A STRUCTURAL INTERPRETATION

of the

RUSSICK LAKE AREA, MANITOBA

A Thesis

presented to

the Faculty of the Graduate Studies

and Research

University of Manitoba

In partial fulfilment

of the requirements for the degree

of

Master of Science

by

Leslie J. Kornik

December 1965

ABSTRACT

This thesis is an attempt to interpret the rock structures in the vicinity of Russick Lake, northern Manitoba. Deformation is thought to be the result of plastic flow. Statistical structural plots of foliation data show single strong maxima that suggest isoclinal folds. These folds are tightly compressed, their axial planes dip north-east at approximalely 30^{0}, and their axes plunge 10^{0} to 20^{0} north to north-east. The pattern of folds presented by a foliation trend map suggests flow movement and flow folding. Field evidence of movement in the gneisses and ptygmatically-folded pegmatitic stringers support this concept of folding. The high grade of regional metamorphism presents indirect evidence of high temperatures and pressures which would favor deformation by plastic flow.

Accompanying the structural interpretation is a brief, general description of the rock units and their relationship to one another. The Sherridon gneiss group is interpreted to be younger than the Nokomis gneiss group; this interpretation supports the work of D. S. Robertson (1953).

The study of a granite body north of Russick Lake established the existence of three zones. These zones were identified on the basis of differences in structure, texture and composition.

TABLE OF CONTENTS

III STRUCTURAL ELEMENTS

IV DESCRIPTION OF STATISTICAL RESULTS

V INTERPRETATION AND DISCUSSION

ILLUSTRATIONS

PLATES

TABLES

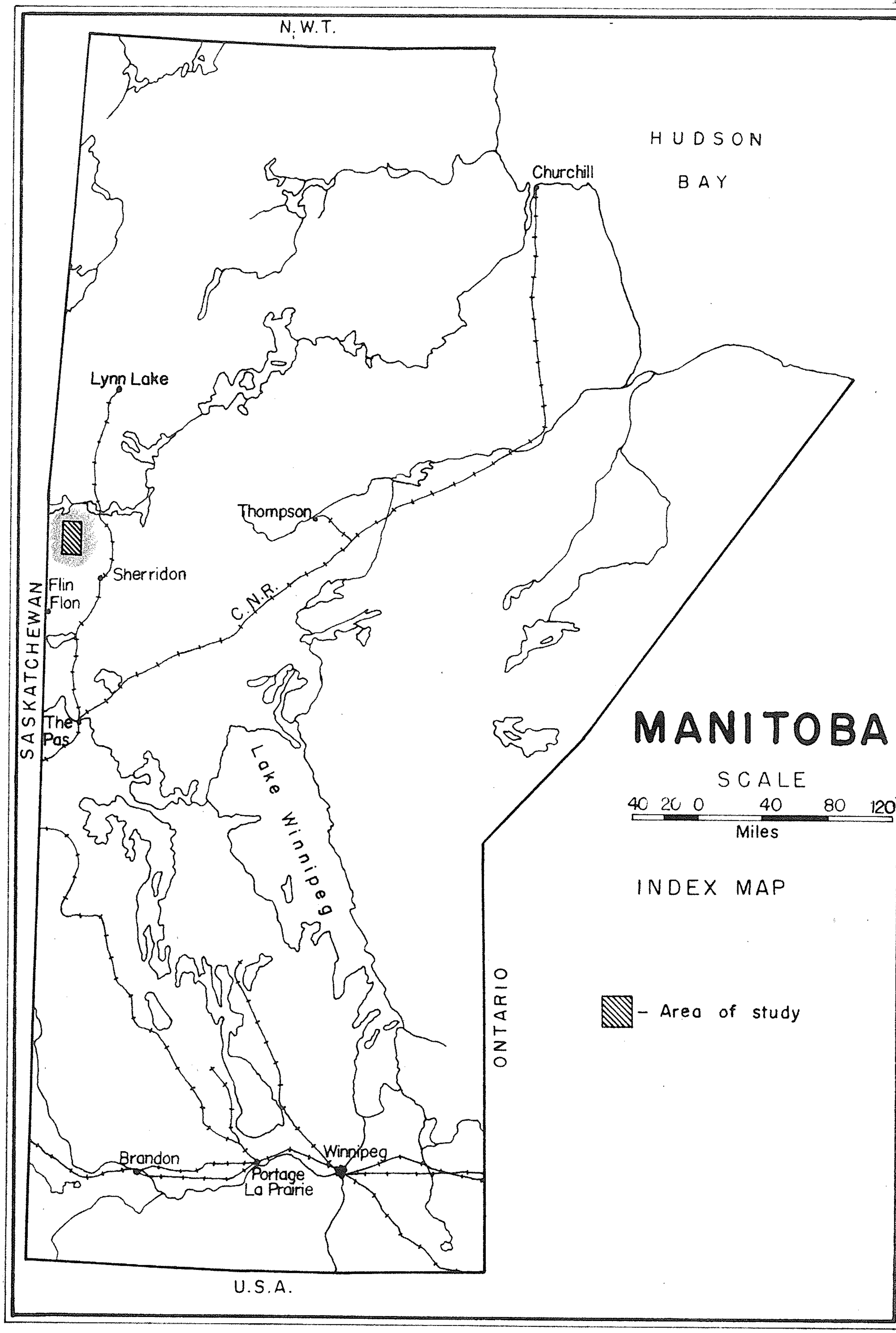

N.W.T.
HUDSON BAY
Churchill
Lynn Lake
Thompson
Sherridon
Flin Flon
C.N.R.
The Pas
SASKATCHEWAN
Lake Winnipeg
MANITOBA
SCALE
40 20 0 40 80 120
Miles
INDEX MAP
ONTARIO
- Area of study
Brandon
Portage La Prairie
Winnipeg
U.S.A.

PLATE I

CHAPTER I

INTRODUCTION

Introduction

The Russick Lake area is situated in northern Manitoba approximately 40 miles north of Flin Flon. The area is bounded by north latitudes 55° 15' and 55° 30' and west longitudes 101° 30' and 101° 45' (Plate 1).

The thesis work comprised mapping the area and drawing a geologic map from the data obtained in the field during the summer of 1963 when the author carried out a field mapping program for the Manitoba Mines Branch. This manuscript includes general petrological descriptions and an interpretation of the relative ages of the rock units in the area. The main topic, however, is the structural interpretation of the area.

Accessibility

The area is accessible to float-equipped aircraft and can be reached by canoe both from the settlement at Pukatawagan on the Churchill River and from Sherridon on Kississing Lake. The Pukatawagan route through the Girouard Lake system requires several portages around rapids to reach the north-east part of the area. Kississing Lake is close to the south-east corner and allows access to this part of the map area. Float-equipped aircraft provide the best means of travel between the small lakes; most of the streams are too small and rocky to allow travel by canoe.

Physiography

The topography of the map area is typical of the Precambrian Shield; it is relatively flat with a maximum relief of approximately 100 feet. The character of the bedrock controls the amount of relief and the shape and form of the pre-glacial topographic elements. These elements have been modified by glacial erosion and deposition. Most outcrops show glacial polish and on some of the north-east sides of the outcrops the striae are preserved. The south-east sides of the outcrops are drift covered, implying glacial movement from the north-east to the south-west.

Most of the rock outcrops in the area are located on the topographic highs; the lows are occupied by muskegs. Portions of the southern part of the map sheet are covered by small glacial sand plains. The topography in these areas is flat or gently rolling with scattered outcrops protruding through the sand. A few smaller sand deposits are found on the south-west sides of some hills. The sand plains are usually covered by sparse jack pine with or without alder underbrush.

The areas underlain by granitic rock are usually the highest and most rugged. Large exposures of granite occur on the north and east sides of the rounded hills.

Lakes in the area show the effects of glaciation. The south and south-west shores of the lakes have good exposures in contrast to the north and north-east shores which have sparse small outcrops between boulder or sand beaches.

The southern part of the area drains into Kississing Lake; the northern part drains into the Girouard Lake system and eventually into the Churchill River. The drainage pattern shows structural control. Contacts between rock types, and the direction of foliation, joints and faults frequently determine the drainage pattern and the lake outlines.

Field Work

The author mapped the area during the summer of 1963. Traversing was done using the pace and compass method at intervals of 1500 to 2000 feet throughout most of the area. In the north-eastern corner of the map sheet, which is underlain by granitic rocks, a wider spacing of traverse lines was used.

Traverse lines were plotted in the field directly on vertical air photographs with a scale of approximately 1 inch to 2640 feet. These traverse lines were then transferred from the photographs to a base map of the same scale.

Measurements of the attitude of the foliation surfaces for structural analysis were made at 500 foot intervals along the traverse lines where possible, or wherever a change in attitude was observed. The attitude of all observed lineations and joints was recorded.

Rock samples were collected to give a complete set of rock types for the area. Thin sections from selected samples were examined by G. D. Pollock (1965) of the Manitoba Mines Branch, for the preparation of his report.

Acknowledgments

The author wishes to express his gratitude to Drs. J. F. Davies and G. D. Pollock of the Manitoba Mines Branch. Their suggestion of the problem and their co-operation helped make the thesis possible. Special acknowledgments are extended to G. D. Pollock for guidance and constructive discussions during the field season and at later dates.

The assistance of H. Leistra, J. Campbell, K. Galbraith, J. Pincock, G. Rapke and L. Richardson, as members of the geologic party, who helped gather the data, was appreciated.

Financial assistance from the Geological Survey of Canada helped make the project possible.

The author would like to acknowledge the able supervision of Professor W. C. Brisbin. His advice and interest in the problem was greatly appreciated.

CHAPTER II

GENERAL GEOLOGY

Introductory Statements

All of the consolidated rocks in the Russick Lake map sheet are of Precambrian age. A greater portion of the area is underlain by Kisseynew gneisses with a few intrusions of syntectonic granites. The north-east corner and the eastern side of the area is underlain by granites, hybrid granites and garnetiferous quartz diorites.

The gneisses have been split into two divisions on the basis of their petrology as follows:

1) Sherridon group, consisting of

   a) a light colored quartz-rich gneiss,

   b) a less abundant dark hornblende-rich gneiss.

2) Nokomis group, which likewise consists of two varieties consisting of

   a) a grey garnetiferous gneiss,

   b) dark amphibolite gneiss.

The basis of this division is reviewed by Robertson (1953).

TABLE I

Table of Formations

INTRUSIVE ROCKS	Pegmatites Granites Quartz Diorites Pyroxenites	INCREASING AGE ↓
KISSEYNEW GNEISSES	Sherridon Gneiss group A) Amphibolite gneiss B) Sherridon gneiss Nokomis Gneiss group A) Migmatite B) Amphibolite gneiss C) Nokomis gneiss	

KISSEYNEW COMPLEX

Sherridon Group

Sherridon Gneiss

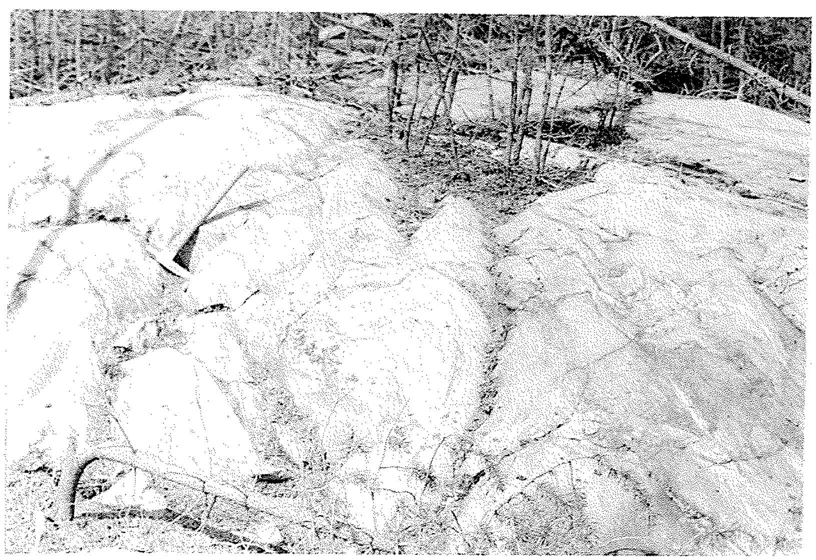
The main rock type of the Sherridon group is the quartz-rich gneiss which has good compositional stratiform layering. Lighter, quartz-rich layers alternate with darker, biotite-rich layers (A, Plate 2). Although the banding is usually distinct it may be poorly defined in places.

The color of the Sherridon gneiss changes rapidly from band to band in the outcrop, ranging from light grey or blue-grey to pinkish grey. These colors are mainly dependent on the quartz content and the color of the feldspars.

This rock type is granular and has a grain size ranging from ¼ to ½ mm. The quartz and the feldspar grains in the gneiss are elongated in the plane of foliation and banding.

Clear quartz occurs in the Sherridon gneiss in an amount equal to or greater than that of the feldspar. Locally, the quartz may comprise up to 80 % of some bands. The biotite in the gneiss has a preferred orientation in the same plane as the compositional banding, and ranges from 1 % to 5 %, averaging 2 % of the total composition. Magnetite is present in small amounts as distinct grains dispersed throughout the rock. Some bands in the gneiss

A. Layered Sherridon gneiss containing irregularly-shaped pegmatitic material.



B. View of folded foliation in Sherridon gneiss. Note the white weathering due to high quartz content.

PLATE 2

have a magnetite content of up to 5 %. Minor amounts of hornblende may also be present in some localities.

Garnets are rare and not usually found in the Sherridon gneiss, though they may be present locally in small amounts. Where present, the garnets occur as small rounded crystals with a bright, light reddish pink color.

Minor lenses, nodules or bands rich in epidote occur in certain areas of the Sherridon gneiss. These bodies are formed of a concentration of green calc-silicate minerals usually surrounded by a pinkish red reaction rim.

Sillimanite-rich knots occur in some outcrops of the Sherridon gneiss (A, Plate 3). The knots are flat lenses ½ inch to 2 inches in length oriented parallel to the plane of the banding. The maximum dimension of these lenses, where it is exposed, forms a measureable lineation.

Sherridon Amphibolite

The Sherridon amphibolites are the subordinate rock type in the Sherridon group and occur as bands or layers in the quartz-rich gneiss. The bands vary from several inches to several hundred feet in width. Occasionally bands may be traced laterally for some distance but the majority are too small to map or correlate.

A. Sillimanite bundles in Sherridon gneiss.

B. "Apparent cross-bedding" in Sherridon gneiss.

PLATE 3

(None are shown on the map.) Individual layers in the bands may have variable texture and composition along and across the strike. The amphibolites are dark green to black in color depending on the percentage of hornblende present.

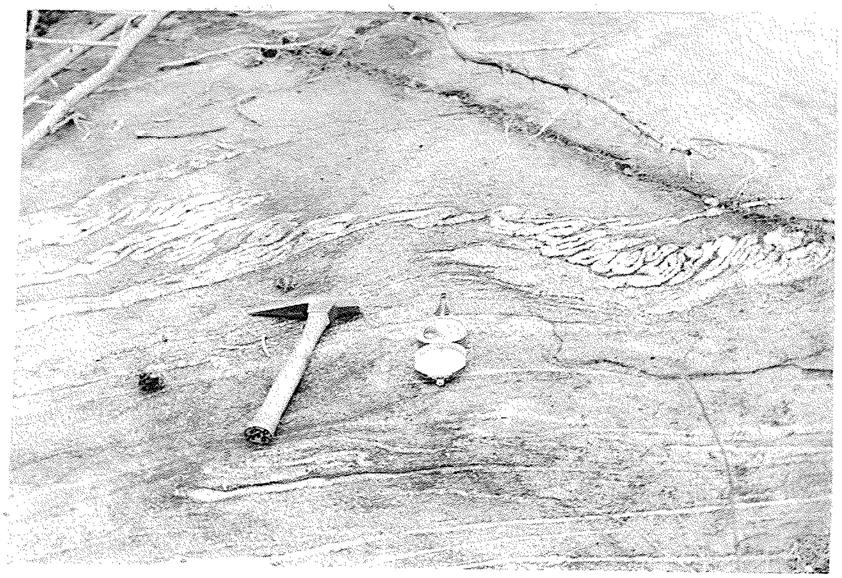
The grain size of the hornblende-rich gneiss ranges from ¼ to ½ mm. The texture of these bands is granular. Some bands have good compositional layering. Lighter layers with more quartz and feldspar alternate with darker layers rich in hornblende. Other bands have the hornblende and biotite concentrated into elongated flat lenses or streaks.

The main minerals in the amphibolites are hornblende, biotite, feldspar, quartz and garnet. Hornblende varies from 10 % to 90 %. Quartz may or may not be present; the maximum garnet content observed was 15 %.

Nokomis Group

Nokomis Gneiss

The garnet-biotite-quartz-feldspar gneiss is the main rock type in the Nokomis group and was named the Nokomis gneiss by Robertson in 1953. It has a distinct foliation due to the orientation of biotite flakes. Banding is not usually present although pegmatitic quartz-feldspar stringers and lenses tend to be oriented in the direction of the foliation (A and B, Plate 4; B, Plate 10). In certain outcrops indistinct banding may be discernable due to



A. Ptygmatic folding of pegmatitic quartz-feldspar material in Nokomis gneiss.

B. Ptygmatic folding of pegmatitic quartz-feldspar material in Nokomis gneiss.

PLATE 4

mineral compositional changes such as the absence or presence of garnet, the relative content of garnet, or to the presence of layers containing epidote-quartz-calc-silicate nodules.

