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by

W. E. Gordon Taylor

THE GEOLOGY OF THE LOWER PRECAMBRIAN ROCKS OF THE CHAMPION-REPUBLIC AREA OF UPPER MICHIGAN (NASA GEOLOGICAL TEST SITE 126)

Prepared at

DEPARTMENT OF GEOLOGY

NORTHWESTERN UNIVERSITY

EVANSTON, ILLINOIS 60201

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

CONTENTS

FOREWORD

by

E. H. Timothy Whitten

In preparation for the anticipated NASA aircraft overflights of the Marquette and Republic Troughs Test Site (#126), it has been necessary to initiate a series of geological structural studies of the area. Although one of the classic areas for structural and metamorphic geology since the work of van Hise and others sixty years ago, many parts of the area remain either unmapped or imperfectly known. Continuing active work by the U. S. Geological Survey, the Cleveland-Cliffs Iron Company, and Bear Creek Mining Company is helping to resolve numerous stratigraphic and structural problems.

The nature of the sub-Animikie rocks and their contact relations with the important iron-ore-bearing Animikie rocks has remained particularly obscure. Dr. W. E. Gordon Taylor addressed himself to this problem and the present report summarizes his work during 1966-67. In an area involving so many complex problems, it cannot be anticipated that one year's work will either (a) resolve all problems, or (b) not require some modification as further work is completed. Work by Northwestern University within the Test Site is continuing; currently Mr. C. Powell and Mr. W. tenKate are engaged in active mapping and field programs. In the near future, it is hoped that all of these studies will lead to a complete and integrated picture of the area.

With this increased familiarity with the structure and stratigraphy of the Test Site, it is hoped that meaningful interpretations of remote sensing data can be made. Of particular interest will be the result of side-looking radar in this highly faulted and folded region which has an appreciable forest and scrub cover.

ABSTRACT

New data and information are presented regarding the lithologies and structure of the Lower Precambrian rocks of the Champion-Republic area of Upper Michigan.

A series of migmatitic rocks has been involved in several deformational episodes and intruded by two major types of granite and by a suite of amphibolitic dykes. The structural evidence suggests that the earlier Michigamme River Granite was emplaced as a sheet during the later stages of the second phase of deformation. The later Amik Lake Granite was probably emplaced during a phase of nondeformation.

Evidence is given which suggests that both the Middle Precambrian (Animikie) and the Lower Precambrian rocks were involved in the third phase of deformation.

I. Introduction

This account represents the final report of an investigation into the Lower Precambrian* rocks of the Champion-Republic area of Upper Michigan, and is based upon two months of intensive field work during October, 1966 and August, 1967 and analysis of rocks and structural data in the laboratory at Northwestern University.

The area under consideration is of approximately 90 km^2 (35 sq. miles) extending westward from highway M95 and is surrounded to the west, north, and south by rocks of the Middle Precambrian* (Animikie Group*; see fig. 1).

Most of the bedrock of the area is covered by thick glacial deposits and at least 95% of the area is densely forested which prevents investigation of all available exposures. This handicap was partly overcome by using numerous tracks which cross the area and by carrying out compass-traverses along certain section lines. However, because of the precise nature of the work, the latter were only undertaken in areas in which geographic position could be located with certainty. Those exposures which were investigated are shown on the lithological map (Map 1).

Mapping was originally carried out on a scale of approximately 4 in. to the mile (1:15,480) using aerial photographs.

II. Lithological Components of the Area

Three major lithological types were mapped in the area. They are megacrystic granites, migmatites, and thick amphibolite dykes. Only those amphibolite veins thicker than 15 m are shown on map 1.

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* U.S.G.S. nomenclature

N.B. Numbers after localities refer to U,V coordinates on the maps.

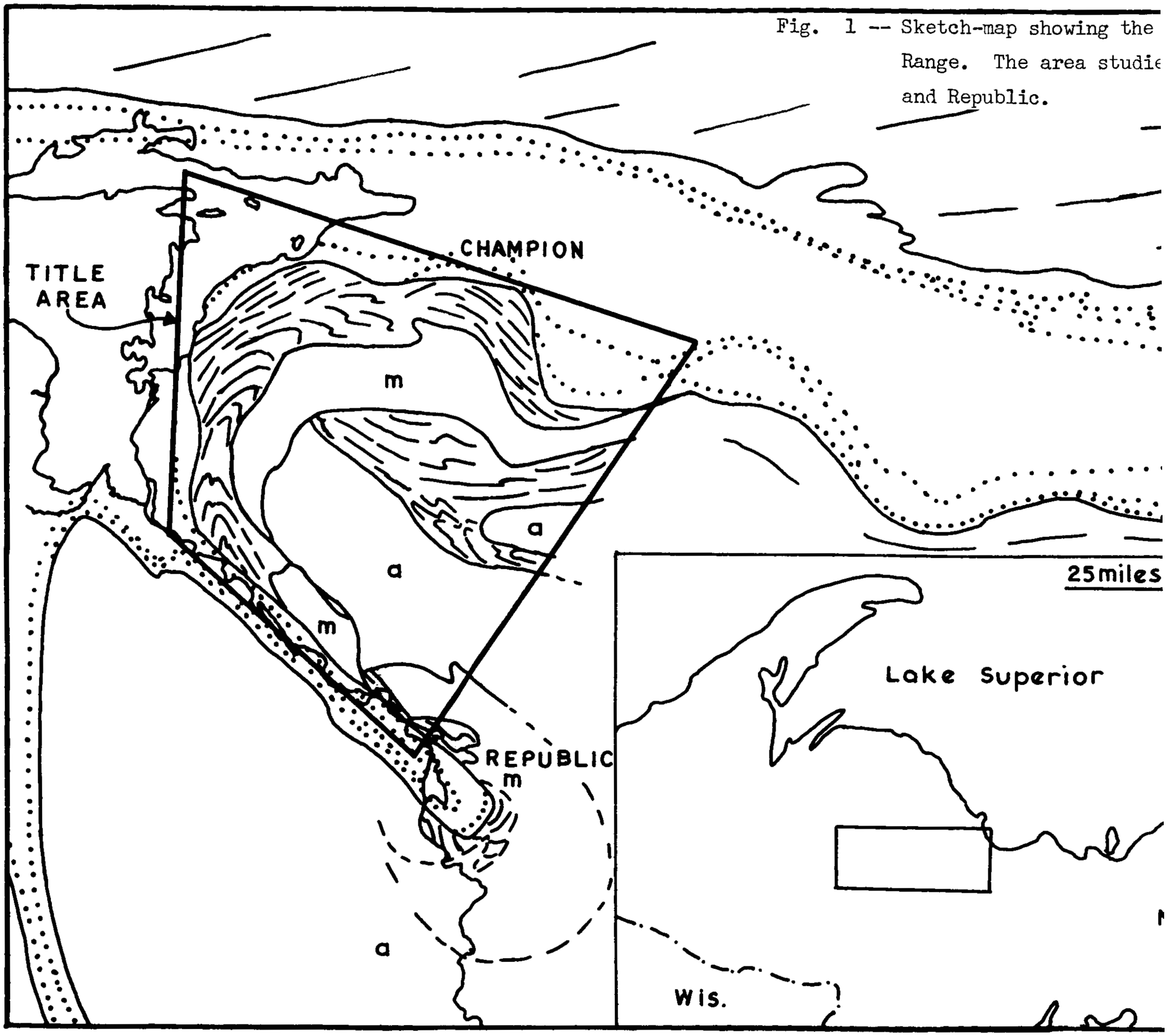
Fig. 1 -- Sketch-map showing the
Range. The area studie
and Republic.
TITLE
AREA
CHAMPION
m
a
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REPUBLIC
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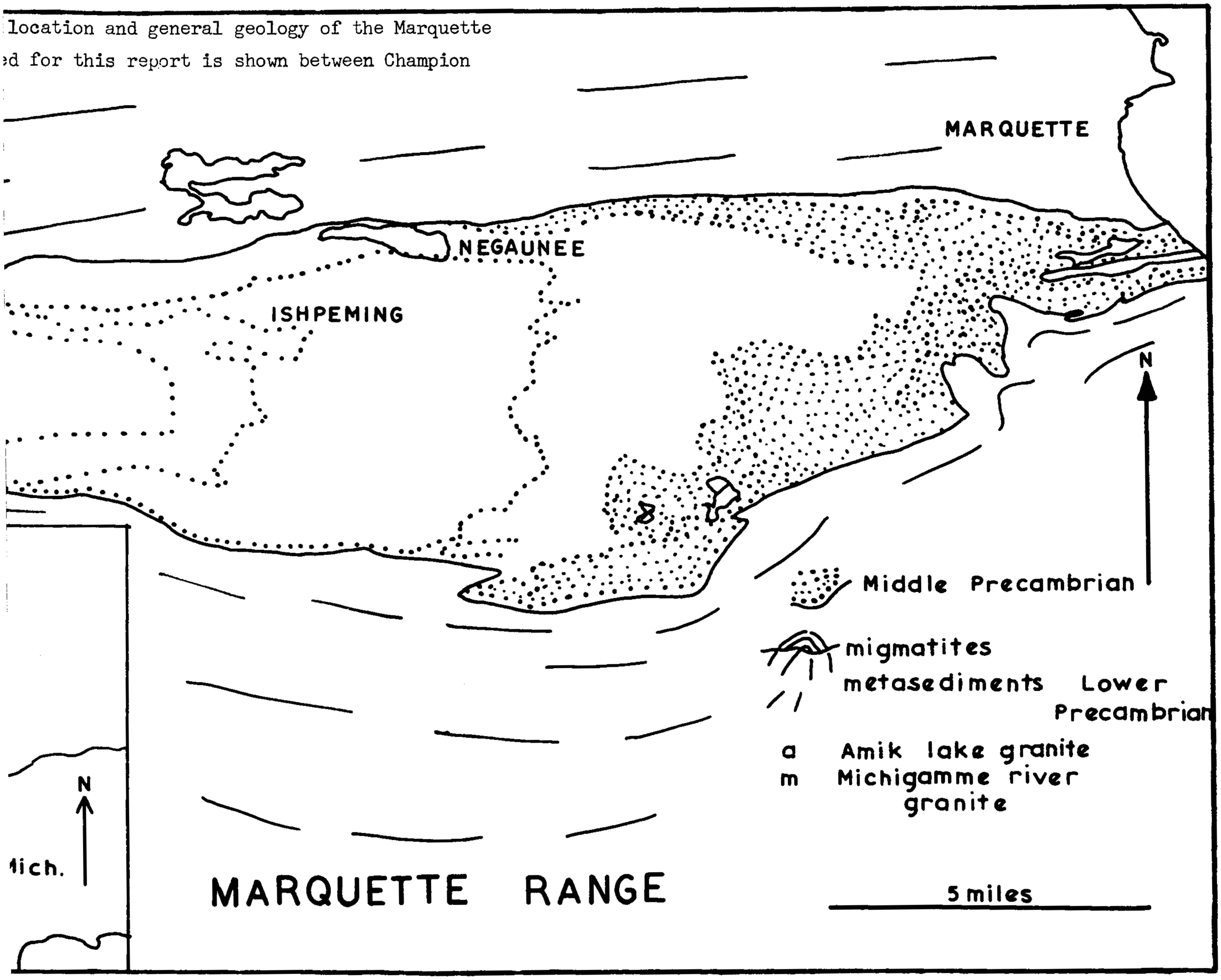
a
25miles
Lake Superior
Wis.

location and general geology of the Marquette
ed for this report is shown between Champion



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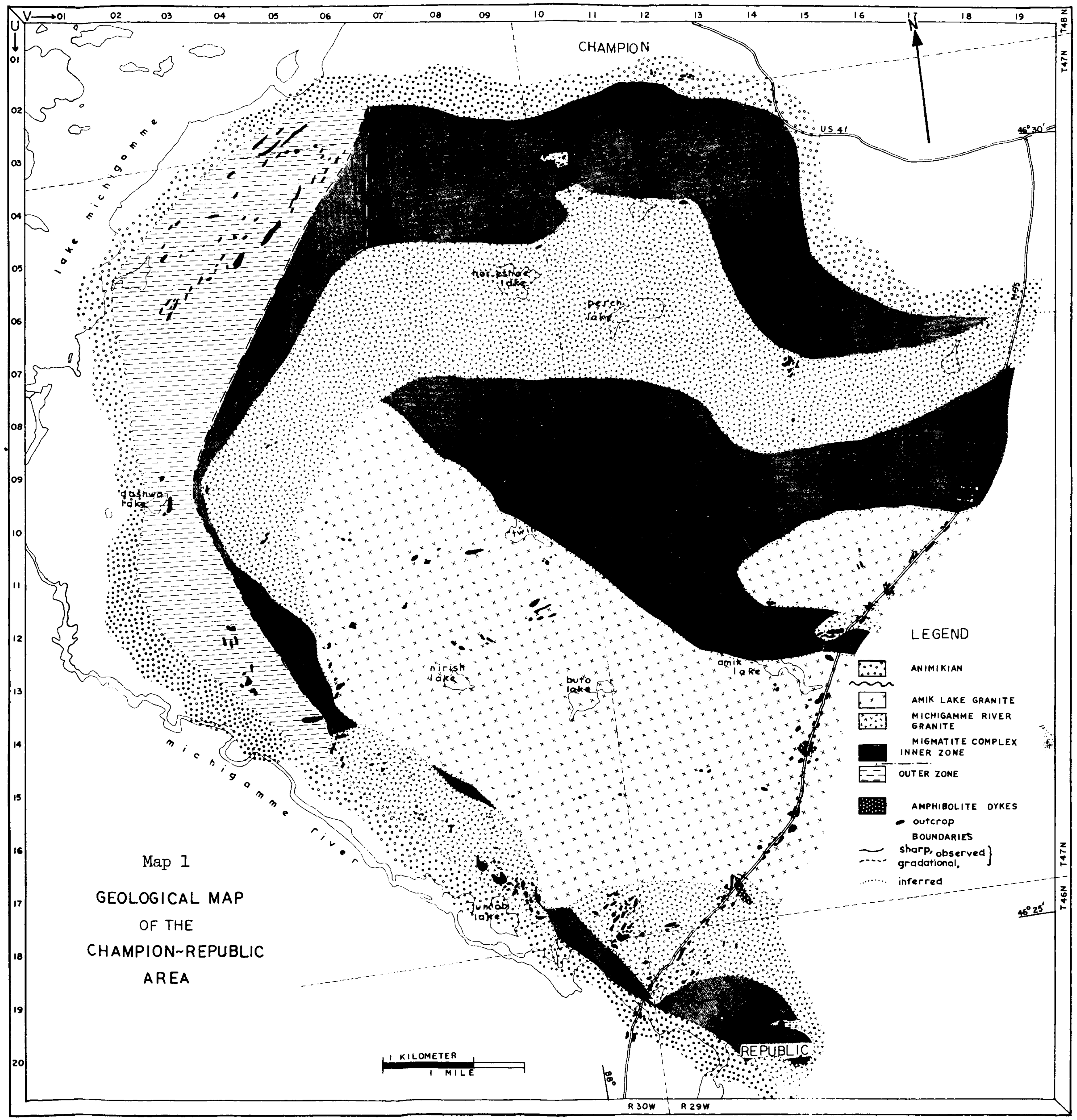

