncommon. Large garnets in the Sherridon quartz-rich gneiss north of Batty Lake have fractures filled with bands of white feldspar and magnetite. The granitoid Sherridon rocks north of Batty Lake and south along File River are high in magnetite.

The complete lack of magnetite in those rocks most nearly resembling normal sedimentary strata, and its abundance in the granites and pegmatites and in the areas of 'soaked' rocks, point to the introduction of most of the magnetite in the meta-sediments as part of regional metamorphic processes. No magnetite was seen in the diorite or in the hornblendite, which is a result of their intrusion late in the metamorphic sequence, as was discussed earlier (page 29).

CORDIERITE

Cordierite occurs in roughly lenticular zones in various parts of the map-area. It is found in both the Sherridon and Nokomis quartz-rich gneisses, and is invariably present in the anthophyllite band east of longitude 100° 50′ in the northeastern part of the area, which corresponds roughly with the region of most intense 'granitization'.

The appearance of cordierite is accompanied by a decided coarsening of texture in the rock, by an increase in the amount of quartz, and by the appearance of wormy lenticles of magnetite. Sillimanite is commonly present, but as cordierite and biotite are quite compatible, and as the sillimanite forms from the biotite, it can be seen that sillimanite is a later product than the cordierite. The plagioclase composition does not vary from the normal in the presence of cordierite so far as has been determined.

The following analyses of cordierite show that it is an iron-rich type with unusual optical properties:

TABLE VI

Analyses and Optical Properties of Cordierite

—	1	2
	Per cent	Per cent
SiO_2	46·55	46·72
Al_2O_3	33·80	35·39
FeO	7·92	8·30
CaO	undet.	0·60
MgO	10·85	9·21
	99·12	100·20
Fe mol	35·63%	37·57%
2V(+)	(87·5°–88·5°)	87°
	α=1·533	1·537
	γ=1·539	1·547
	$\gamma-\alpha$=0·006	0·010

1. Gem quality cordierite from the Sherridon quartz-rich gneiss west of Walton Lake; optically pure. Analyst, D. S. Robertson.

2. Cordierite from anthophyllite band north of Batty Lake; optically, about 97 per cent pure; chlorite and quartz impurities. Analyst, D. S. Robertson.

Eight occurrences of optically positive cordierite were recorded from the literature by Folinsbee (13). An occurrence in India (22) of an optically positive cordierite with an optic angle (2V) of 74 degrees and the two above by the writer bring the recorded total to eleven. The application of the above optical properties to Winchell's curves (46) shows as little correspondence as do many of Folinsbee's optical points. The powder pattern[1] of the No. 2 cordierite specimen corresponds almost exactly with that of a pure magnesium cordierite described by S. J. Shand (32), as might be expected because of the similar sizes of the iron and magnesium ions that replace one another. Folinsbee suggests that a high lime (CaO) content increases the optic angle, which is possibly the reason for the positive character of these cordierites. How much calcium can be admitted without appreciably changing the lattice constants is not known. The change in cell volume is probably linear, with increase in calcium after a maximum of no-distortional substitution.

The megascopic breakdown of cordierite to chlorite has been observed north of Batty Lake, and thin sections almost invariably show incipient alteration. As stated earlier, the quartz-rich gneisses are invariably coarsely recrystallized where cordierite occurs, and have the appearance of being 'soaked' with quartz, generally accompanied by coarse, wormy blebs

[1]A 'powder pattern' is a type of X-ray picture that reflects a characteristic physical property of any mineral, namely, its 'lattice' or fundamental structure.

of magnetite. West of Walton Lake, a series of lenticular quartz blebs culminates in an 8-foot, roughly spherical pod containing 'gem' cordierite in well-formed orthorhombic crystals up to 3 inches in length. North of the power-line on the west side of the map-area, cordierite is found in gneiss that is nearly 100 per cent quartz and feldspar, with minor garnet, undoubtedly a very highy siliceous sediment originally. The cordierite impregnates the rock and occurs in quartz-rich pegmatite stringers that cut across the bedding. Magnetite occurs in quantity, disseminated in the rock and in wormy fashion in the pegmatites. Northeast of Three-finger Lake, cordierite is very common in the quartz-rich rocks. Both 'impregnation' types of quartz-feldspar pegmatites that parallel the bedding[1] and definite crosscutting types contain bright blue cordierite. One of the latter type of particular interest, a white plagioclase-quartz pegmatite 1 inch wide, carried a central band of cordierite for more than 3 feet, as if the cordierite had been the last mineral to crystallize in the pegmatitic sequence.

The cordierite in the anthophyllite band appears in the form of stringers and blebs rather than in discrete grains. Magnetite-spinel occurs in blotches and intergrowths, and traces of pyrite were observed in many specimens. Rutherford, discussing the occurrence of optically positive cordierite from Sherridon (30, p. 387) says: "Cordierite studied in the specimens occurs in grains or aggregates of microscopic dimensions and is usually associated with patches of sulphides, chiefly pyrite and some galena which occurs as part of the interstitial filling between the large grains of garnet" and (p. 388): "There is some suggestion that this cordierite may be related to the sulphide mineralization since the grains of megascopic size are associated with the sulphides".

The problem of the genesis of the cordierite has been considered in the past as part of the broader anthophyllite-cordierite assemblage problem, as discussed on page 20. Is there merely a recrystallization and redistribution of material under the influence of pressure and heat, or has there been addition of material through the medium of solutions? The lack of cordierite in the anthophyllite band to the west can hardly be considered as due to the existence of different equilibria in the system; that is, there is not enough of a chemical variation in the break-down of magnesium gedrite to iron gedrite and cordierite to give the quantities of cordierite observed, and no other magnesium mineral is present in quantity to the west. Its non-occurrence may, however, be considered as due to the lack of the actual cordierite-forming material.

