AN INVESTIGATION OF THE FOLDING IN FORGIE TOWNSHIP, ONTARIO

A THESIS

PRESENTED TO
THE DEPARTMENT OF GEOLOGY
OF
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IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
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by

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ABSTRACT

Recent work of J.C. Davies, of the Ontario Department of Mines in the region west of Kenora, Ontario, has revealed rock distribution patterns which suggest re-folded folds. This thesis presents the results of a detailed study of the folding in a small portion of the area mapped by Davies. Pertinent data were collected both by field work and by examination of thin sections cut from oriented specimens.

Interpretation of these data indicates that two sets of folds with different axial directions may have been superimposed. Although the evidence for an early period of folding is inconclusive the phase of folding which has been identified is of simple geometry and appears to have been produced by a mechanism of differential passive slip. Because of the complexity of the rock distribution pattern little could be determined about the geometry and style of the earlier set of folds, other than that they were nearly isoclinal and that their axial plane probably dipped to the east.

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INTRODUCTION AND OBJECTIVES

The northern part of the Lake of the Woods district of Ontario is underlain by a series of predominantly volcanic rocks of complex structural history. Although there have been several geological reports (Lawson, 1885; Greer, 1930, Parsons 1911 and 1912) written concerning this region, there has been very little investigation of the structural geology.

The most recent work in this region, a map and report on the High Lake - Rush Bay area (Davies, 1965), shows a surface distribution of formations that suggests superimposed folding. The objectives of the present work were to do an intensive structural study of a small portion of Davies' map area to establish the geometry of the folding, the relationships of the various structural elements, and to attempt an interpretation of the structural development.

Selection of the area to be studied was based on the surface distribution of rock as mapped by Davies. The chosen area was small, so that the complexity of the folding might be studied in some detail.

ACKNOWLEDGEMENTS

The research for this thesis was carried out in the Geology Department of the University of Manitoba during the 1964-65 Academic year.

Professor W.C. Brisbin suggested the problem and provided encouragement and advice throughout the work.

J.C. Davies of the Ontario Department of Mines made available his preliminary and final maps of the area and discussed the geology of the area with the author.

R. Pryhitko, provided assistance in the preparation of the thin sections and the photographic work.

I wish to express my sincere thanks to each of these individuals for their generous assistance and guidance and to the Geological Survey of Canada for the financial support it has provided.

LOCATION AND TOPOGRAPHY

The area selected for study is approximately one and one quarter miles square, in the north central part of Forgie Township, Ontario. It is located about one hundred and ten miles east of Winnipeg and one half mile south of the Trans-Canada Highway. (See Plates 1 and 2). The Rush Bay road traverses the area from north to south and the Trans-Canada pipeline crosses the area from east to west.

The topography is typical of the glaciated shield of northwestern Ontario. It consists of rounded rock ridges separated by low swampy areas and the maximum relief is approximately fifty feet. The rock ridges are almost completely covered by moss and other organic material, leaving very little exposed rock. In many locations, however, the moss can be easily removed to expose the rock surface.

PLATE 1

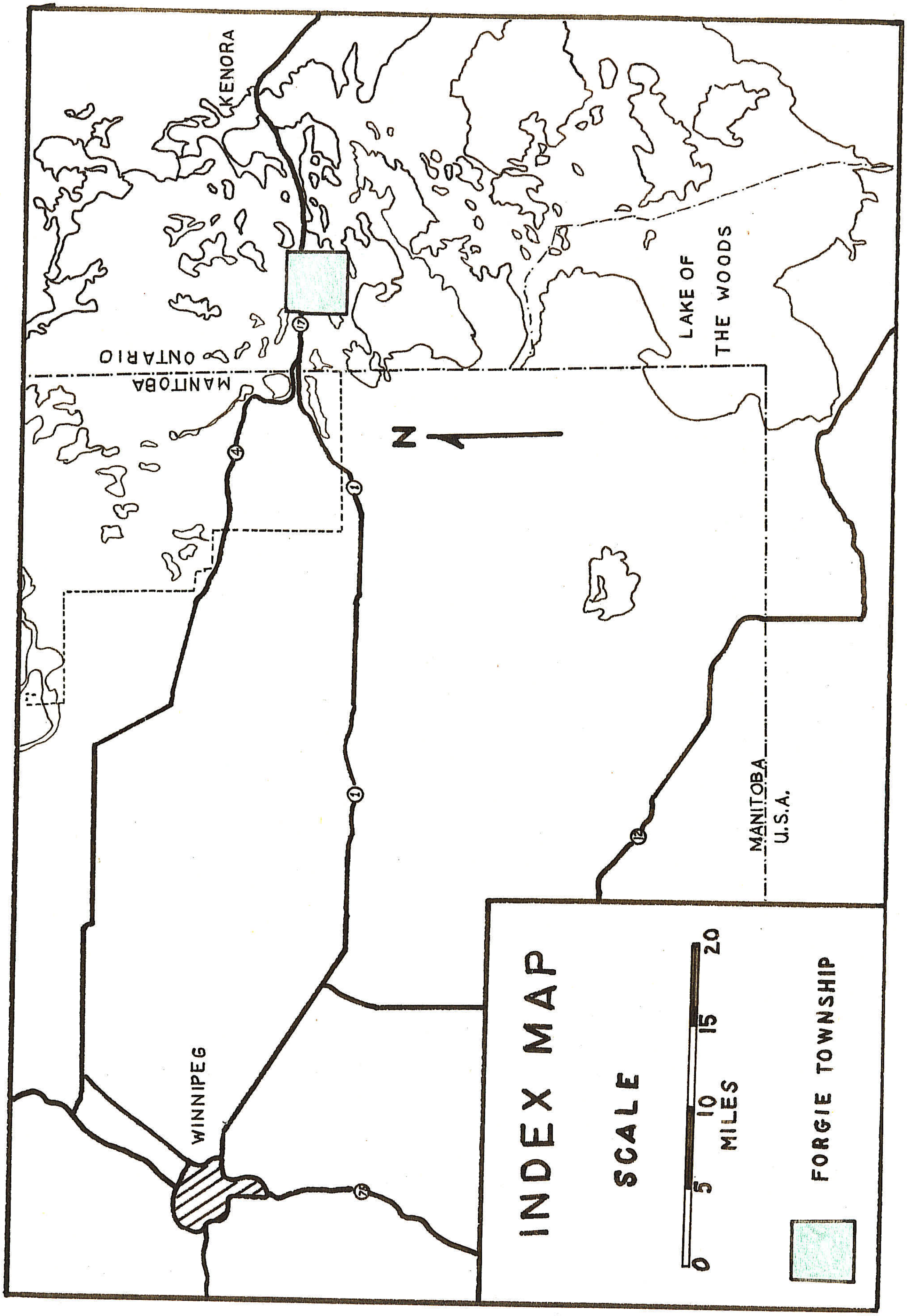
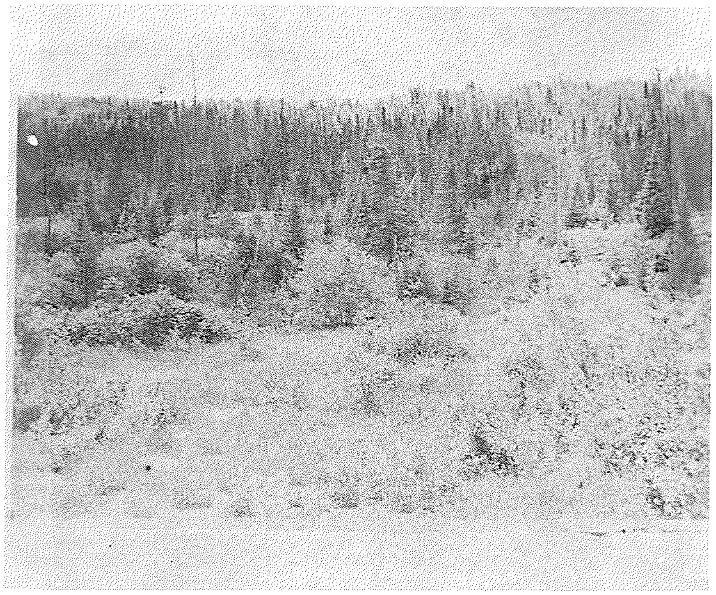

KENORA
ONTARIO
MANITOBA
LAKE OF THE WOODS
N
17
4
1
1
12
75
MANITOBA
U.S.A.
WINNIPEG
INDEX MAP
SCALE
0
5
10
15
20
MILES
FORGIE TOWNSHIP

PLATE 2



A. Typical terrain of thesis area. Looking south from station 4-2.

B. Small outcrop in thesis area.

PREVIOUS WORK

The most comprehensive of the early geological maps of the Lake of the Woods region is that of Lawson (1885) who considered the volcanic sequence there to be quite distinct from any previously mapped and introduced the name Keewatin series for it. He subdivided the series into four units on the basis of lithology.

Parson (1911-1912) visited the various mines of the Lake of the Woods region and in his report generally concurs with the interpretation of Lawson.

A new approach to the classification of the Keewatin rocks was introduced by L. Greer (1930) for his map of the Shoal Lake portion of the region. The earlier writers named the rocks with emphasis on their present mineralogy and texture. Greer, on the other hand, used an entirely genetic classification.

Davies (1965), like Greer, classified the rocks according to a pre-metamorphic terminology. This author has chosen to accept classifications as presented by Davies.

GENERAL GEOLOGY

The area of volcanic rocks delineated by Lawson (1885) as the type area of the Keewatin series of Archean age, extends west from east of the Lake of the Woods to near West Hawk Lake in Manitoba; and from the Northwest Angle of Minnesota north to the Trans-Canada Highway. Forgie Township lies on the north boundary of this belt of volcanic rock.

The Keewatin series includes flows, tuffs and agglomerates, along with minor amounts of clastic sedimentary rocks. All of these have been metamorphosed so that they now are hornblende schists and quartz mica schists. However, there are enough remnants of the original volcanic and sedimentary characteristics that the rocks can be classified on this basis.

This series has been intruded by acidic stocks and batholiths and a few basic stocks, sills and dikes. All of these intrusive rocks have been interpreted to be early Precambrian in age, (Greer, 1930). The acidic intrusive rocks occur mostly as roughly circular or elongate bodies ranging in size from a few hundred yards to seven miles across. Basic intrusive rocks appear to be of two ages. Most of the basic rocks are approximately the same age as the extrusive rocks (see page 8). A number of diabase dikes have a cross cutting relation to the Keewatin series and are of distinctly later age.

The following descriptions of the rock types of the thesis area apply in general to the rocks as they occur throughout the Keewatin series in the Lake of the Woods region. Davies (1965), for the purpose of mapping has separated the volcanic rocks into three units, basic, intermediate and acidic. The following descriptions are made on this basis.

(a) Basic Volcanic Rocks.

The characteristic rocks of the Keewatin series are basic lavas. In outcrop or hand specimen they are a dark green grey color with little difference between the fresh and weathered surface. The texture ranges from medium to coarse-grained. The rock ranges from completely massive to well foliated; the foliation may be so dominant that the rock displays schistosity.

The two predominant minerals are hornblende and plagioclase, which normally make up over eighty per cent of the rock. There are about equal amounts of each. In places the grain size is so coarse that Davies refers to the texture as "gabbroic" (also see Lawson, 1885, p.p. 41).

