STRUCTURAL PETROLOGY AND ECONOMIC FEATURES OF THE PRECAMBRIAN ROCKS OF LA JOYITA HILLS

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Master of Science
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by
Lawrence J. Herber

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Contents

Illustrations

ABSTRACT

Quartz-potassium feldspar-biotite gneiss, quartz-potassium feldspar-biotite schist, amphibolites, pegmatites, and finer grained zones are present in the Precambrian gneiss complex of La Joyita Hills. The attitudes of relic beds, foliation, mineral lineation, fold axes, joints, faults, and pegmatites recognized in these rocks were recorded. Petrographic, petrologic, and structural petrologic studies of the gneiss complex were made.

The gradational contacts of the schists with each other and with the gneiss series, the presence of rounded grains of zircons and stringers of zircon grains that sub-parallel the foliation, the spatial distribution of the schists, and the composition of the rocks of the gneiss complex suggest that the rocks are metasediments.

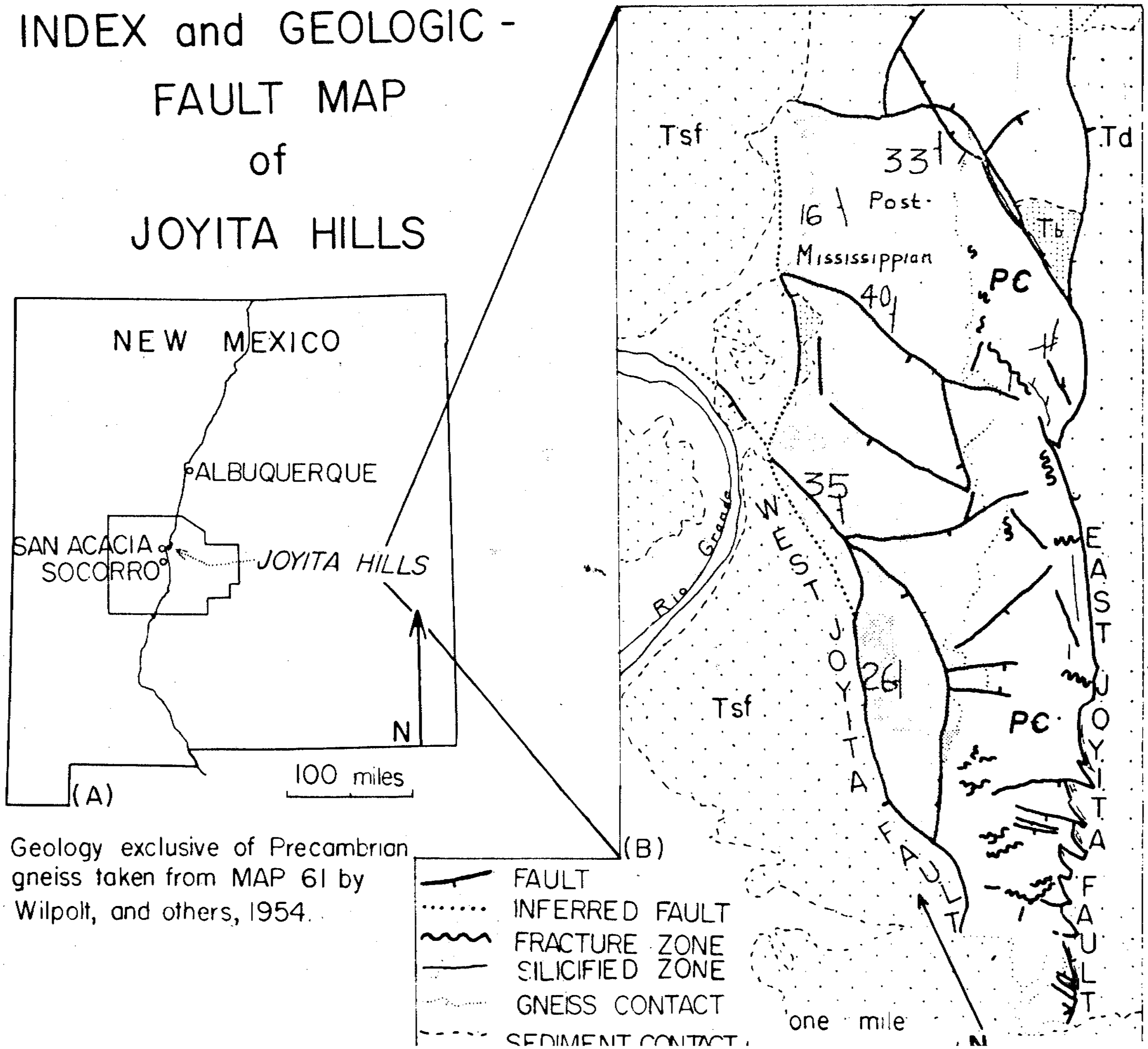
The coarse texture of the rocks, the similarity of attitudes of megascopic mineral lineation and axes of small folds, the steep attitude of the schistosity, and the local crosscutting relationships of schistosity and bedding on the noses of small folds suggest a metamorphic terrane with isoclinal folding exhibiting axial plane cleavage and a b lineation. As evidenced by deformation of the foliation and relic bedding, a period of deformation followed metamorphism.