The typical Nokomis gneiss is a grey color on both the fresh and weathered surfaces. Some of the outcrops are a blue-grey color. It has a granular texture and the grain size ranges from ¼ to ½ mm.

The typical Nokomis gneiss contains biotite, quartz, feldspar and invariably garnet and graphite. Biotite content varies from 5 % to 15 % and occurs as small black flakes having a preferred orientation in the plane of the foliation. Clear quartz and light grey to cream colored feldspar make up the bulk of the rock. The average quartz content of the gneiss is 30 % and the average feldspar content is 50 %.

The garnet content of the Nokomis gneiss ranges from a few scattered crystals to local concentrations which make up 25 % of the rock. The average content is 2 to 3 %. The garnets are colored pale pink to purplish-pink and are ¼ to 1 mm. in size. Locally, in the vicinity of pegmatitic portions of the outcrop the garnets are of a larger size and may reach 1 to 2 inches in diameter. They have a rounded shape with poor crystal faces and many inclusions. These garnets may not be single crystals but aggregates of smaller crystals.

Graphite, which is characteristic of the Nokomis group, occurs as small, thin plates scattered among the biotite flakes. The graphite is of the same dimensions or slightly smaller than the biotite. Sillimanite is present in certain localities and occurs as sheaf-like bundles of very fine, fibrous needles oriented in the same plane as the biotite.

Some bands of Nokomis gneiss contain ellipsoidal bodies composed of epidote-rich material having their long dimensions in the plane of the foliation. The nodules appear to be zoned and have more quartz at the centres than at the rims. Nodules range in size from 3 inches to 18 inches in the long dimension; ½ to 3 inches in the other dimension.

Nokomis Amphibolite

The second rock type in the Nokomis group is the hornblende-rich gneiss. These amphibolite bands are approximately a hundred feet in thickness and can be traced laterally for some distance. They are strikingly layered; the layers ranging in thickness from $\frac{1}{16}$ inch to 3 inches. These layers are alternately leucocratic and melanocratic.

The amphibolites in the Nokomis group are dark colored, fine grained and have a granular, sugary texture.

The amphibolites contain hornblende, feldspar, quartz, biotite and garnet. The mafic content ranges from 10 % in the lighter layers to 80 % in the darker layers. Quartz is scarce, or absent, in the darker layers. The lighter layers contain more feldspar than the darker layers and usually have a higher percentage of minor sulfides which stain the weathered surface a rusty color.

In the southern portion of the area, in the lower belt of Nokomis gneiss, isolated discontinuous outcrops of amphibolite are found in a zone approximately parallel to the Sherridon-Nokomis contact. A hook-shaped body of poorly layered amphibolite more mafic than average and of a variable composition, occurs in the Nokomis gneiss near the middle of Russick Lake.

Lense-like bodies of mafic minerals are present in some Nokomis gneiss outcrops. The long dimension of these lenses may range in length from several inches to tens of feet. These bodies are composed of 60 % to 90 % biotite and/or hornblende. The other minerals in these lenses are feldspar and quartz. Garnet is also a common constituent.

Nokomis Migmatite

The term migmatite was first introduced by Sederholm in 1907 to mean a mixed rock. Barth (1962, p. 358, 360) states:

> ..They look like mixed rocks, and they originate by the mixture of older rocks and later erupted

> granitic magmas, and therefore the name migmatite is the most appropriate. This 'magmatic' portion can arise in place and not be connected with a granitic magma; migmatites may be special products of metamorphic differentiation. ...
>
> ... owing to the metasomatic processes, the mixing of the igneous and sedimentary components has been so intimate that every mineral molecule of the rocks has received contributions from both sources. ....

The Nokomis migmatite consists of a mixture of Nokomis gneiss and pegmatitic and granitic material. The pegmatitic and granitic material in the Nokomis gneiss is in the form of lenses, stringers, pods, and coarsely crystalline layers or sill-like bodies. The introduction of the granitic and pegmatitic material into the gneiss causes a recrystallization and an increase in grain size in the gneiss.

The boundaries between the gneiss, migmatite and hybrid granite are transitional and determined by the amount of pegmatitic and granitic material in the outcrop. The gneiss gradually loses its character with the introduction of pegmatitic and granitic material and grades into a migmatite which in turn grades into a hybrid granite. Outcrops of Nokomis gneiss were defined as containing up to 33 % pegmatitic and granitic material. If the outcrops contained more than 33 % but less than 67 % pegmatitic and granitic material they were classified as migmatite. Outcrops containing more than 67 % pegmatitic and granitic material were classified as a hybrid granite.

INTRUSIVE ROCKS

Granites and Pegmatites

Most of the granite bodies are weakly foliated (A and B, Plates 5 and 6). The foliation is formed by the parallelism of biotite flakes, feldspar crystals and quartz lenses. The edges of the granite bodies commonly have a well developed foliation or may have a gneissic lit-par-lit structure. The granite in the north-east corner of the area is a hybrid granite which contains many skialiths and lacks the igneous character of the other granites. All of the granites in the area have either a pink or cream color on both the fresh and weathered surfaces. Color changes were observed in outcrops and in hand specimens.

The grain size varies from fine to coarse; the average grain size is fine to medium grained. The granites are composed of potassium feldspar, plagioclase, quartz and biotite. Garnet and sillimanite may also be present.

The author determined the existence of zoning in the granite body northeast of Russick Lake (Plate 7). Three zones were identified on the basis of differences in structure, texture and composition.

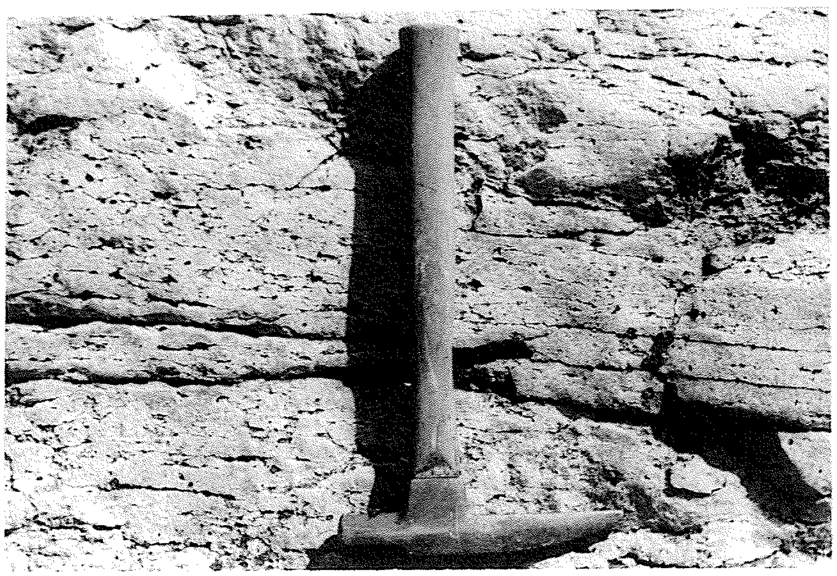
An outer zone is present rimming the body except on the southwest side. This zone appears to consist of 'granitized' gneiss

A. View along strike of foliation in the outer zone of the zoned granite.

B. View showing dip of the foliation in the outer zone of the zoned granite.

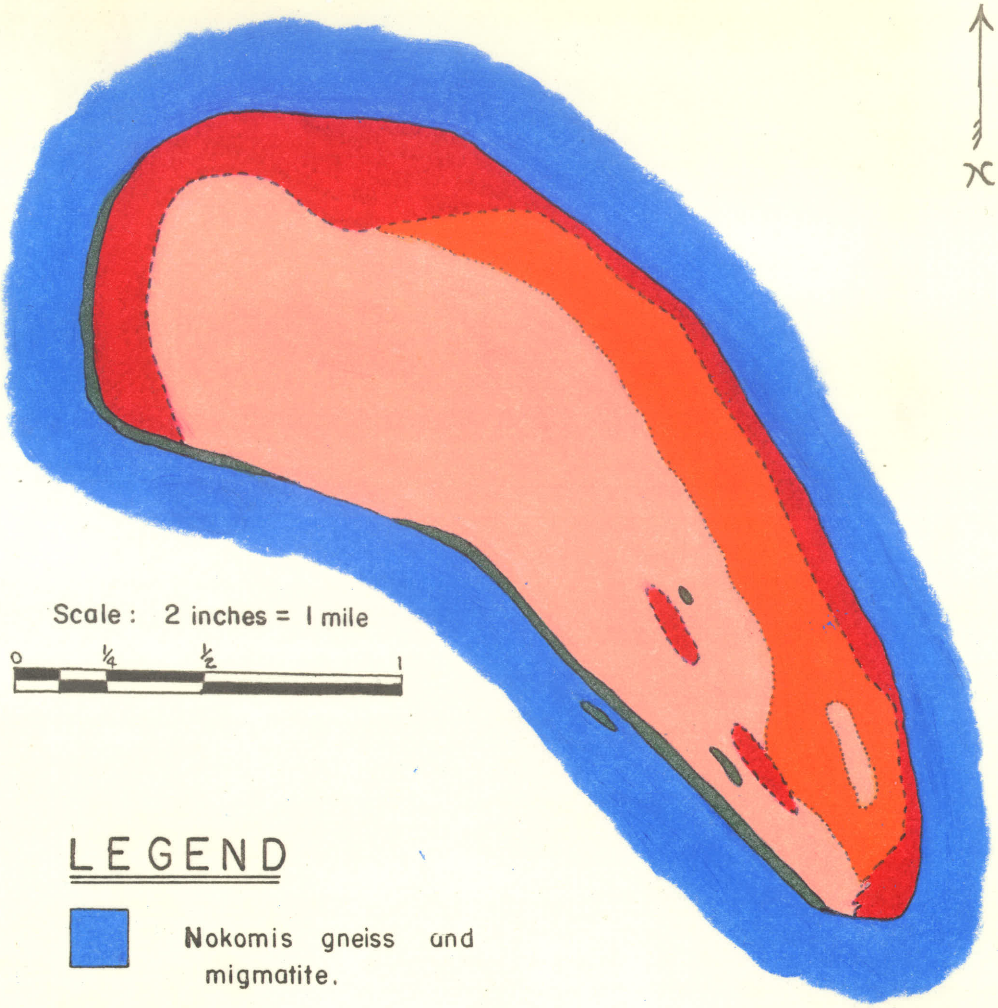
PLATE 5

A. Massive granite containing patches of wispy foliation as shown near the head of the geological pick.



B. Foliation in the outer zone of the zoned granite accentuated by weathering.

PLATE 6



LEGEND

Nokomis gneiss and migmatite.

Nokomis amphibolite.

Outer zone of granite (granitized, relict structures and amphibolite inclusions).

Second zone of granite (massive, fine to medium grained, with occasional garnet).

Inner zone or core (foliated, presence of sillimanite bundles).

ZONING IN GRANITE

PLATE 7

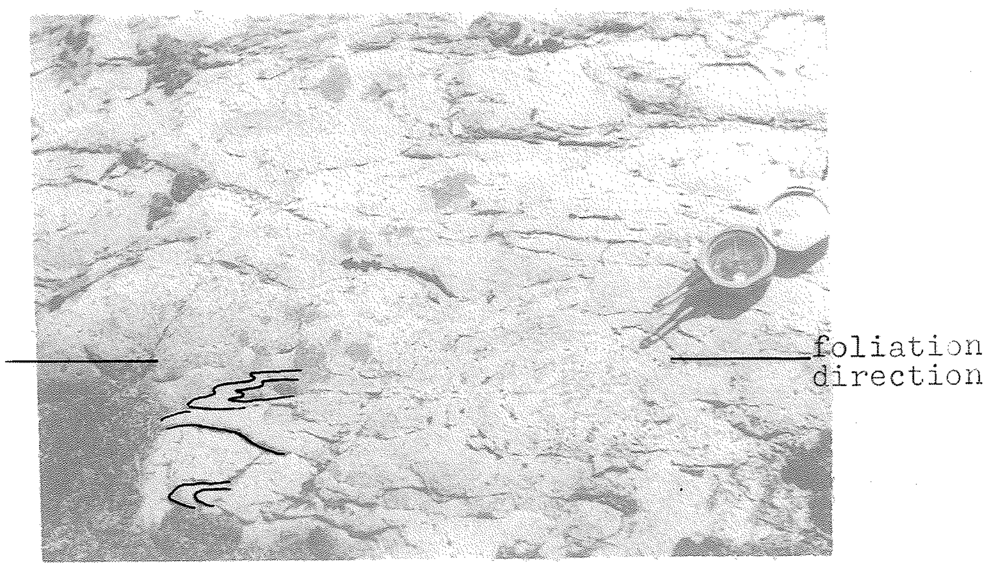
and migmatite. Strong foliation and layering as well as other relict, gneissic structures are common in this zone (Plates 5 and 6). These relict structures are faint banding or foliation, faint ghost-like remnants of ptygmatically-folded, pegmatitic material and wisps of foliation.(A, Plate 6; A and B, Plate 8). Many inclusions of amphibolite occur in this outer zone in various stages of assimilation (A and B, Plate 9; A, Plate 10). Some of the xenoliths appear very fresh and have sharp conformable contacts with both the surrounding granite and the granitic and pegmatitic material intruded along its layers (A, Plate 10). Other inclusions appear in various progressive stages of assimilation until they fade into a hornblende-rich patch displaying a faint relict layering. No contact thermal metamorphic effects are present in the amphibolite or migmatite adjacent to the granite.

The second zone is present only along the northeast side of the granite. This zone is occupied by a massive, uniform, fine to medium-grained granite. A weak foliation may be present in places.

The third and largest zone, the core, is determined by the presence of sillimanite,which occurs as patches or felted masses in a foliated granite. Muscovite is also present in small amounts. This zone appears more highly weathered than the other two zones.

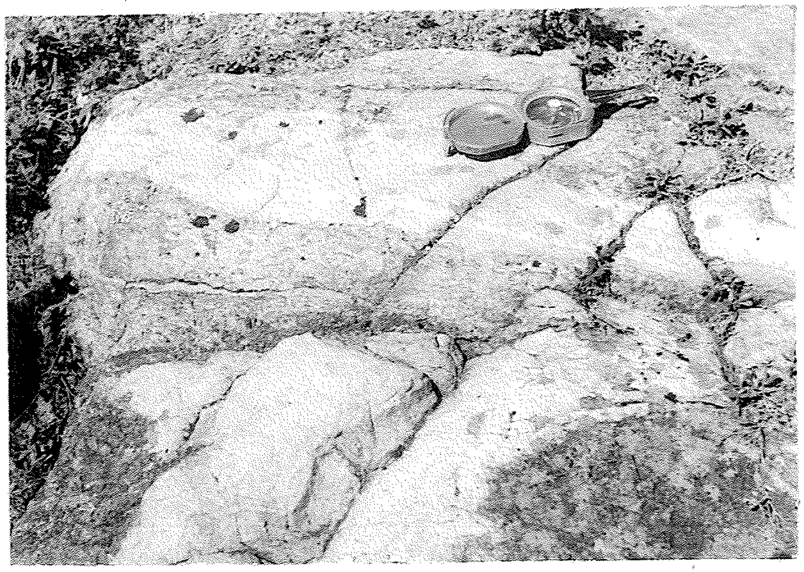
Three modal analyses of granites in the area are shown in Table 2.These analyses, provided by the Manitoba Mines Branch,

A. Remnant ptygmatically-folded pegmatitic material in 'granitized' portion of the zoned granite.

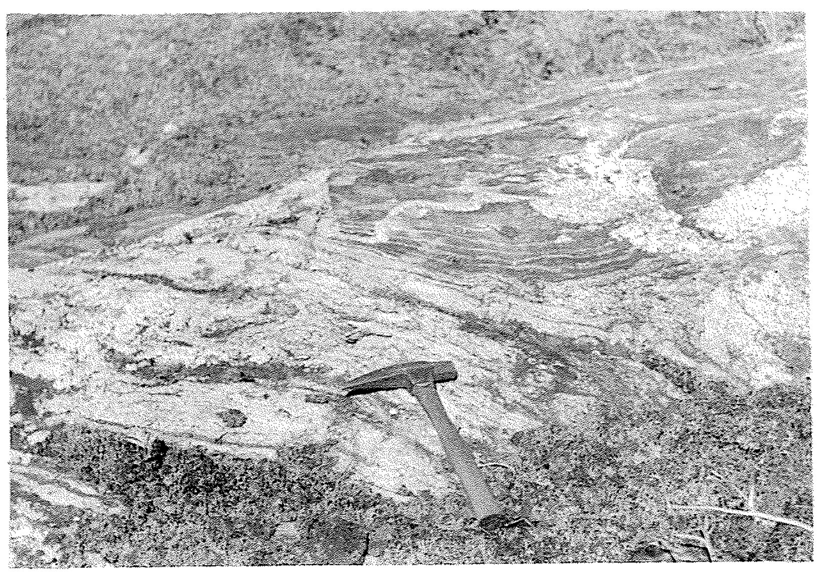


B. Remnant ptygmatically-folded pegmatitic material in 'granitized' portion of the zoned granite.

PLATE 8



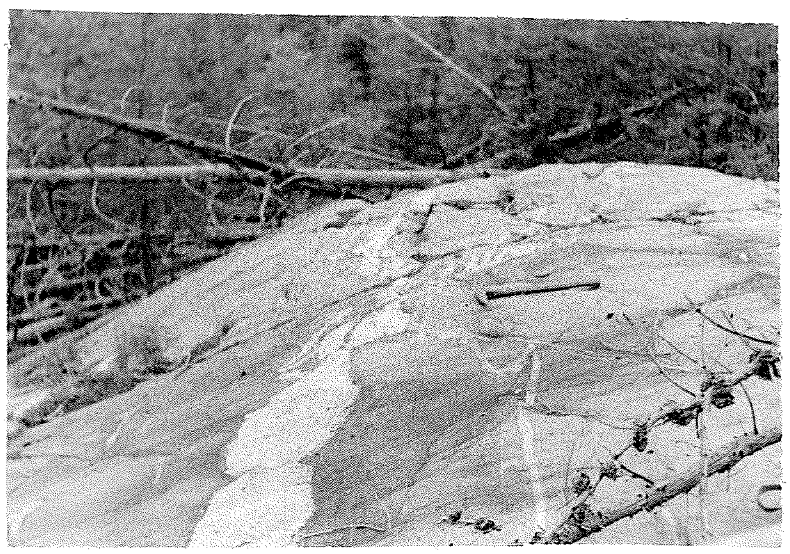
A. Partly assimilated remnants of amphibolite in the granite.