(b) Intermediate Volcanic Rocks

The rocks of intermediate composition are light to dark grey in colour and fine to medium grained. Some of them are of pyroclastic origin and Davies (1965,p.9) has noted intermediate agglomerates in the general area. The more acidic intermediate types consist of quartz, feldspar and biotite with a few scattered hornblende crystals. The more basic intermediate types typically display a mosaic of hornblende and plagioclase crystals with some biotite and quartz. The rocks of intermediate composition contain more of the accessory minerals, such as calcite and iron oxide than either the basic or acidic types.

(c) Acid Volcanic Rocks

The acid volcanic rocks are rhyolitic and dacitic tuffs, agglomerates and flows. These rocks are usually creamy white in color and are very tough and compact. The individual grains in these rocks are too fine to be distinguished in hand specimen except for the large quartz eyes which occur in some of the rhyolites.

In the thesis area most of the acidic rocks are tuffs. These show a fine bedding on the weathered surface and feel rough to the touch. There are also massive rhyolites, some with quartz eyes up to one quarter inch across. At one location (Station 4-2) an acid agglomerate with rounded elongate clasts was observed.

All of the acidic rock types consist of very fine quartz and feldspar with much of the feldspar having been altered to sericite. Varying amounts of biotite are also present.

(d) Sedimentary Rocks

The most common sedimentary rocks of the region are greywackes and arkoses. Davies has mapped large areas of these along with some argillite and conglomerate in Ewart Township to the west of Forgie Township. There are several extensions of the sedimentary rocks into Forgie Township. Only one specimen collected by the writer is believed to be of sedimentary origin (specimen 2-2). It is made up of medium size quartz grains in a matrix of quartz and sericite. The latter was derived from feldspar of which there are some remnants.

(e) Regional Structure and Stratigraphy

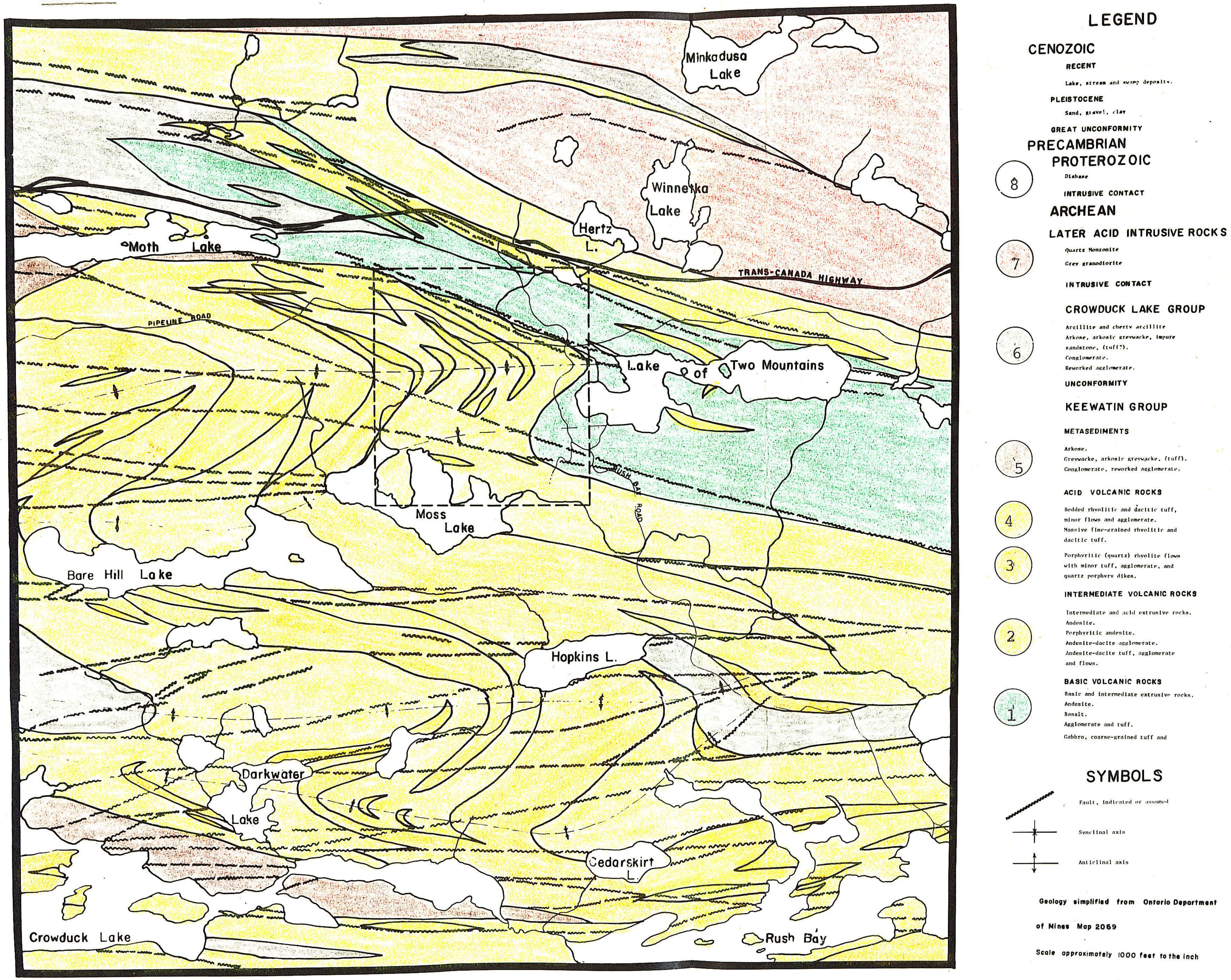
Lawson (1885) has placed these various rock types in a regional stratigraphic series in which he distinquishes four main units. These are from oldest to youngest, hornblende schist, agglomerate schist, and two mica schist units. Lawson realized that these units were heterogeneous within themselves but considered they could be identified well enough to trace them. On this basis he worked out a generalized regional picture of the structure of the Keewatin series.

Although Lawson's division of the Keewatin into units and his structural interpretation are no longer used, his overall concept of the origin and development of the area has not been challenged. Lawson's interpretation is that the area was a large basin filled with a great thickness of volcanic materials of all kinds; flows, tuffs and agglomerates of all compositions along with some sedimentary material. This series was characterized by very rapid changes in lithology both along and across the strike and no single unit of uniform composition shows any great continuity. The volcanic sequence has been intruded by various igneous bodies and folded more or less complexly into a series of folds with axial traces which strike approximately east-west.

It seems likely that the intrusion and folding, as well as the regional metamorphism which has so profoundly altered the appearance of many of the rocks, all occurred as a part of a single orogeny which Greer (1930) has tentatively dated as Algoman.

Davies' (1965) map of Ewart and Forgie Townships gives a much more detailed picture of surface rock distribution. The geologic map of Forgie Township has been simplified for presentation here (Plate 2) and is reduced to a scale of approximately 3500 feet to the inch. Prominent on this map is the overall east-west trend of numerous faults and lineaments, the traces of axial planes, and the elongation of the acidic pluton. Bedding and foliation not shown on Plate 2 also add to this trend; these are shown in Plate 6.

PLATE 3 GEOLOGIC MAP OF FORGIE TOWNSHIP

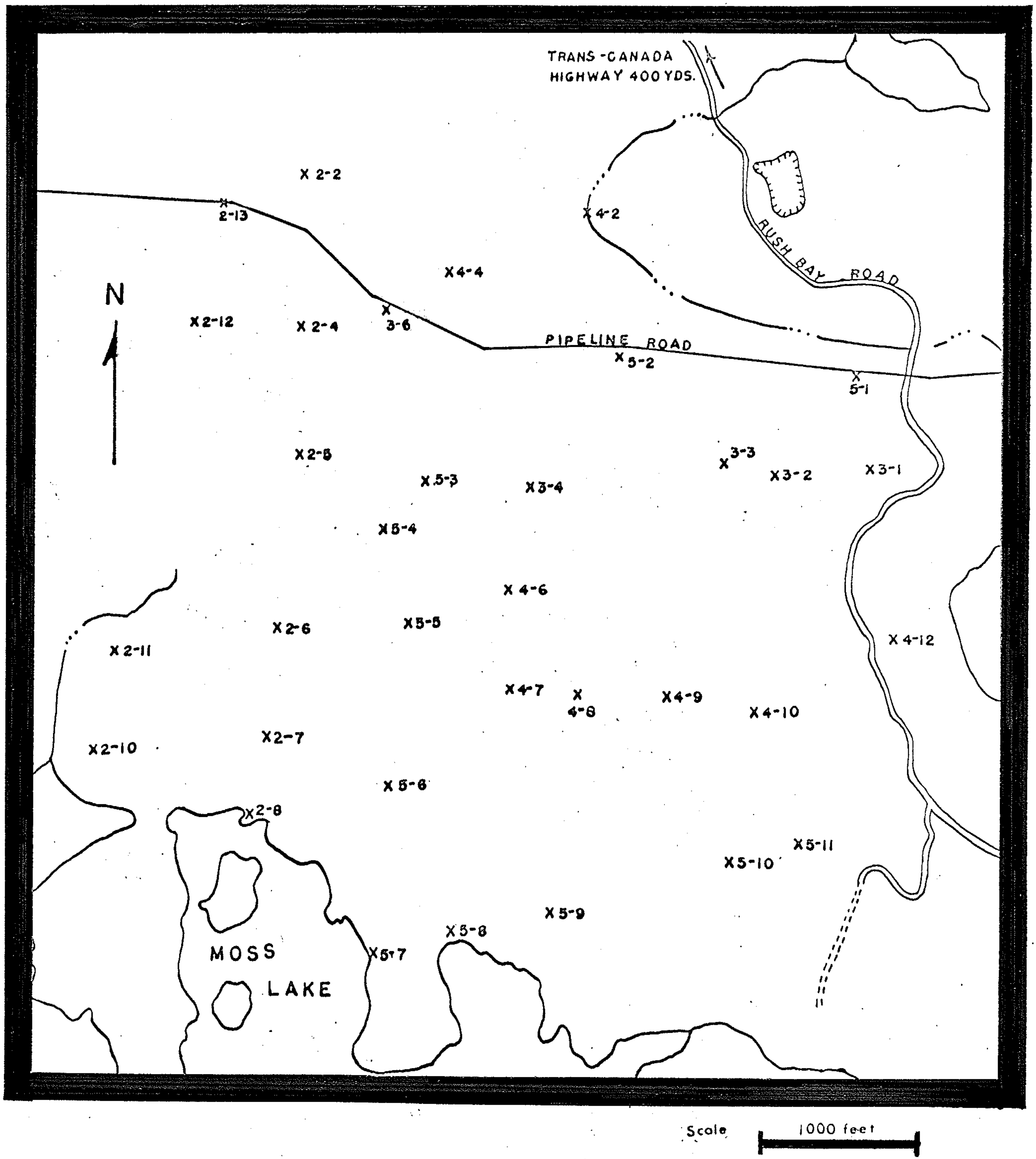


FIELD WORK

Traversing was done in the thesis area during five days in the fall of 1964. Location was maintained by pace and compass and by connecting the traverses as often as possible to points that could be identified on an enlargement of this portion of Davies' map.