Map 1
GEOLOGICAL MAP
OF THE
CHAMPION-REPUBLIC
AREA
CHAMPION
REPUBLIC
US 41
M-95
lake michigamme
michigamme river
horseshoe lake
perch lake
qashwa lake
nirish lake
bufo lake
amik lake
junco lake
46°30'
46°25'
88°
T48N
T47N
T46N
R30W
R29W
1 KILOMETER
1 MILE
LEGEND
ANIMIKIAN
AMIK LAKE GRANITE
MICHIGAMME RIVER GRANITE
MIGMATITE COMPLEX
INNER ZONE
OUTER ZONE
AMPHIBOLITE DYKES
outcrop
BOUNDARIES
sharp, observed
gradational,
inferred

5-1 5-2

(A) GRANITES

Two distinct types of granite have been recognized, a coarsely megacrystic variety called the Amik Lake Granite* and a more even-grained but still megacrystic variety called the Michigamme River Granite*. The Michigamme River Granite occurs as a concentric margin to the Amik Lake Granite which crops out over the center of the area. The junction between the two granites has been observed at only one exposure at a road junction north of Republic (16651375). Here the junction is complicated by small-scale faulting but appears to be narrowly gradational and irregular and suggests that the Amik Lake Granite was emplaced into the Michigamme River Granite possibly by intrusion. Neither of the varieties is chilled against the migmatites which constitute the country rocks.

The Michigamme River Granite. The outer margin of this granite is everywhere in contact with the migmatite complex and in most places is discordant to the primary foliation in migmatites. In a large exposure (Locality 2 of Ayres, in Snelgrove, Seaman and Ayres, 1944) south-east of Republic the planar foliation is continuous from the granite into the migmatites in which it is approximately parallel to the axial-plane foliation of the second-phase minor folds in the migmatites. The parallelism between the two foliations has been verified in other localities where the contact is not observed. To the north at Champion (03451025) a poorly foliated variety has intruded the migmatites. Throughout the area the outer contact is sharp, even in localities where the country rock is granitic gneiss.

The metamorphic effects of emplacement of the granite have not been studied in detail but the formation of biotite clots in the country rocks in

* To avoid confusion with previous nomenclature of the granites, the two varieties were named after localities in which they were best exposed. This procedure was agreed after consultation with Mr. Zainuddin who is carrying out a detailed petrological and petrochemical investigation of the granites in the vicinity of Republic.

Michigamme River Granite

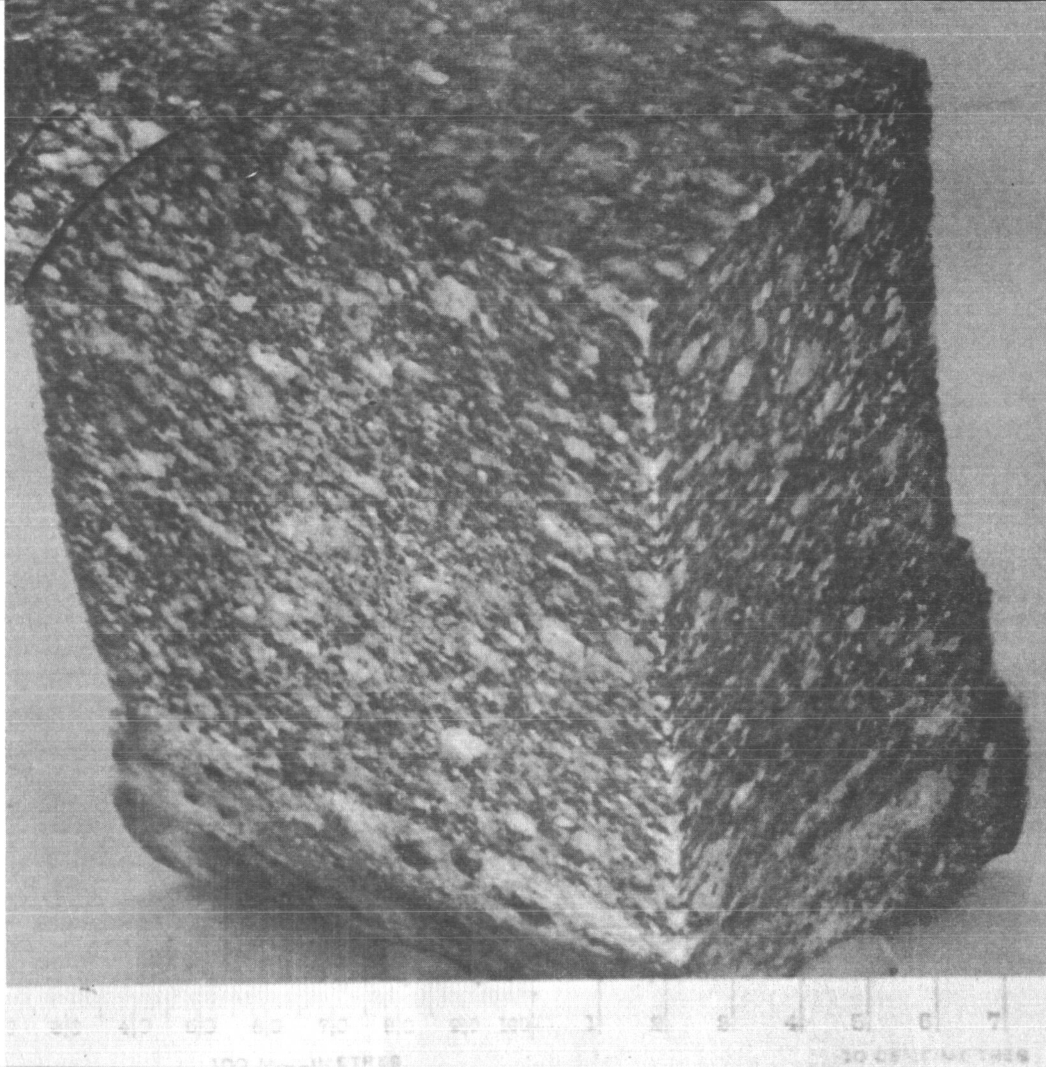
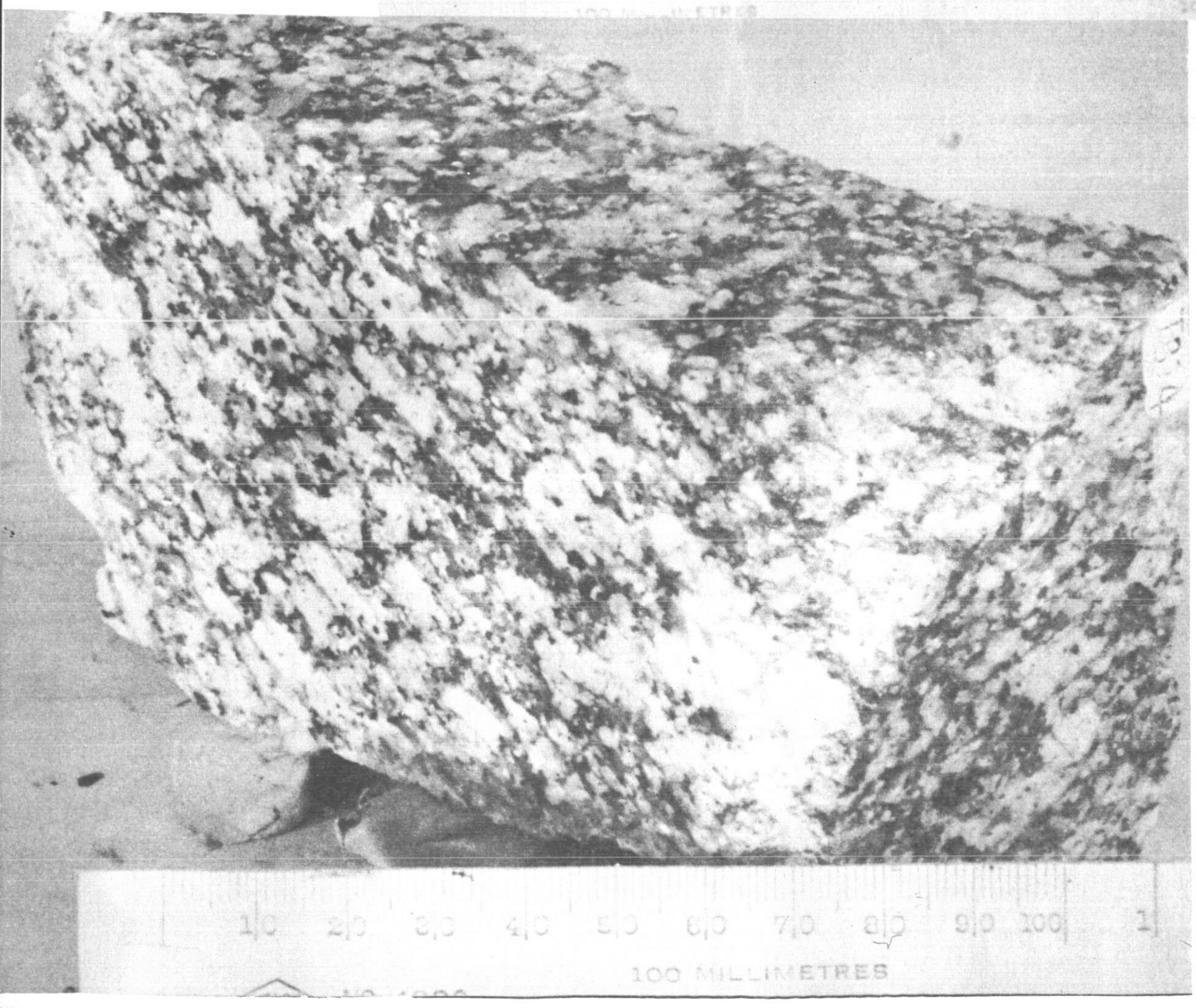
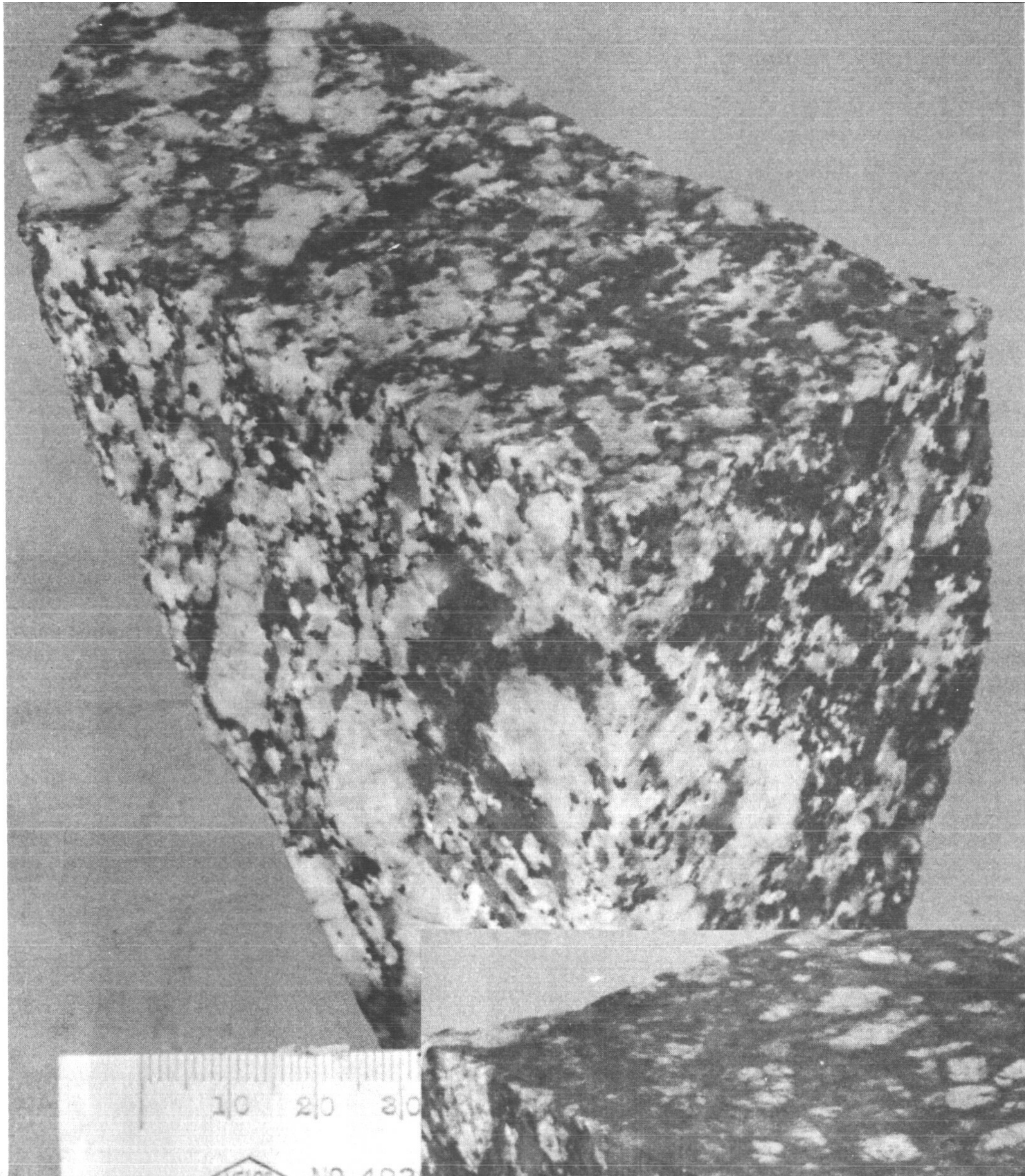
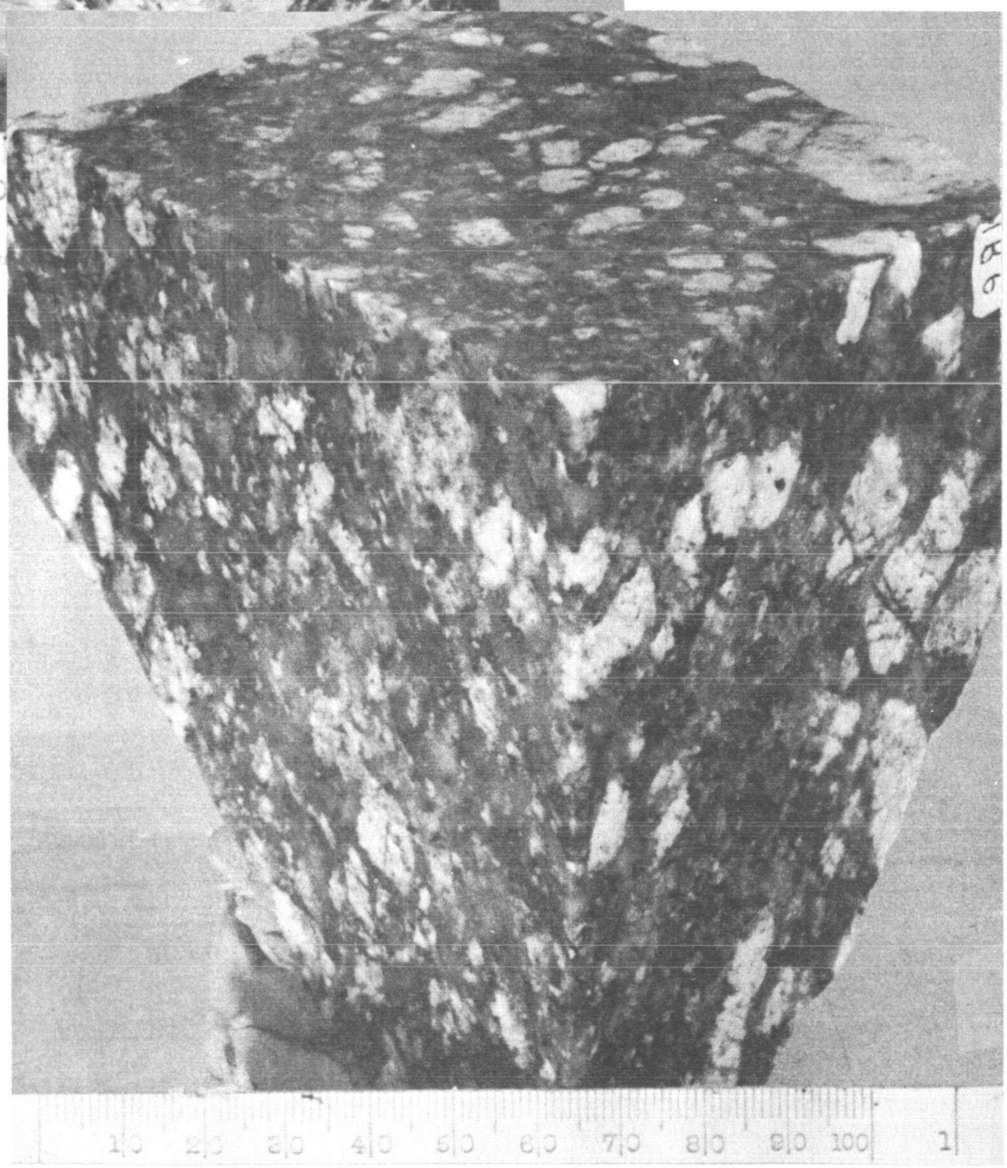