B. Partly assimilated remnants of amphibolite in the granite.

PLATE 9

A. Pegmatitic and granitic material intruded along amphibolite layers. The amphibolite is a remnant block in the granite.



B. Relatively undeformed, pegmatitic material intruded into massive, clean-looking Nokomis gneiss. The foliation direction is roughly parallel to the pick handle.

PLATE 10

were determined by thin section point counts. Sample 1 is from the second zone of the large zoned granite body. Sample 2 is from the inner core of the same body. Sample 3 is from the granite intrusion south of the south-east tip of the zoned granite body. The ratio of potassium to soda-lime feldspars indicate that they are both granodiorites. Mineralogically, the three samples are very similar except for the absence or presence of minor amounts of muscovite and garnet.

Pegmatitic material is present in most of the map area. The color of the pegmatites varies from white to pink. They occur as dikes, sills, pods, lenses and many other irregular forms in all the rock types.

TABLE 2

Modes of Granites

Sample Number	1	2	3
Quartz	29.3 %	31.8 %	34.3 %
Plagioclase	47.6 %	47.2 %	47.6 %
Potassium feldspar	19.4 %	18.0 %	9.4 %
Biotite	3.7 %	2.8 %	7.1 %
Muscovite	---	0.2 %	0.1 %
Garnet	---	---	1.5 %

Garnetiferous Quartz Diorites

Large areas in the northern part of the map sheet are underlain by quartz diorites. Many of these outcrops are intruded by pegmatitic and granitic material which may make up 20 % to 50 % of the total outcrop. In one locality the quartz diorite appeared to have been fragmented and the fragments separated by intrusive material. These blocks could be visually fitted together showing a separation movement of approximately a foot. Some outcrops of quartz diorite contain wisps and remnants of garnet-biotite-quartz-feldspar gneiss that probably are Nokomis gneiss.

The quartz diorites are a medium to dark grey on the fresh surface and weather to a lighter grey color. They are inequigranular, medium to coarse grained, and are usually massive except for a foliation developed locally by the alignment of biotite flakes.

Feldspar, quartz, biotite, and garnet comprise the mineral assemblage present in the quartz diorites. The average amounts of these minerals are; plagioclase (65 %), quartz (20 %), biotite (10-15 %) and garnet (2-5 %). Feldspar crystals are the largest present and may range up to 10 mm. in size. Garnets range in size from ½ to 3 mm. The garnets are arranged in clusters or aggregates of many smaller crystals. These clusters are approximately 1 inch in diameter.

Pyroxenite

Five small bodies of pyroxenite, from 50 to 500 feet across were found in the Nokomis gneiss. These bodies are roughly circular in outline and have conformable contacts with the surrounding Nokomis gneiss.

The fresh rock is dark green and is composed mainly of large crystals of pyroxene, up to 2 inches across. The pyroxene crystals are extensively altered to hornblende and in places to biotite. Feldspar occurs in minor amounts. Chalcopyrite and pyrrhotite occur in minor amounts in some of the pyroxenite bodies. The outcrops weather to a brown color and have a rough, pitted appearance.

Origin and Age Relationships

The origin and relative ages of the Kisseynew gneisses still remain a problem. No clues to origin, other than the composition of the gneisses, are present in the area. The author agrees with the interpretation of the origin as presented by Byers and Dahlstrom (1954).

> "The Kisseynew gneisses have been formed by the regional metamorphism of rocks of widely different composition including those of sedimentary, volcanic, and intrusive origin. That the bulk of the gneisses are highly altered sediments and that the color banding is coincident with the original bedding is perfectly clear from their mineralogical and chemical composition. If further evidence were

necessary it can be easily found in those areas of less intense metamorphism where the sediments still retain their original characteristics and from where they can be traced along strike into typical gneisses. The biotite and the biotite-garnet gneiss and granulites are the metamorphic equivalents of sandstones, greywackes and thinly bedded sandstones and quartzose shale. "

"The hornblende gneisses and the amphibolites are of diverse origin. Some can be traced into relatively unmetamorphosed rocks which are of volcanic origin. Other bands are just as clearly derived from argillaceous sandstones. However some amphibolites are undoubtedly metamorphosed basic intrusions."

The relationship between the groups of gneisses and the stratigraphy within the groups is a problem. Byers and Dahlstrom (1954) state:

"The gneisses in general are so complexly folded and lack recognizable marker horizons that, with the data available, it is next to impossible to work out a stratigraphic succession and to estimate the thickness of the various formations. However, the general stratigraphic sequence appears to be as follows: gneisses and schists representing greywacke and interbedded argillite, and calcareous argillite, gneisses derived from conglomerate, and gneisses, granulite and quartzite developed from arkoses and sandstone. The total maximum thickness is probably not very great as the gneisses dip gently over large areas and elsewhere the complex folding has undoubtedly produced repetition of the formations."

There is no evidence of a major break between the Nokomis and Sherridon groups. Recent workers, Robertson (1953), Pollock (Davies et al. 1962), suggest that the contact is transitional. Robertson (1953) determined from the Moody Lake anticline, that the younger rocks are Sherridon and that the older rocks are

Nokomis. In this case he concluded that the Sherridon gneiss is post-Nokomis and that it occupies synclinal areas within the Nokomis gneiss. J. F. Davies et al. (1962, p. 94) state;

> "The Nokomis rocks, however, can be traced into 'post-Sherridon' rocks of the Sherridon map area, where apparently the stratigraphy should be reversed and the Sherridon structure considered synclinal, as also postulated by Sherritt Gordon geologists..."
>
> ....Pollock, (personal communication) in mapping the area between Kississing Lake and the Manitoba-Saskatchewan boundary, found Nokomis-type rocks overlain by Sherridon-type rocks."

The author is also of the opinion that the Nokomis gneisses are older and are overlain by the younger Sherridon gneisses. This follows from the structural interpretation that the Sherridon gneisses occupy synclinal areas within the Nokomis gneisses.

The relationship of the intrusive rocks to the gneisses and to one another is more readily established. This relationship, as shown in Table 2, the Table of Formations, is determined from the following evidence. The pegmatites are found cutting every other rock type. Two ages of pegmatites are present (B, Plate 4); an older deformed pegmatite that is pre- some stage of deformation, and a younger pegmatite that is still relatively undeformed. Granites and pegmatites are found intruding the garnetiferous quartz diorites and the gneisses. Remnants of Nokomis gneiss are present in the quartz diorites. Remnants of amphibolites and gneissic structures are found at the edges of some granite bodies. The pyroxenite bodies are found only in the Nokomis gneiss and are assumed to be intrusive features. Their relative ages can be established only as being post-Nokomis.

The history of the zoned granite northeast of Russick Lake presents a problem. An intrusive origin is suggested by the amphibolite xenoliths, found in different stages of assimilation, in the outer zone. The recrystallization of the granite to a xenomorphic texture implies that the intrusion occurred before or during the period of regional metamorphism. The relict structures found in the outer zone of the granite suggest that the granitization of the adjacent paragneiss took place after their folding. The surrounding gneiss has been folded and suggests that the granite itself was affected by folding.

The fact that the granite is metamorphosed restricts its emplacement to before or during the period of metamorphism. The granitization of deformed gneiss indicates that at least the last part of the granitization process occured after deformation had begun. If granitization is assumed to be a later metamorphic process, then the granite magma may have been intruded before the period of deformation. However, if granitization is assumed to be due to igneous emanations, the magma may have been intruded during or after the deformation. The probable answer is that the intrusion was before or during the early part of metamorphism and deformation.

The history of the zoned granite appears to be as follows; The intrusion and solidification of the magma formed the inner and intermediate zones, and part of the outer zone. The outer zone was then added to by granitization of the surrounding gneiss and migmatite during the later stages of the regional metamorphism.

CHAPTER III

STRUCTURAL ELEMENTS

Introduction

The five structural elements measured in the field were foliation, lineation, joints, faults and folds. These elements are discussed in the following paragraphs.

Planar structures

Primary features, such as primary bedding are not present in the outcrops. Foliation, compositional banding and color banding are the only planar structures observed. These three structures occur together in the Sherridon gneiss where they are all parallel to one another.

Compositional banding in the Sherridon gneiss is produced by changes in the relative amounts of the four constituents; quartz, potassium feldspar, plagioclase and biotite. This compositional banding is accentuated by the color banding. The color banding is due to the variation in the amount of black biotite, pink potassium feldspar and white quartz and plagioclase in the different layers.

Foliation

Foliation is the only planar feature in the Nokomis gneiss. The foliation is due mainly to the parallel arrangement of platy minerals and is not as prominent as in the Sherridon gneiss. The Nokomis gneiss is more uniform in color and composition than the Sherridon gneiss. However, pegmatitic lenses and stringers that tend to occur parallel to the foliation surfaces are an aid in the determination of the foliation direction in the Nokomis gneiss.

Lineations

Two types of lineations were observed in the field; minor fold axes and mineral elongation.

Large areas in the Sherridon gneiss have lineations in the form of elongated bundles or knots of sillimanite-rich material. These bundles are flat and have an ovoid shape in the plane of the foliation (A, Plate 3). The alignment of hornblende crystals or aggregates of hornblende crystals, in bands of amphibolites in both the Nokomis and Sherridon groups produces a measureable lineation. Occasionally the feldspar in these mafic-rich bands is concentrated into flat lenses or streaks. The longest dimension of these lenses or streaks also constitutes a lineation.

Minor fold axes are found in both groups of gneisses. The Nokomis gneiss has many ptygmatically folded stringers of pegmatitic quartz-feldspar material (A and B, Plate 4). The axes of these folded stringers are lineations easily measured in the field. Other related lineations are corrugations in the foliation surface which occur at the contact between the gneiss and the pegmatitic material.

Joints

All of the joints in the area are vertical or steeply dipping. More than one joint set is present in most outcrops. The interval between joints ranges from 1 inch to tens of feet. A few of the individual joints are filled with pegmatitic material. One pegmatite in a joint displayed zoning. This filled joint had a central pegmatitic quartz zone surrounded by pegmatitic quartz-feldspar material. Epidote-filled joints are found in several locations in the area.

Faults

Many strong lineations are discernable on the air photographs of the area. On the ground these lineations are usually depressions in the topography with little or no outcrop.

Slickensides and sheared zones accompanied by chloritization, epidotization or mylonitization are observed along some of these lineations. The lineations possessing these features are considered to be faults. The remaining lineations observed on the air photographs are classified as possible faults.

.Folds

Minor folds, in the form of ptygmatically-folded pegmatitic stringers in the Nokomis gneiss and folded foliation surfaces in the Sherridon gneiss, are very common. Noses of larger folds are rarely seen in one single outcrop. All the larger folds, small enough to be observed in a single outcrop, are tight isoclinal plunging folds. The major folds constructed from the geologic map and the structural trend map are also tightly folded and essentially isoclinal.

CHAPTER IV

DESCRIPTION OF STATISTICAL RESULTS

Introduction

This chapter contains descriptions of the patterns and geometry of the statistical plots of the structural data. Statistical plots of foliation, lineations and joints were made on Schmidt equal area nets. The lower hemisphere was used for all plots.

The following statistical plots contain all the data obtained in the field. The large number of foliation measurements necessitated the division of the map sheet into six sub-areas. (See index map on accompanying Geologic Map of Russick Lake Area.) These sub-areas were determined on the basis of structural homogeneity and convenience. The contacts between the two major gneiss groups were used as boundaries of sub-areas wherever possible. The lineations and joints are divided into two groups; those occurring in the Sherridon Group and those occurring in the Nokomis Group and the granitic areas.

No attempt was made to redistribute the field data. Visual examination of the sub-areas shows a fair distribution of data without large concentration in any part. The results should not be biased by any particular portion of the sub-area.

Foliation

The pattern of the plots of poles to foliation surfaces are shown in Plates 11, 12 and 13. All of the plots of foliation data from the area have a single strong concentration.

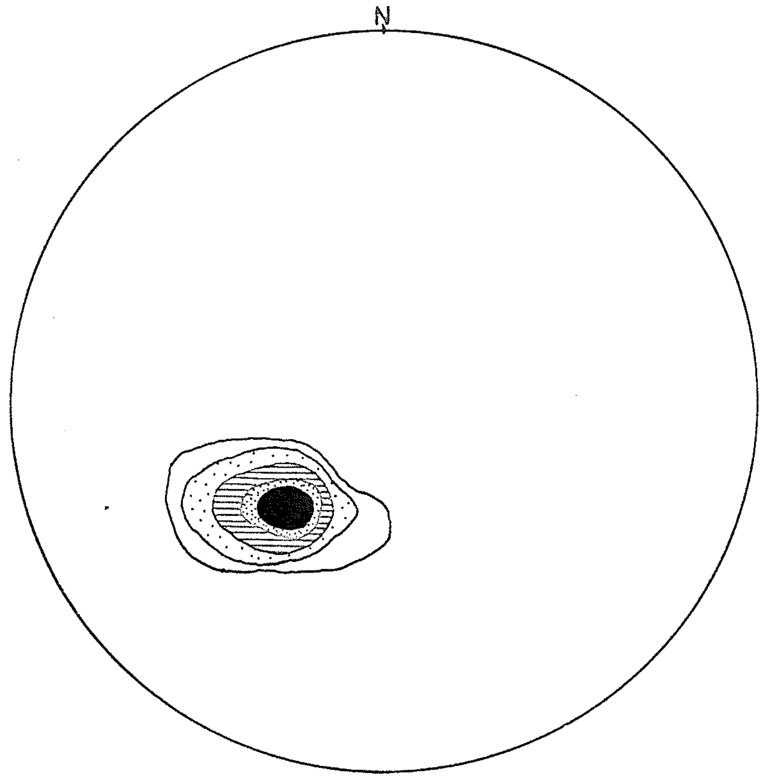
Equal area net plots of foliation data from sub-areas A and B are shown in Plate 11. The highest contour value is 40 % of the poles plotted per 1 % area on the net. The centre of the concentration in sub-area A represents the pole to a plane which has a strike azimuth of 132^{0} and a dip of 35^{0} northeast. The centre of the concentration in sub-area B is the pole to a plane having a strike azimuth 149^{0} and a dip of 35^{0} northeast.

Foliation data from sub-area C is shown in Figure A of Plate 12. The centre of the single concentration is the pole to a plane having a strike azimuth of 150^{0} and a dip of 30^{0} northeast. Some spread of the lower value contours is present. Sub-area F (Figure B, Plate 12) also has a single concentration, however, it is not as well defined as the preceding plots. The centre of the concentration is the pole to a plane striking 135^{0} azimuth and dipping 30^{0} to the northeast.

Foliation data from sub-areas D and E are presented in Plate 13. These equal area nets contain a single, strong concentration and a spread of the lower value contours. The shape of the low value

Sub-area

A

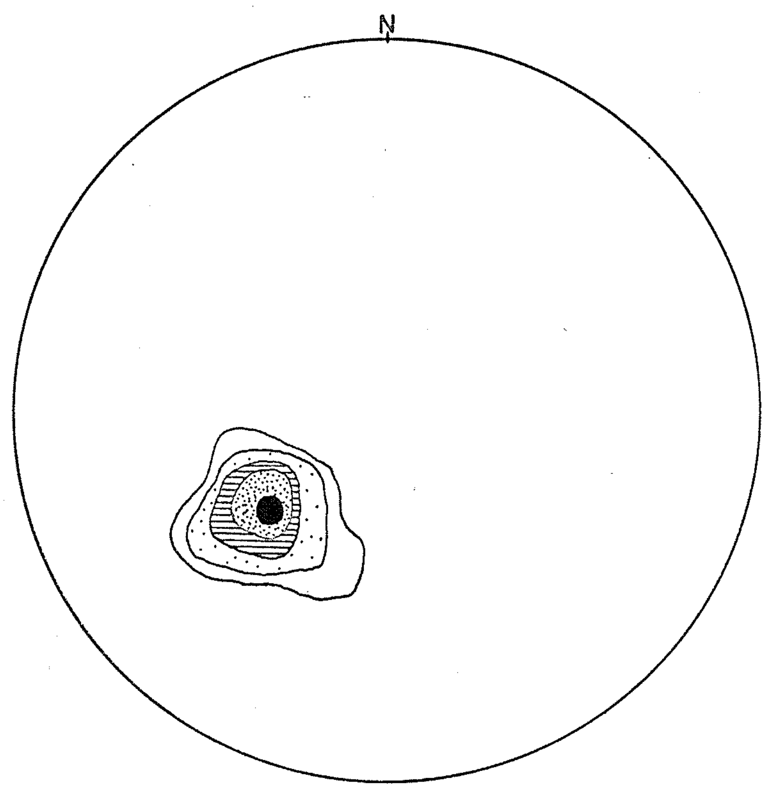


A.