It was originally hoped that there would be sufficient outcrop and enough distinction between rock types that units could be traced easily on the ground and that oriented specimens could be located with relation to the folding itself. In actual traversing, however, this was found to be impossible and the remaining traverses were planned in such a way as to complete a grid of specimens over the entire area. (See plate 4). The attitudes of planar and linear features were measured with a Brunton compass. Oriented specimens were taken at intervals of three to four hundred yards and at additional locations which, according to Davies' work, would be critical to a structural interpretation.

PLATE 4



SPECIMEN LOCATION MAP

PREPARATION AND EXAMINATION OF THIN SECTIONS

In order to relate the attitudes of features seen in thin section to those observed in the field, the specimens had to be re-orientated in the laboratory. This was performed with the apparatus shown in Plate 5-A. The table's perimeter is graduated in degrees and its legs mounted on levelling screws. An open sight alidade was modified to pivot on the centre of the table to assist in aligning the directional markings on the specimens as accurately as possible. The inclinometer of a Brunton compass was used to measure dips.

Whenever possible, in cutting the chip for a thin section, the surface to be glued to the glass slide was ground and polished and the orientation mark placed on this face before the chip was separated from the specimen. In this way the mark made while the specimen was intact is still visible on the finished thin section (Plate 5-B). The possibility of error and the inaccuracies that develop from several transfers of the orientation mark were greatly reduced by this system.

An epoxy resin (1) was used for the thin sections prepared for this study. The epoxy, unlike other thin

(1) Epoxy-patch resin, a product of Hysol Corporation, Olean, N.Y., Los Angeles, and Toronto, Ontario.

PLATE 5

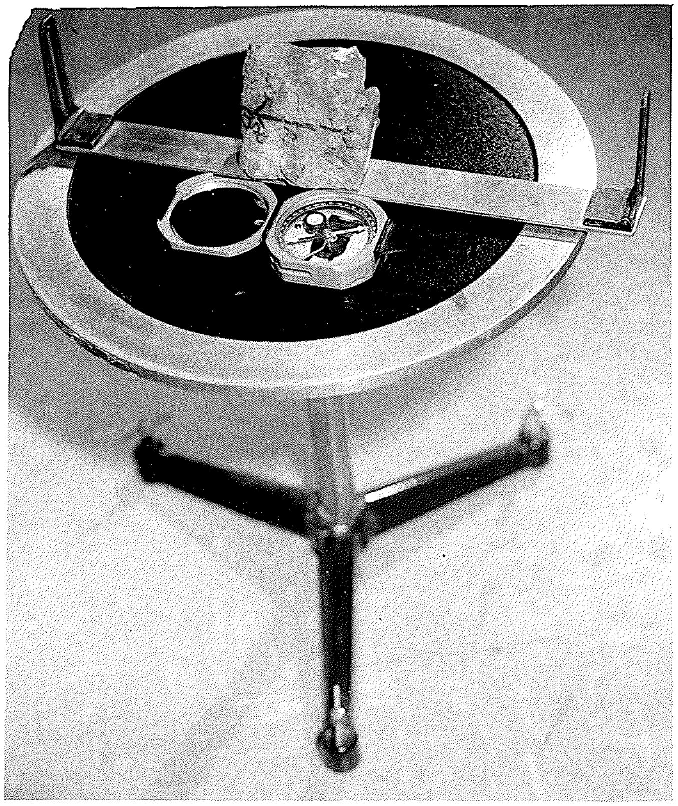


Table and alidade used for orienting specimens in labatory.

Orientation mark pencilled on bottom of rock slice

Oriented thin section

section cements, was liquid at room temperature and had a relatively long drying time. It was easy, therefore, to work out the bubbles between the glass and the rock chip. Once set, the glue was very tough, much more so than Lakeside 70 or Canada balsam.

The permanence of this cement is to its disadvantage. If a chip is improperly aligned or has bubbles under it, it cannot be separated from the glass and it is necessary to start over again with a new chip.

The rocks of this area do not lend themselves to a conventional miscrosopic study. Statistical determination of lattice orientation of quartz, mica or calcite was not possible. The quartz and biotite that are present are generally so fine grained that the highest power of the microscope is required for good resolution and the author was unable to determine the position of the optic axes of the grains. Further, the two main rock types consist either of quartz and biotite or of hornblende and plagioclase. No single mineral is common to all or even a reasonable majority of the specimens.

The attitudes of directional penetrative inhomogeneities in the thin sections were determined. These features were either the intersection of a planar element of the rock with the plane of the thin section, or a lineation in the plane of the thin section. Horizontal sections were cut first to determine the strike of planar elements and, if present in the horizontal plane, the bearing of linear ones.

The dips of planar elements were determined from additional sections, cut in a vertical plane perpendicular to the strike of the feature.

From those specimens in which the plane of foliation could be accurately determined, sections were cut parallel to the foliation to reveal any lineations that might be in the plane. Such sections were oblique planes so that attitudes of lines within them could not be read directly in terms of true plunge and bearing. It was necessary to plot the thin section plane and the attitude of the line within it on a stereogram to determine the true plunge and bearing of the linear feature.

A problem arose in distinguishing between true mineral lineations and apparent lineation formed by low angle intersections of foliation with the plane of section. Fortunately, in this work, all the mineral lineations measured in thin sections are within a fairly small range of the stereogram. (Plate 18-A). This would indicate that they are true lineations; if they were random intersections, they would be scattered randomly on the stereogram.

MACROSCOPIC DATA

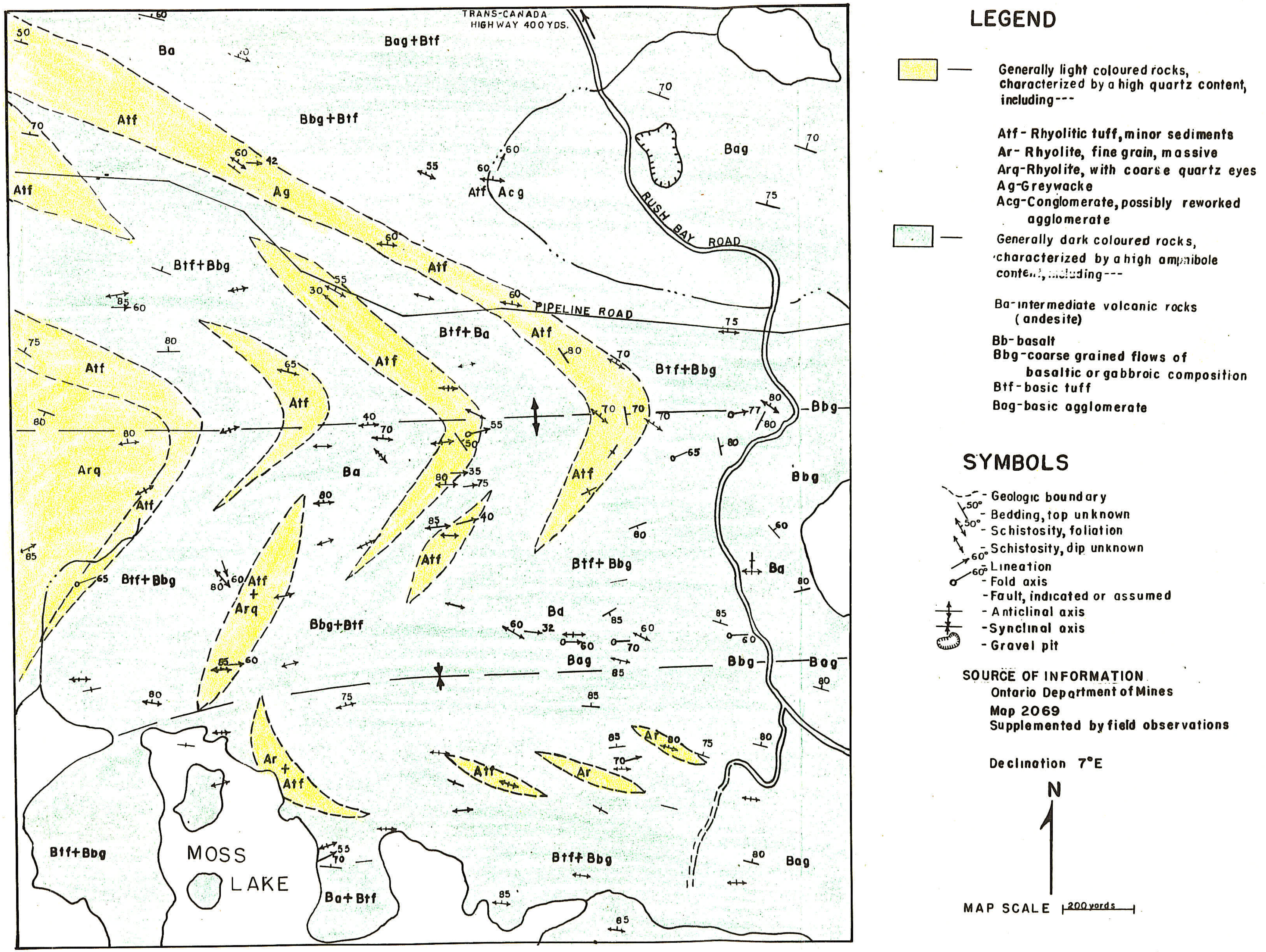
A geologic map of the study area is presented in Plate 6. This map is a composite of the work of Davies and observations made by the author. It differs from Davies' original maps in that more small areas of acidic rocks have been added, (compare with Plate 3). The scarcity of clean bare outcrop combined with the fact that the rock types were not easily separated into distinct units creates the situation whereby the borders of the various rock type areas had to be chosen somewhat arbitrarily. The complex legend used by Davies, (Plate 2) has not been used for Plate 6. Instead, in trying to find the most reliable contacts to depict the geometry of the folds, the intermediate volcanic rocks have been grouped with the basic volcanic rocks in the hope that the contacts separating the acidic and basic units most accurately show the present configuration of the bedding surfaces.

The rock distribution pattern indicated in Plate 6 was based on field observation and the interpretation of aerial photographs. An aerial photograph of the area is shown in Plate 7. The curved trend lines, faint in the photograph but drawn on the overlay, have been interpreted by Davies to be bedding or contact surfaces.

The contacts on the map were interpreted to conform to these trends and the outcrop distribution of the various rock types.