Fig. 2 -- Photographs of representative granite rocks





Amik Lake Granite



an exposure to the north of Republic (Locality 1 of Ayres, in Snelgrove et al., 1944) is thought to be due to contact metamorphism.

The granite consists of plagioclase (An_{20-29}), microcline-microperthite, quartz, biotite with small amounts of epidote, muscovite, and ferruginous opaques. Commonly the plagioclase is extensively sericitized which renders compositional determination difficult. Approximate average modal composition of this granite is given in Table 1.

The granite is extremely variable both in mineralogy and texture. The most common variety being a grey rock with fairly large pink megacrysts of microcline set in an even-grained coarse matrix of quartz, plagioclase, and biotite with other accessories. The megacrysts of microcline form a fairly prominent linear structure in the strong foliation which, in turn, is defined by the planar orientation of minerals, especially biotite and occasionally by the plane of elongation of inclusions and small xenoliths. In a few localities the granite takes on an _augen_ appearance but it is not certain whether this structure developed during the formation of the foliation or was caused by subsequent deformation.

The Amik Lake Granite. As mentioned above the transition between the two types of granite is either sharp or narrowly gradational. Commonly, the foliation within the Amik Lake Granite does not seem to parallel that of the Michigamme River Granite; but in places (_e.g._, 16651375) the two foliations are nearly concordant.

The granite consists of quartz, microcline-microperthite, plagioclase (An_{24-30}), and biotite with small amounts of muscovite and ferruginous opaques. The average modal composition is given in Table 1(B).

Table 1

Modal composition of the granitic rocks

<table>
<tr><th></th><th>A*</th><th>B+</th><th>C#</th><th>D#</th><th></th></tr>
<tr><td>Number of samples</td><td>4</td><td>2</td><td>7</td><td>2</td><td></td></tr>
<tr><td>Quartz</td><td>38.6</td><td>31.8</td><td>38.3</td><td>31.9</td><td></td></tr>
<tr><td>Alkali feldspar</td><td>31.4</td><td>37.0</td><td>17.9</td><td>1.4</td><td></td></tr>
<tr><td>Plagioclase</td><td>25.7</td><td>27.0</td><td>40.4</td><td>29.5</td><td></td></tr>
<tr><td>Biotite</td><td>4.0</td><td>2.9</td><td>3.2</td><td>37.1</td><td></td></tr>
<tr><td>Muscovite</td><td>0.2</td><td>0.8</td><td rowspan="2">0.2</td><td>0.1</td><td></td></tr>
<tr><td>Others</td><td>0.1</td><td>0.5</td><td>nil</td><td></td></tr>
<tr><td></td><td>100</td><td>100</td><td>100</td><td>100</td><td>volume percentage</td></tr>
</table>

A - Amik Lake Granite

B - Michigamme River Granite

C - Migmatitic Granite Gneiss

D - Feldspathic Schist

* Determined by combined slab and thin section method (Nesbitt, 1964).

+ Determined by using two thin sections of areas 320 mm^2 for each sample.

\# Determined by using one thin section of area 320 mm^2 for each sample.

The modal composition of the granite is variable but texturally the rock is reasonably homogeneous. The rock consists of large tabular pink or white megacrysts of microcline-microperthite set in a greyish-white matrix of plagioclase, quartz, and biotite. The megacrysts are crudely aligned parallel to a mineral foliation.

An average modal composition (Table 1(A)) indicates that in comparison with the Michigamme River Granite the Amik River Granite is richer in quartz but poorer in alkali feldspar.

<u>Veins</u>. The veins within the granitic rocks of the area include pegmatites and aplites.

Many NE-SW trending coarse-grained pegmatites occur in the Amik Lake Granite. The pegmatites are mainly composed of alkali feldspar, muscovite, quartz, and some plagioclase. A few of the veins are zoned but most have a complex intergrowth between the constituent minerals. Pegmatites appear to be not so abundant in the Michigamme River Granite and have been observed only within the famous "Pegmatite Knob" exposure north of Republic (Locality 1 of Ayres, op. cit.). Here thick pegmatites trend N-S and dip at about 40° to the west. Thinner E-W trending pegmatites also occur.

Alpite veins occur in both granites but especially in the northern part of the area. Most of the veins trend E-W.

Xenoliths. Various rock types from the migmatite complex occur as xenoliths in both granite types. The margins of the xenoliths in every observation were seen to be sharp. The xenoliths vary greatly in size from a few centimeters to over a meter in diameter.

Biotite schlieren occur aligned parallel to the foliations in both granite types, and probably represent the final stages of the digestion of country rock xenoliths.

(B) THE MIGMATITE COMPLEX

Around the north, south, and west margins of the granitic rocks and as enclaves within the granites the Sub-Animikie metasedimentary rocks have been involved in migmatization.

Two zones of progressive migmatization can be recognized, the boundary between which is broadly gradational. The outcrop pattern of the zones is complicated by the successive structural phases, but migmatization probably commenced before the first structural phase.

Outer migmatite zone. The outer boundary of this zone is not found in the area under discussion, but would be drawn where the last igneous portion crops out.

The host rocks are schists and amphibolites and the igneous portion consists of concordant veins of granite gneiss and microgranites. In some exposures coarse pegmatite veins which are often blatantly discordant to the primary foliation occur. All these veins show sharp to narrowly gradational contacts with the country rocks.

Inner migmatite zone. The boundary of the inner and outer zones is drawn where the igneous portion constitutes at least one-half of the total rock. The primary foliation in the rocks becomes progressively nebulous and amphibolitic schists become dislocated suggesting that plastic flow has taken place.

Banded pelitic and semi-pelitic schists give rise to lit-par-lit migmatites which consist of quartzo-feldspathic bands alternating with biotite-quartz bands both of which are coarsely crystalline and in a few localities have an augen appearance. An average modal composition of these rocks is given in Table 1(D).

Semi-pelitic schists and psammitic schists have recrystallized and biotite is commonly segregated into the hinge areas of minor folds.

Micrograntic veins are common, apparently structureless, and nearly everywhere discordant to the primary foliation.

To the south of Champion and in the vicinity of Republic a foliated granite-gneiss crops out. This rock has been traced by sporadic exposures but the field evidence is inconclusive concerning the origin of this rock. There are two possibilities: either it was formed by in situ reconstitution of an arkosic sediment or by igneous intrusion during the phase of progressive migmatitization. An average modal composition of the granite gneiss is given in Table 1(C).

Pegmatites, which are commonly deformed by second phase structures, are ubiquitous within this zone. A cursory investigation suggests that the trend of the pegmatites is in a NE-SW direction.

(C) AMPHIBOLITES

Several types of amphibolitic rocks have been recognized in the Champion-Republic area. They will be considered in chronological order.

Near the western boundary of the Lower Precambrian rocks, outcrops of a distinctive banded amphibolite schist occur. Attempts to trace this marker band proved futile. Other banded amphibolites are observed to be very common in the outer migmatite zone and may represent the metamorphosed equivalents of basic igneous or pyroclastic rocks deposited before the first recognizable structural phase.

Other amphibolitic schists appear to have been emplaced either during or just preceding the second phase of deformation. Most are not foliated but exhibit minor second-phase folds.

Thick amphibolitic dykes are frequently observed to transect the Amik Lake and Michigamme River Granites (e.g., along the M95 highway). In many exposures the margins of the thickest dykes are schistose and many of the dykes are foliated parallel to the margins. Figure 3 shows that there are two main dyke directions approximately at right angles to one another. Many thin dykes are extremely rich in biotite and it is questionable that these dykes were originally of a basic igneous origin. A lamprophyric origin is perhaps more probable.

III. Structure

The geological structure of the Lower Precambrian rocks of the Champion-Republic area is more complex than previous workers envisaged. A preliminary account of the structural sequence was presented in a previous report (Taylor, 1967). Subsequent work has shown that the sequence is even more complicated.