54 poles to foliation in Nokomis gneiss
contoured at 5-10-20-30-40 %

Sub-area

B



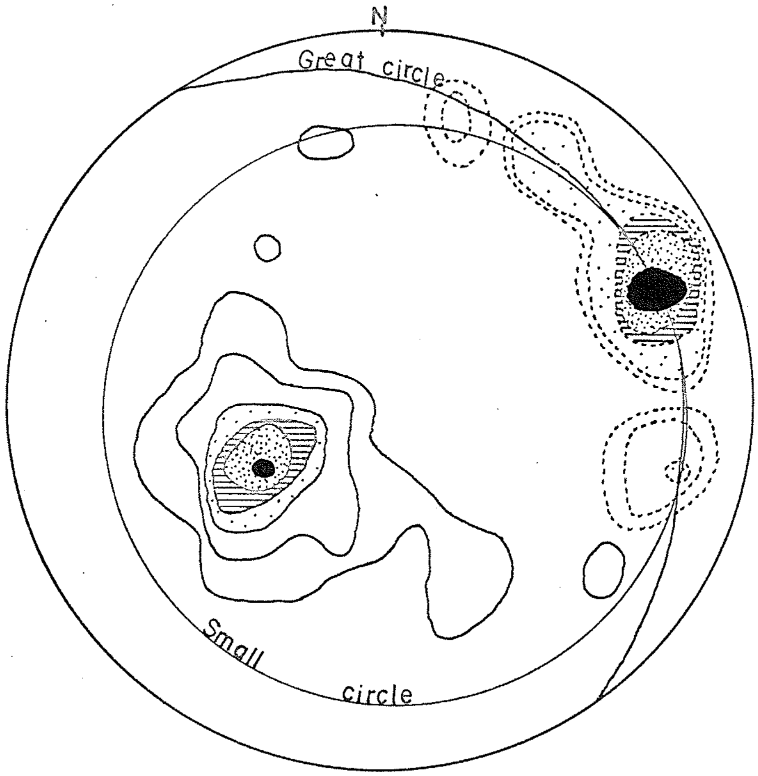
B.

92 poles to foliation.in Sherridon gneiss
contoured at 5-10-20-30-40 %

PLATE II

Sub-area

C

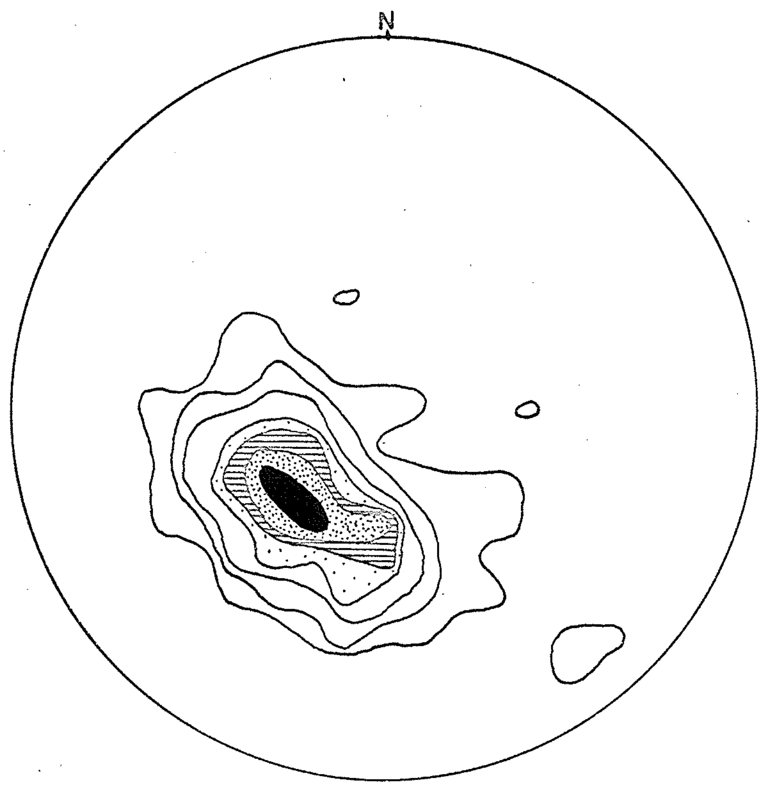


A.

114 poles to foliation in Nokomis gneiss
contoured at 1-5-10-15-20-25 % —
37 lineations contoured at 3-5-10-15-20 %---

Sub-area

F



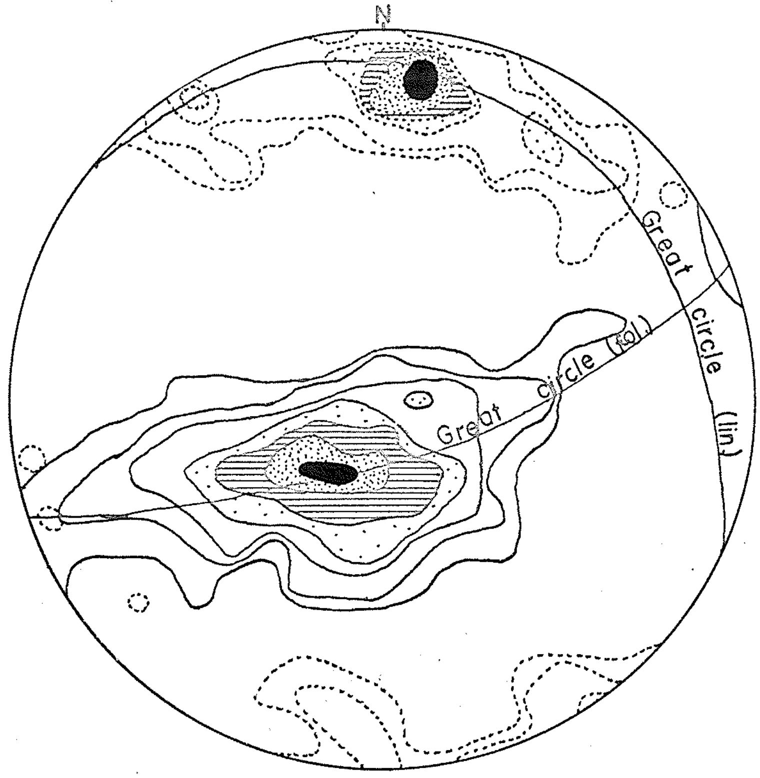
B.

171 poles to foliation in Nokomis gneiss and
granitic area
contoured at 1-3-5-7-10-12-15 %

PLATE 12

Sub-area

D

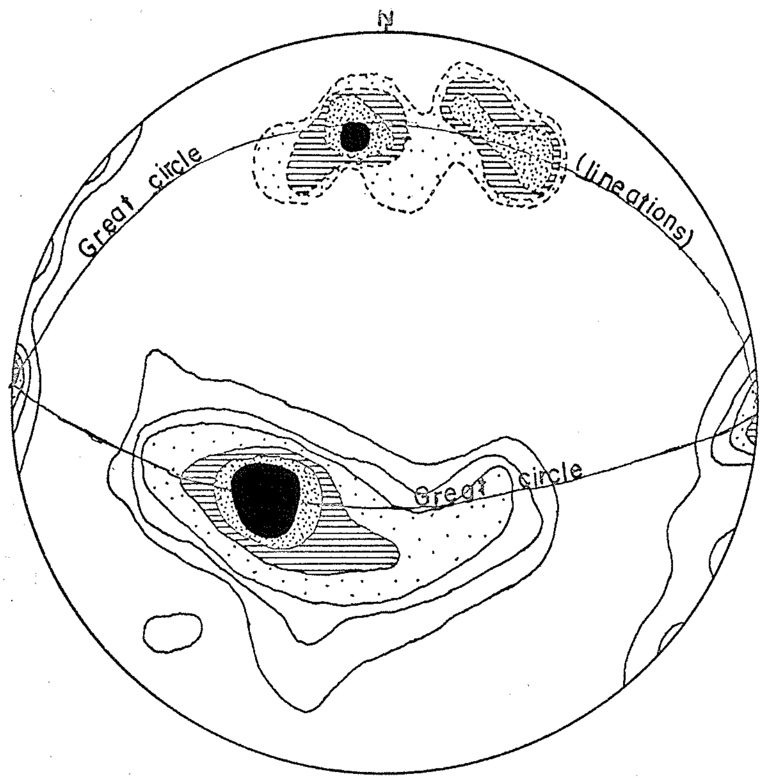


A.

341 poles to foliation in Sherridon gneiss
contoured at 1-2-3-5-7-10-12 % —
46 lineations contoured at 2-4-8-12-16-20 %---

Sub-area

E



B.

260 poles to foliation in Nokomis granite body area
contoured at 1-2-3-5-7-10 % —
23 lineations contoured at 5-10-15-20 %---

PLATE 13

contours in the plot of sub-area D is irregular, however, the direction of elongation of the contours indicates a spread of points falling approximately along a great circle girdle represented by a plane with a strike of 070^{o} azimuth and a dip of 78^{o} to the south. The pole to this girdle is a line bearing 340^{o} azimuth and inclined 12^{o} from the horizontal. The centre of concentration of sub-area D is the pole to a plane having a strike azimuth of 122^{o} and a dip of 20^{o} to the northeast. The girdle in the equal area net of sub-area E is a plane striking 096^{o} azimuth and dipping 65^{o} to the south. A line bearing 006^{o} azimuth and inclined 25^{o} is the pole to this girdle. The pole to the plane with an azimuth of 143^{o} and a dip of 35^{o} to the northeast is the centre of the concentration in sub-area E.

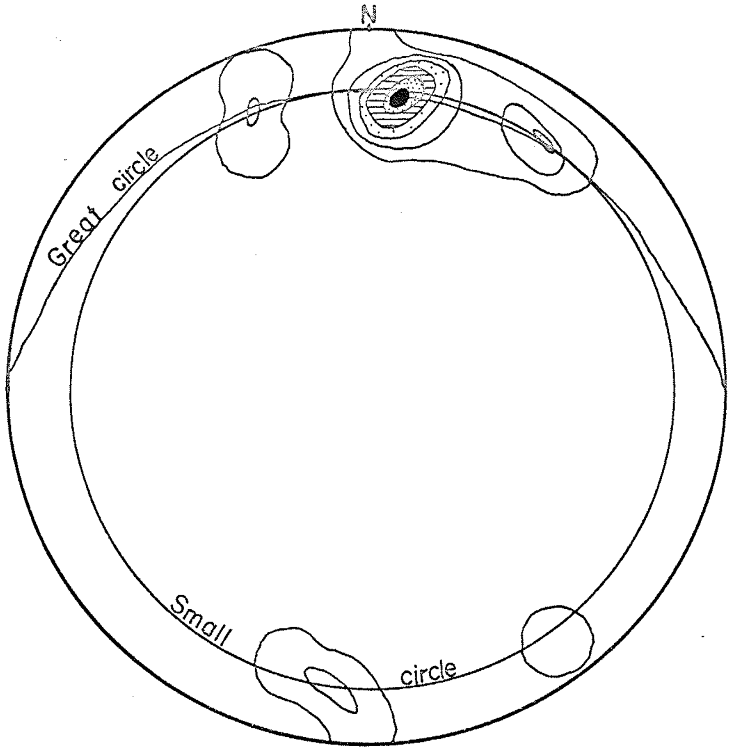
Lineations

Seven statistical plots of lineations are presented. All the lineation types are plotted together as they are all parallel to one another. These nets have from one to three concentrations in patterns which can be fit to either a great circle girdle or a small circle girdle. The degree of fit for the great circle or small circle varies for each net.

Figure A of Plate 13 represents a plot of all the lineations in sub-area D, which contains the majority of lineations in the Sherridon gneiss. A high concentration of lineations occurs at an azimuth of 006^{o} and an inclination of 20^{o}. The spread of the lineations may be considered to fall along a great circle (azimuth 134^{o} and dip 20^{o} northeast) or along a small circle girdle. The small circle is the intersection of a tilted cone, with a base angle of approximately 20^{o} and an apex angle of 140^{o}, with the lower hemisphere surface. The axis of the cone is tilted approximately 10^{o} north and west of the centre of the net.

Figures A and B of Plate 14 represent a division of the lineations in the Sherridon gneiss into two types. Figure A contains 20 mineral lineations and shows a single, strong maximum at an azimuth of 007^{o} and an inclination of 20^{o}. This can be fitted by a great circle girdle having a strike of 088^{o} azimuth and a dip of 20^{o} north. However, this girdle does not include the two low concentrations in the south portion of the net. A small circle with a vertical axis and an apical angle of 140^{o} fits all the concentrations and the spread of the lineations. Figure B, Plate 14 showing fold axes in the Sherridon gneiss, has one strong concentration and several weaker ones. The strongest concentration is located at an azimuth of 005^{o} and an inclination of 10^{o}. The spread of the lineations in the north and east portions of the net may be fitted by a great circle striking 160^{o} azimuth and dipping 24^{o} east. The concentrations may also be fitted by a small circle of large radius having the vertical axis tilted 5 to 10^{o} east of the centre of the net.

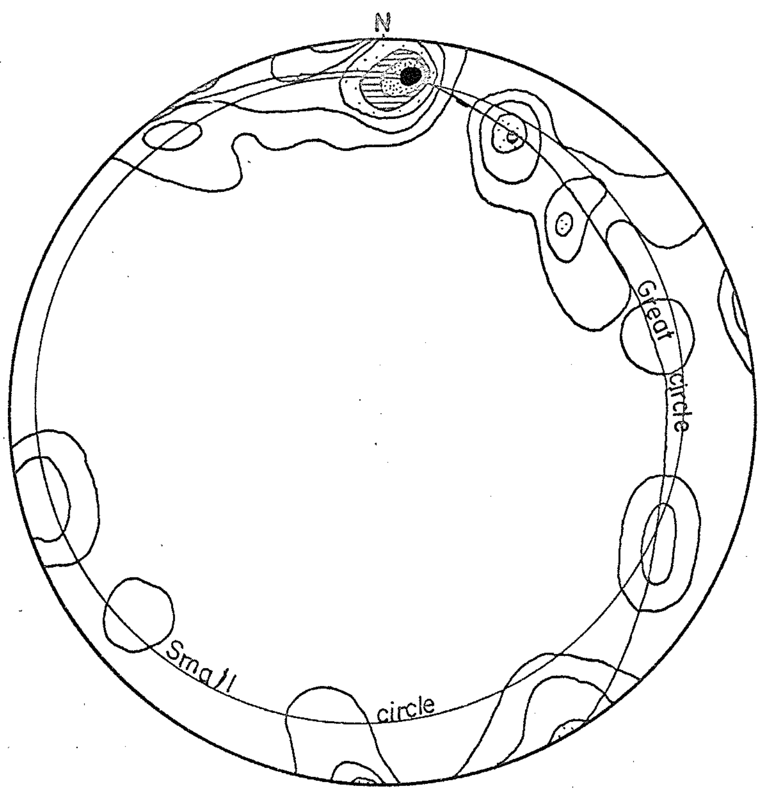
Lineation data from sub-area E is contained in Figure B, Plate



Sherridon Gneiss Mineral Lineations

A.

20 lineations of sillimanite bundles in Sherridon gneiss contoured at 5-10-15-20-30-40 %



Sherridon Gneiss Minor Fold Axes

B.

33 lineations in Sherridon gneiss contoured at 3-6-9-12-15-18 %

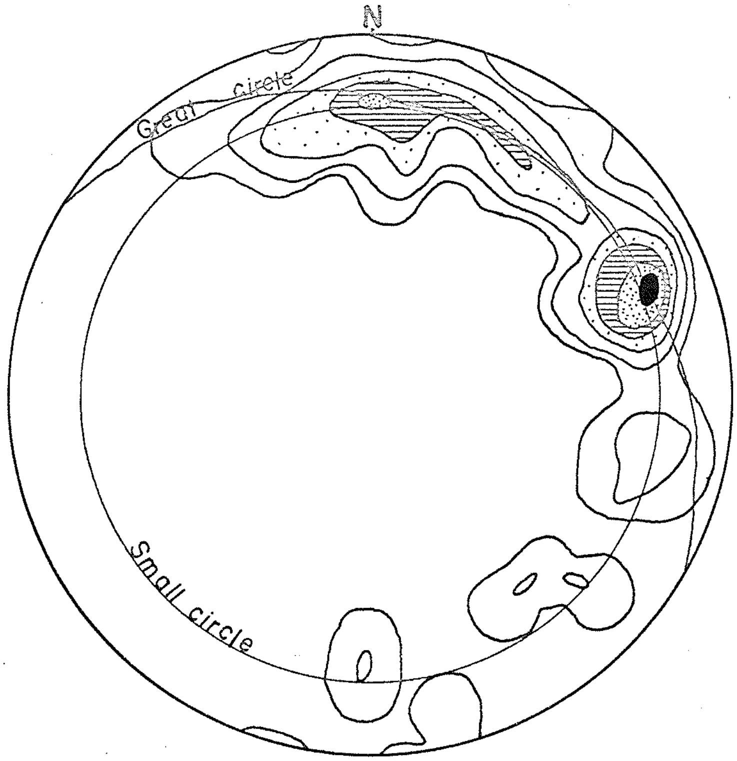
PLATE 14

13. Two strong concentrations are present; one at an azimuth of 354° and an inclination of 26° and the other at an azimuth of 025° and an inclination of 20°. These two centres may be placed on a great circle girdle having a strike of 090° azimuth and a dip of 28° north.