As stated earlier (page 20), continuous metasomatism must provide the answer. Early solutions introducing quantities of iron, as evidenced by the development of magnetite in the 'granitized' gneisses, also formed cordierite. Later solutions removed iron and magnesium from biotite, leading to the development of sillimanite. Cordierite and biotite are, apparently, quite compatible, but where sillimanite appears it replaces biotite, and potassium, iron, magnesium, and, possibly, silica are carried off in solution. It is quite possible that the material removed during sillimanite formation, as in the following equation,

[1]'Impregnation pegmatites' is a name given to pegmatites that generally lie in the plane of foliation and appear to be the result of material 'seeping up' through the rock. They have vague, discontinuous boundaries, vary considerably in thickness, and commonly include small, coarsely grained pieces of wall-rock. They occur only in quartz-rich gneisses.

$$(OH)_2K(Al,Mg,Fe)(Al,Si_3O_{10}) \rightarrow Al_2SiO_5 + K,Mg,Fe)$$
$$\text{Biotite} \rightarrow \text{Sillimanite}$$

contributed to cordierite formation at lower grades (higher structural levels) of the metamorphism. There is no petrographic evidence in these rocks that cordierite becomes unstable in the presence of sillimanite; and we have the reverse time relationship to that described by Eskola (10) at Orijarvi, where cordierite rims large sillimanite crystals and is obviously later. The common belief, that cordierite and sillimanite should be antipathetic due to differing stress-stability fields, is apparently not tenable.

SILLIMANITE

Sillimanite is of limited amount but widespread occurrence in the map-area. It occurs in elongate, lens-like bodies (*See* Plate II B) generally paralleling the strike of the gneisses, and these gneisses can be recognized even before the identification of the sillimanite itself by the coarser grain of the rock. In some cases the sillimanite occurs in blade-like sheaths, in one observed instance reaching a length of 3 inches, and is crystallographically independent of any parent mineral. West of Walton Lake, such sillimanite occurs in quantity in sheared rocks that carry no biotite or garnet. Cordierite appears slightly farther west, and reaches a maximum development in large pods, as previously described. In this case, some control in the development of sillimanite may have been due to shearing stress, as the large size of the crystals is not reached anywhere else; but in the main there is no evidence of such a control.

Most occurrences of sillimanite can be traced megascopically into biotite. In thin section, this relationship appears to be one of removal of potassium and basic elements from biotite, with the development of needles and blades of fibrous sillimanite. Sillimanite winds in and out of the foliation, and this, together with the coarse texture of the rock, the presence of cordierite, and, possibly, the lack of epidote in association with the plagioclase in the vicinity, indicates that shearing was no more prominent in this coarse zone than elsewhere in the rock. Shearing is, consequently, not believed to be the agent conditioning the formation of sillimanite.

Sillimanite has long been considered a 'stress' mineral, developing only in areas of high differential pressure, but occurrences in this region add support to the mass of information that suggests that sillimanite may form in many ways, even as a hydrothermal mineral, with or without stress.

Watson (41) describes late sillimanite in the migmatites of Kildonan, Scotland, and shows that the development is due to late hydrothermal solutions, "a metasomatic product of granitization". She also discusses examples of uncontaminated sillimanite pegmatites and sillimanite selvedges to veins connected with granites. Sharma (32) describes two stages of sillimanite formation in meta-sedimentary rocks, the earlier as fibrous aggregates after biotite and the later as veinlets and larger sillimanite crystals transecting earlier biotite-fibrolite growths. All, he states, are due to the action of solutions facilitating recrystallization and diffusion. G. R. Joplin (19) states that the "permeation zone" in which sillimanite occurs and "which is essentially one of granitization" is equivalent to the sillimanite zone of the Scottish highlands, apparently suggesting that the production of this mineral is related to magmatic soaking. Read (26) regards the "sillimanite zone" as intimately related to migmatitic injection.

The occurrence of sillimanite in the Batty Lake area is conditioned, as is the case of cordierite, by the action of magmatically derived solutions intimately associated with 'granitization', which at the stage of sillimanite formation preferentially attack biotite and remove iron, magnesium, and potassium in their passage through the gneiss.

If, at later stages, sillimanite became mobile, it might fill cracks in earlier minerals, as described by Watson and Sharma. This does not mean, however, as suggested by Watson, that sillimanite thus formed cannot be used as an indication of a certain grade of metamorphism. Metamorphic grades are relative conditions expressed by mineral assemblages (metamorphic facies and sub-facies), and although sillimanite production may be a part of, or an adjunct to, 'granitization', its presence still indicates, even in veins, those conditions that in the main are expressed by 'high-grade' assemblages.

GARNET

Garnet is a ubiquitous constituent of rocks of all types in the map-area except limestones. Because it originates, in the main, as a result of recombination of original materials of the rock, it may reach equilibrium with the other minerals in the rock at varying chemical compositions for the same grade of metamorphism if the original chemical compositions of the rock types in which the garnet exists are different. It seems possible, therefore, that garnet might be used to differentiate rock types or stratigraphic units in areas where definite identification is doubtful, especially in the case of the quartz-rich rocks of the Nokomis and Sherridon groups. The megascopic appearance of the garnet supports this suggestion, the garnet in the Nokomis quartz-rich gneiss occurring as small, rounded, and pinkish grains, whereas the Sherridon quartz-rich gneiss carries large, reddish, poikiloblastic garnet.

Lattice constants and refractive indices were determined for several garnets, and representative results are given below. The garnets in the hornblende gneisses have quite different physical properties from those in the more siliceous rocks, whereas the garnet from the anthophyllite gneiss is very similar to that in the hornblende gneisses. The Nokomis garnet, as indicated below, usually has a higher lattice constant (a°) and lower index of refraction (n) than that of the Sherridon, but the differences, so far as the work has shown, are neither constant nor distinctive. It seems probable, however, that if a statistical study were made on numerous samples, the garnet could be used to differentiate rock types, thus assisting greatly in the determination of structure.

—	a°	n
Sherridon hornblende gneiss	13·248	1·795 ± 0·001
Anthophyllite gneiss	13·247	1·777 ± 0·001
Nokomis biotite gneiss	13·289	1·787 ± 0·001
Sherridon biotite gneiss	13·261	1·790 ± 0·001

Bruce and Matheson (8) give analyses of two garnets of interest (*See* Table VII), but their locations are unfortunately not sufficiently precise to identify the stratum from which they were obtained. Specimen No. 1 appears to be from a quartz-rich rock, either Nokomis or Sherridon, and No. 2 is from the hornblende-rich foot-wall rock of the Sherritt Gordon mine. A little manganese is normal in garnets from rocks of this type (45).