Five phases of deformation have been recognized by investigating the minor structures within the migmatite complex. In order to simplify the following

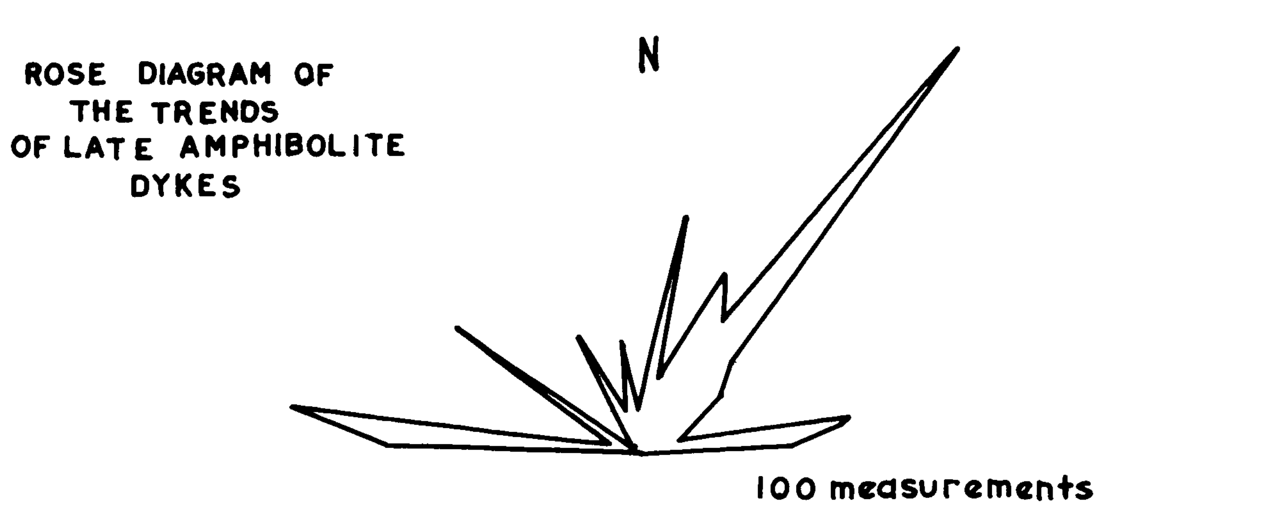


Fig. 3 -- Rose diagram of the trends of late amphibolite dykes.

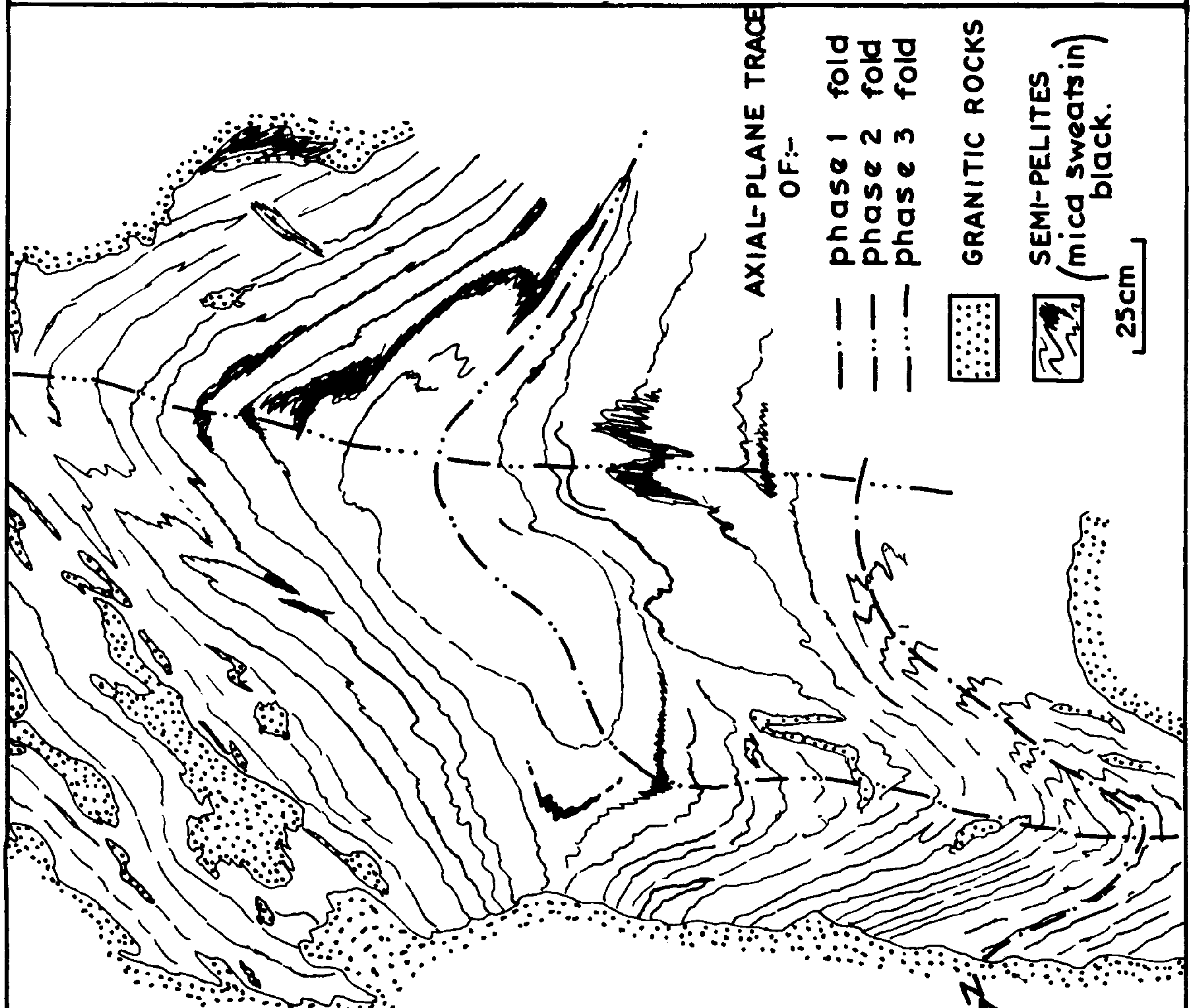


Fig. 4 -- An example of the evidence for polyphase folding. The exposure represented is inclined at about 30° towards the east.

account the structural history is considered under the following headings:-

a) Early phases,

b) Middle phase,

c) Late phases.

Each phase is thought to be a discrete event and deformation of earlier structures by later ones is ubiquitous. In an exposure north of the Michigamme River Bridge along the M95 highway (18751195) minor folds of the first three phases are observed. Here they produce a complex interference pattern (fig. 4).

Over 2,000 measurements of minor structures have been made for structural analysis of the area. These data are deposited at the Geology Department, Northwestern University.

Measurement precision for the structures. A simple series of tests was carried out in order to investigate the operator error in measuring structural elements. Differing structural elements were selected at three separate localities:

a) Strike of foliation at (11751485),

b) Amount and direction of plunge of a steeply plunging fold (18751195),

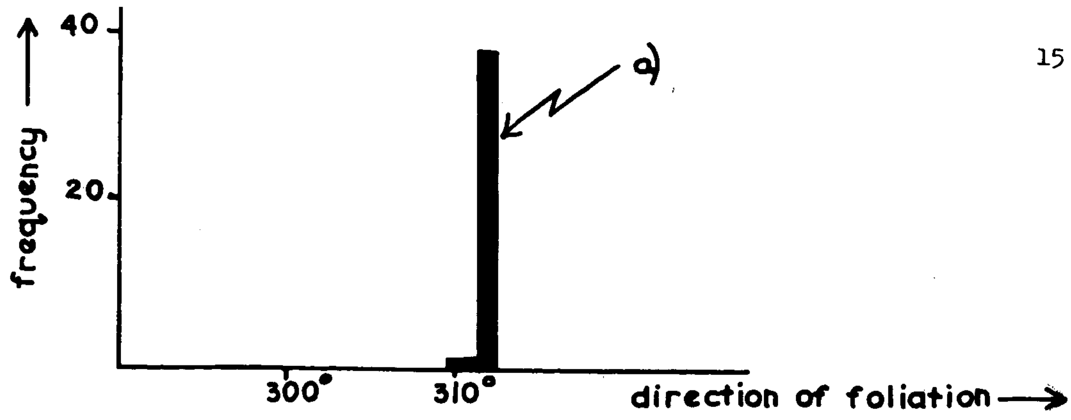
c) Amount and direction of plunge of a gently plunging fold (19851155).

Ten measurements were taken on four separate occasions to yield 40 measurements for each structure. These measurements are summarized in figure 5. It can be seen that for structural elements a) and c) the variation about the mean value is small ($< 2^{\circ}$), but for b) the variation is greater. Obviously, great care must be taken when measuring the plunge of steeply plunging folds.

Frequent checks were made to determine the deviation (if any) caused by magnetic rocks (e.g., Animikie iron formations). Measurements were corrected by reading the sun's position (Fraser, 1963). In some localities the deviation was as much as 85°.

(A) EARLY PHASES

Tight to isoclinal folds with angular hinge areas are the earliest minor



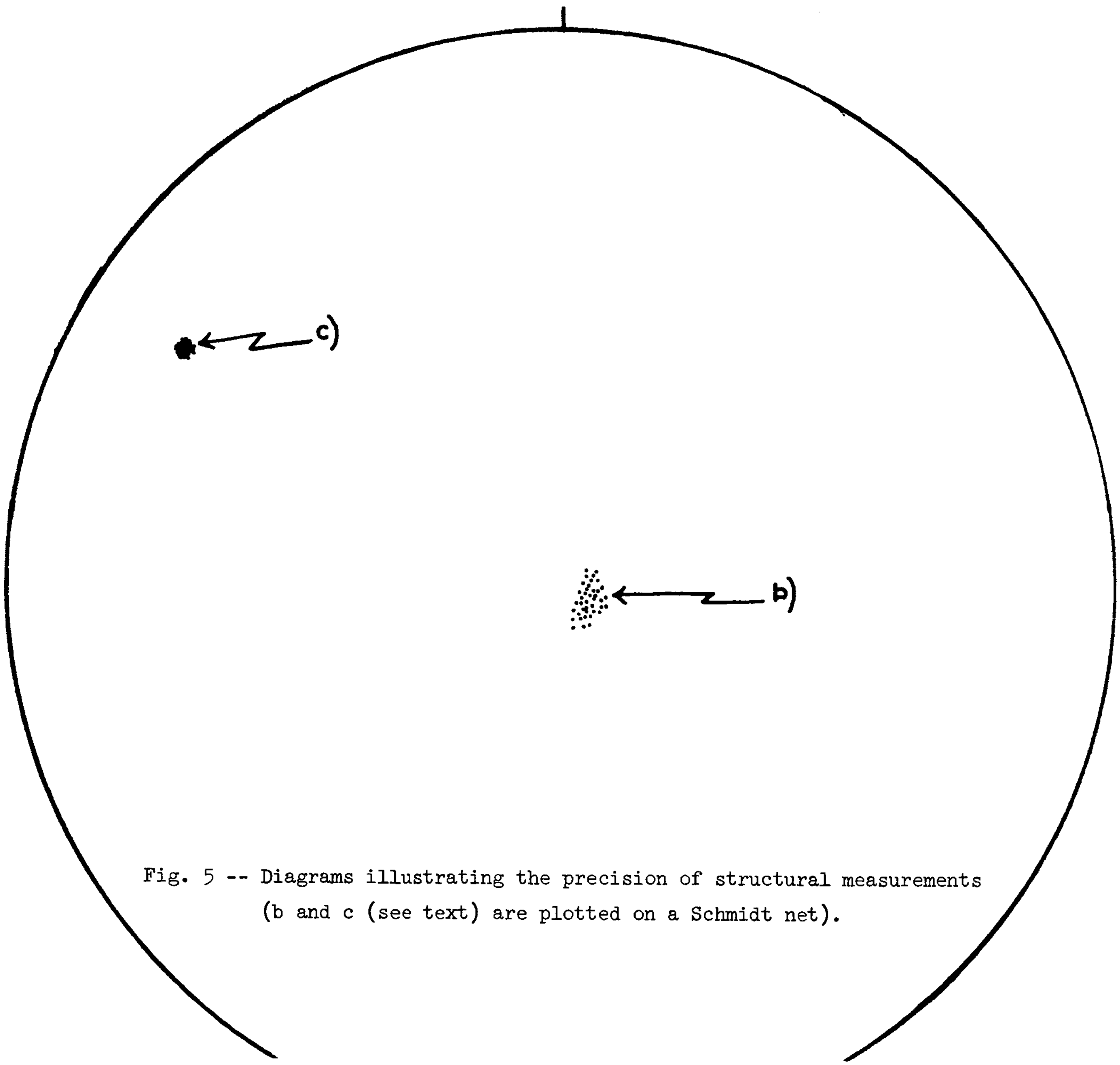


Fig. 5 -- Diagrams illustrating the precision of structural measurements (b and c (see text) are plotted on a Schmidt net).

folds recognised in the area (figs. 4, 6(i)). The plunge of these folds is extremely variable. A strong penetrative schistosity (S_1) has been developed approximately parallel to the axial-plane of these minor folds. Plots of this schistosity are shown on figure 7 and tend to confirm field observations that the S_1 surface is tightly folded. No major fold of this first phase of deformation has been observed.

During this first phase extensive flowage and migmatization of the rocks occurred and commonly produced dislocation of the more competent rocks (fig. 6(ii)). A suite of pegmatites was emplaced during the later stages of this deformation phase (fig. 6(iii)).

The styles of the folds of the second phase of deformation are extremely variable and appear to be controlled by the nature of the material being deformed (fig. 6(iv),(v)). The plunges of the minor folds are variable in value but tend to be towards the west. A general pattern of the pitch of the folds has been deduced. In south and west districts the pitch of the minor folds on the axial-plane foliation (S_2) is high to very high, whereas in the north the pitch is low to very low. The axial-plane foliation (S_2) of the second phase folds is, in some places, delimited by alignment of amphiboles and/or micas. Plots of S_2 (fig. 8) show that the planar foliation is folded by third phase structures.