Lineations in sub-area C, (Figure A, Plate 12) plot as a spread with a single strong concentration. The centre of the concentration is at 070° azimuth inclined 20°. Either a great circle or a small circle can be drawn to fit the spread. The great circle has an attitude of 148° azimuth and dips 25° to the northeast. The small circle that fits the spread is the trace of an essentially vertical cone having an apical angle of approximately 140°.

All of the lineations obtained in the map area are plotted in Figure B of Plate 15. One strong concentration and several weaker ones are observed in the net. The centre of the strongest concentration is at an azimuth of 002° with an inclination of 22°. The pattern of the lineations in the net can be fit to a great circle girdle striking 130° azimuth and dipping 25° northeast. Alternately the pattern can be fit to a small circle corresponding to an essentially vertical cone having an apical angle of 140°. Figure A, Plate 15 contains lineations from Nokomis gneiss and migmatite areas. This plot has a pattern similar to Figure B, Plate 15. It differs only in the position of the maximum concentration. The maximum concentration in Figure A is at azimuth 070° with an inclination of 20°.

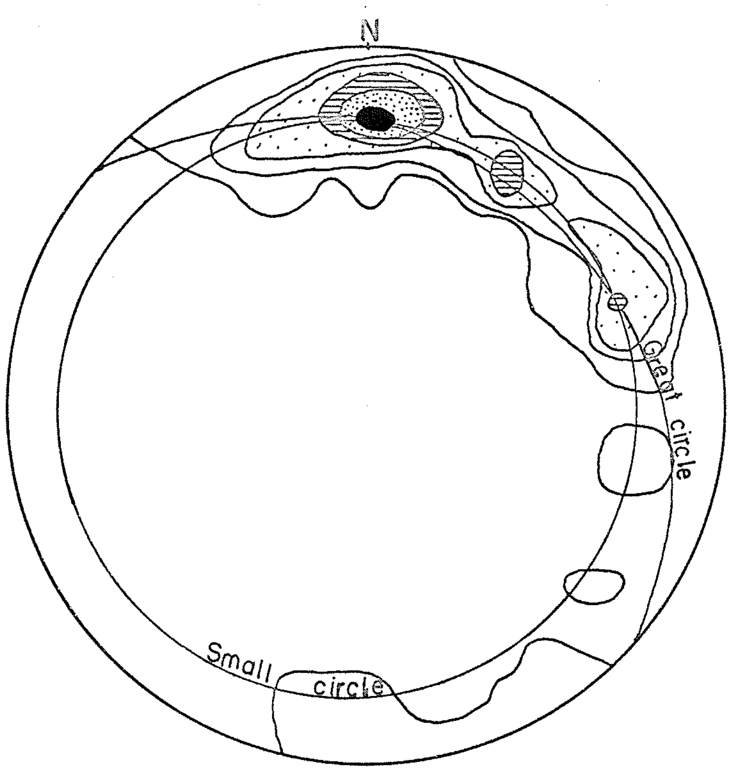
Nokomis
Gneiss and
Migmatite
Areas



A.

67 lineations in Nokomis gneiss
contoured at 1.5-3-6-9-12-15 %

Map
Area
Synoptic



B.

121 lineations in the map area
contoured at 1-3-5-8-10-12 %

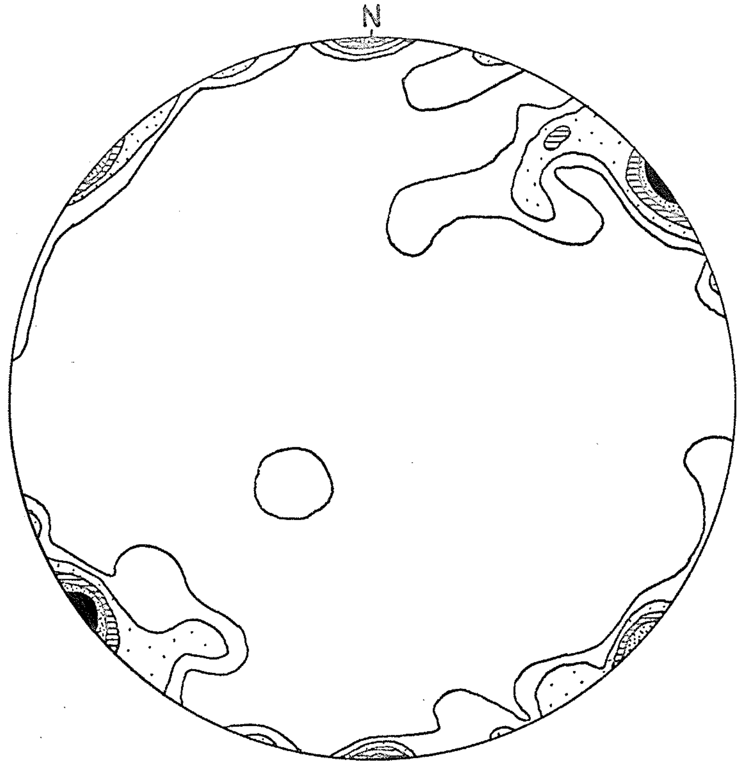
PLATE 15

Joints

Poles to all the joints measured in the area were plotted on a Schmidt net and contoured to produce the synoptic plot presented as Figure A, Plate 17. The joint data were then separated into two groups; one containing the data from the Sherridon gneiss area, and the other containing data from the Nokomis gneiss and granitic areas. The joints recorded in the Sherridon gneiss are shown in the equal area net in Figure A of Plate 16. The joints from the other areas are plotted in the equal area net shown in Figure B of Plate 16.

The synoptic plot of the map area contains 106 poles to joints (Figure A, Plate 17). This plot presents four concentrations at the periphery of the Schmidt net; three strong concentrations and a fourth weaker one. The strongest concentration of poles to joints represents the most frequently sampled joint set striking northwest to southeast and dipping vertically. The next strongest concentration represents a joint set striking northeast to southwest and dipping vertically. The weakest of the three strong concentrations represents a joint set striking east to west and dipping vertically. The fourth weak concentration is produced by a joint set striking north to south and dipping vertically.

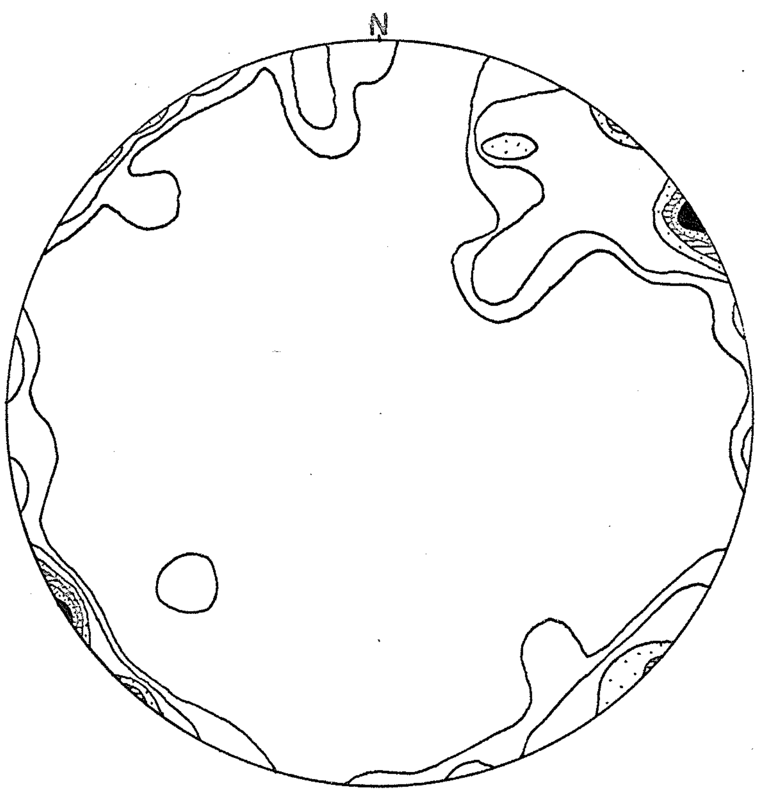
The equal area net (Plate 16, Figure A) containing the plot of poles to joints in the Sherridon gneiss area, has three evident



Sherridon Gneiss

A.

50 poles to joints in Sherridon gneiss
contoured at 2-4-8-12-16 %



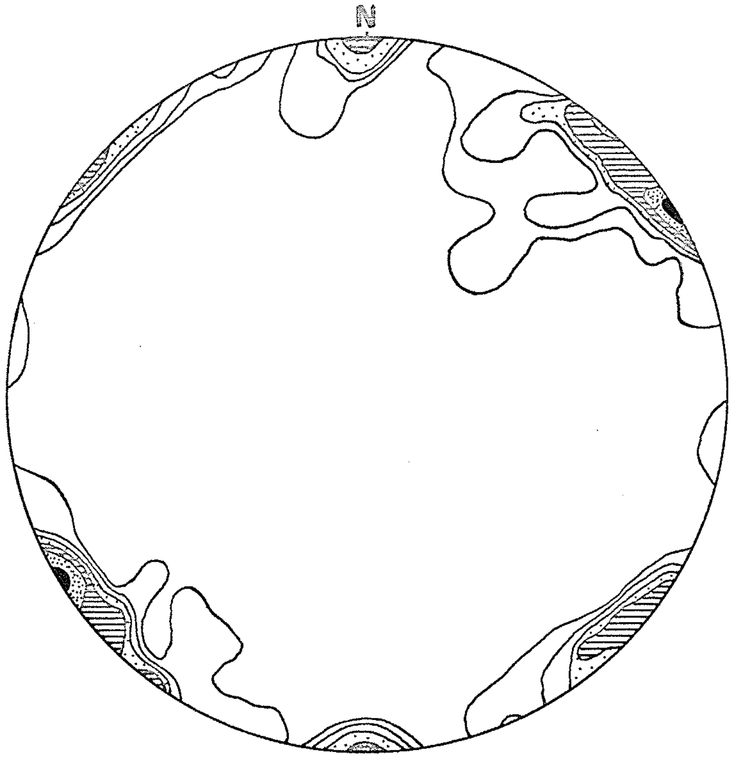
Nokomis Gneiss and Granitic Areas

B.

56 poles to joints in Nokomis gneiss
contoured at 1-3-7-10-15-20 %

PLATE 16

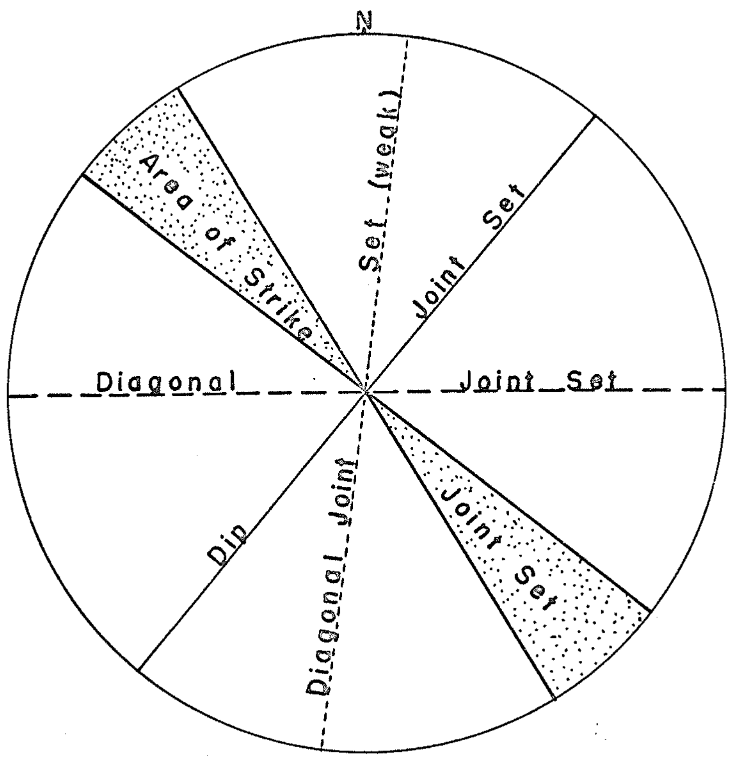
Map Area



A.

106 poles to joints in map area
contoured at 1-3-5-7-10-15 %

Diagramatic
Synoptic
Stereogram



B.

Joint system for area with
joint sets labelled

PLATE 17

concentrations. The strongest concentration represents a joint set striking northwest to southeast and dipping vertically. The next strongest concentration represents a joint set striking northeast to southwest and dipping vertically. The weakest concentration is produced by a joint set striking east to west and dipping vertically.

The plot of the poles to joints in the Nokomis gneiss and the granitic areas(Figure B, Plate 16) has two strong and two weak concentrations. The strongest concentration is a broad concentration containing two adjacent maxima which is produced by a joint set, of variable strike, striking northwest to southeast and dipping vertically. The weaker of the two strong concentrations represents a joint set striking northeast to southwest and dipping vertically. The two weaker concentrations are produced by joint sets striking north to south and east to west and both dipping vertically.

CHAPTER V

INTERPRETATION AND DISCUSSION

Introduction

This chapter reviews and discusses the structural data, and other evidence and features observed in the field. Possible interpretations are drawn from the evidence and presented and discussed.

Pattern of Foliation

The patterns obtained in all the statistical plots are basically similar. These plots contain one strong maximum with a concentric spread around this concentration. This pattern can be produced by two structurally different models. The first model contains simple, essentially parallel, dipping foliation surfaces. The second model has isoclinally-folded foliation surfaces with essentially planar parallel limbs. The complex folding present in the area suggests the second model to be more valid.

The two foliation plots on Plate 13 can each be interpreted to contain a girdle in addition to the single strong concentration. Examination of the sub-areas represented by these nets explains the presence of the girdles. In Figure A of Plate 13 the girdle is produced by the large refolded isoclinal fold near the centre of sub-area D. This refolded fold is more clearly visualized on the structural trend map on Plate 18. The foliation strike direction at the north end changes approximately 180 ^{o}, from north-west, to west, through south, to south-east, around the nose of the fold. The dips remain shallow to moderate around the fold except for steeply dipping north-south attitudes along the western limb. This change is expressed as a girdle on the net.

The foliation pattern in Figure B of Plate 13 is produced in sub-area E by the shape of the granite body. This body can be visualized as having three sides, an arcuate north side and essentially planar west and south sides. The dips are moderate and fairly constant, between 35^{o} and 45^{o} along all the edges of the granite body except for vertical dips along the western edge. This tautozonal foliation pattern suggests a north-plunging, plug-like body if the assumption, that the granite remains concordant with the foliation in the subsurface, is made. In the net, the vertical foliation surfaces along the west edge of the granite produces the weak concentration at the periphery of the net. The arcuate north edge produces a spread of foliation strike directions and a girdle on the net.

Pattern of Lineations

The two main gneiss groups contain different kinds of lineations but these lineations are all parallel. The Sherridon gneiss has two types of lineations; mineral elongations and axes of minor folds of foliation surfaces. Separate plots of the mineral elongations and the fold axes were made in an attempt to separate these two types of lineations (A and B, Plate 14). However, these two plots were similar and showed that the two types of lineations are parallel. The lineations in the Nokomis gneiss are mainly fold axes of ptygmatically-folded pegmatitic material.

Sherridon Lineations

The lineations in the Sherridon gneiss are either mineral elongations or axes of minor folds of foliation surfaces. The mineral elongations may be formed either perpendicular to the direction of tectonic transport, or along it (Billings, 1954, pp. 352-362; Badgley, 1959, pp. 53, 216). Mineral patches may grow perpendicular to tectonic transport or may be elongated by stretching or flowage parallel to the transport direction (Badgley, 1959).

The other lineations in the Sherridon gneiss, the axes of minor folds of foliation surfaces, also have these two possible orientations in relation to the direction of flow movement depending on whether laminar or linear laminar flow was in operation. Laminar flow movement, along the layers of a stratiform sequence, could produce folds in the foliation surfaces by rotation of the layers. This rotation could perhaps be due to viscous drag between adjacent layers moving at different velocities. These folds produced by rotation would have their axes perpendicular to the direction of movement.

The other possible orientation for the fold axes is a direction parallel to the flow movement. Carey (1962) states that flow movement over long distances produces folds or wrinkles with axes parallel to the direction of flow. These folds are produced locally by alternate distension and compression of the material during transport. The material is distensible, but not compressible, and the compression must be taken up by folding. The fold axes are actually produced, perpendicular to the local distension and compression movement, by rotation. However, these fold axes are parallel to and directly related to the major mass transport direction.

Folds with axes parallel to the direction of tectonic transport may also be produced by linear laminar flow operating on former folds. This linear movement in laminar flow would rotate the former fold axes into a new position approaching the direction of linear movement.

Nokomis Lineations

Lineations in the Nokomis gneiss are fold axes in ptygmatically-folded pegmatitic stringers. This pegmatitic material is folded by movement along foliation surfaces in a well foliated gneiss. The pegmatitic material probably originated as intrusive dikes cutting the gneiss. These dikes may have been originally randomly oriented or may have been oriented in a preferred direction. The pegmatitic stringers in the outcrop are both concordant and discordant, dependent on the amount of local flow movement, with the foliation.