TABLE VII

Analyses of Garnets

—	1	2	Recast	Per cent
			1	
SiO_2	39·02	39·40	Almandine	64·0
Al_2O_3	21·20	21·60	Pyrope	20·5
Fe_2O_3	2·27	(4·31)[1]	Grossularite	5·8
FeO	27·59	(25·51)	Spessartite	10·5
MgO	4·90	4·90	2	
CaO	4·60	4·50	Almandine	63·8
MnO	2·43	1·30	Pyrope	21·6
			Grossularite	3·3
	102·01	101·00	Spessartite	11·9

[1]It seems probable that some FeO has been included with the Fe_2O_3 in this case. Recalculation of 2·04 per cent Fe_2O_3 as FeO would result in the FeO totals being almost the same.

Garnet on the whole is a remarkably stable mineral. Occurrences in pegmatite and, indeed, in granite-like material are common, with no evidence of the slightest alteration. In the Sherridon group north of Batty Lake, garnets are considerably sheared and are partly altered to dark green chlorite. It would seem that in this case, retrogressive metamorphism has been initiated by shearing stress, the high, and probably slowly lowering, temperature of the granite having no effect on the stability of the garnet. Possibly the presence of manganese oxide (MnO) has some bearing on the stability as it does on the metamorphic grade at which garnet appears, as suggested by Tilley, Harker, and others.

A band of hornblende gneiss in the Sherridon group develops small segregated clots of plagioclase and quartz, which give the gneiss a checkerboard appearance. This is apparently followed during continued metamorphism by the development of garnet in the feldspar of the clots and gradual disappearance of the feldspar as the garnet grows. Finally, the rock appears as a hornblende gneiss with red garnet, or as a hornblende gneiss with red garnet surrounded by white rims that are predominantly quartz, and that weather strikingly white against the red garnet and the dark hornblende. It was thought at first that the diffusion of material from the hornblende to the feldspar supplied the garnet with its growing material, but in that case the hornblende should show some compositional change. However, there is no evidence of such change except that in some cases the hornblende adjacent to the garnet is partly altered to chlorite, as discussed below. There is no bleached hornblende around the garnet and no variation whatsoever in the optical properties of the hornblende as there would be if iron were being lost to the garnet. It is obvious only that garnet starts its growth in the feldspar, and that iron and magnesium are supplied from some unknown source.

In the quartz-rich gneiss, garnet is commonly associated with feldspathic bands, which may be a further indication of growth in feldspar. These occurrences, however, may indicate a 'tailing' of feldspar around mechanically stable garnet during deformation. The poikiloblastic garnet encloses quartz but rarely encloses plagioclase, and in instances where garnet clots were seen 'growing together' it was obvious microscopically that the garnet is forming in the feldspar and around the quartz.

It has been noted in many of the hornblende gneisses that chlorite develops from hornblende and biotite in the immediate vicinity of garnet, even to the exclusion of its occurrence elsewhere in the rock. It has been suggested by Harker (15) that chlorite forms where garnet affords protection from lateral pressures, and he sketches crumpled phyllites as examples (15, p. 335). The chlorite in such cases is developed in a plane normal to the stress direction. In the present observed instances, however, the chlorite occurs indiscriminately around garnet grains and bears no apparent relation to stress directions, as might be expected if the 'strain shadow' protection hypothesis holds.

The origin of garnet is still a problem. Harker (15) states that garnet takes the place of chlorite in regional metamorphism, with the possible addition of iron from magnetite. Tilley (38) discusses the standard modes of origin from biotite and chlorite and shows that the reaction—biotite+quartz→almandine+orthoclase—is by no means proved for crystalline schists. He also presents evidence to indicate that most almandine garnet does not form from chlorite without the addition of iron. Ambrose (2), studying the genesis of garnet in the Missi series near Flin Flon, Manitoba, thought that epidote, biotite, and magnetite all played a part. Levin's study of the Gore Mountain garnet (21) showed that garnet growth was initiated in feldspar, the garnets replacing plagioclase laths in some cases. Harker states (15) that Becke was probably the first to recognize the role of feldspar in basic rocks, postulating the reaction—olivine+anorthite→almandine.

The growth of garnet in the feldspar clots of the Sherridon hornblende gneiss, with gradual disappearance of the feldspar, shows that feldspar substance forms part of the garnet. Iron, magnesium, and manganese must be added. There is no petrographic evidence of any reaction except in the minor development of chlorite adjacent to the garnet. As this chlorite-garnet relationship has been observed in other hornblende gneisses it appears that:

hornblende (and biotite)→chlorite: chlorite+anorthite→garnet

may be the relationship govering the formation of some of the garnet. In the case of biotite, at least, potassium is removed in the reaction, and as no feldspar is observed as a product it must be removed in solution. This suggests the other apparent source for iron and magnesium, namely, that of metasomatic introduction in solution. However, experience has shown that the plagioclase-hornblende assemblage can give rise, isochemically, to an assemblage containing garnet. Also, if addition from an external source provides the iron and magnesium in the hornblende gneisses, it should also provide these ions in the quartz-rich gneisses, and abundant chemical data from other areas, showing that the assemblage changes are in isochemical environments, militate against the introduction hypothesis.

The importance of plagioclase in garnet formation, whatever the source of the basic ions, should be stressed. The localization of growth in the feldspar may be due to the packing indices (12) of the minerals concerned, namely:

Mineral	*Packing Index*
Plagioclase	4·9
Hornblende	5·7
Garnet	6·6

Under the metamorphic conditions prevailing at garnet growth, a mineral of high-packing index would be stable, and when garnet becomes physically stable and can form from the materials present, the mineral of low-packing index provides a locus of growth for it.