By using the pattern of minor folds of this phase, it can be demonstrated that the rocks of the migmatite complex occupy the hinge area and part of the limbs of a major second phase fold (fig. 9a). Unfortunately, there are no distinct lithological units which can be used to demonstrate the nature of this fold. However, when this fold is reconstructed (fig. 9b) from structural evidence it is found that the present geometry of the fold varies consistently from south to north. The interesting geometry of this fold will be elaborated in a future publication.

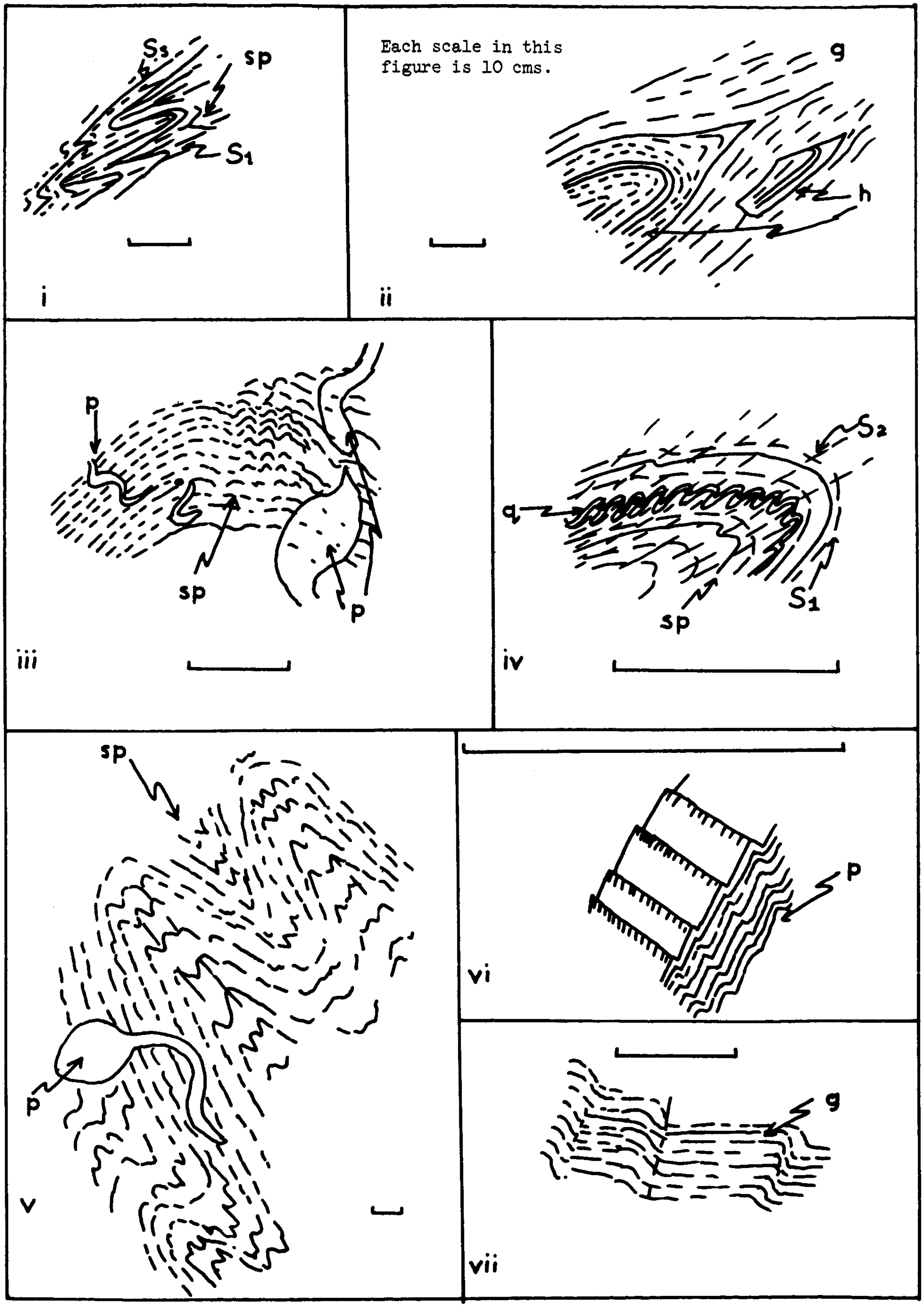


Fig. 6 -- Minor structures within the migmatitic complex; (i), (ii), (iii) -- phase 1; (iv), (v) -- phase 2; (vi) -- phase 4; (vii) -- phase 5; (g-granite gneiss, h-hornblende schist, p-pegmatite, q-quartz vein, sp-semi-pelitic schist; S_s-bedding, S_1- foliation of phase 1, S_2-foliation of phase 2).

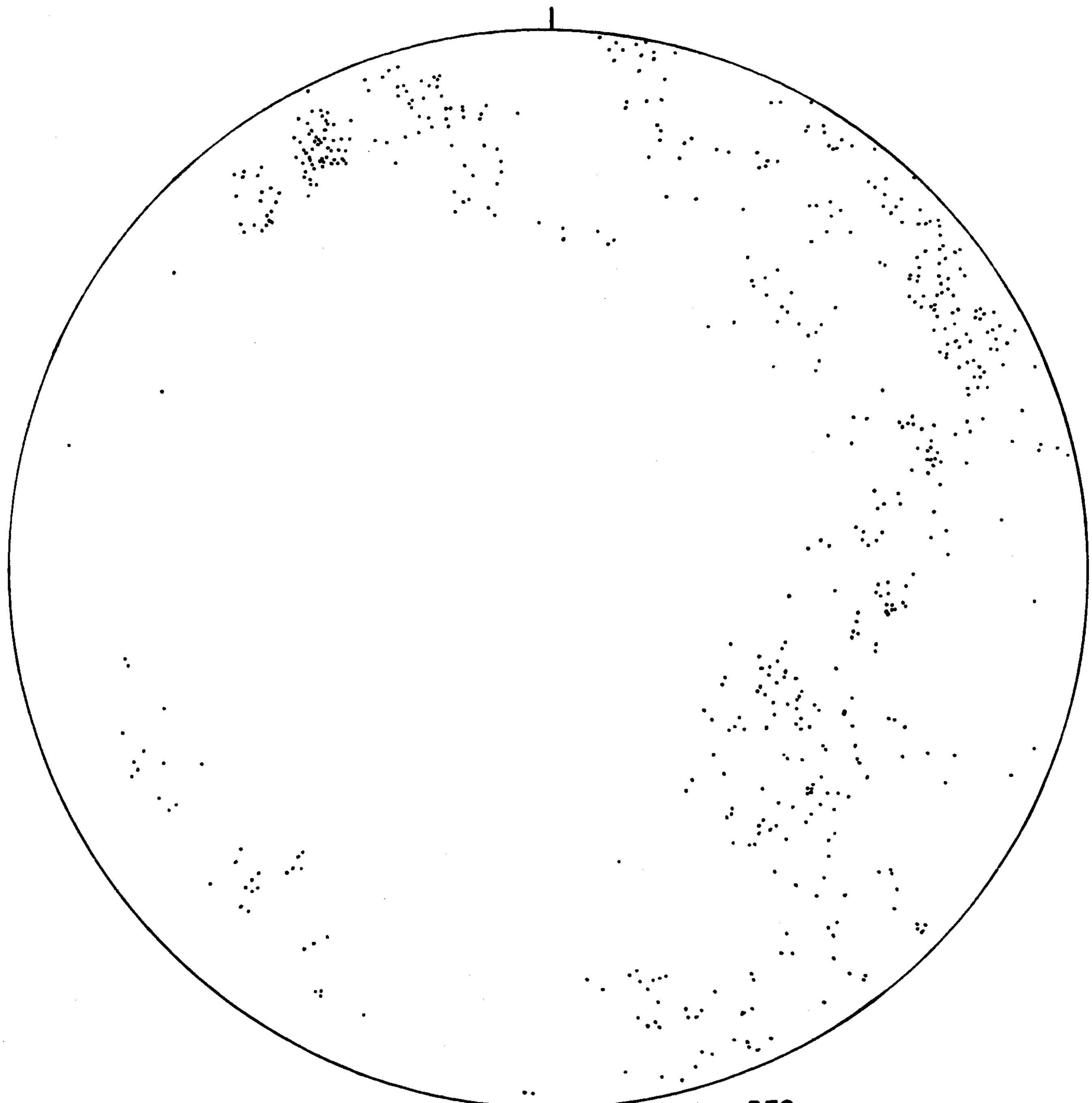


Fig. 7 -- Poles of S_1 (Schmidt equal-area net).

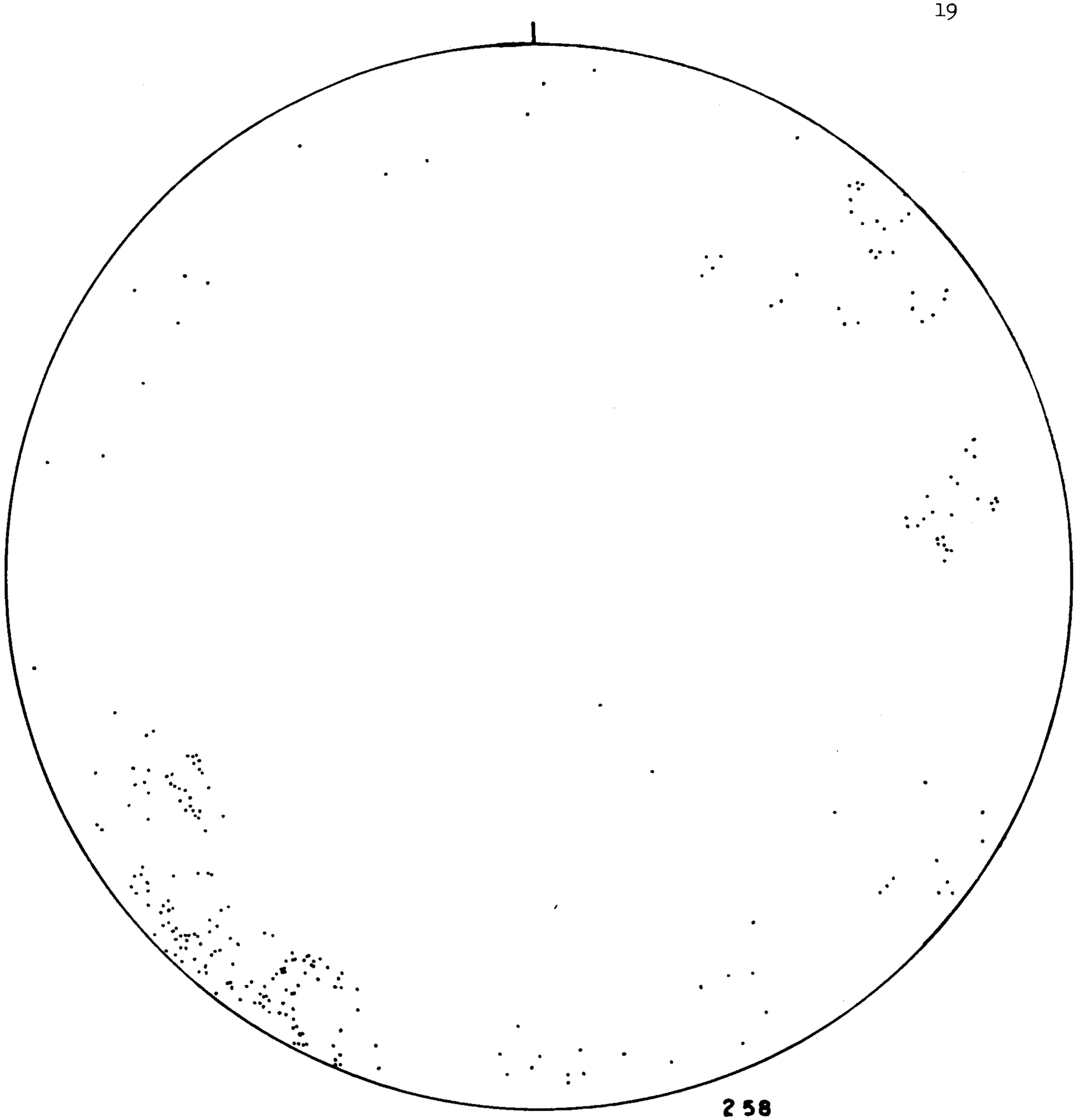


Fig. 8 -- Poles of S_2 (Schmidt equal-area net).