Laminar flow movement along the foliation surfaces would produce randomly oriented lineations in originally randomly oriented pegmatitic dikes. The dikes would require a preferred orientation to produce lineation concentrations by laminar flow. However, in order to produce a lineation concentration parallel to the lineations in the near-by Sherridon gneiss the original pegmatite dikes would require a unique orientation. The dikes must have a preferred orientation (be parallel) and also have the lines of intersection between the dikes and flow layers parallel to the lineation direction in the Sherridon gneiss. This arrangement is very special and, therefore, is considered as an unlikely explanation.

Linear laminar flow could produce concentrations of fold axes in ptygmatically-folded dikes by rotation. Laminar flow would produce ptygmatic folds in discordant dikes. Linear movement in laminar flow would rotate the fold axes into a position approaching the direction of flow. Linear flow would produce the parallelism of lines of intersection of discordant pegmatitic dikes and other lineations with the direction of flow.

Discussion

Laminar flow could produce the lineation patterns perpendicular to the transport direction if a unique original orientation is assumed for the pegmatite dikes in the Nokomis gneiss. Linear laminar flow on the other hand could produce the lineations parallel to the direction of linear flow movement. Outcrop evidence, bent or warped fold axes and different orientations for immediately adjacent fold axes in the same folded dike, suggests a linear movement. However, the evidence is not conclusive and no definite conclusion can be presented. Mechanics of flow folding are not yet completely understood and perhaps some unknown process is controlling the observed pattern of concentration.

Lineation Patterns

All of the sub-areas, except sub-area C, have single lineation concentrations in the north portion of the nets and spreads which can be fitted by great circle girdles. Sub-area C also has a single concentration and a similar spread, but in the east portion of the net. It appears as if the lineations in sub-area C have been rotated 70^{o} clockwise with respect to the concentrations in the other sub-areas. In the granite body (sub-area E) the lineation concentration is roughly parallel to the plunging zone axis of foliation directions.

In the preceding chapter the lineation patterns may be fitted to both great circles and small circles. The lineations in the Nokomis gneiss fit into a small circle because of certain limitations. The fact that the lineations lie in the plane of the foliation, limits their inclination from zero to the maximum dip of the foliation. The majority of the dips are gentle to moderate. The relative absence of steep foliation and horizontal or nearly horizontal lineations limits the lineation pattern to a position near the periphery of the nets. The variation of the foliation direction from a northwest-southest to an east-west direction places the concentrations of the lineations in the north and east portions of the nets. A glance at the geologic map shows this gradual change in the foliation direction. The foliations in the southeast part of the map trend northwest to southeast and change to an east-west direction in the northwest part of the map area. These limitations cause the lineations to plot near the periphery in a position that is best fitted by a small circle with a vertical or near-vertical axis. This vertical axis, however, is due to the change in foliation direction without a change in the amount of dip. These changes produce the effect of rotation about a vertical axis.

Pattern of Joints

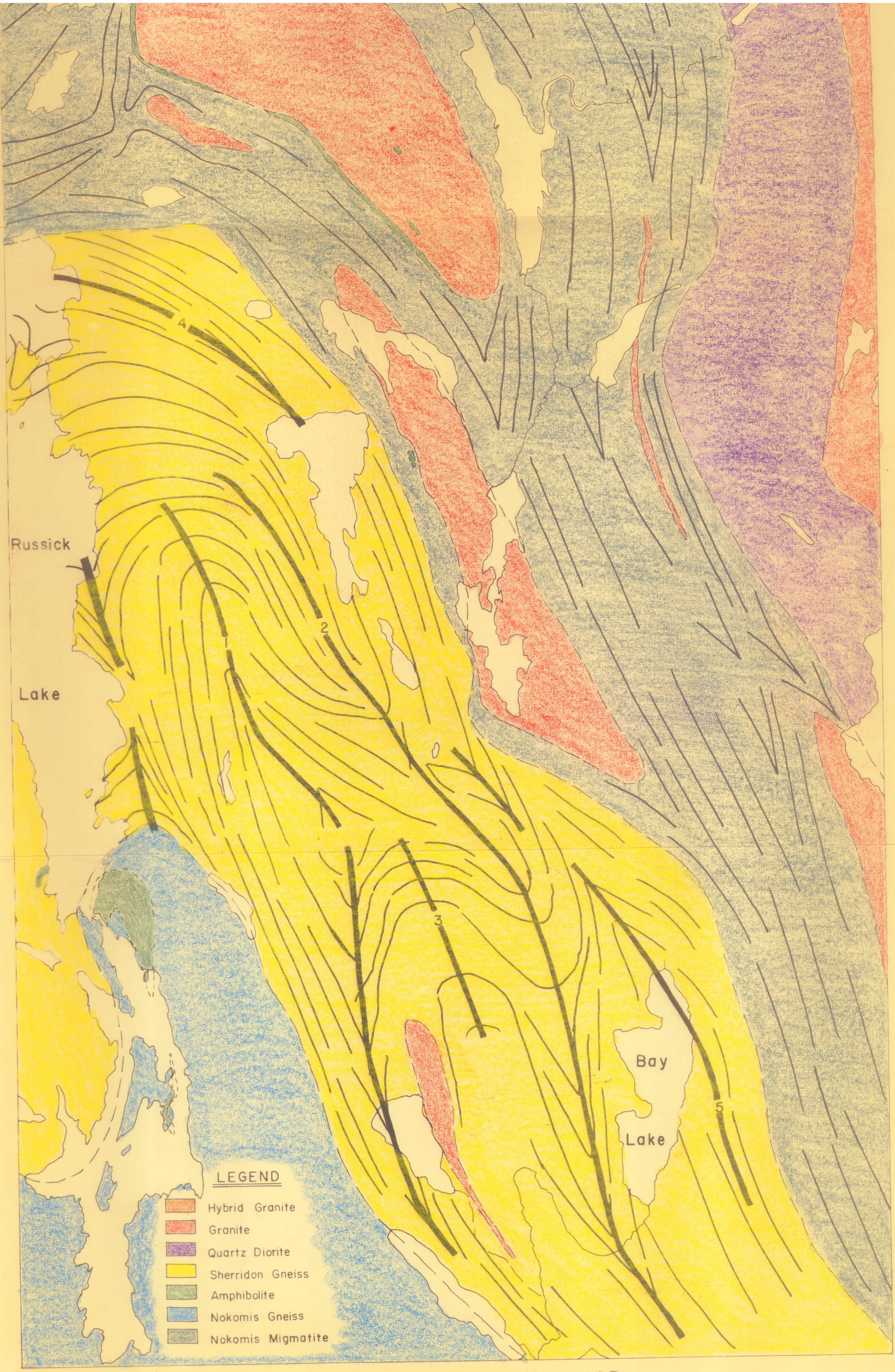
The plots of the poles to the joints present a clear picture of the joint system. The pattern of joints shown in the equal area nets indicates poles distributed along the peripheries signifying that the majority of the joints are vertical or steeply dipping. Four sets of joints are present in the area, a strike-joint set, a dip-joint set and two diagonal-joint sets (Figure B, Plate 17). These sets are related to the foliation using the geometrical classific-ation (Billings, 1958).

The most prominent set in the equal area nets is the strike-joint set. This set is approximately parallel to the strike and perpendicular to the dip of the foliation. The variation in the direction and amount of dip of the foliation causes a variation in the direction and dip of the strike-joint set. Perpendicular to the strike-joint set is the dip-joint set which strikes northeast. Two weaker diagonal-joint sets, a set striking east and a set striking north are present in the area.

A comparison of the joint pattern from the Sherridon gneiss area and the Nokomis gneiss area shows them to be very similar. The only difference is the presence of a weak east-west diagonal-joint set in the Sherridon gneiss area which is not present in the Nokomis gneiss and granitic areas (Plate 16, Figures A and B). The excellent grouping of the joints into sets and the relation of the sets to the foliation would suggest that the joints are related to the folds. This grouping would attribute the origin of the joints to post-deformational stresses in the folded rocks.

Structural Trend Lines

Trend lines of the structures in most of the Sherridon gneiss area can be plotted with the aid of air photographs (Plate 18). These trend lines are continuations of the strike of the foliations plotted on the map and outline the structure and form of the folds in this belt. The Nokomis gneiss areas lack the stratiform layering and the outcrop expression of this layering which is present in the Sherridon gneiss. The results of a similar representation of the structures in the Nokomis gneiss are more interpretive and less reliable. The extrapolation of foliation data and the use of trend lines in the Nokomis gneiss is undertaken only to show the main trends.



STRUCTURAL TREND MAP

PLATE 18


Russick
Lake

Plate 18 is an interpretation of the fold pattern observed in the area as outlined by the extension of the foliation data from air photographs. The structural pattern is reduced to its essential features by also plotting the traces of the axial planes of the interpreted folds.

The Sherridon gneiss belt thins to the east and widens considerably to the west. This pattern can be interpreted in several ways. One interpretation of the change in width, is flow movement with transfer of material from the thinner portions to the thicker portions of the belt. Another interpretation is that changes in the third dimension are as great as in the other two observable directions; the thicker portions of the belt then represents a deeper and broader infolding of Sherridon gneisses. The complexity of the problem illustrates that a simple statement of the origin or cause of the observed fold pattern is not possible.

In Plate 18 the traces of five long axial planes and several shorter ones are shown. These traces are of the axial planes of the interpreted folds and in all likelihood also represent a component of the main direction of material transfer by flow. A close parallelism of the traces of axial planes and the boundaries of the Sherridon gneiss exists. The small granitic body, intermediate in position between Bay Lake and Russick Lake, has been elongated parallel to the contacts of and the foliation in the surrounding gneiss. This body has probably changed shape by flowage from its attenuated southern end to its thickened northern end. It also exerted some influence on the flow pattern in the surrounding gneiss and may be responsible for the broad open fold, shown by axial line 3, immediately north of it. The presence of this granite body may also have influenced the position of the axial line passing between it and the southern Sherridon-Nokomis contact.

The north part of the large fold, whose axial trace is shown by line 2, appears to be refolded about axial line 1. This refolding can be interpreted as representing one single period or two stages of folding. Carey states that one period of flow can produce the refolding by a change in the flow direction with time (Charlesworth and Lambert, 1964). Wynne-Edwards (1957) believes the viscous drag of slower moving synformal portions of the folds causes the faster moving antiformal nose to shift towards the synformal area and produce refolded folds. The noses of the antiforms curve towards the area ahead of the slower moving synformal areas.

The pattern of the folding observed in the Sherridon gneiss can be produced by flow movement from several different directions. Foliation surfaces and axial planes of the folds are in the plane of the main laminar flow movement.

One interpreted direction of laminar flow is essentially horizontal movement in the plane of the foliation perpendicular to the concentration of lineations in the Sherridon gneiss. The other possible direction of laminar flow is movement parallel to the concentration of the lineations. The direction of movement that best fits the lineation patterns is laminar flow along the planes containing the axial planes and the foliation surfaces, and parallel to the lineations. Lineations perpendicular to the direction of laminar flow would be rotated into the direction of the movement by nonuniform (linear) laminar flow.

The interpreted pattern of the structural trend lines in the Nokomis gneiss belt to the north also infers movement and folding. (See Figure 18). The influence of the large zoned granite body upon the surrounding trend lines is evident. The mass of the granite body diverted the flow around it. The main flow movement was probably north and west around the north side of the body. The pattern in the gneiss at the west edge of the granite mass suggests that the granite body was forced against the adjacent gneiss. The movement of the gneiss around the north side of the granite mass probably caused some westward movement of the granite body. The gneiss along the western edge of the granite was carried along and folded by this motion.

Discussion of Plastic Flow

The grade of regional metamorphism of the area is high and sillimanite occurs in the majority of the gneisses. This implies the rocks were deeply buried and subjected to high temperatures and pressures during some period in their history. Individual outcrops in the field show that the rocks were mobile and moved by plastic flow (B, Plate 2; A and B, Plate 4). An increase in temperature and pressure affects the 'effective viscosity' of rocks and promotes movement by flow. Griggs demonstrated that a 3-fold increase in compressive stress gives rise to a 100-fold decrease in the equivalent viscosity of wet alabaster (Dobrin, 1941). The author recognizes that wet alabaster is not rock material but believes that the results have some bearing on rock behavior. Another important factor is time. Houwink (1958) states that time plays an important role in deformational processes. A deformation, which when executed quickly, is completely elastic, may become plastic if it is executed slowly. Plastic deformation also requires a stress greater than the yield value for the material concerned. The magnitude of the stress is probably not very large as the high temperature, pressure and long period of time involved would lower the yield value considerably. The environment of the gneisses during metamorphism definitely places them in the region of plastic deformation (flow folding) rather than in the region of elastic deformation (shear folding). Field evidence implies that plastic deformation occurred and the grade of metamorphism shows that conditions were reached to enable plastic deformation to take place.

Robertson (1953, p. 40-41) also arrived at a similar interpretation when he stated;

> "...folding occurred in the main during metasomatic metamorphism, they (the rocks) have reacted in a plastic way to produce complexly folded welts."

> ...the anticline is of an....."extremely complicated shape, and can be accounted for only by assuming extreme plasticity during deformation."

The author believes that the interpreted pattern of folding within the belt of Sherridon gneisses resembles a pattern produced by laminar flow of rocks. Outcrop evidence suggests the movement is in the plane of the foliation and that no transfer of material occurs across the layer boundaries. This agrees with the definition of laminar flow in that the fluid particles move downstream in smooth and regular trajectories without appreciable mixing between different layers of fluid (Shapiro, 1961). The foliation planes may be folded or contorted by movement but are not disrupted by actual transfer of material across the layers.

The fact that the pattern of the folds produced by plastic deformation resembles the pattern of viscous flow is not accidental. Viscous liquids and plastic solids obey the same laws during flow. The only difference is that a plastic solid has a yield value which a liquid does not possess. However, the yield value becomes smaller when long periods of time, and high pressures and temperatures are involved so that the plastic solid approaches a liquid in its behaviour (Houwink, 1958).

A study of the contacts between the two main gneiss groups shows the contacts to be straight lines or simple curves. The gneisses in the group on either side of the major contacts and the gneiss types within the groups are always conformable. This simple relationship indicates that the contacts are not complexly folded. However, complex folding within the different gneiss groups is present. This folding within the different gneiss groups themselves suggests contact control as a factor in the folding.

The basic theories of viscous flow emphasize the drag effects of boundaries on a moving fluid (Shapiro, 1961). This drag effect is perhaps the reason why all the contacts in the gneisses are conformable. The different gneiss types would have different "effective viscosities" and thus different rates of flow. Therefore their contacts would act as boundaries and produce drag effects. The boundaries of the gneiss groups and the boundaries within the gneiss groups would act as barriers to flow movement. These boundaries would keep flow movement parallel to and within the boundaries.

Flow movement in an isotropic, homogeneous mass would have only external boundary effects. However, the layered gneisses are anisotropic and heterogeneous. These internal properties would also exert a control on the direction of flow movement.

Regional Structures

On a regional scale the Sherridon type gneisses occur as elongate or approximately circular areas enclosed in Nokomis type gneisses. The Nokomis gneisses change outwards from the contacts with the Sherridon gneisses. They usually grade from gneisses at the contact, into migmatites and eventually into granitic areas away from the contacts.

The Kisseynew gneiss belt and the Sherridon gneiss areas within this belt have a regional east-west trend. The present distribution of Sherridon gneisses is probably controlled by regional fold structures. Deep erosion removed the bulk of the former sedimentary series and left the Sherridon gneisses only in synclinal areas. Metamorphism and plastic deformation aided by pre-tectonic and syntectonic granitic intrusions modified the former fold patterns.

The former structures were refolded by plastic deformation obeying laminar flow laws. Pre-existing folds, lithologic boundaries and other anisotropic features influenced the pattern of plastic flow.

CHAPTER VI

SUMMARY AND CONCLUSIONS

The gneisses in the Russick Lake area belong to the Kisseynew Complex, which is divided into two groups. These two groups are distinguished by mineralogical and compositional differences. The majority of the early workers in the Kisseynew Complex established the Sherridon gneiss group to be younger than the Nokomis gneiss group. The Sherridon group is always surrounded by gneisses of the Nokomis group and structural relationships indicate an infolding of the Sherridon gneiss in the Nokomis gneiss. However, the relative ages cannot be established unequivocally.

Primary features are not present in the area and all planar and linear elements are assumed to be due to the deformational processes. The foliation and compositional banding may represent primary bedding accentuated by metamorphic differentiation and migmatization.

A high degree of symmetry is obtained in the statistical equal area nets of the plots of lineations and poles to foliation and joints. The high concentrations in the foliation data are interpreted to represent isoclinal folding in the gneisses. The lineations and joints are related to the foliation surfaces. The lineations in the Sherridon gneiss, mineral lineations and fold axes of folded foliation surfaces, plot in a single concentration in the north part of the nets. The lineations in the Nokomis gneiss, the axes of ptygmatic folds, are best fitted by a small circle girdle in the northern and the eastern portions of the nets. These lineations were produced by the folding of intrusive dikes that were oriented across the direction of deformational movement. The joints are related geometrically to the foliation surfaces. The pattern of the joints is controlled by the shape of the gneissic bodies and the foliation direction. The joints plot into four sets; a strike-joint set, a dip-joint set, and two diagonal-joint sets.

The structures that best fit the structural data are plunging isoclinal folds produced by plastic flow. The metamorphic grade of the area suggests elevated temperatures, pressures and stresses over a long period of time. The rocks were in the 'zone of flowage' where folding is of an extreme type (Harker, 1939, p. 178). The pattern of flow resembles viscous flow of a liquid and is controlled by compositional banding within the Sherridon and Nokomis groups and by the major contacts between them.