GENERAL CONSIDERATIONS

Precise field and petrographic work in the Batty Lake area have demonstrated the sedimentary origin of the Nokomis and Sherridon gneisses. The Nokomis group was originally composed of coarse, unsorted detrital material, which graded up through limestones and orthoquartzites into the Sherridon group, which consisted of much better sorted material.

Attempts at zonal mapping of 'index minerals' in areas of this type are highly impractical, but recognition of varying facies and sub-facies facilitates the interpretation of the regional metamorphism. In general, the metamorphism is of higher grade in the east than in the west, having both a better development of 'high-grade' minerals (cordierite and sillimanite) and large areas of granitoid material. The relation of these 'high-grade' minerals to the passage of solutions from depth indicates the association of regional metamorphism with 'granitization'.

'Granitization', a process of feldspathization, first develops a plagioclase feldspar and then a potash-rich feldspar in the meta-sedimentary rocks. The plagioclase development may be due, in part, to recrystallization and redistribution of material already present, but the potash-rich character of some of the granitoid gneisses demands considerable introduction. Although the 'granitized' rocks are commonly tonalites or granodiorites, it is true that granite-like bodies have resulted where the material that was invaded and soaked was arkosic or where enough alkali had been introduced. Associated with the alkali introduction is that of iron and magnesium, as shown by the development of magnetite and the anthophyllite-cordierite assemblages. In so far as iron-magnesium metasomatism precedes feldspathization, there may be evidence of the 'basic fronts' of some European students.

The cause of regional metamorphism and 'granitization' in this area appears to be the proximity of magmatic material at depth. Solutions, carrying alkalis, iron, and magnesium, passed upwards, at different stages, soaking through the overlying sedimentary beds. Although alkalis and iron were probably added from the eruptive source, it is not obvious that magnesium was so added. Granites do not normally introduce this element in metasomatic processes, and no magnesium-rich minerals are associated with the granitoid gneisses. Magnesium may, however, be derived from the gneisses at depth as in the biotite→sillimanite reaction (*See* page 34). It is true that the granitoid gneisses have a much lower biotite content than the ungranitized gneisses. However, difficulties, such as that of the cordierite-anthophyllite concentration in the anthophyllite band, appear to mitigate against this latter hypothesis. Could enough magnesium, driven off from broad areas at depth, be channelled up along a relatively narrow band? If the band offered a permeable channel, solutions from depth might 'stream' towards it. In general, a sedimentary origin for the magnesium seems more probable than a magmatic derivation, for which there is no evidence.

In conclusion, it would seem that the control of bedding on the development of elongate areas in which cordierite and sillimanite are formed is significant, and was evidently of greater importance than fractures in this area. The location of the areas is probably governed by the proximity of cupolas of eruptive material at depth.

CHAPTER IV

STRUCTURE

GENERAL STATEMENT

The rocks of Batty Lake map-area are entirely gneissic, and, as folding occurred in the main during metasomatic metamorphism, they have reacted in a plastic way to produce complexly folded welts (*See* Plate III A), which are almost invariably overturned. Folds trend north to northwest, swinging more to the west in the northern half of the area. They are overturned to the west and south except north of Batty Lake where they are, in part, overturned to the east.

The main faults of the area trend slightly east of north parallel with the Molly Lake fault of the Sherridon area to the west. Minor faults trending west of north occur in the north of the area and are apparently of bedding-plane type. A fault that is apparently older than the others mentioned separates the Kisseynew from the Amisk in the southwest part of the area.

The strike and plunge of drag-folds and linear elements are shown on the map. In some areas the relation of these features to larger scale structures can be shown. The apparent orientation of sericite flakes as the alteration product of potash-rich feldspar has been noted, but has not been related to major features. Linear elements of four kinds were noted, namely: elongation of hornblende grains, elongation of mineral clots, fine crenulations, and slickensides. The slickensides almost invariably strike about east-west and probably indicate the directions of latest movement.

FOLDS

Three, broad northwesterly trending synclines[1] exposing large areas of Sherridon gneiss are the most conspicuous structural features of the area. They represent an early stage of deformation, and were subjected to later stresses. Subsequent folding is indicated by the overturning of these broader folds to the southwest, and by later, intersecting, northeasterly trending fold axes, as west of Batty Lake and southeast of Nokomis Lake. Minor tight folds within the major synclines are common, and plunges measured on linear elements, which, apparently, reflect the attitudes of these smaller folds, indicate that the folds may not always reflect the major structure.

The granite body south of Moody Lake domes the overlying rock and separates the Swamp Lake and Batty Lake synclines of Sherridon rocks. This granite can be considered either the cause of the late, northeast-trending folds or, as seems preferable, a result of forces causing the folding and intrusion. Forces resulting in its emplacement have a profound effect on the rocks to the north of Moody Lake. The narrow anticlinal welt of Nokomis rocks extending southwest from a lake due north of Batty Lake

[1]*See* footnote, page 9.

appears to have been originally a broad area of Nokomis strata separating two synclinal basins of Sherridon beds. It is now, strangely enough, overturned to the southeast. Linear elements along the east side of the granite mass to the south trend slightly west of north and plunge at shallow angles. North of Batty Lake and along the east limb of the tightly overturned anticline, the trend shifts slightly to the north or northeast. On the northwest limb of the anticline and on the band of Nokomis farther northwest, the plunges are to the southwest.

The structure of this band due west of the lake north of Batty Lake, where there appears to be a flattening of the anticline in the Nokomis group, is concluded to have an extremely complicated shape, and can be accounted for only by assuming extreme plasticity during deformation.

A syncline in the Nokomis group just east of Wood Lake on the south border of the map-area plunges north, but the syncline immediately adjacent to it at the north end of the long lake east of Wood Lake appears to plunge south. These structures lie in an area where there is a sharp break in plunge attitudes, all plunges to the west of the lake east of Wood Lake being to the north, and all to the east of it being to the southeast. This might suggest a fault separating two blocks with differing attitudes. Augen-gneiss occurs on the west shore of the long lake east of Wood Lake, possibly suggesting some displacement accompanied by granulation.

An anticline plunging northwest brings up Nokomis rocks between the Sherridon and Walton Lake synclines. This fold is cut off by the Derby Lake fault.