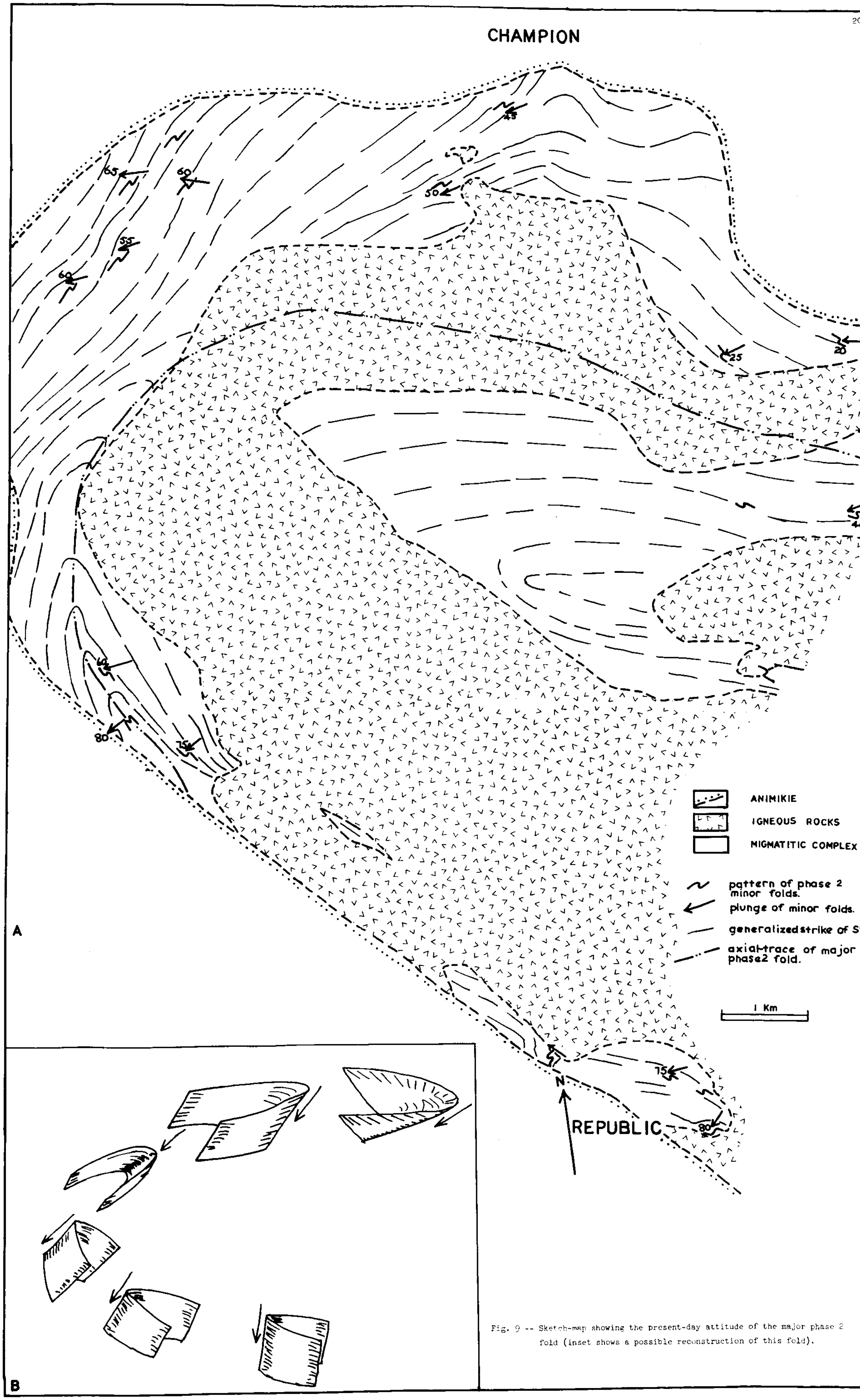


Fig. 9 -- Sketch-map showing the present-day attitude of the major phase 2 fold (inset shows a possible reconstruction of this fold).

The Michigamme River Granite. As mentioned above the granite has a distinct foliation parallel to the axial-surfaces of the second-phase minor folds. These two foliations may be compared by the data presented in figures 8 and 10. The alkali feldspar megacrysts are arranged in a crude lineation which tends to plunge gently to the north-west. It is obvious from maps 1 and 2 and from the data presented in figure 10 that the Michigamme River Granite has been folded by the middle phase deformation.

(B) MIDDLE PHASE

This phase is recognized by close to open minor folds having axial-plane traces which trend approximately NW-SE. The plunge of these folds is variable and depends upon the initial attitude of the foliation which was folded. In the hinge areas of a few of the minor folds, a crenulation foliation is developed. Plots of the axial surfaces (S_3) of these folds are demonstrated in figure 11.

The axial-plane trace of a major antiform can be followed starting north of Lake Amik up to Twin Lake (Map 2).

(C) LATE PHASES

Two series of kink-bands and crenulations (fig. 6(vi),(vii)) are observed to affect all of the rock types in the area investigated. Although best developed along the schistose margins of the late amphibolite dykes which transect the granites, they are not widespread in their development.

Phase four crenulations possess E-W trending axial-surfaces (S_4) and the plunge of these crenulations is largely controlled by the attitude of the surface which is being folded.

Phase five is recognized by kink-bands with axial surfaces (S_5) which trend N-S and have a sub-vertical dip. This phase demonstrates more brittle conditions of deformation. Plots of S_4 and S_5 are shown in figure 12.

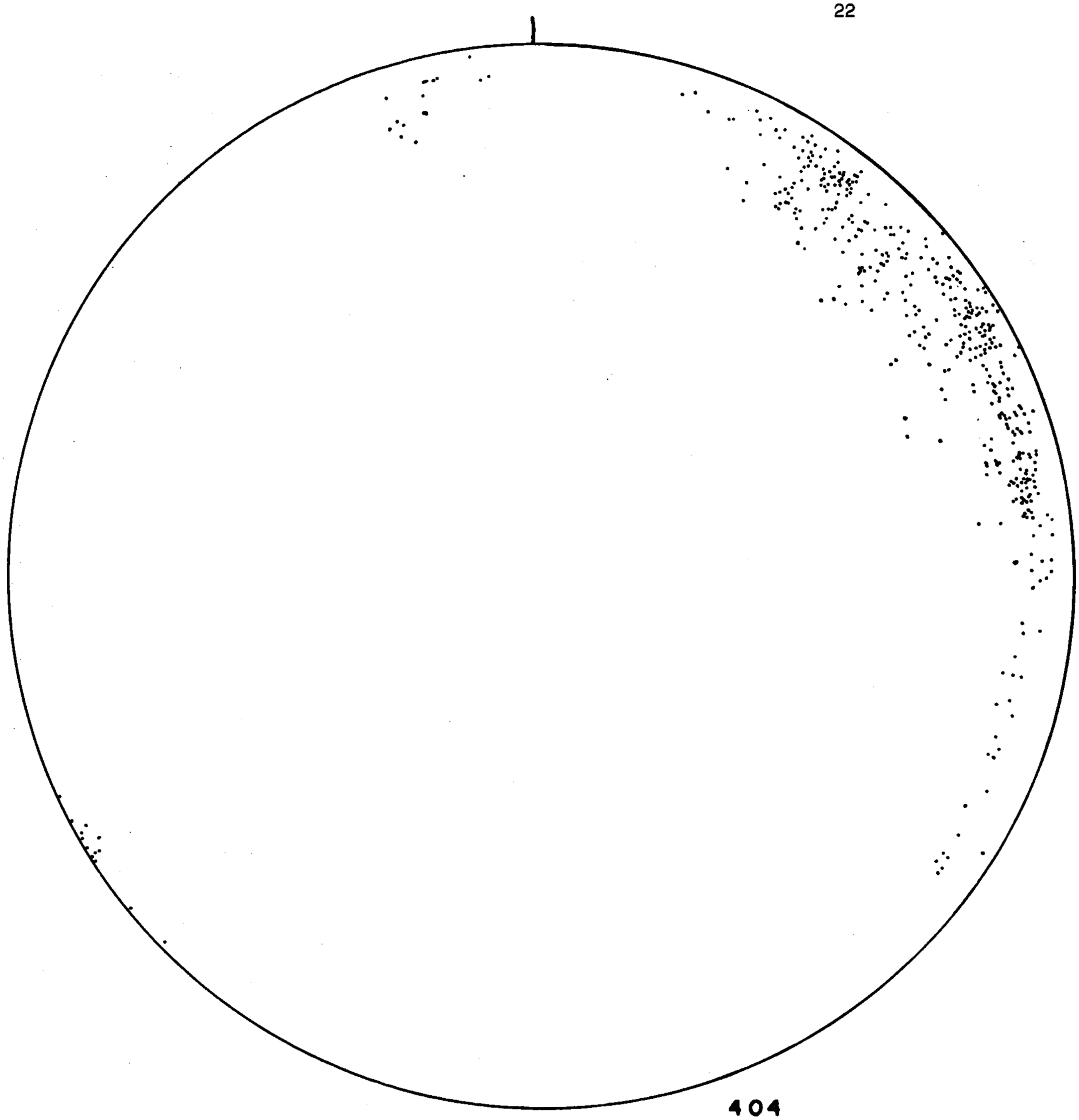


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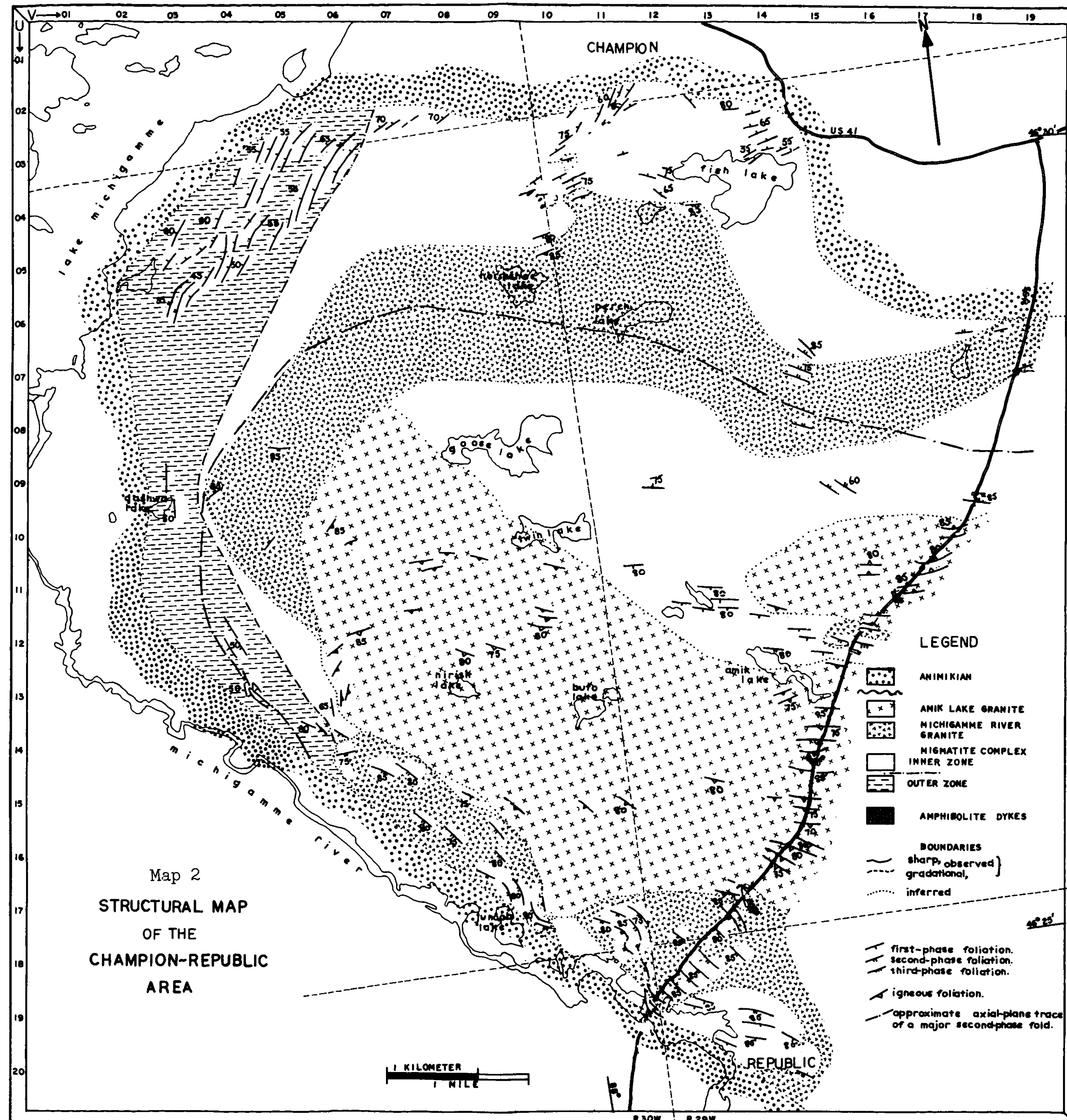
Fig. 10 -- Pole of the foliation within the Michigamme River Granite (Schmidt equal-area net).