The structural trend pattern (Plate 18) illustrates the close relationship between the boundaries of the gneiss types and the interpreted folds. Laminar flow along the foliation surfaces produced the observed lineation pattern. The direction of laminar flow could be perpendicular to or parallel to the lineation concentrations depending on whether laminar flow or linear laminar flow occurred. If laminar flow occurred the lineation patterns could be produced by an essentially horizontal flow movement perpendicular to the lineations. On the other hand, if linear laminar flow occurred, the direction of flow movement could be along the lineation concentrations. The direction of flow movement that best fits the lineation patterns appears to be flow along the foliation surfaces in a direction perpendicular to the lineation direction. Transfer of material is assumed to be from the narrower portions of the gneiss belt to the wider portions, a flow movement in a north-west direction. This transfer of material was along the path of least resistance to flow movement and does not necessarily have any direct relationship to principal stress directions.

SELECTED BIBLIOGRAPHY

Badgley, P. C.,
(1959) Structural Methods for the Exploration Geologist, Harper and Brothers, New York.

Barth, T.F.W.,
(1962) Theoretical Petrology, Second Ed., J. Wiley and Son, New York.

Billings, M.P.,
(1954) Structural Geology, Second Ed., Prentice Hall, New York.

Byers, A. R., and Dahlstrom, C.D.A.,
(1954) Geology and Mineral Deposits of the Amisk-Wildnest Lakes Area, Saskatchewan., Department of Mineral Resources, Province of Saskatchewan, Report No. 14.

Carey, S.W.,
(1962) Folding, Journal of the Alberta Society of Petroleum Geologists, Vol. 10, No. 3, March 1962.

Charlesworth, H.A. K, and Lambert, R.St.J.
(1964) Recumbent Folding in Metamorphic Terranes, . Bulletin of Canadian Petroleum Geology, Vol. 12, No. 4.

Davies, J.F., Bannatyne, B.B., Barry, G.S., McCabe, H.R.,
(1962) Geology and Mineral Resources of Manitoba, Manitoba Mines Branch.

Dobrin, M.B.,
(1941) Some Quantitative Experiments on a Fluid Salt-dome Model and Their Geological Implications, American Geophysical Union Transactions, 1941.

Harker, A.,
(1939) Metamorphism, Second Ed., Methuen and Co. Ltd., London.

Houwink, R.,
(1958) Elasticity, Plasticity, and Structure of Matter, Second Ed., Dover.

Pollock, G.D.
(1965) Geology of the Russick Lake Area, Manitoba Mines Branch Publication 63-2, 1965.

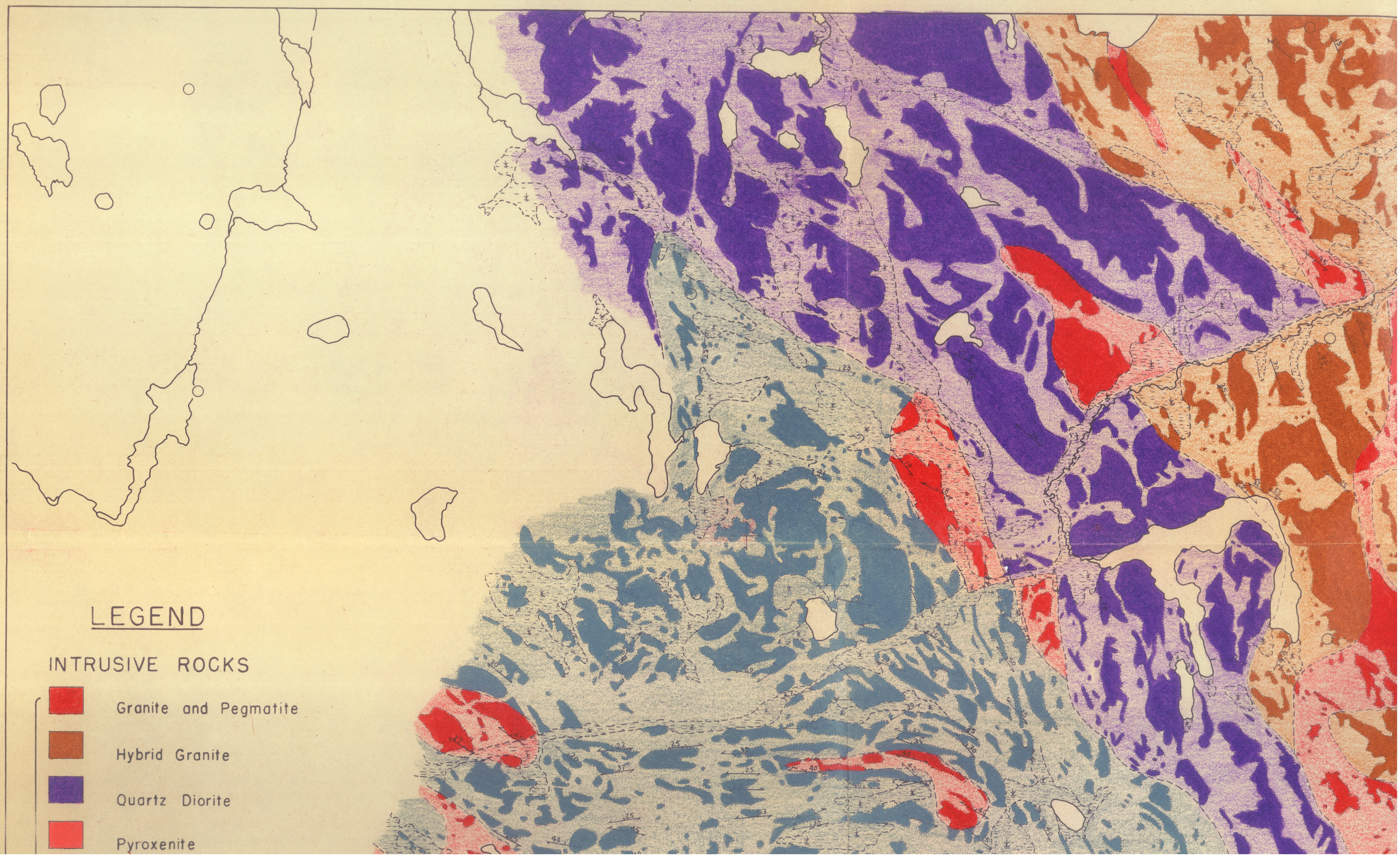
Robertson, D.S.,
(1953) Batty Lake Map Area, Manitoba, Geological Survey of Canada, Memoir 271.

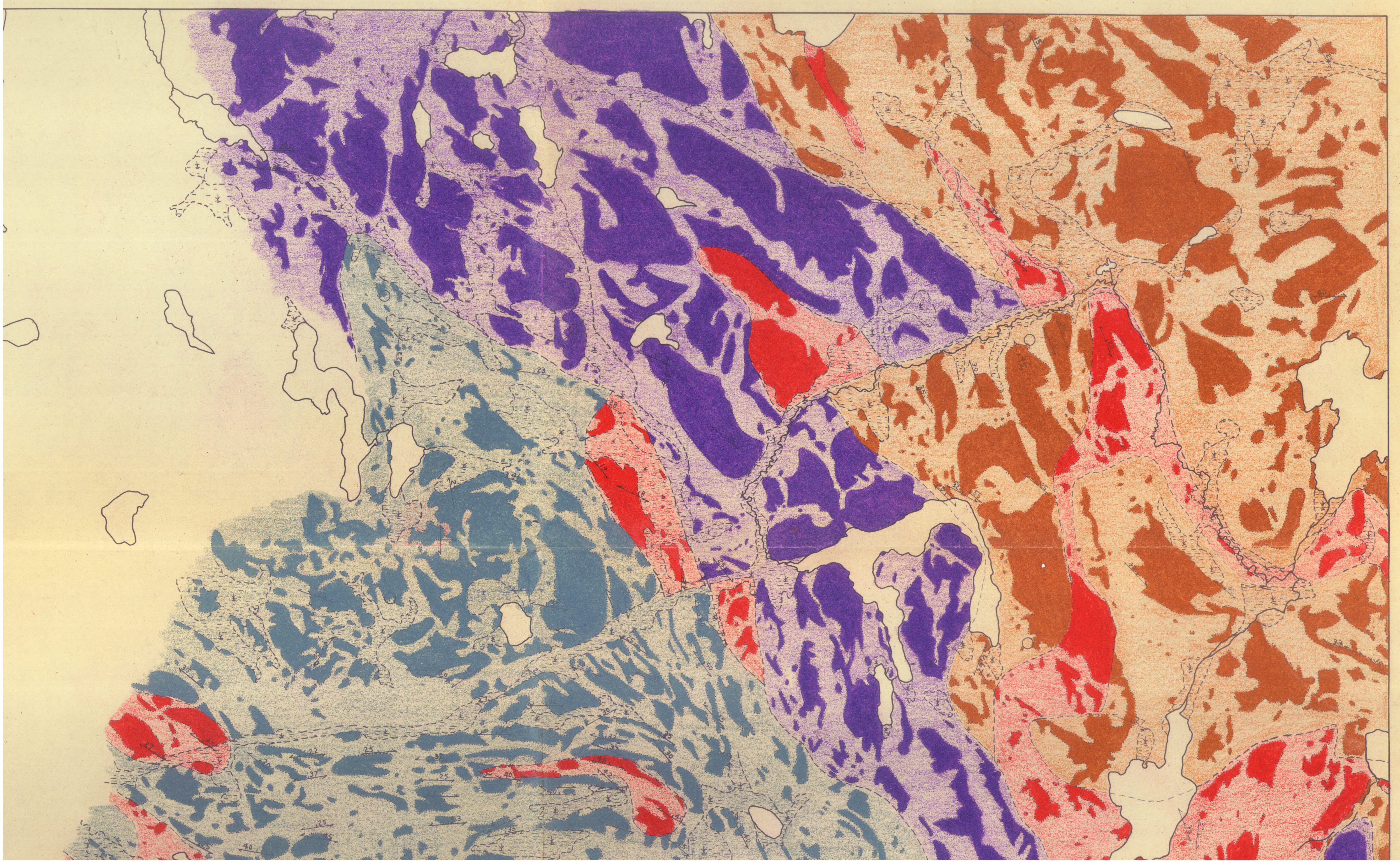
Shapiro, A.H.,
(1961) Shape and Flow, The Fluid Dynamics of Drag, Anchor Books, Doubleday and Co. Inc., Garden City, New York.

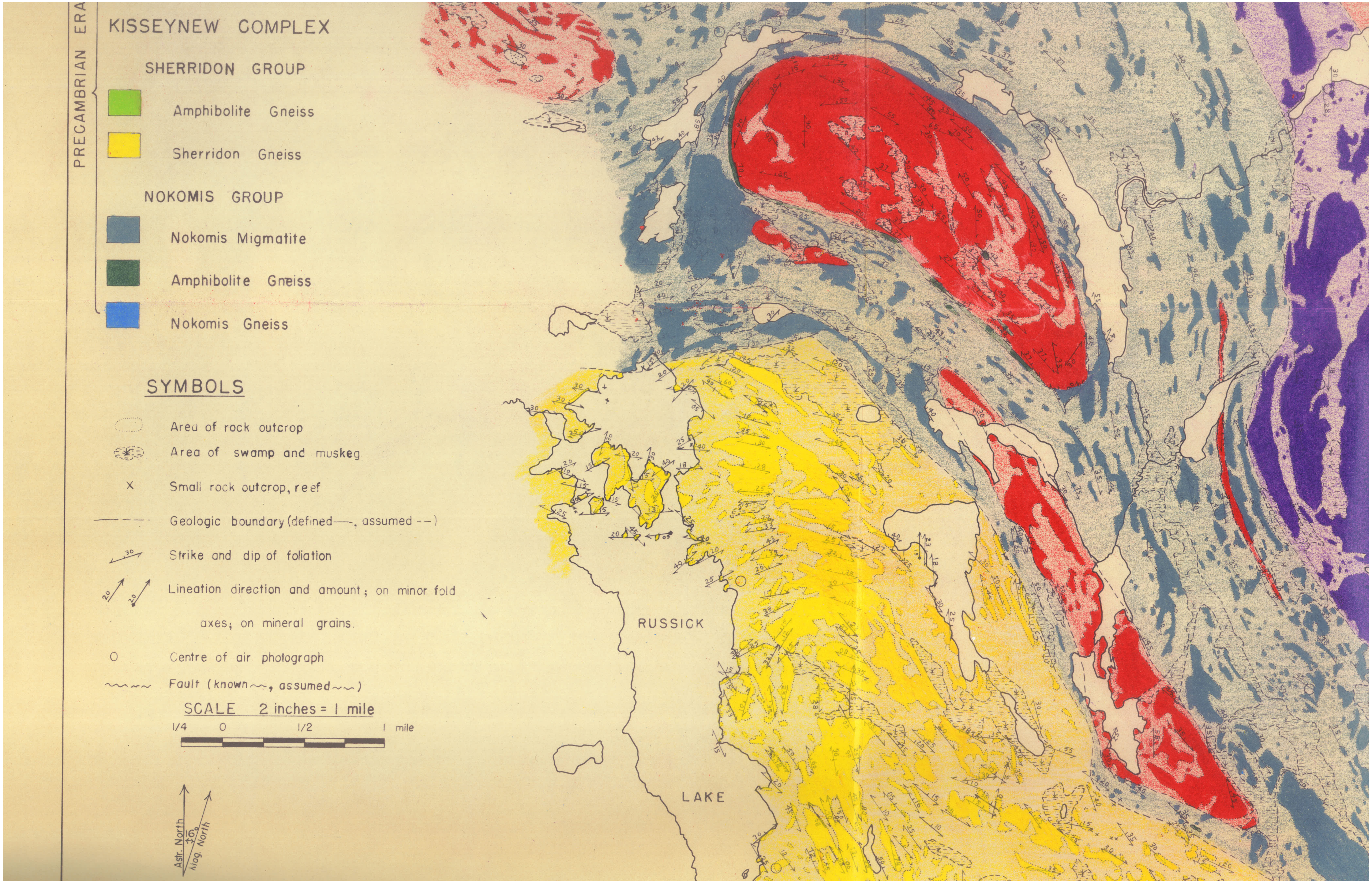
Wynne-Edwards, H.R.,
(1957) Structure of the Westport Concordant-Pluton in the Grenville, Ontario, Journal of Geology, Vol. 65.

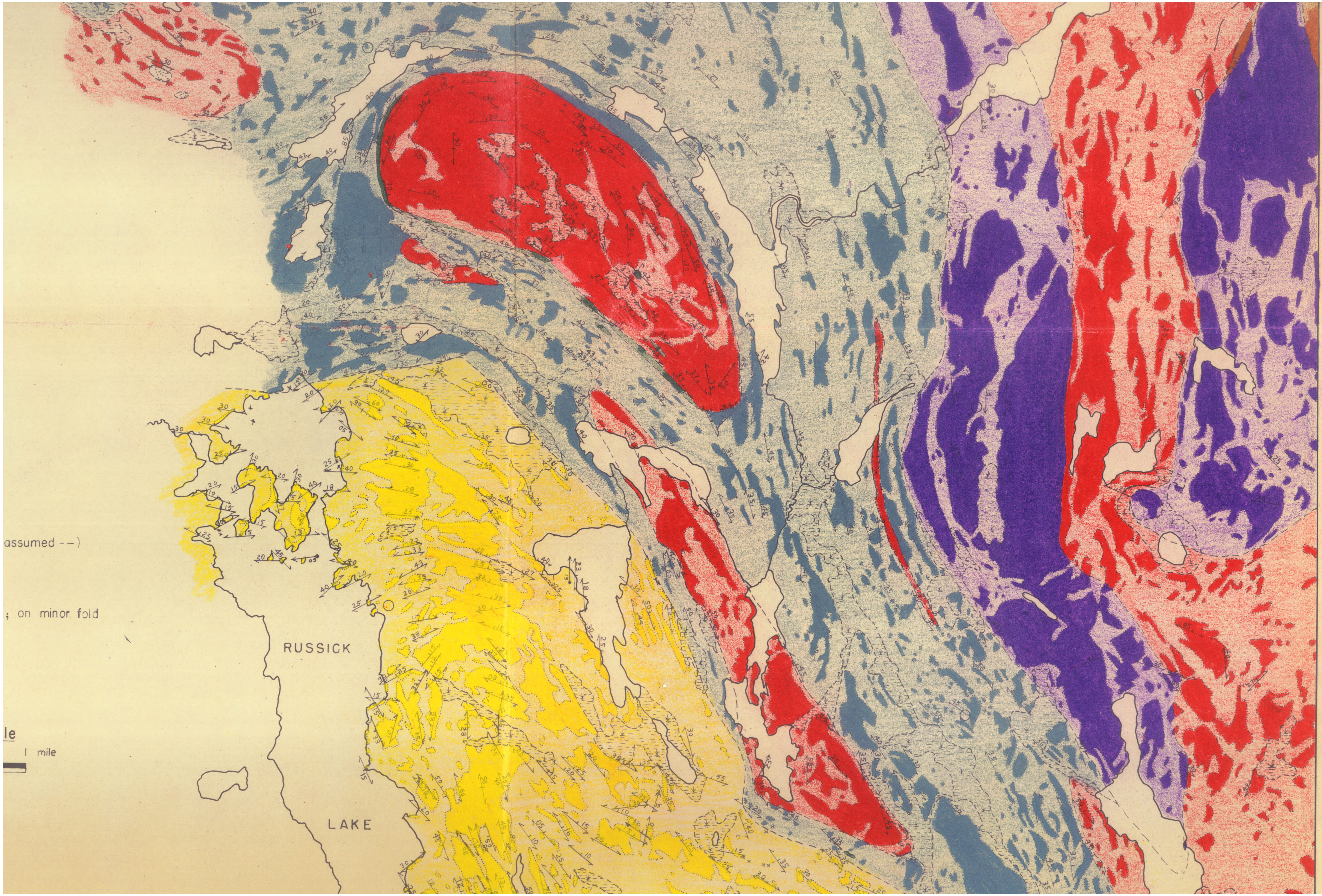
\-\-\-\-\-\-\-\-\-\-\-\-
(1963) Flow Folding, American Journal of Science, Vol. 261.