A basin-like structure in the Nokomis group between Evans and Nokomis Lakes abuts the Evans Lake area (*See* Figure 1), which was studied in some detail.

EVANS LAKE STRUCTURES

The Evans Lake area (Figure 1) represents a minor bulge on the southeast side of a basin-like syncline in the Nokomis group. Fold axes curving from northeast to north are roughly parallel with the main axis to the west. They are crossed by a northwest-trending fold marked by a 'bulging out' of the rocks of the area to the southeast. The appearance of small folds, many linear elements, and good outcrops make this small area an ideal site for the attempted correlation of linear elements and larger structures. The terminology of Sander-Cloos, as shown in Figure 2, is followed throughout the discussion.

From Figure 1 it can be seen that the elongation of hornblende grains is Lin_A and that of minor warps is Lin_B, with reference to the tight, north-trending folds on either side of Evans Lake. Drag-folds, as might be expected, are also Lin_B. Over most of the larger area, however, hornblende grains are elongate in the plane of foliation parallel with the major axis or Lin_B. Why, then, at Evans Lake should they appear to be oriented normal to the fold axis, parallel with Lin_A?

An attempt to aline these linear elements with the hornblende grains of the larger area was made by considering them as related to the late, northwesterly trending fold axis. This, however, cannot be done for the reason that the minor warps and drag-folds formed prior to, or at the same time as, the northwest-trending syncline, as shown by the fact that those on the south limb plunge northward and those on the north limb plunge southward, with some of them horizontal at the fold axis. The photomicrograph (Plate III B) shows a cross-section in A-C (*See* Figure 2) of quartz-mica gneiss, and similar patterns were seen in hornblende gneisses. Fracturing of the mica and hornblende grains shows that they formed in oriented position before the minor warps and, in all probability, in conjunction with the north-trending folds.

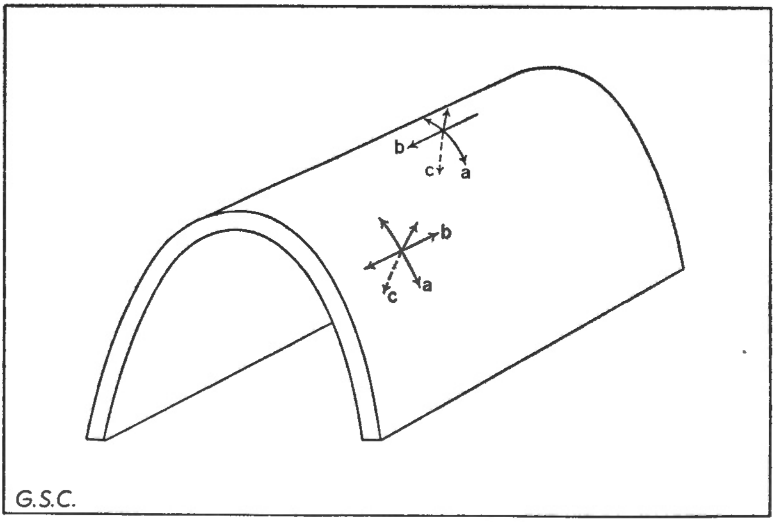

Figure 2. Diagram of a fold, showing orientation of linear elements, a (Lin_A) and b (Lin_B). Lin_B is everywhere parallel with the fold axis. Lin_A changes in angle of slope, depending on position on fold, but has a constant direction. A third element, c (Lin_C), is normal to both a and b.

A similar situation is described by Fairburn (11) for the Claire River syncline. He states that "tectonic axes" indicate *directions normal to which movement has taken place*, and he then relates fold axes (minor warps in the present instance) to shearing or rolling actions during the formation of a flexure fold, and relates the development of crystal elongation to post-tectonic crystallization after movement in the bedding planes that parallel the fold axis. He finds no time relation between the two sets of axes.

In the Evans Lake area, the crystal elongation is obviously developed first, as shown by photomicrographs such as Plate III B mentioned above. The fracturing of the hornblende and mica grains shows that they had formed prior to the minor warps.

Kalliokoski (20) describes linear elements in Amisk "greenstone" as follows: "Fine needles of hornblende show a near horizontal lineation. Locally these sheets of greenstone or amphibolite form small wrinkles that plunge down dip in the plane of the foliation. Such a structural system may originate by shearing and compression of inclined arcuate strata if the compressive force acts from the convex side of the curved strata. Because of shearing during compression, the small needles of hornblende are oriented in the plane of foliation. As the circumference shortens because of centripetal compression, the excess length is accommodated by wrinkling". The situation as observed there is essentially the same as that at Evans Lake.

It is suggested that at Evans Lake, as the rock formations of the basin began to 'bulge' (or as they were compressed by the granite from the southeast), stretching and shearing in the beds developed the hornblende needles in the direction of the 'bulging' or *normal to the 'stretching'*. Further bulging formed the north-south trending folds as folding became necessary to relieve the compression. Continuation of the process produced the pronounced northwest-trending syncline.

LINEATION IN GENERAL

With the Evans Lake structures in mind, it is of interest to refer to lineation in the southeastern part of the map-area. The lineations, mostly mineral clots (hornblende and biotite), are approximately parallel with drag-folds and small fold axes. However, inspection of the map shows that a constant strike of north 10 to 20 degrees east is maintained even through abrupt shifts in the attitudes of the folds, except in the southeast corner of the area, east of the long lake east of Wood Lake, where the lineation invariably plunges to the southeast. This might suggest a fault separating two blocks with differing attitudes, as suggested earlier (page 41)[1]. File River might represent such a fault line; it would parallel the other major faults in the area. However, no fault was observed along the river, nor was any offset discernible in the mapped units on either side.

Although the linear elements proved to be of considerable help in interpreting structures in small areas, they present a vexing problem over larger areas. This problem exists throughout the Kisseynew at least as far west as the Saskatchewan boundary. It is difficult to explain the constancy of elements, other than slickensides, which have no apparent relation to even large structural variations and which themselves may change direction abruptly where there is otherwise no observed major structural variation.