Map 2
STRUCTURAL MAP
OF THE
CHAMPION-REPUBLIC
AREA

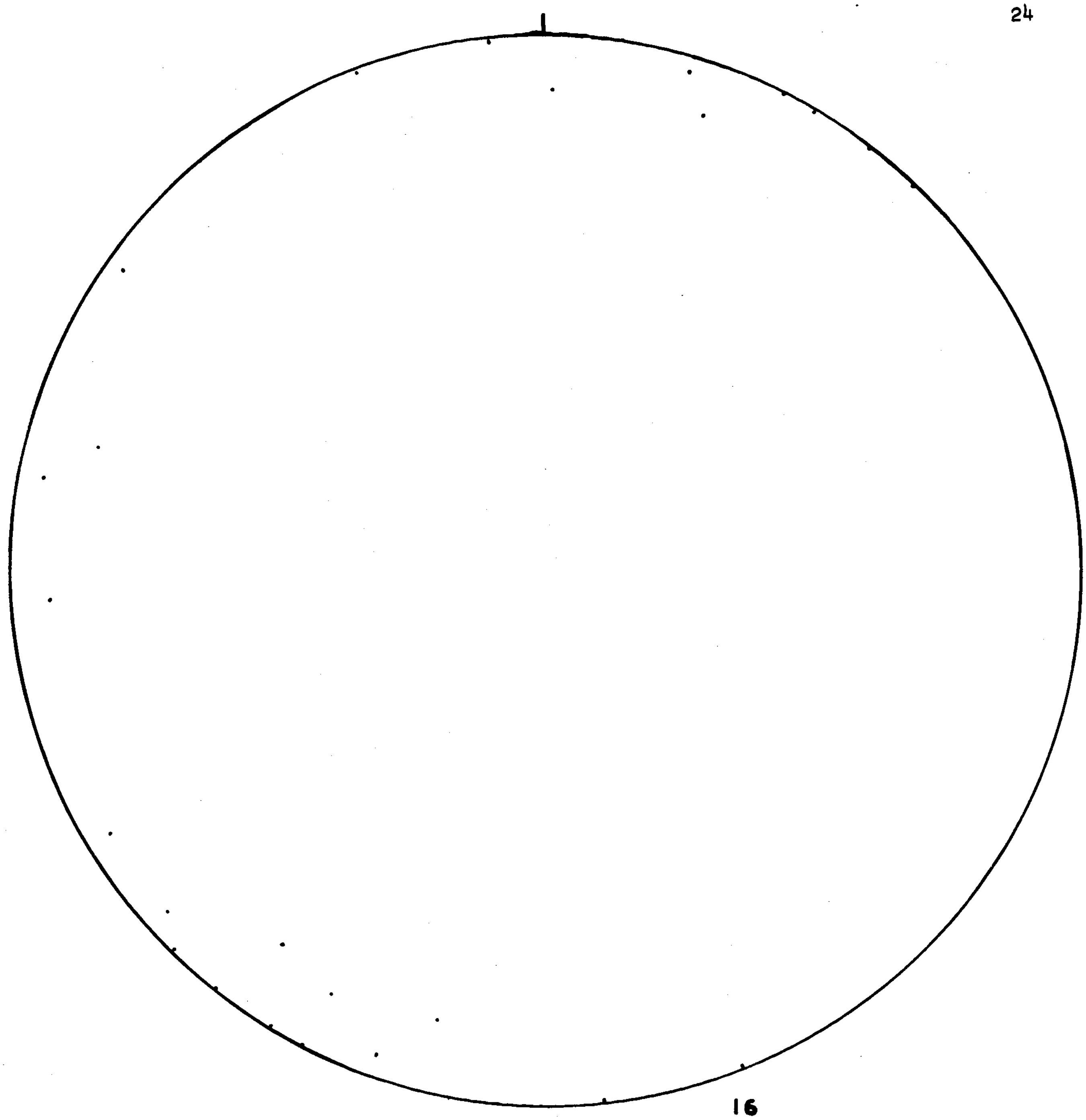


Fig. 11 -- Poles of the axial-planes of the phase 3 minor folds (Schmidt equal-area net).

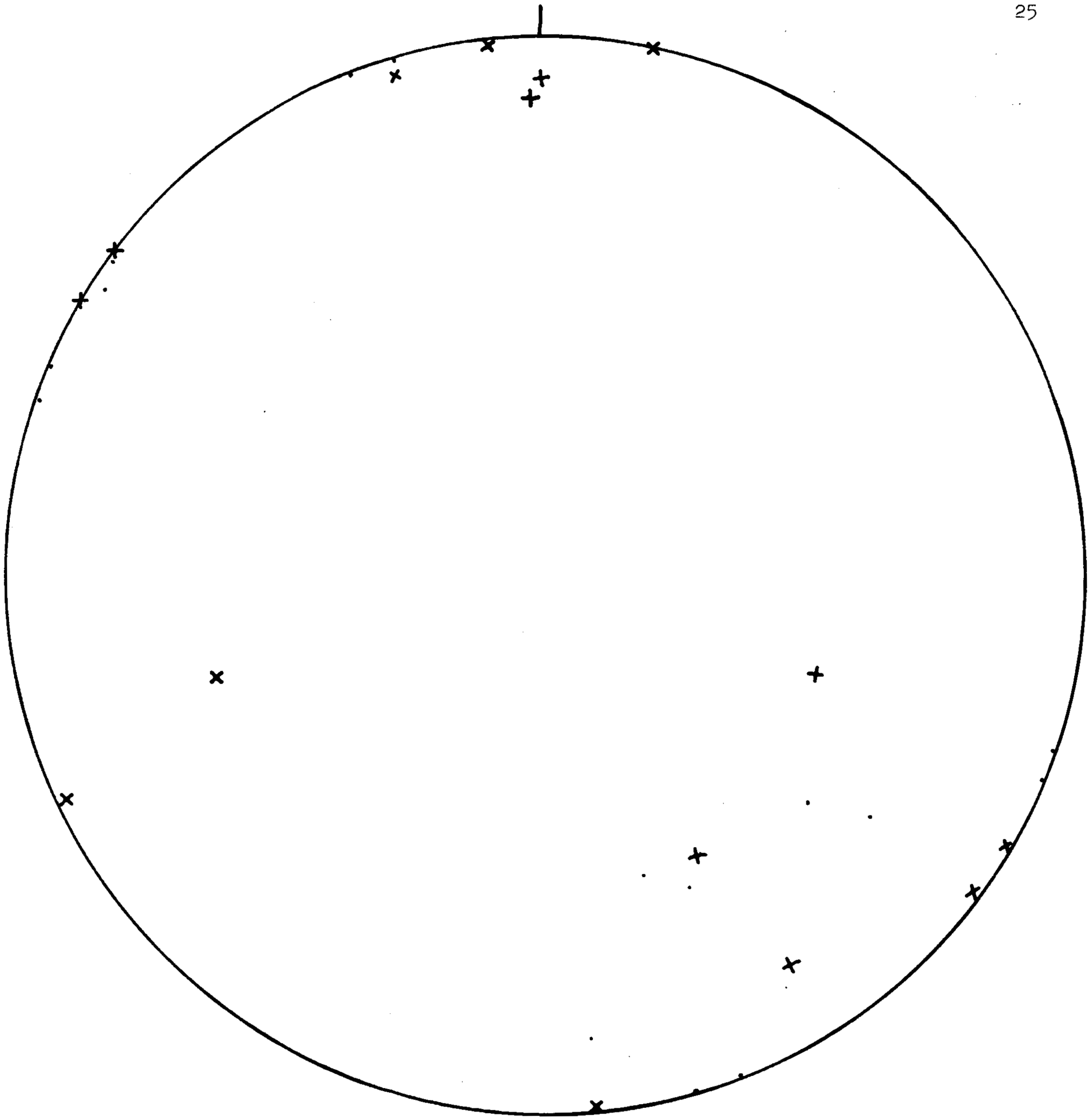


Fig. 12 -- Poles of the axial planes of the phase 4 (crosses) and phase 5 (dots) minor folds (Schmidt equal-area net).

(D) STRUCTURE OF THE AMIK LAKE GRANITE

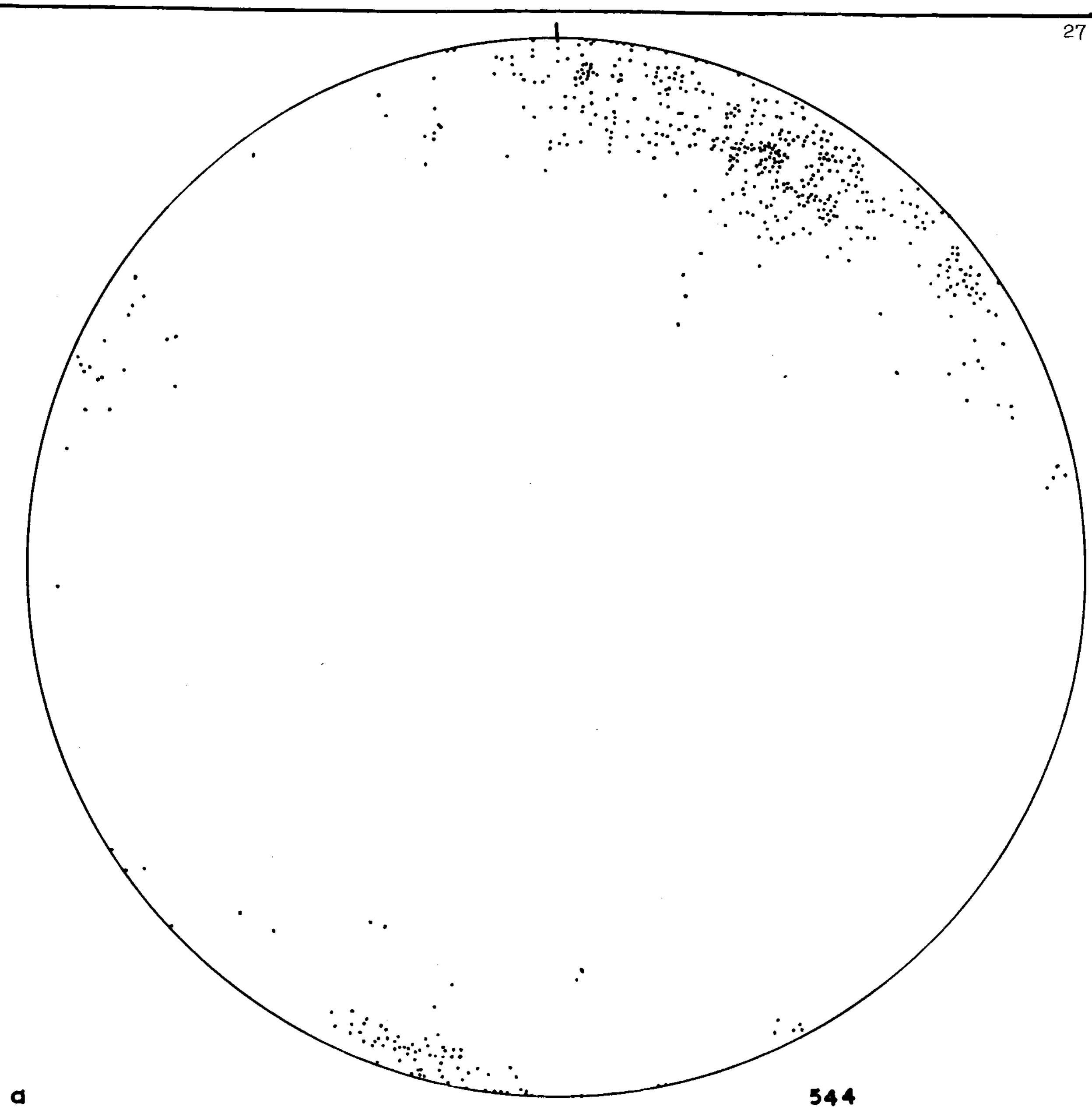
The Amik Lake Granite is characterized by a strong foliation along which microcline megacrysts are crudely aligned. The structural relationship of this foliation to that found in the Michigamme River Granite is not definitely known. Plots of the foliation within the Amik Lake Granite are shown in figure 13a. The pattern is somewhat dissimilar to that of the Michigamme River Granite (fig. 10). Although there is insufficient depth of exposure to postulate the attitude of the contact, a possible reconstruction of the north-western part of the Amik Lake pluton is shown in figure 13b. Locally, however, the foliation is deformed and open folds with NW-SE trending axial-surfaces are formed (*e.g.*, 11551615). These folds are very similar to those of the third fold phase in the migmatite complex.

IV. The Relationship of the Lower Precambrian Rocks to the Middle Precambrian

While this investigation was primarily concerned with the structure of the Lower Precambrian rocks, the structures of some of the Middle Precambrian rocks (Animikie Group) were investigated in the vicinity of Republic and Champion in order to obtain new evidence on the relationship between the Lower and Middle Precambrian rocks.

This topic has been a source of controversy for 70 years, partly because the actual contact between the two groups of rocks is not exposed in the area investigated and partly because previous workers experienced difficulty in distinguishing between a basal quartzite (Ajibik) and migmatitic rocks.

Smyth (in Van Hise and Bayley, 1897) considered that the Animikie rocks were deposited unconformably upon the Lower Precambrian rocks. Several localities were cited as evidence for this conclusion including an actual exposure of the contact which has since been covered by waste material from the Republic mine.



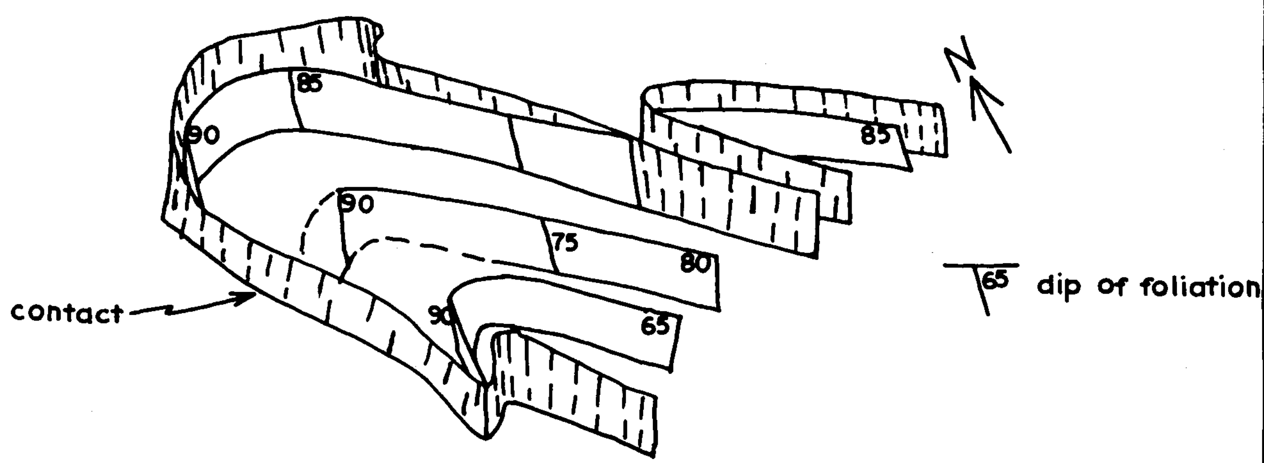


Fig. 13 -- a) Poles of the foliation within the Amik Lake Granite (Schmidt net).

b b) A sketch reconstruction of the attitude of the foliation.