PLATE 6

Geologic Map of Area of Study



LEGEND

🟨 — Generally light coloured rocks, characterized by a high quartz content, including---

Atf - Rhyolitic tuff, minor sediments
Ar - Rhyolite, fine grain, massive
Arq - Rhyolite, with coarse quartz eyes
Ag - Greywacke
Acg - Conglomerate, possibly reworked agglomerate

🟩 — Generally dark coloured rocks, characterized by a high amphibole content, including---

Ba - intermediate volcanic rocks (andesite)
Bb - basalt
Bbg - coarse grained flows of basaltic or gabbroic composition
Btf - basic tuff
Bag - basic agglomerate

SYMBOLS

- Geologic boundary
50° - Bedding, top unknown
50° - Schistosity, foliation
- Schistosity, dip unknown
60° - Lineation
60° - Fold axis
- Fault, indicated or assumed
- Anticlinal axis
- Synclinal axis
- Gravel pit

SOURCE OF INFORMATION
Ontario Department of Mines
Map 2069
Supplemented by field observations

Declination 7°E

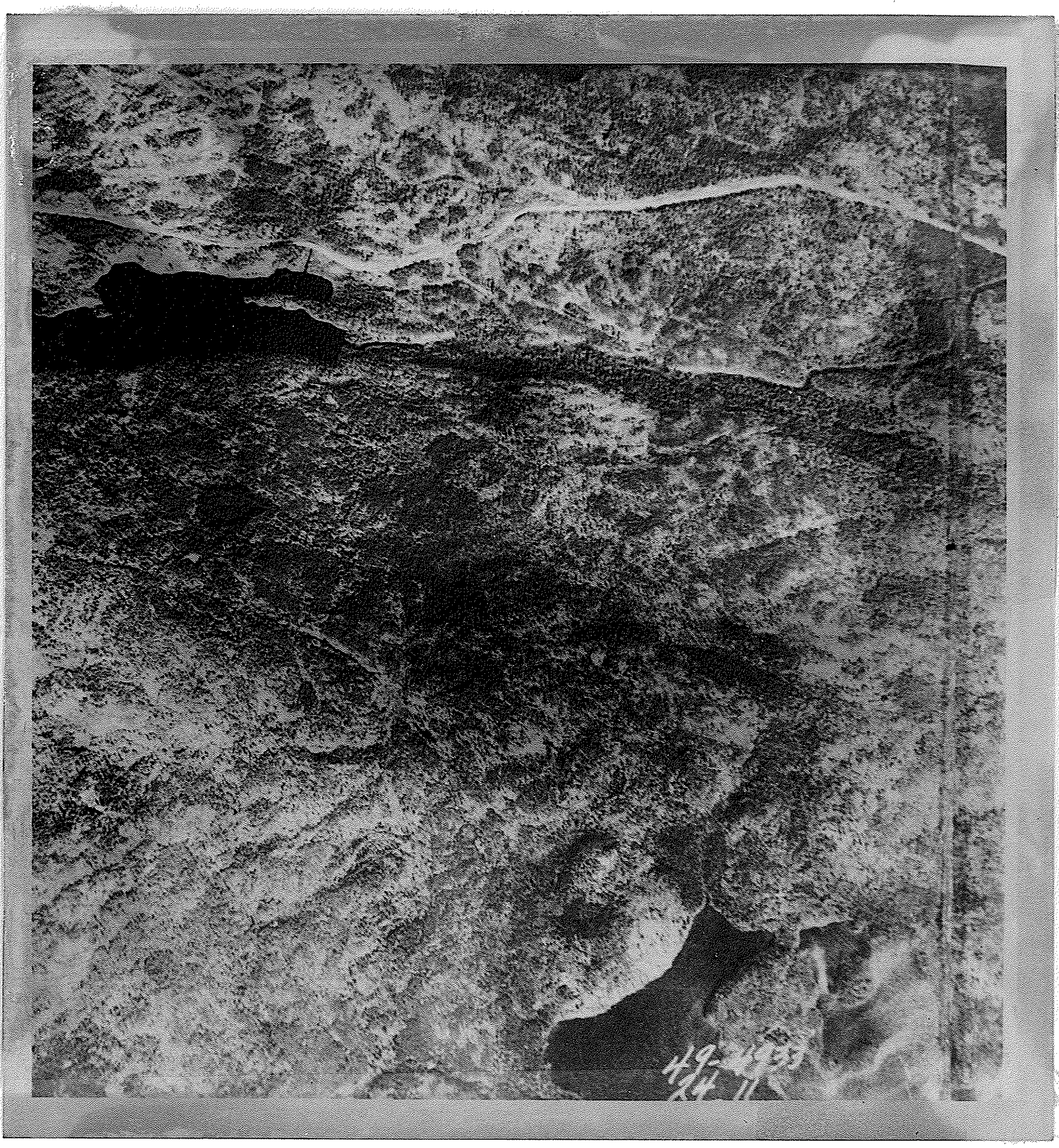
N

MAP SCALE 200 yards

PLATE 7

Aerial photograph showing the trend lines which were a guide to drawing the shape of the contacts on the maps. Scale approximately 1/3 of a mile to the inch.

PLATE 7



Aerial photograph showing the trend lines which were a guide to drawing the shape of the contacts on the maps. Scale approximately 1/3 of a mile to the inch.

MESOSCOPIC DATA

The mesoscopic data that were gathered for this work consist mostly of attitudes of foliations, bedding and lineations measured from outcrops, oriented hand specimens and thin sections. The characteristics of small scale folds in bedding were recorded and, where possible, the attitudes of the fold axes and axial planes were measured.

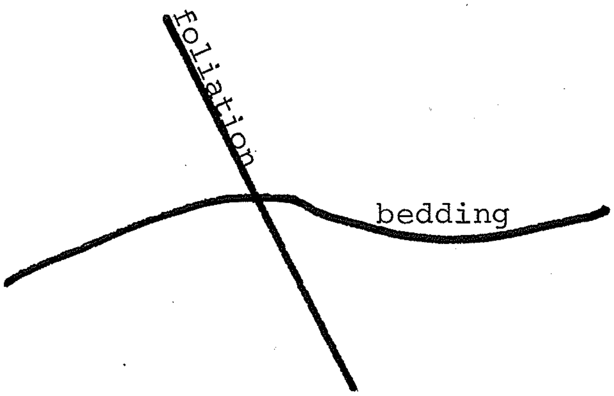
Bedding in the rocks of the area was recognized by changes in color and texture. The layers ranged in thickness from a fraction of an inch to several feet. Bedding was most easily recognized where it was at an angle to the foliation. (Plate 8).

On the mesoscopic scale the foliation is planar, or gently rolling surfaces along which the rock splits easily. In some specimens, platy minerals are aligned parallel to foliation. Throughout the area the foliation dips steeply and strikes approximately east-west.

Both bedding-foliation intersections and mineral lineations were observed in outcrop and hand specimens. Intersection lineations were not measured directly in the field. Their position was determined from known attitudes of bedding and foliation at the particular location with the aid of a stereonet. A few faint mineral lineations were measured directly in the field.

PLATE 8

Foliation at an angle to bedding in outcrop.



Small folds were observed in several outcrops throughout the area. The amplitude and wave length of these vary from about two inches to a little over a foot. The best examples of small folds were found in acid volcanic rocks; less well preserved examples were found in the basic volcanic rocks (Plates 9, 10). The folded surface in all observed cases appeared to be bedding. However, it was not possible to trace individual beds for long distances because all the units involved in any one fold are very similar in appearance and the bedding surfaces are discontinuous. With a few exceptions the small folds were difficult to see. With increasing familiarity with the rocks of the area, and increasing proficiency in identifying these structures, it was possible to estimate that approximately half of the outcrops of the area contained folds of this type. However, only in a few places could reliable measurements be made of the attitude of the axes and axial planes or could the position of the noses and limbs be seen clearly.

The single occurrence of agglomerate observed by the writer in the thesis area was located at Station 4 - 2. (Plate 4). The outcrop consists of two patches, each about ten square feet in area (Plate 2B and 11). The matrix material is rhyolitic tuff, and the fragments are of similar material but more compact and slightly harder.

The fragments are partly rounded as if water worked.

PLATE 9

Small scale fold in acidic rock near station 2-7.

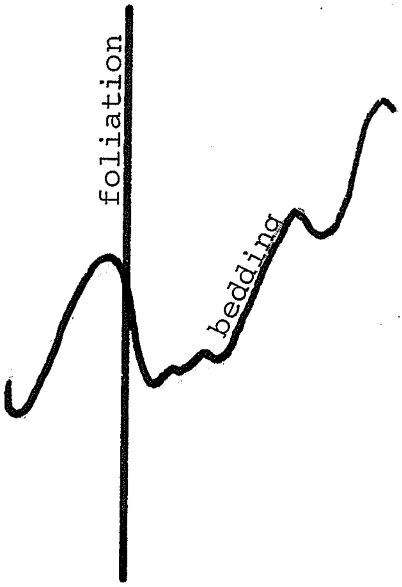
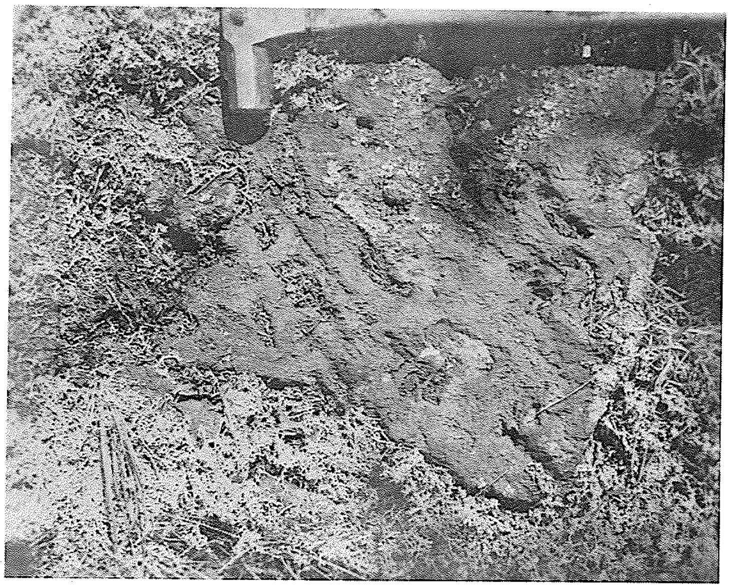


Plate 10



Small scale fold in basic rock

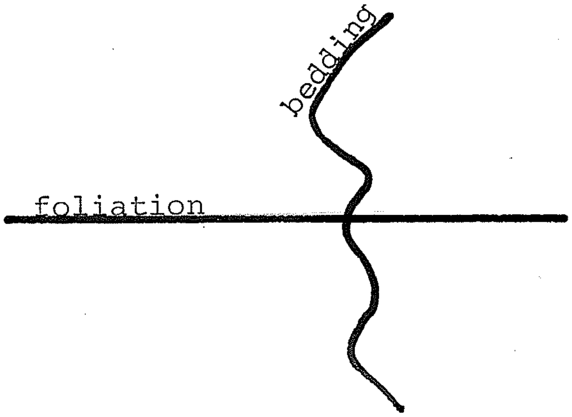


PLATE 11

Stretched fragments at station 4-2.

If the fragments were nearly equidimensional when the agglomerate was deposited, they have since been strongly deformed. They now have dimensions similar to triaxial ellipsoids. Measurements of the dimensions of these distorted clasts were difficult to make; however the dimensions of their orthogonal axes seem to be in the order of 15:5:1 with the longest dimension up to two feet. The shortest axis appears to be perpendicular to the foliation and the long axis appears to plunge in the same direction as the axes of the small folds.