FAULTS

The most prominent fault in Batty Lake map-area is that in the southwestern corner separating the Kisseynew meta-sedimentary gneisses from Amisk rocks. Drag-folds are well developed in both the Nokomis quartz-biotite gneiss and in the Amisk 'greenstones', and they indicate that the fault is of normal character with north side down. North of the many-armed lake near the southwest corner of the map-area, augen-gneiss, flaser gneiss, and mylonite are developed in the meta-sedimentary rocks where pronounced shearing is in evidence. Sheared areas were not observed in the 'greenstones'. Other parts of the contact are tightly crenulated, but not markedly sheared. No evidence of distortion was noted south of the round lake in the southeast corner of the area, where a prominent scarp probably related to the fault just to the north is developed facing north.

[1]*See also* 18, fig. 3, p. 45.

The Amisk-Kisseynew fault is displaced to the left by a fault trending north through Nokomis Lake to Walton Lake. The development of mylonite is apparently characteristic of this fault and mylonitic material can be observed between Nokomis Lake, the lake to the south, and along the river north of Nokomis Lake. 'Splashy' development of orange-pink feldspar and iron-rich epidote are also commonly observed, and together with the occurrence of considerable pyrite indicate that some material was introduced along the fault plane. This feldspar-epidote introduction in its most flamboyant development can be seen on the west shore of the lake south of Nokomis Lake immediately south of the narrows.

The fault extending south from Derby Lake in the northwest corner of the area is roughly paralled with the Nokomis Lake fault, and probably represents a continuation of the Molly Lake fault of the adjacent Sherridon map-area. Outcrops south of Three-finger Lake are, unfortunately, too sparse to permit of recognition of the fault in that area.

Bedding-plane faults are undoubtedly more common in the area than indicated on the map. Evidence of movement is indicated in many places by discontinuous beds of sericite schist or by slight intensification of gneissic foliation. In most instances it is difficult or impossible to estimate how much movement has taken place, and in some places there is no observable offset.

Minor displacement along fractures was occasionally noted, but is much rarer in this area than farther west and south (29), and is probably related to the physical environment of the rocks during deformation.

CHAPTER V

MINERAL DEPOSITS

GENERAL STATEMENT

No commercially workable mineral deposits have been found in the Batty Lake area. Copper, zinc, and gold prospects have been described (44), and later prospecting has uncovered numerous mineralized zones, all of which, however, are thought to be small and of low grade.

The deposits can be classified into four main types, depending on their relationships to stratigraphy or associated intrusive rocks:

(a) Those related to the Nokomis-Sherridon contact
(b) Those related to the anthophyllite band in the Sherridon group
(c) Those showing no particular relationship to stratigraphy or intrusion
(d) Those related to diorite or hornblende intrusive rocks (and possibly to the Amisk contact)

DEPOSITS RELATED TO THE NOKOMIS-SHERRIDON CONTACT

STAR LAKE SULPHIDE DEPOSITS (1)[1]

Three small pits were seen on the long point on the south shore of Star Lake south of the island in the lake. These lie within hornblende-rich rocks interbedded with brown-stained, coarse-grained, friable beds containing diopside and clinozoisite. Pyrite was the only sulphide identified.

BING AND PEACE RIVER GROUPS (2)

The Bing and Peace River groups lie about 1¼ miles northeast of the south end of Walton Lake. Some sixteen trenches were observed in this immediate area, but all are rusted and badly slumped. Wright says (44): "Rock types noted include: bedded quartzite, quartz-mica gneiss, and dark grey to black micaceous and hornblendic gneisses. Some quartzite beds are nearly white and are almost pure quartz. Some of the micaceous gneiss contains disseminated graphite". The presence of graphite in these beds probably indicates that they are near the top of the Nokomis, and the orthoquartzites described by Wright and seen in the field are undoubtedly Sherridon. Very large garnets were noted in some of these quartzites, and the general appearance of the rock was similar to that of other occurrences of the Sherridon (*See* Plate I B).

Pyrrhotite and chalcopyrite were noted in the dumps, and are stated by Wright to occur in small lenses and veinlets near pegmatites and quartz veinlets in the garnetiferous mica gneiss and disseminated through dark hornblende gneiss. He reports a channel sample assay from the Peace River group as yielding 0·2 per cent tin; 0·10 per cent copper; 1·7 ounces silver a ton; and a trace of gold and lead.

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[1]Numbers in parentheses appear on the accompanying geological map and indicate the location of the deposits.

DOUGLAS GROUP (3)

The Douglas group lies about $\frac{3}{4}$ mile south of the south end of Walton Lake. The bedrock there is highly rusted, grey to white, in part garnetiferous, Nokomis sedimentary gneiss, with interbedded black hornblende gneiss and sills of pink granite. Some trenching was done just west of lime-rich beds that, apparently, represent the Nokomis-Sherridon contact limestones. Pyrite and chalcopyrite were identified in these beds. Wright (44, p. 63) states: "North of the granite the schist is cut by pegmatite, and lenses and veinlets of massive pyrrhotite and disseminated chalcopyrite occur across a width of 12 feet. The pegmatite carries pyrrhotite in small grains".

NOKOMIS RIVER SULPHIDE DEPOSITS (4)

East of Nokomis River and a mile north of the power line, four pits about 5 feet deep and 10 to 12 feet long have been excavated in a silicified meta-limestone. Veinlets and disseminated flecks of pyrite are shot through the silicified material, and a little chalcopyrite was observed. The host rocks trend northwest and dip about 30 degrees northeast.

WALTON RIVER SULPHIDE DEPOSIT (5)

An elongate, heavily rusted lens of graphite and pyrrhotite was discovered just northwest of the sharp bend of the river leading from Walton Lake. It lies just south of a lime-rich zone, and corresponds to lenses of graphite and pyrrhotite found in Sherridon map-area to the west. Bodies of this type carry no valuable materials in this part of the province.

BATTY LAKE SULPHIDE DEPOSIT (6)

Several trenches are excavated in black garnetiferous hornblende gneiss southwest of the west end of Batty Lake. These trenches expose a heavily rusted and slightly sheared zone some 400 feet west of the Nokomis-Sherridon contact. The trenches are badly slumped and overgrown, and pyrrhotite was the only metallic mineral identified in the dumps.