Lamey (1937) reinvestigated the basal conglomerate of the latter exposure and concluded that the pebbles and matrix of the rock were not solely derived from the Lower Precambrian granites. This conclusion does not preclude Smyth's original interpretation of the relationship.

Ayres (in Snelgrove, Seaman and Ayres, 1944), reinvestigated Smyth's localities and described additional exposures. His study shows that the boundary between the Lower and Middle Precambrian rocks at most localities is intensely sheared and the nature of the relationship is indetermininate.

In the present study, two hypotheses which may be interrelated were tested:

a) that the second phase foliation (S_2) in the migmatite complex and the Michigamme River Granite is folded by the Republic synform,

b) that the minor folds (and hence the major synform) within the Animikie rocks were generated at the same time as the third phase folds of the migmatite complex.

The detailed structural map and profile of the Republic area (fig. 14) suggest that S_2 is indeed folded by the Republic synform.

The second hypothesis was tested by selecting two exposures--one of Animikie rocks and the other of migmatitic rocks--along the M95 highway near the Michigamme River Bridge to the west of Republic (fig. 15). Plunges of the fold axes and azimuths and dips of the axial-planes of the minor folds were measured from the southern exposure. The plunges of the third-phase fold axes and the azimuths and dips of the axial-planes of these folds were measured from the northern exposure. These readings are displayed in figure 15. While it can be seen that the attitude of the axial-planes of the two sets of minor folds are similar, the plunges of the minor folds are markedly different. Even within the Animikie rocks of the southern exposure, there is a great variation in the direction and value of the plunge. This variation could be interpreted as being caused by inhomogeneous progressive deformation. The difference in general

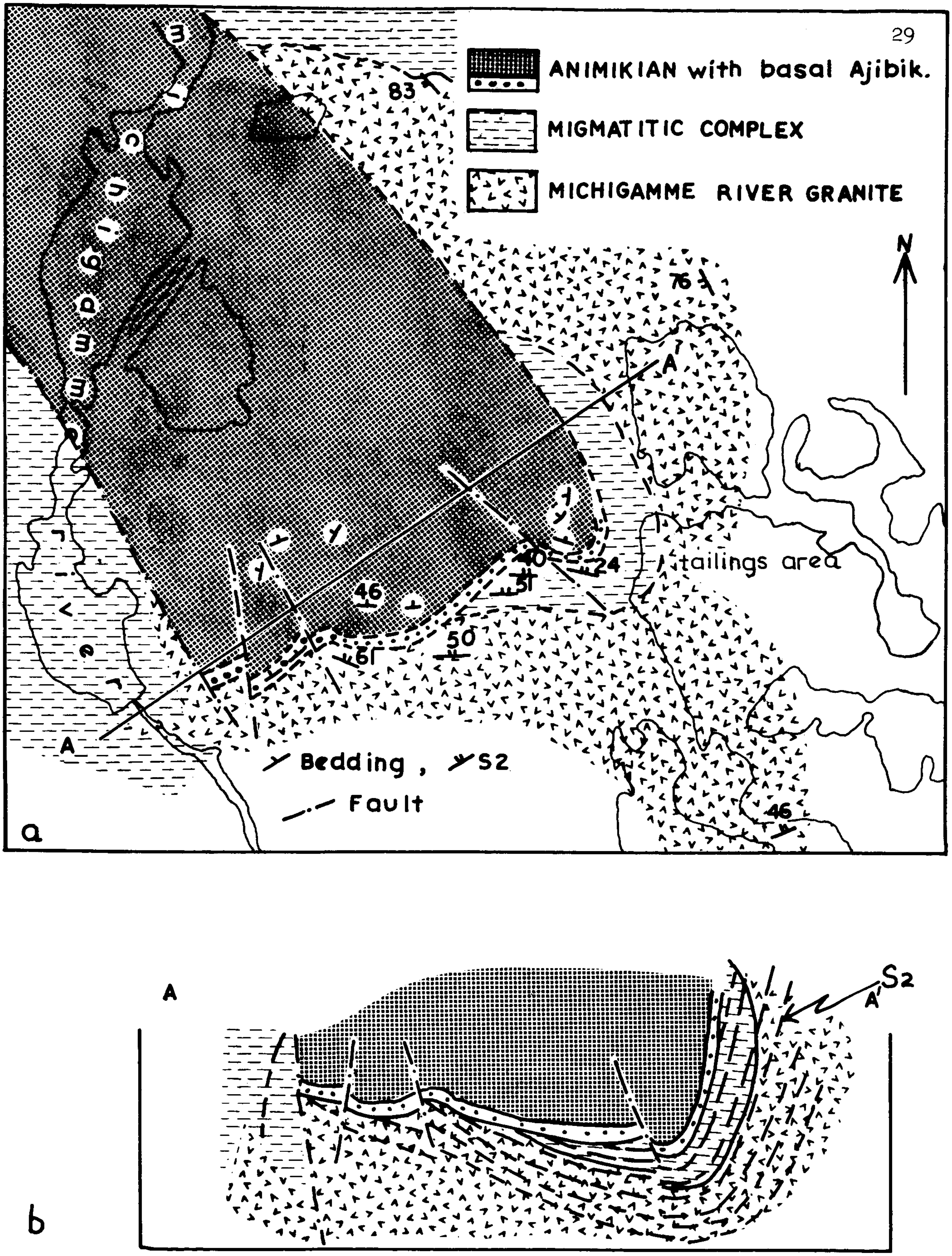


Fig. 14 -- Map and cross-section demonstrating the relationship of S_2 to the folding of the Animikie rocks in the Republic area.

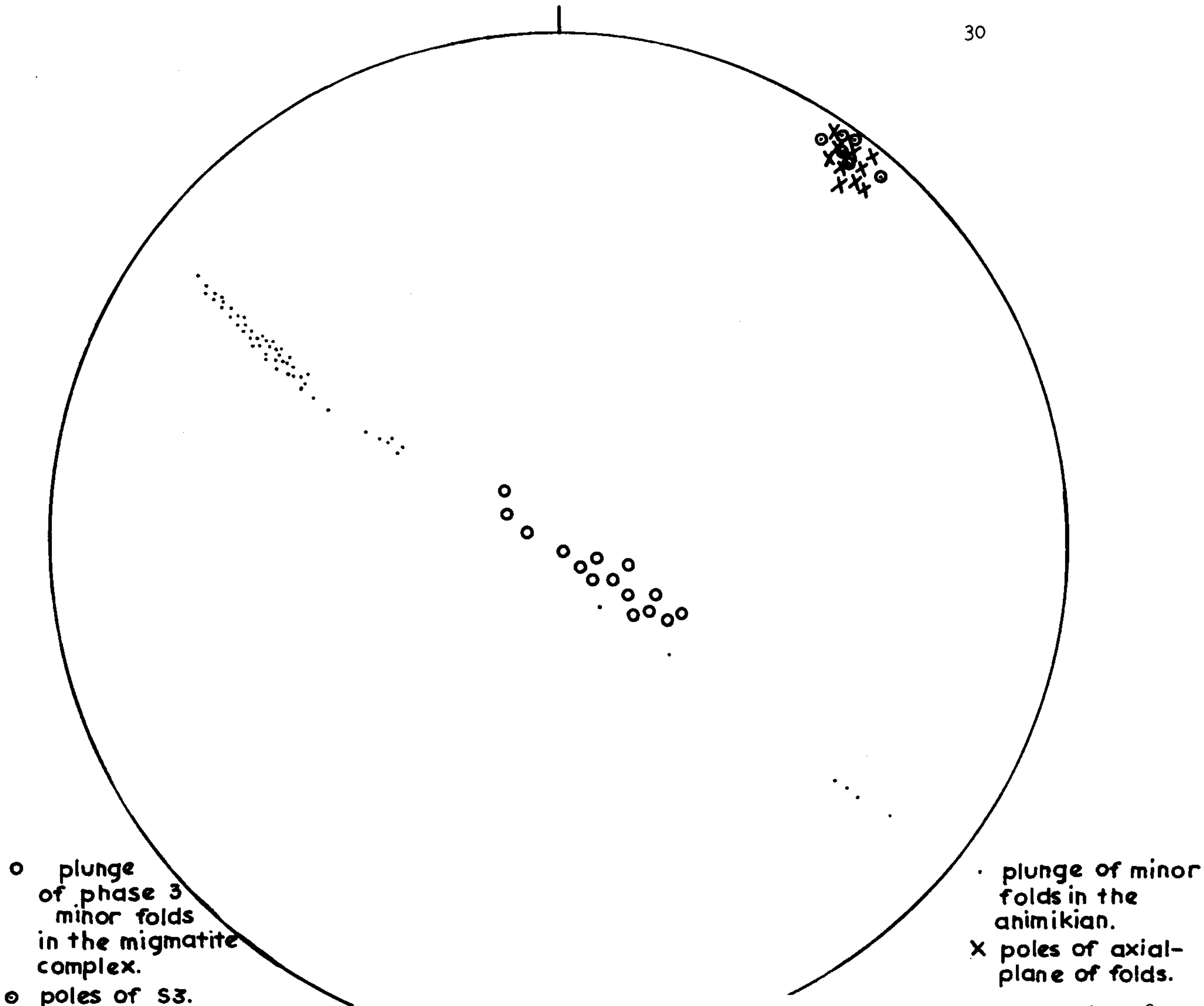
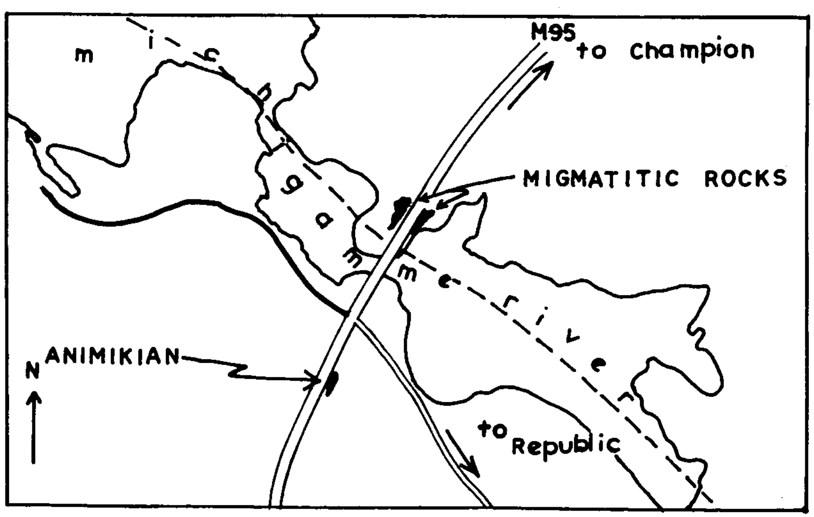


Fig. 15 -- Structural data demonstrating the relationship between phase 3 structures in the migmatitic complex and Animikie rocks near the Michigamme River bridge, Republic (Inset).



amount of plunge of the two fold sets could be explained as being due to the difference in the original attitude of the folded layers (i.e., sub-horizontal bedding in the Animikie rocks and a sub-vertical series of foliations in the migmatitic rocks).

Inspection of certain drill-hole cores that cross the Animikie-granite contact obtained by the Cleveland-Cliffs Iron Company proved inconclusive.

In conclusion, it can be said that the boundary between the Lower and Middle Precambrian rocks occupied a distinct movement zone during mutual folding of both groups of rocks and that most of the original evidence on the nature of the contact has been obliterated. It is also probable that this phase of mutual folding is equivalent in age to the third-phase of minor folds recognized in the Lower Precambrian migmatite complex.

V. Conclusions

The relative age of the Amik Lake Granite is problematical; no radiometric age dates are available from this general area. Undoubtedly, the granite was emplaced before the third-phase of deformation, but its relationship to the Michigamme River Granite is unsure. No xenoliths of the latter granite have been found in the former. The only exposure which shows the junction between the two granites suggests that the Amik Lake granite was emplaced into solidified Michigamme River Granite. The foliation within the Amik Lake Granite is probably caused by plastic "flow," but any serious interpretation of the foliation within the granite must await further work.

From the outcrop pattern of the Michigamme River Granite (map 1), it is conceivable that the original form of the granite was a sheet emplaced along the lower limb of the major second-phase fold.

Summary. The following sequence of events may be deduced in the rocks of the Champion-Republic area:-

Phase I,--deformation and migmatization of metasedimentary and metavolcanic rocks.

Emplacement of amphibolitic dykes.

Phase II,--deformation (probably flat-lying folds with axial-plane trend NE-SW) with simultaneous emplacement of the Michigamme River Granite and pegmatite veins.

Deposition of the Middle Precambrian metasedimentary rocks.

? Emplacement of the Amik Lake Granite and pegmatites.

Intrusion of thick amphibolitic veins.

Phase III,--generation of folds with NW-SE axial-trace trends.

Phase IV,--crenulations locally developed with E-W axial-plane trends

Phase V,--kink-bands locally developed with N-S axial-surface trends.

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