MICROSCOPIC DATA

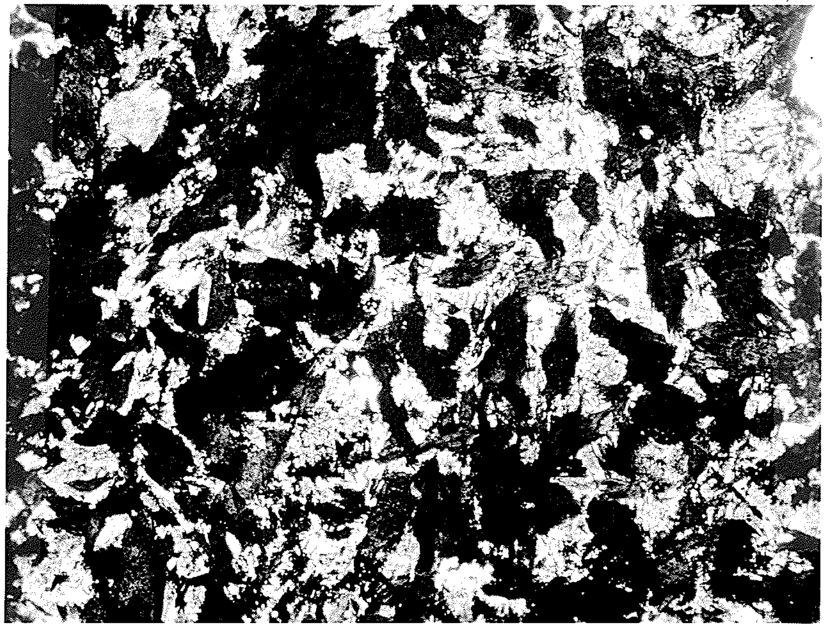
This section deals only with the microscopic fabric of the rocks. The data collected microscopically on the attitude of planar and linear features were included in the compilation of mesoscopic data. The texture and mineralogy of the rock types (see page 17) precluded the analysis of crystal lattice orientation.

The foliation in the area is very uniform in attitude but is variable in intensity and in constitution. The rocks range from massive, with no penetrative planar features disernable even in thin section (Plate 12-A) to highly fissile.

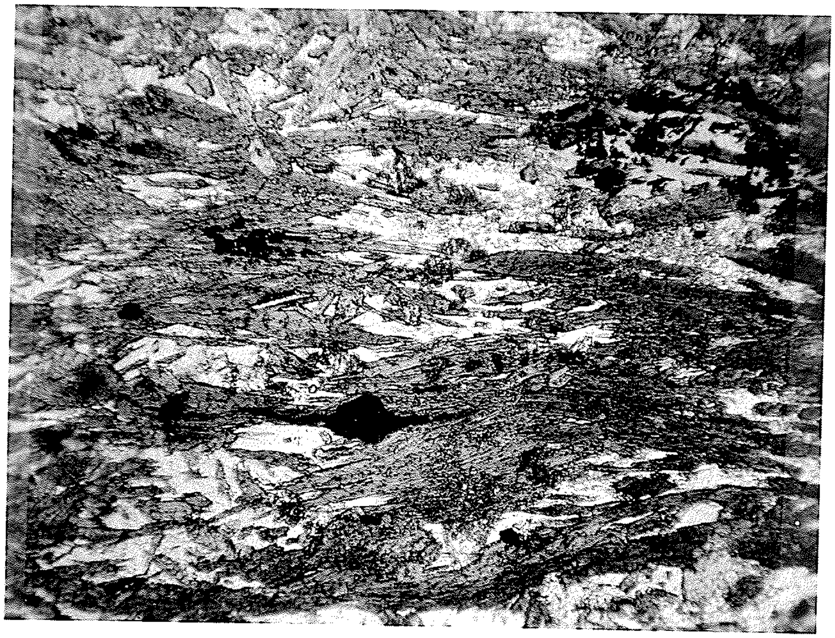
In its simplest form foliation occurs as a parallel arrangement of 001 faces of tiny biotite crystals or by the confinement of long axes of hornblende laths to a single plane. The latter type of foliation is illustrated in Plate 12-B. Examination of thin sections cut parallel to foliation has shown that in most specimens the hornblende axes are randomly oriented within the plane and the biotite flakes show no direction of preferred elongation in the plane.

Foliation may also be marked by compositional lenses. Monomineralic lens-shaped clusters are arranged in parallel orientation but may or may not be accompanied by parallel alignment of the crystals within the cluster.

PLATE 12

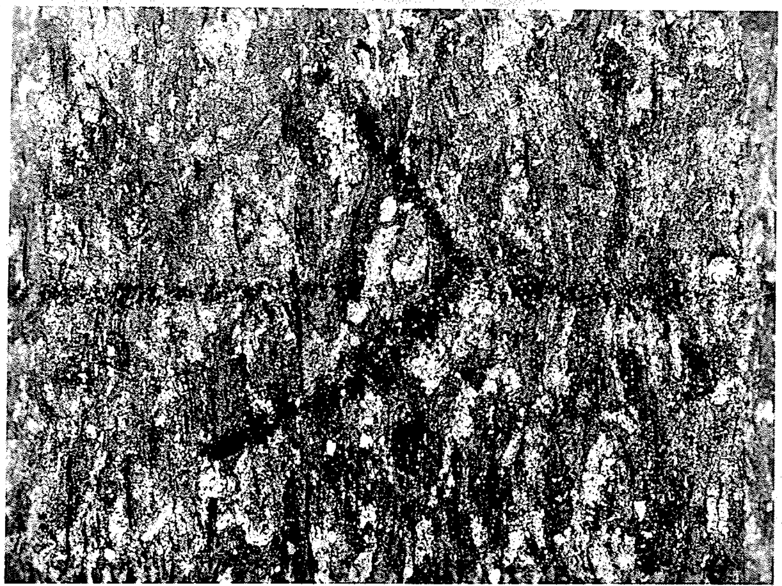


A. Photomicrograph thin section 2-13, plane of section horizontal, north to the right. Random orientation of hornblende crystals. X10 cross nicols

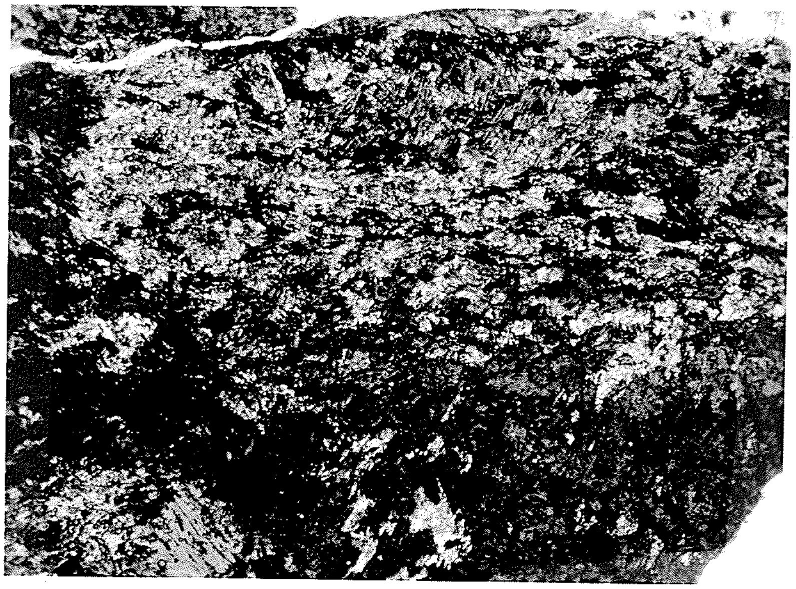


B. Photomicrograph thin section 2-10, plane of section horizontal, north to the top. Strongly preferred orientation of hornblende crystals. X10 cross nicols

PLATE 13



A. Photomicrograph thin section 5-10, plane of section horizontal, north to the right Compositional lenses (magnetite, hornblende and feldspar) parallel to the alignment of hornblende lath long axes. Note orientation arrow penciled on bottom of rock slice. X 10 cross nicols



B. Photomicrograph thin section 2-4, plane of section horizontal, north to the top. Hornblende laths lie at an angle to compositional lenses. Laths run NNE-SSW- composition lenses run east-west. X 7.5 cross nicols

Plate 13-A illustrates the former, Plate 13-B the latter.

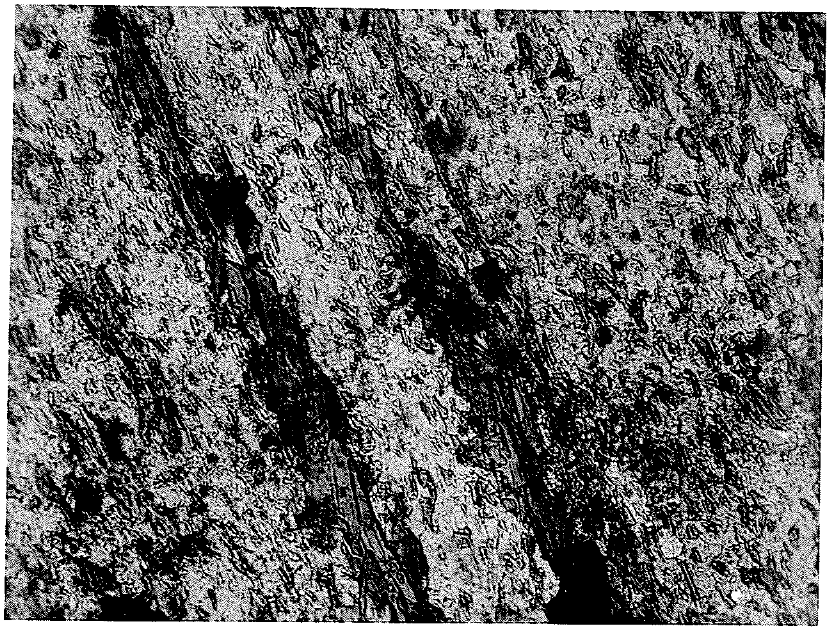
Lineations in the form of crenulations, mineral lineations, elongate clusters of minerals, and intersection lineations that were observed by the author lie in the foliation plane. The most common lineations are mineral lineations. Examples of mineral lineations were found in outcrop and in thin sections. In comparison to the conspicuous orientation and grouping of mineral grains that mark the foliation, these lineations are very poorly developed.

When foliation is marked by the long axes of hornblende crystals restricted to a plane, a lineation may be marked by these long axes tending toward a single preferred direction within the plane. Such a preference for a single direction is much less pronounced than the preference for a plane.

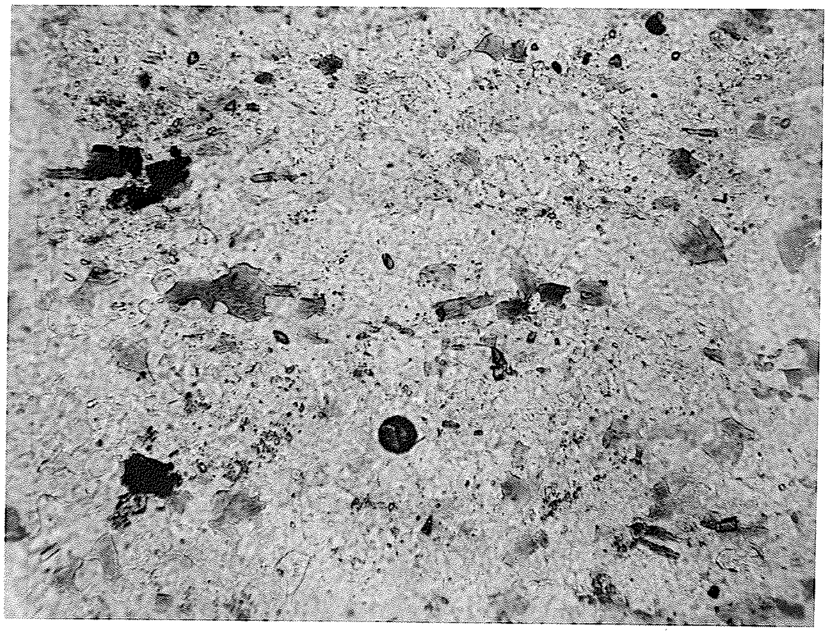
The same situation may occur with biotite grains in the acidic volcanic rocks. Plate 14-A illustrates this alignment of biotite clusters and grains. Plate 14-B shows another variation of this type of lineation. The lineation is very faint but does indicate a measureable direction. Nearly equidimensional biotite flakes are arranged in chains within the plane of foliation. This arrangement could be a faint trace of bedding but there is no evidence to support this interpretation.