The close proximity of all the above deposits to the Nokomis-Sherridon contact may be of importance. A similar situation exists in Sherridon map-area to the west, where the Bob Lake, Sheila Lake, and Camp Lake deposits lie on the lime-rich contact, and the Sherritt Gordon orebodies close to it. The contact zone, because of its limy composition, may be chemically significant in ore localization.

DEPOSITS RELATED TO THE ANTHOPHYLLITE BAND (7, 8)

Three large pits were observed in the anthophyllite band, one at the west end of a small lake east of Elken Lake and two in the tight fold midway of Batty Lake.

A large pit about a mile west of Elken Lake lies entirely within the anthophyllite band, which is heavily rusted at that point. Disseminated pyrrhotite and a few grains of chalcopyrite were observed. The pit is badly weathered, and at first glance resembles a rusty shale talus slope. Cordierite occurs in the band in this vicinity.

The large pit lying within the tight fold of the anthophyllite band on the north shore of Batty Lake shows heavily rusted material similar to the above. The rock is badly weathered, and fresh specimens could not be obtained. A polished section showed considerable limonite but no relict sulphide. Cordierite was found in a second pit on an island southeast of the above-described locality, where the rocks are somewhat less weathered. Sillimanite also occurs there in the quartz-rich gneisses on both sides of the anthophyllite band.

DEPOSITS SHOWING NO RELATIONSHIP TO INTRUSION OR STRATIGRAPHY

WOOD LAKE PROSPECT (**9**, approx.)

During 1948, Peter Stewart opened a small gold prospect in a tightly folded, north-plunging anticline just west of Wood Lake. The mineralized zone lies within crumpled quartz-biotite gneiss of the Nokomis group, which contains minor sillimanite. Chalcopyrite and galena are associated with arsenopyrite and gold in disseminated flecks and small stringers. Large plates of greenish microcline accompany the mineralization.

ELKEN LAKE PROSPECT, AND OTHERS (**10, 11**)

The prospect at Elken Lake was described by Wright (44), but was not seen by the writer. According to Wright, chalcopyrite and sphalerite are distributed in small lenses through a schistose zone some 10 to 20 feet wide in a fine-grained, bedded quartzite. Assays indicated a low gold content.

At the west side of the map-area northwest of Elken Lake, two large pits and several smaller ones were noted in garnetiferous, ridgy Sherridon quartzite. Pyrrhotite and minor chalcopyrite were observed in the pits. Creamy white, fine-grained pegmatite dykes cut the quartzites in this vicinity, and some of them carry considerable cordierite.

DEPOSITS RELATED TO DIORITE OR HORNBLENDITE INTRUSIONS (AND POSSIBLY TO THE AMISK CONTACT)

EVANS LAKE SHOWINGS (**12**)

During the winter of 1946, Peter Stewart, of International Mining Corporation, explored small gold showings west of Evans Lake (*See* Figure 1). Three showings were discovered in this area, the 'main showing' and one other located, respectively, on the east and west limbs of an overturned southerly plunging anticline. A small stock of granite cuts the Nokomis hornblende gneiss and fine- to coarse-grained diorite (some of which may be of metamorphic origin), and stringers of granitoid and pegmatoid material are common across the entire nose of the fold. Gold, with pyrite, pyrrhotite, and arsenopyrite, occurs in the silicified parts of the hornblende gneiss and diorite. Pyrite is the most common sulphide.

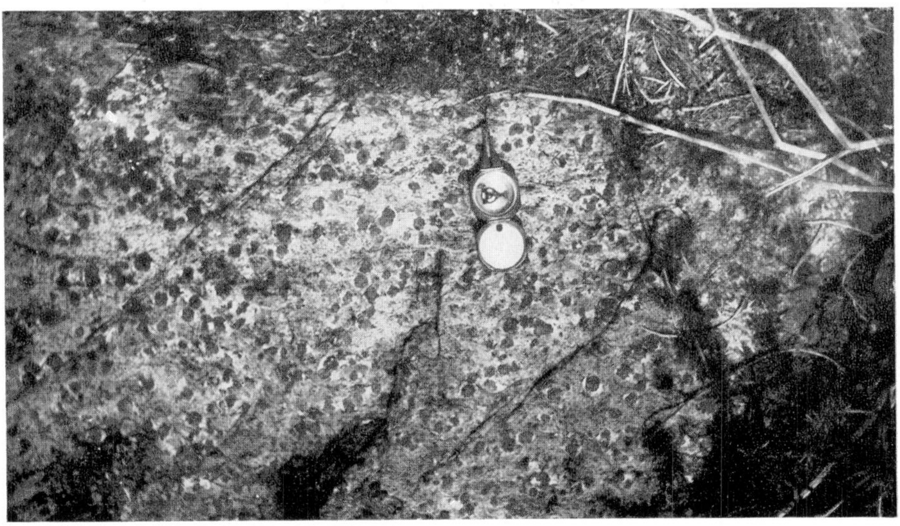
In three polished sections of 'grab' samples taken from the 'main showing' only one minute fleck of gold was seen, and it was intimately associated with pyrite. Drill records, however, show that areas of intense pyritization are barren, and suggest that the gold is associated with concentrations of arsenopyrite.

Similar deposits, some carrying galena, have been discovered to the south of the Evans Lake showings, near the granite contact.[1] The granite stock appears to be truly intrusive. It is probably related to the large body of granite to the south, and to the mineralization. The gold content is not confined to the hornblende-rich rocks but continues southward across the northwest trending cross-fold in the quartz-biotite gneiss. The intrusion of the stock and the location of the gold-bearing deposits may be governed by some structural relationship at the point where the nose of the overturned fold meets the cross-fold axis.

[1]Harrison, J. M.: Geol. Surv., Canada, personal communication.