\-\-\-\-\-\-\-\-\-\-\-\-
(1963) Flow Folding or Lateral Compression, Seminars in Tectonics IV, The Nature and Origin of Folds, Department of Geological Sciences, Queens University, Kingston, Ontario.

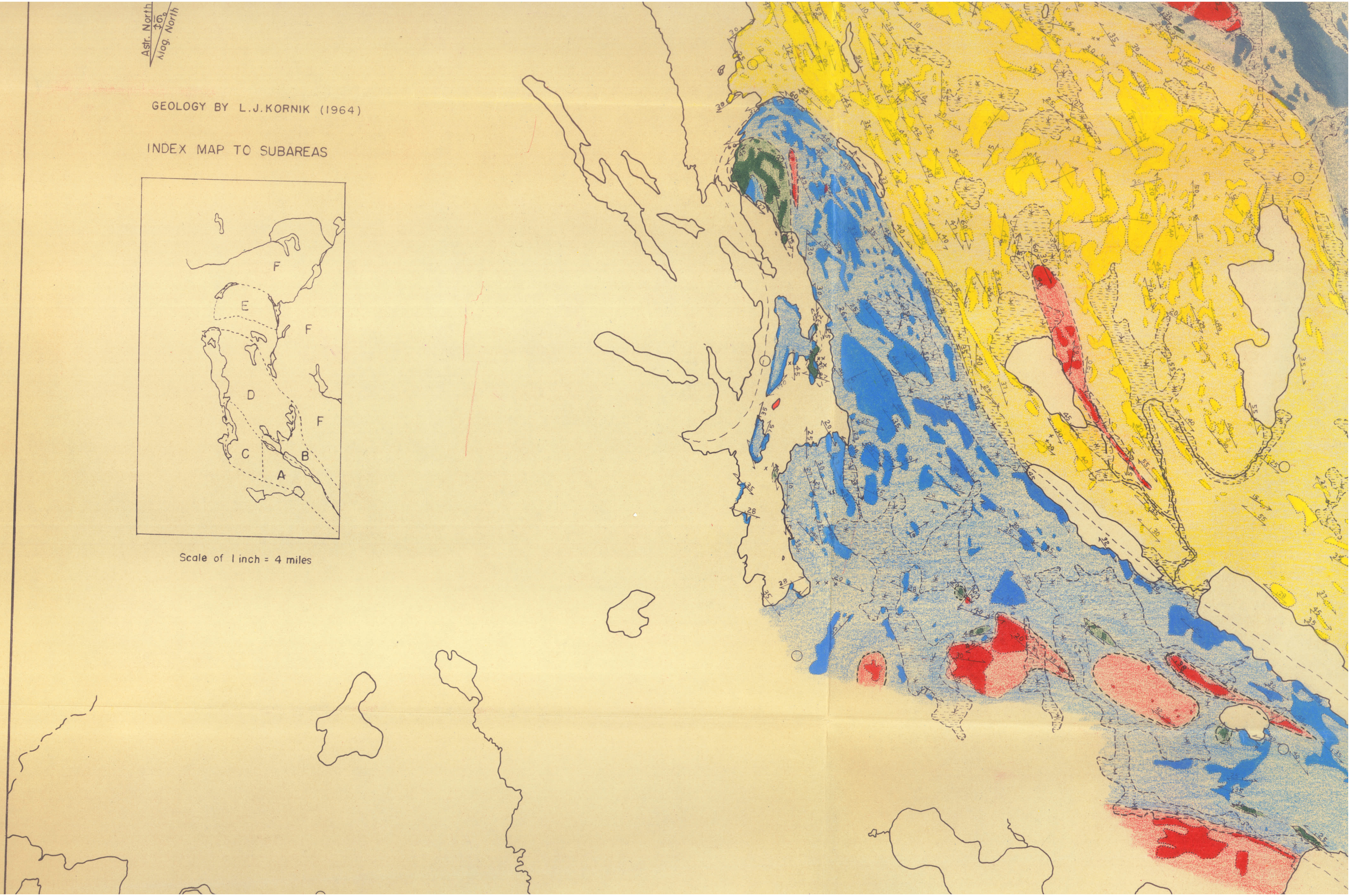

LEGEND
INTRUSIVE ROCKS
Granite and Pegmatite
Hybrid Granite
Quartz Diorite
Pyroxenite

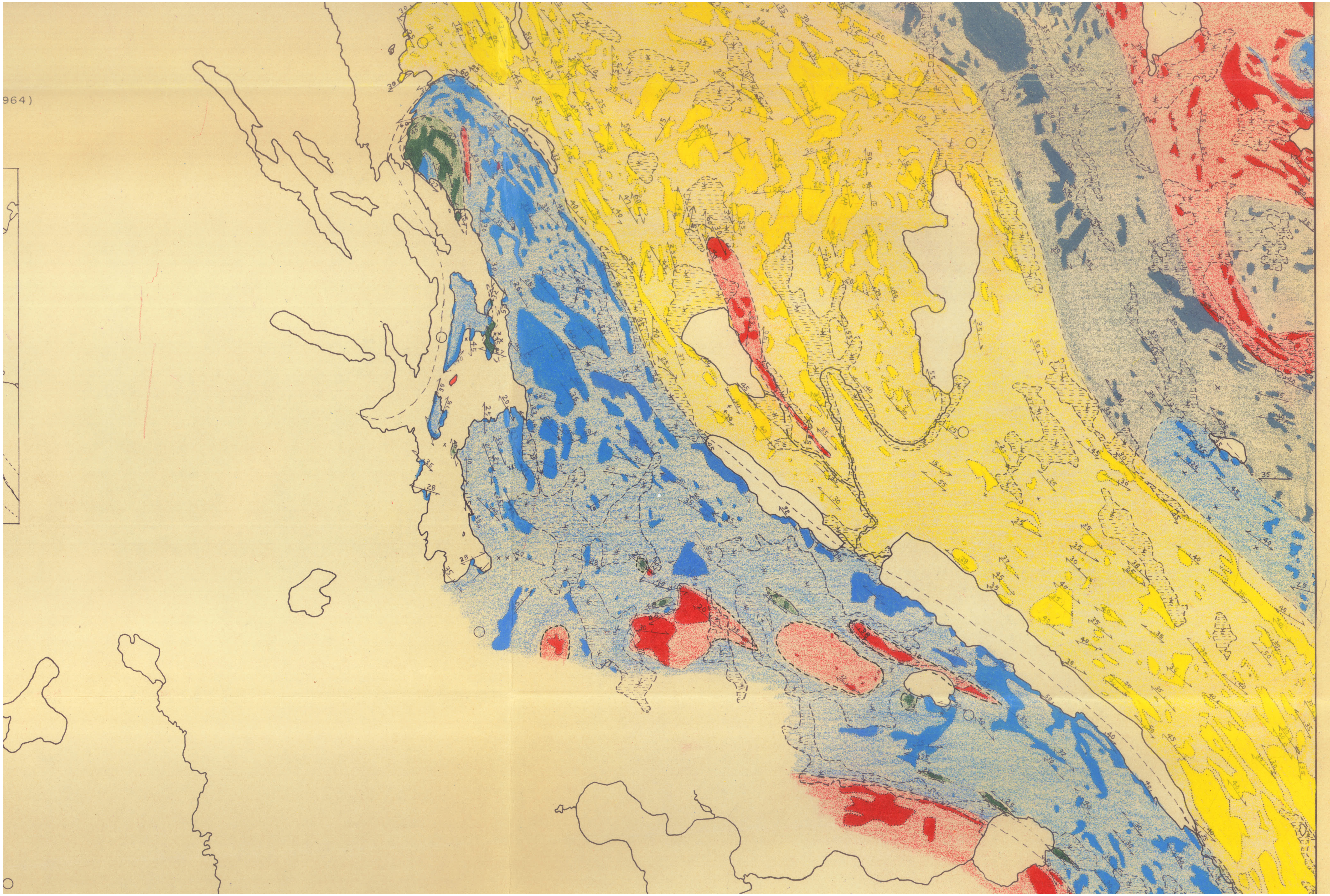


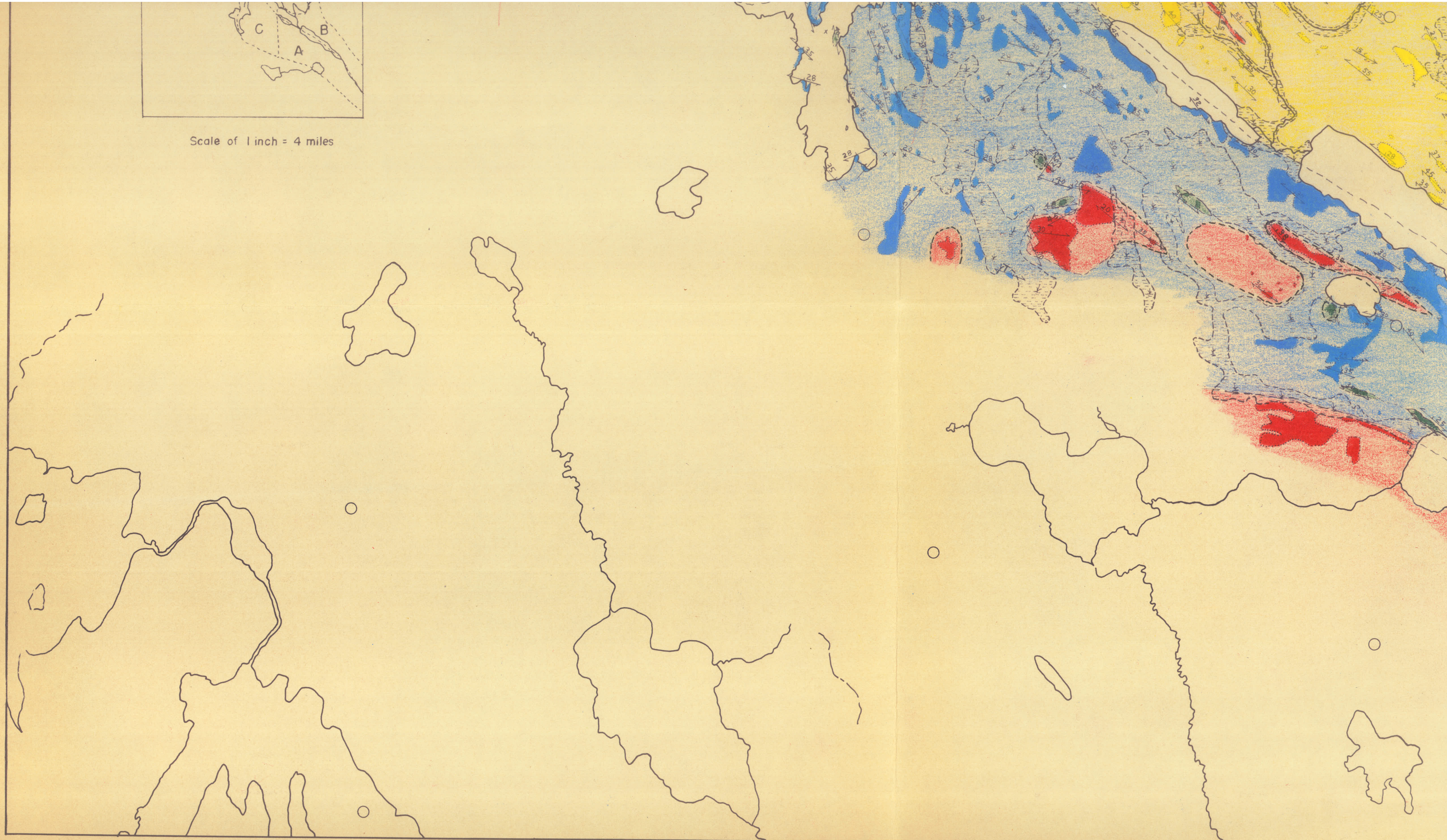

PRECAMBRIAN ERA
KISSEYNEW COMPLEX
SHERRIDON GROUP
Amphibolite Gneiss
Sherridon Gneiss
NOKOMIS GROUP
Nokomis Migmatite
Amphibolite Gneiss
Nokomis Gneiss
SYMBOLS
Area of rock outcrop
Area of swamp and muskeg
Small rock outcrop, reef
Geologic boundary (defined—, assumed --)
Strike and dip of foliation
Lineation direction and amount; on minor fold axes; on mineral grains.
Centre of air photograph
Fault (known~~, assumed~~)
SCALE 2 inches = 1 mile
1/4 0 1/2 1 mile
Astr. North
16°
Mag. North
RUSSICK
LAKE



assumed --)
; on minor fold
RUSSICK
LAKE
1 mile

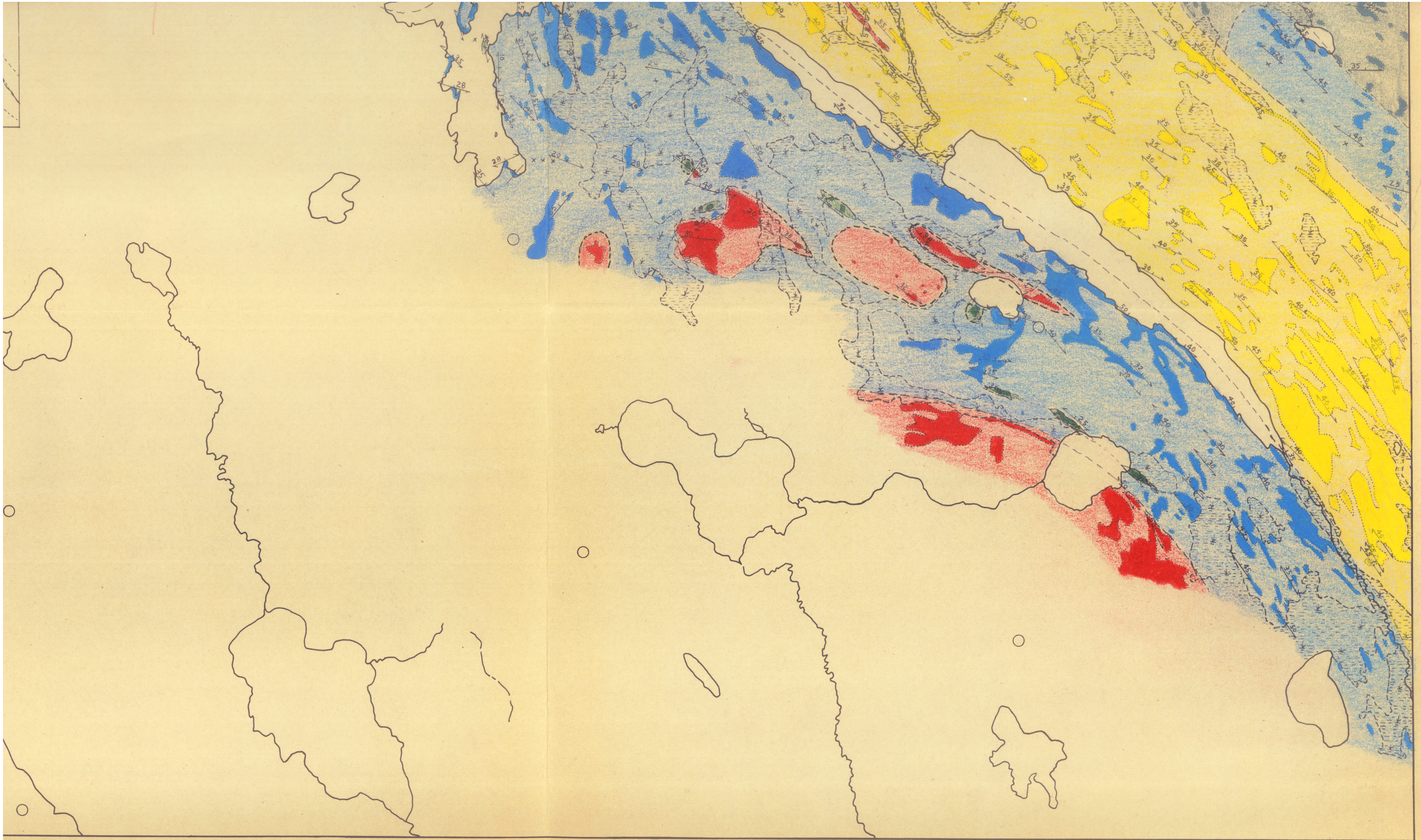

Astr. North
16°
Mag. North
GEOLOGY BY L.J.KORNIK (1964)
INDEX MAP TO SUBAREAS
F
E
F
D
F
C
B
A
Scale of 1 inch = 4 miles


964)



Geologic Map of

RUSSICK LAKE AREA



Geologic Map of

RUSSICK LAKE AREA