The intersection lineations are simply the intersection of bedding and foliation.

PLATE 14



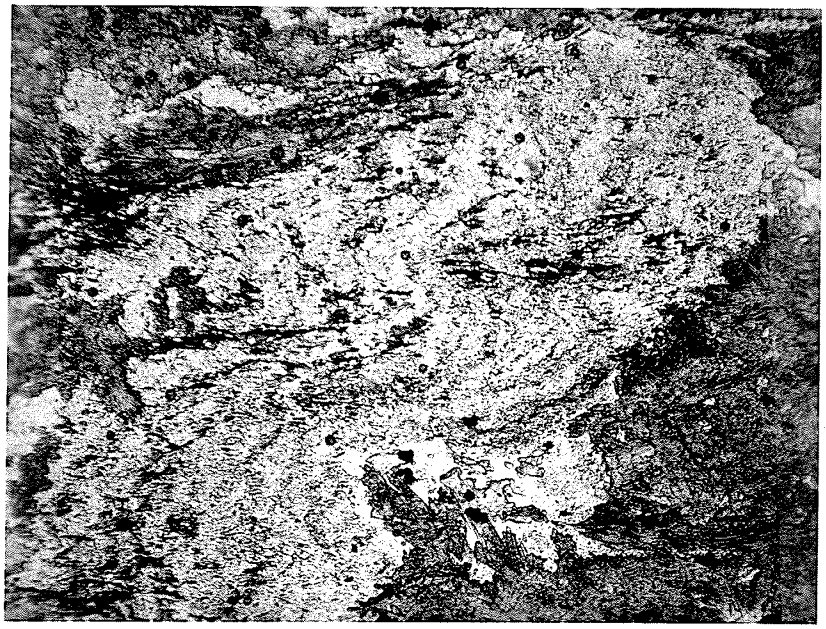
A. Photomicrograph thin section 3-6F, attitude of plane of section strikes 100° and dips 65° to the north. Looking to the north. Lineation in acidic volcanic rock formed by alignment of elongate biotite clusters and parallel orientation of individual grains. Lineation plunges 60° in a direction 090° . X30 cross nicols



B. Photomicrograph thin section 2-7F, attitude of plane of section strikes 090° dips 85° north. Looking to the north. This is a section cut in the plane of foliation. Faint lineation marked by chains of equidimensional biotite grains runs right to left horizontally across the photo, actually plunges 65° in a direction 075° . X 120 cross nicols

Bedding occurs in places as layers of varying mineral composition. In most of the thin sections where bedding was observed it is folded. The folds visible in thin section range in size from tiny crenulations, (Plate 16) to rather well developed folds (Plate 15) with distinct limbs and noses and clearly defined axial plane foliation.

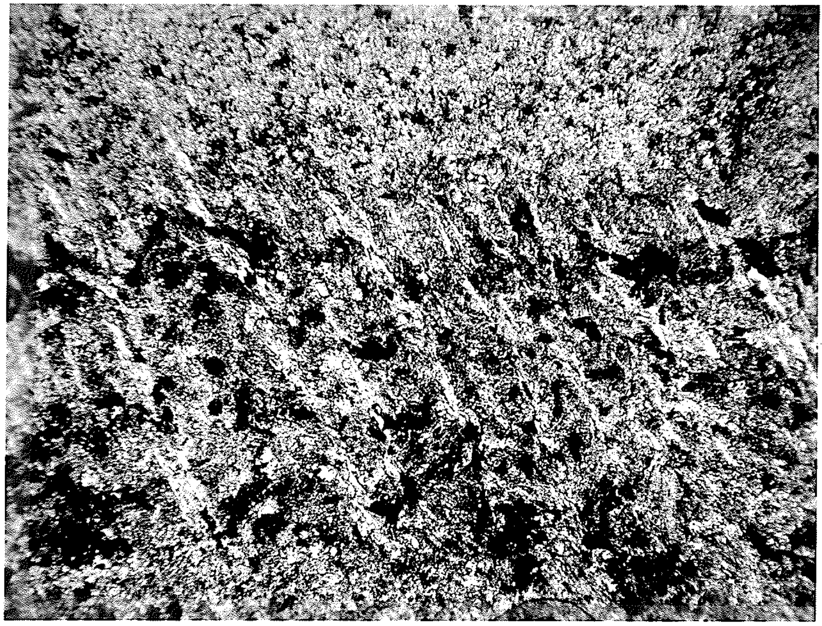
PLATE 15



A. Photomicrograph thin section 4-11, plane of section horizontal; north to the top. Folds in bedding. Bedding is marked by wavy lines of biotite (dark colour) in a matrix of very fine quartz and sericite. The foliation is marked by the orientation of the individual biotite grains. X 33 cross nicols

B. Photomicrograph detail of above X82.

PLATE 16



Photomicrograph thin section 3-4, plane of section horizontal; north to the top right corner. Foliation at an angle to bedding, kink bands occur in bedding. X 20 cross nicols.

INTERPRETATION

This section presents an interpretation of the structural geometery of the thesis area, as derived from a combination of the observed data and related information compiled by other workers. The movements that produced this geometery are discussed briefly.

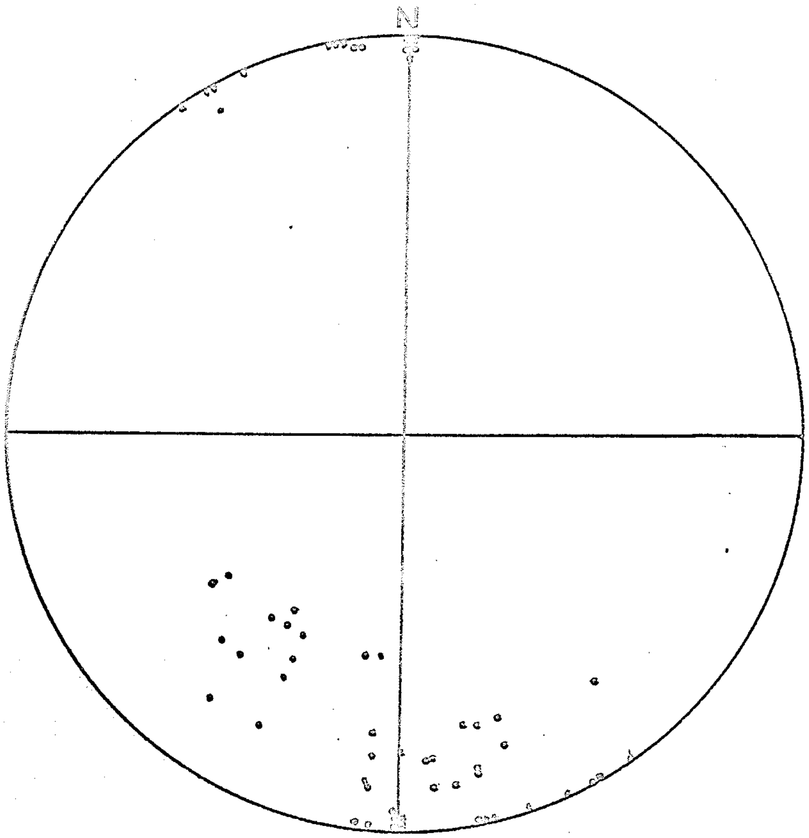
(a) STEREOGRAPHIC PLOTS

As a first step towards an interpretation, all of the data on the attitudes of planar and linear features were plotted on stereograms. The four stereograms showing poles to foliation, poles to bedding, lineations, and small fold axes are presented in Plates 17 and 18. The number of points plotted in each diagram was insufficient for conventional statistical analysis so that all of the structural elements were plotted on lower hemisphere Wulff nets.

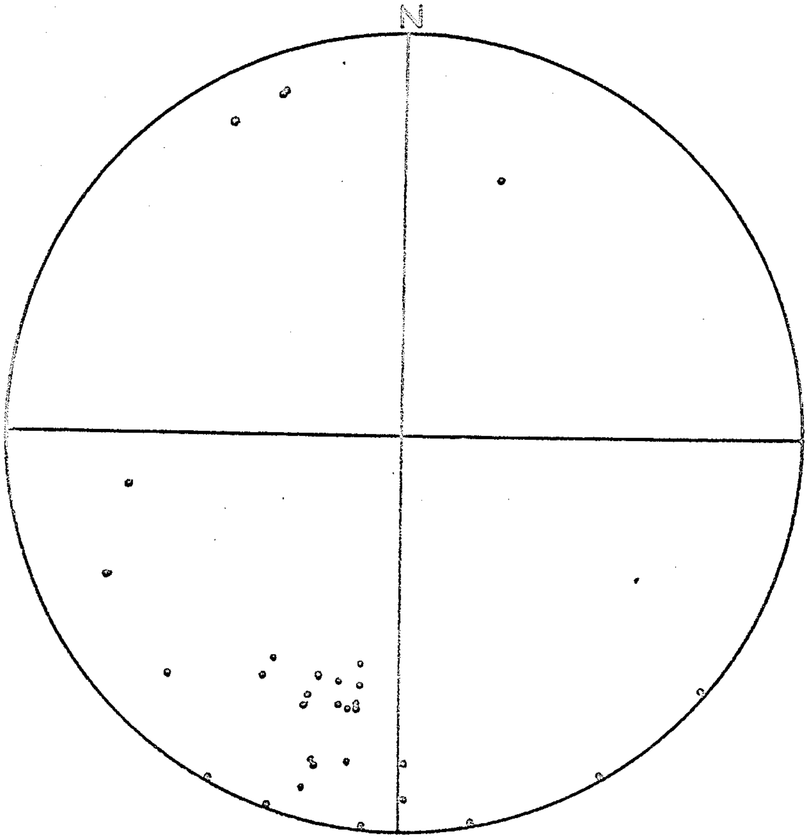
The diagrams showing the orientation of poles to foliation and poles to bedding (Plate 17A and 17B) have broad groups of poles in the same general area of the net, which suggests that bedding and foliation are close to being parallel.

The diagrams showing the distribution of lineations and small fold axes (Plate 18A and 18B) indicate that both of these structural elements are clustered in a confined area located at approximately the same position on both stereograms.

PLATE 17



A. Stereogram of poles to foliation. (51 points)



B. Stereogram of poles to bedding. (31 points)

Combination of the data from these diagrams into a synoptic stereogram (Plate 19) provides a satisfactory method for the determination of the geometeric relationships between these structural elements.