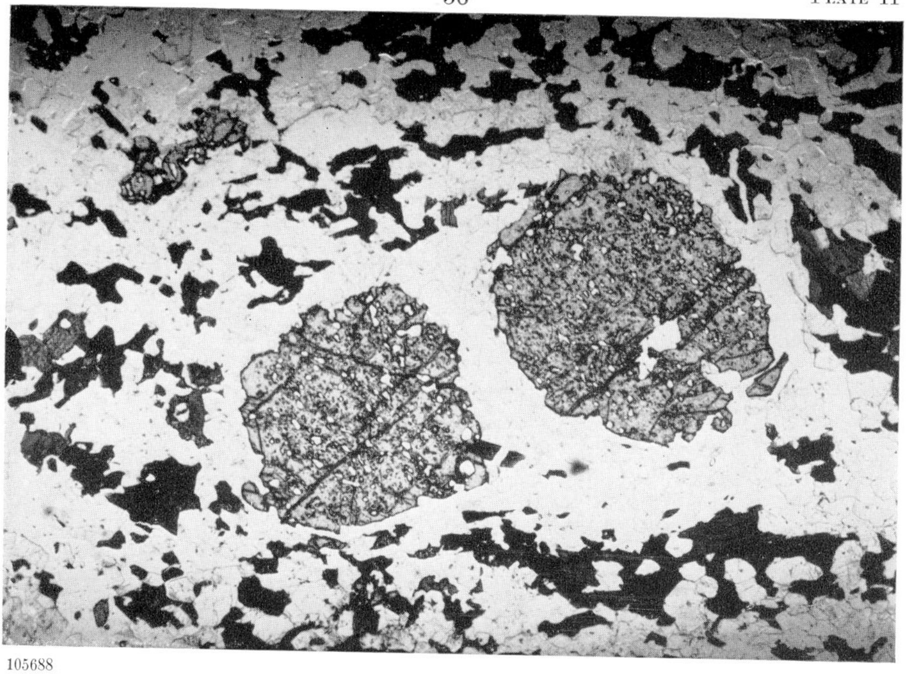
6-1-1949

A. Sand plain northeast of Nokomis Lake. (Page 2.)



2-4-1947

B. Large red almandine garnet in creamy white Sherridon gneiss north of Elken Lake. (Pages 15, 45.)

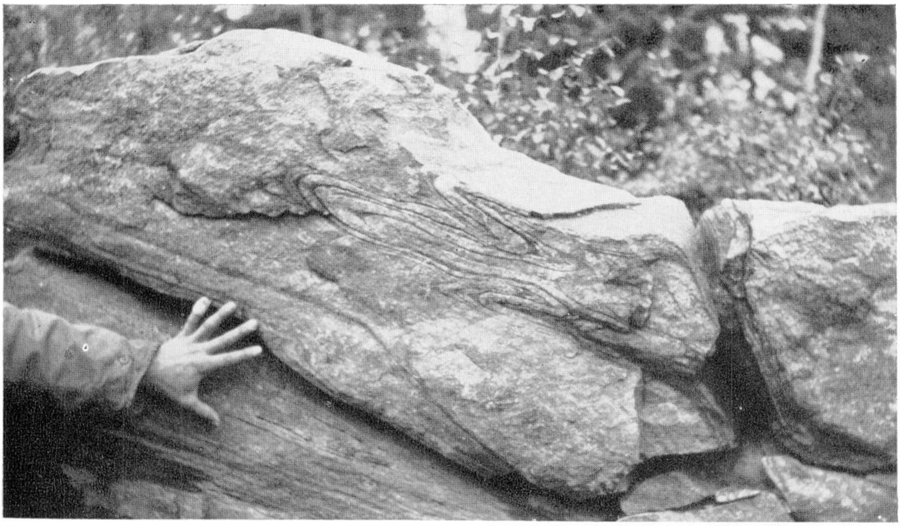


105688

A. Photomicrograph of poikiloblastic garnet in sedimentary hornblende gneiss of the Sherridon group. X12. (Page 18.)

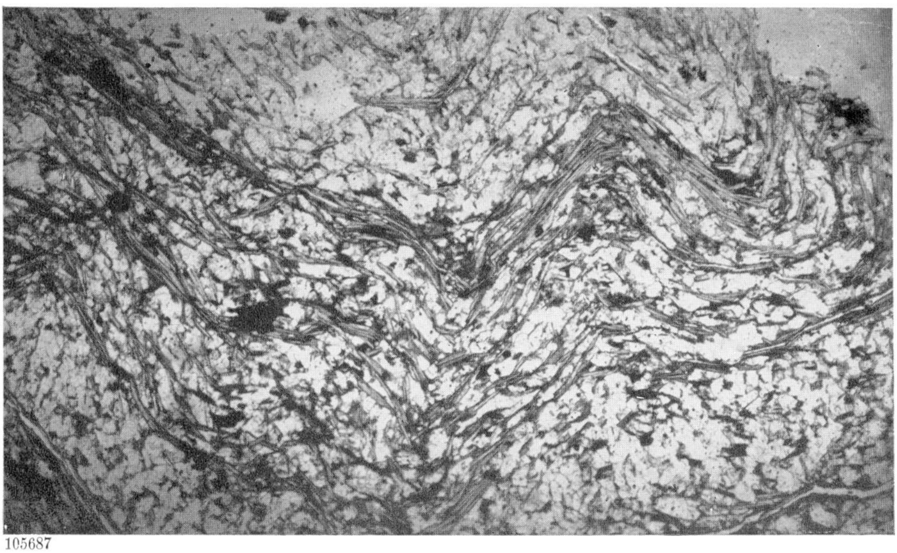
105686

B. Photomicrograph of sillimanite developed in the quartz-rich gneisses of the Sherridon group west of Weldon Lake. Dark mafic minerals are biotite flakes; material with high relief is almandine garnet; the sheet-like mass in lower right-hand corner is sillimanite, as are light-coloured flecks developing in the mass of biotite in the centre. X5. (Page 34.)



5-3-1949

A. Folds overturned to the south in Nokomis-type gneiss on the railway south of Sherridon, indicating complexity possible during plastic deformation. (Page 40.)



105687

B. Photomicrograph of crenulations (minor warps) in the foliation of Nokomis quartz-biotite gneiss of the Evans Lake vicinity. X12. (Page 42.)

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