The estimated average orientation of lineations and small fold axes is 65° in a direction 085°. This direction is at right angles to a great circle which may be considered to represent the girdle of poles to observed bedding attitudes (see Plate 19). This relationship is consistent with cylindroidal folding of the bedding with fold axes plunging in the direction of the linear features. The concentration of bedding poles on the bedding pole circle indicates the orientation of the limbs, and the presence of only a single concentration on the pole girdle suggests the fold is isoclinal. The axial plane, following this reasoning should be parallel to the limbs, that is perpendicular to the centre of this concentration (Plate 19).

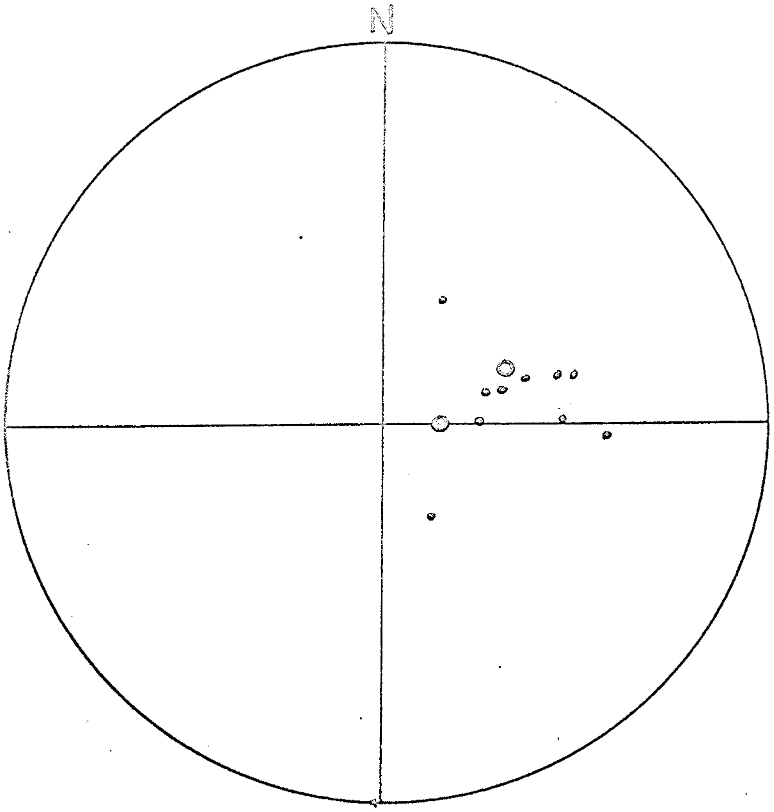
The estimated average foliation orientation coincides with that of the axial plane as interpreted above (compare Plates 17A and 19). It strikes approximately 085° and dips about 80° to the north.

(b) ROCK DISTRIBUTION PATTERN

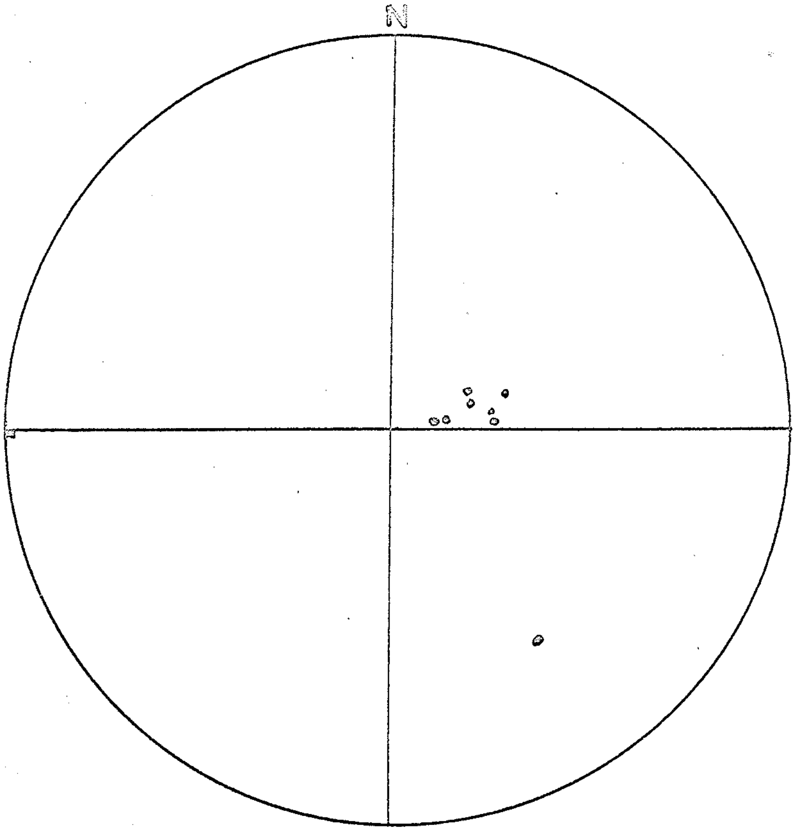
Along an east-west trend through the centre of the map area there is a series of curved lenses of acidic rocks. Davies (1965) shows an east-west anticlinal axial trace passing through these lenses where the curvature is greatest.

This axial trace has been adopted for Plate 6, the

PLATE 18

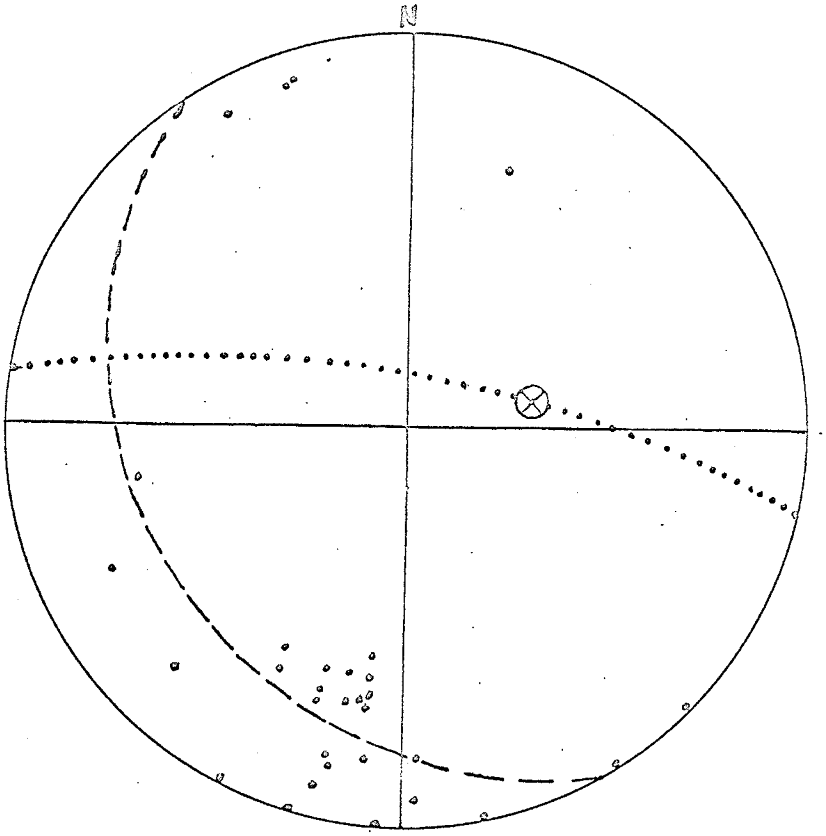


A. Stereogram of lineations. Mineral lineations are indicated by solid dots, intersection lineations by small open circles.



B. Stereogram of small fold axes.

PLATE 19



Synoptic stereogram. The position marked on the dotted great circle is the average position of the lineations and small fold axes. (compare with Plates 19A and B) The interpretation of the orientation of bedding expressed as a pole circle is shown by the dashed lines. The poles to bedding from Plate 18B have been included for comparison. These data suggest a cylindroidal fold with the axial plane in the position shown by the dotted line. This coincides with the average foliation position. The positions of these features are not based on statistical techniques but represent an estimate of average positions as made by the author.

geologic map of the thesis area. These curved structures are in the proper orientation to represent a section, although not a right section, of the fold described by the stereograms. The only discrepancy is that the stereograms indicate an isoclinal fold while on the map the trace of the limbs of the fold are at 90° to one another.

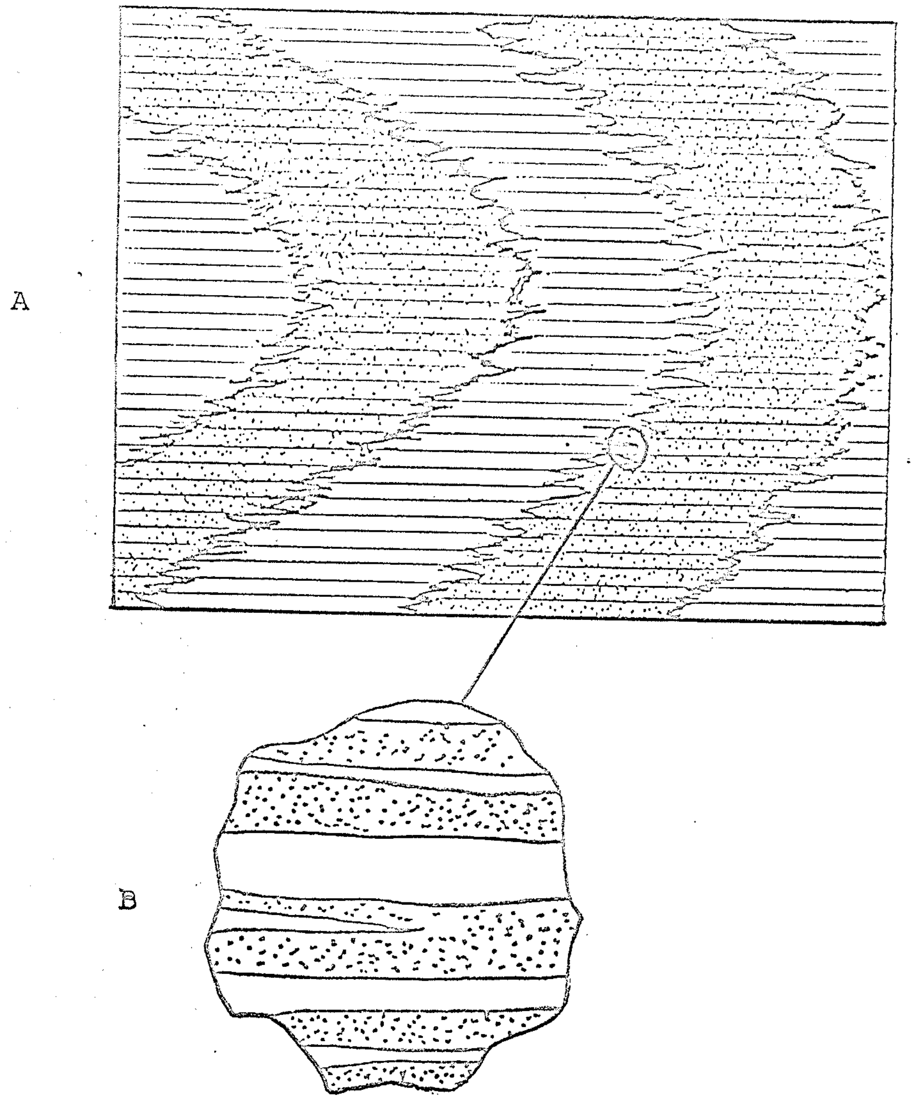
A possible explanation for this apparent disagreement is the development of small isoclinal folds on the limbs of the major fold depicted on the map. In a single outcrop where the attitudes are measured, a large number of these small folds can obscure the overall bedding attitude. As a result predominantly isoclinal attitudes are measured in the field. Plate 20 (after Turner and Weiss, 1963) illustrates this condition.

(c) SUPERIMPOSED FOLDING

From the data discussed so far, the deformational features of the map area may be interpreted to be a single large fold, with the orientation shown in the synoptic stereogram and with the development of many small isoclinal folds on the limbs. A fold with this orientation and shape is depicted in three dimensions in Plate 21; in this diagram a single continuous bed has been drawn to mark the fold. However, no such continuous unit has been identified.

A factor that complicates this interpretation of the structure is the pattern of the contacts on the surface. The contacts that have been drawn in Plates 3 and 6 outline "bent lenses" and "hooks" of acidic rock surrounded

PLATE 20



The bedding-foliation relation on two scales.
(A) On the scale of the map, bedding is at a distinct angle to foliation.
(b) On the scale of a single outcrop bedding appears to be parallel to foliation
Diagram after Turner and Weiss Page 95.

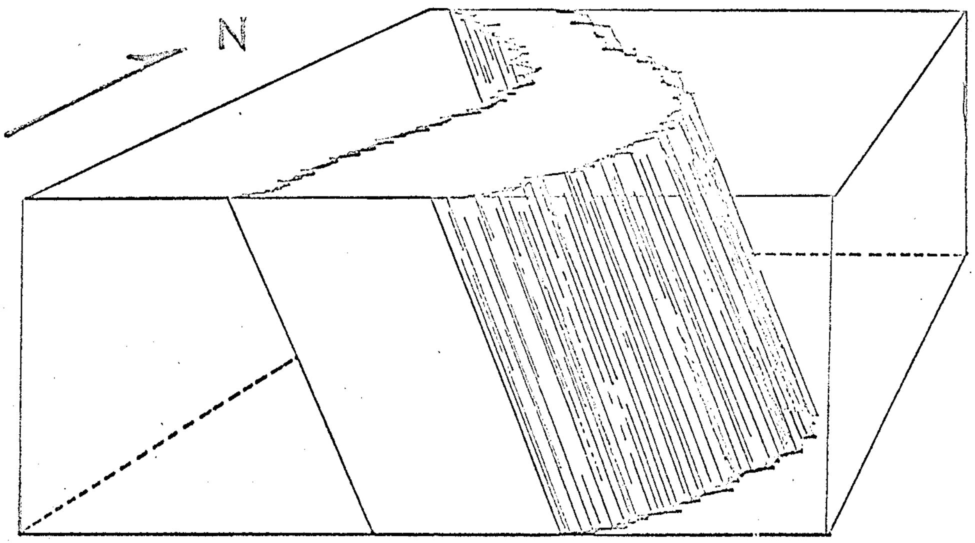
by basic rock. The pattern is inconsistent with simple layering which has undergone one period of deformation. The pattern might be explained by a complex stratigraphy with abundant lenses and pinchouts. However, it seems unlikely that the lenses would be so frequently centered on the axial plane of the fold, or that the pattern would be so repetitive.

A more reasonable hypothesis to explain the complexities of the pattern is, that the area has undergone two periods of folding. As Davies (1965 p.27) has pointed out, the pattern of rock distribution in this area bears a definite resemblence to patterns that S.W. Carey (1962 p. 101) refers to in his discussion of superimposed folding. Also, W.C. Brisbin (personal communication) has worked to the south-west of the thesis area where he has interpreted two periods of deformation.

If cross folding has taken place it would be very difficult to relate the pattern of the contacts observed in the thesis area to a specific system of refolded folds. There is no stratigraphic evidence to indicate the number of acidic and basic units that are involved in the folded section or in which direction tops and bottoms of the various units face.

In spite of the lack of data to support a hypothesis of two periods of folding, it is possible to relate the surface distribution of the contacts and the geometery of the structure to a system of superimposed folds. The

PLATE 21



Hypothetical continuous bed as it would appear if deformed by the fold indicated by the stereograms and the aerial photograph trend lines.

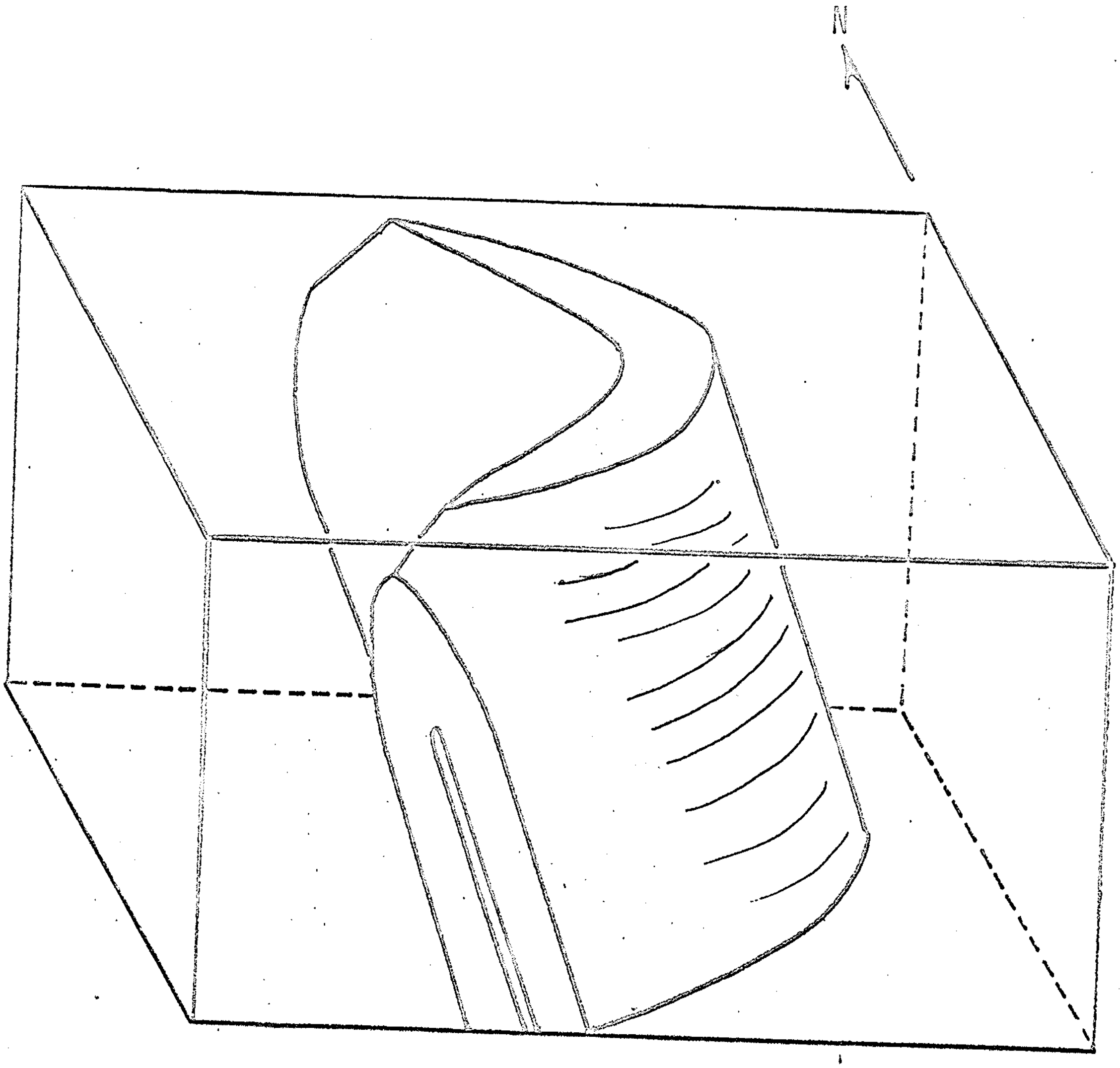
following paragraphs discuss one way that this can be done.

A "bent lens" could represent the crest of a first period anticline which has been folded during a second period of deformation so that the earlier fold is now "bent" and doubly plunging. Plate 22 is a block diagram indicating how such a fold would appear in three dimensions.

The first period fold illustrated in this diagram is shown as isoclinal. This interpretation is based on the distribution of bedding poles in the synoptic stereogram, Plate 19. The pattern of poles to bedding in this diagram is similar to one which would result from a single event producing a single fold. If two periods of folding have taken place it is necessary therefore to interpret that the first period folding was isoclinal. The stereogram of small fold axes also indicates this for there is no scatter of the axes, a condition that would be expected from refolded folds unless the first set was isoclinal. Refolding of an isoclinal fold would produce a stereogram pattern similar to a simple fold produced by a single event of deformation.

Interpretation of cross folding beyond the above discussion is unwarranted at the present time because of the lack of stratigraphic data and evidence bearing on the direction in which the beds face.

PLATE 22



Three dimensional diagram of one possible way that a "bent lens" pattern could be produced by two periods of folding.

(d) KINEMATIC ANALYSIS

Although no final decision can be reached with regard to superimposed folding it is possible to discuss the mechanism of deformation during the development of the fold which has been readily identified. There is evidence that this fold was produced by a mechanism of differential passive slip. In several outcrops to the east of the thesis area, small scale folds have been observed in which shear deformation is unmistakable. (Davies, 1965 p.25). Within the thesis area itself no clear cut examples were observed but there are suggestions of differential slip such as those shown in Plate 15. The foliation, not only in these examples, but throughout the area represent planes along which the slip may have occurred. As well, the foliation is in the axial plane position and the folds are cylindroidal; although these facts do not preclude other fold mechanisms, they are requirements of folding by passive slip. (Turner and Weiss p. 480).

If shear folding (passive slip folding) has taken place, one more feature of the earlier period folds can be interpreted. The shear folds should plunge in the direction of the intersection between the foliation and the layering being folded. The intersection lineations plunge steeply to the east, so that the layering, previous to the shear folding must have been dipping steeply in an easterly direction. Hence if an earlier set of folds was present their limbs and axial plane must have dipped steeply to the east.

Little evidence was found in the thesis area to indicate the direction of the slip movements. The mineral lineations that are present might be taken to indicate the slip direction but they vary in orientation only slightly from the axial direction of the folding. Such a small divergence between the slip direction and the axes of the folds would require an extremely large displacement up and down the dip of foliation to produce the amount of horizontal displacement that has occurred.

W.C. Brisbin (1965) has studied deformed pebbles in the southern part of Ewart Township and has interpreted the direction of slip producing the second period folds to be up and down the dip of the foliation. He has interpreted these near vertical differential movements to be a result of the upward intrusion of granitic masses in the form of the several small stocks that are exposed in the northern Lake of the Woods region.

(e) SUMMARY

In summary, the evidence is consistent with the interpretation of a single large fold plunging steeply to the east. The limbs of this fold are not smooth but are distorted by abundant smaller scale, isoclinal folds parallel to the main fold. The folding may have resulted from differential passive slip.

The only indication that the structural history is more complex than this, is the unusual rock distribution pattern of Davies (1965) map. This pattern strongly suggests that the folds delineated on Davies map have refolded an earlier set. If earlier folds were present the evidence indicates that they were isoclinal with axial planes dipping steeply in an easterly direction.

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