The Precambrian rocks of La Joyita Hills are felspathized. Jointing, pegmatitization, and faulting are superimposed upon the metamorphosed and felspathized rocks.

A search for beryl in the pegmatites using heavy liquids was unsuccessful.

Detailed investigations of Precambrian terrane elsewhere in New Mexico may reveal rocks with similar metamorphic and structural histories.

INDEX and GEOLOGIC - FAULT MAP of JOYITA HILLS



Geology exclusive of Precambrian gneiss taken from MAP 61 by Wilpolt, and others, 1954.

Fig. 1

INTRODUCTION

The Precambrian gneiss complex of La Joyita Hills, the subject of this investigation, forms a narrow, linear outcrop about 15 air miles north, northeast of Socorro, and $1\frac{1}{2}$ miles east of the Rio Grande (Fig. 1).

The major part of the gneiss complex is inaccessible to motor vehicles that are not equipped with four-wheel drive. However, the southern end of the area is accessible with difficulty to ordinary touring car throughout most of the year via Rosa de Castillo arroyo.

Several reconnaissance maps of the gneiss complex have been prepared in conjunction with mineral and fuel investigations. Lindgren, Graton and Gordon (1910, p. 240) describe the gneiss complex as a coarse gneiss which encloses dark bands of hornblende schist. Lasky (1932, p. 56) refers to the gneiss complex as a coarse-grained granite which grades locally into biotite gneiss and contains numerous unoriented aplite and pegmatite dikes. Wilpolt and others (Map 61, 1954) consider the same rocks to be Precambrian granite.

The author began a study of the gneiss complex in the summer of 1961 primarily to determine its igneous, or metamorphic, and structural history. Beryl (identified by X-ray methods) had been found in a pegmatite from the gneiss complex so a less intensive study of the pegmatites, with emphasis on their structural control and economic significance was included.

The study involved detailed mapping of structural features; i.e., relic bedding, lineation, foliation, and joints, on enlarged aerial photographs (scale approximately 1:14000). Supplementary laboratory work: petrographic, petrologic, and structural petrologic investigations were also undertaken.

The analysis of the data strongly suggests that the gneiss complex consists of calcareous, arenaceous, and volcanic sediments which have undergone metamorphism and a subsequent stage of deformation. Intense felspathization also occurred.

Detailed investigations of Precambrian terrane elsewhere in the state may reveal areas with similar metamorphic and structural histories.

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GENERAL GEOLOGY

Geomorphology

Air photo and field studies of the gneiss complex indicate that it can be divided into two parts:

1. An orange colored gneiss characterized by low, gently rounded hills and a partially developed rectangular drainage pattern comprising the northern two-thirds of the gneiss complex (Plate II).

2. A dark colored gneiss characterized by low, rugged hills and an irregular drainage pattern comprising the southern one-third of the gneiss complex (Plate II).

The geomorphic subdivision of the gneiss complex coincides with a subdivision based on textural and compositional variations.

The factors which are significant to the evolution of the landforms are:

1. Faulting. Transverse faulting, faulting in an easterly direction, controls some of the westward flowing streams in the northern part and has divided the orange colored gneiss into a series of rectangular blocks. Transverse faulting on the west side of the southern part of the gneiss is less obvious as is also the rectangular pattern.

2. Lithology. Locally, in the northern part, prominences of quartz-potassium feldspar schist and quartz-potassium feldspar-biotite schist dominate the topography. Conversely, in the southern part, weathering of the less resistant amphibolites has produced notches in the dark gneiss.

Although differences of elevation are greater in the southern part of the gneiss complex, a relief of more than two hundred feet is seldom exceeded.

Structural setting

The gneiss complex occupies the eastern part of the Joyita Hills.

Although the structure of the Joyita Hills is not the object of this study, the following evidence supports the view of Wilpolt and others (1954, Map, 61) that the Joyita Hills are a tilted horst.

1. The eastern edge of the gneiss complex is in fault contact with Tertiary volcanics. The fault surface strikes to the northeast, dips to the southeast from fifty to sixty degrees, and exhibits slickensides that plunge with the dip to the southeast. The gneiss edge also forms a conspicuous topographic ridge relative to the surrounding volcanic plains and is locally silicified. Isolated contacts of gneiss with conglomerate or limestone dip steeply to the east. The volcanics in contact with the gneiss dip eastward, contrary to the regional westward dip of the volcanics farther east.

2. On the western side, a non-conformable contact exists between the gneiss complex and the post-Mississippian sediments. Fault contacts between the gneiss complex and the post-Mississippian sediments occur only locally. The depositional contact with the post-Mississippian sediments dips to the west at angles of twenty to forty-five degrees. Westward from the contact the sediments maintain a dip of about twenty degrees.

The depositional contact of the gneiss with the sediments, and the uniform, relatively steep attitude of the sediments westward from the contact indicate that the gneiss and the sediments, together comprising the Joyita Hills, reacted as a unit to westward tilting.

PETROLOGY AND PETROGRAPHY

On the basis of megascopic color, composition, and texture, eight distinct rock units are recognized. In general, microscopic studies support the field observations. Exact quantitative compositional analysis using standard size thin sections was not attained because of the coarse texture and gradational nature of many of the rocks. Therefore, textural studies constituted most of the petrographic work.

The units recognizable in the field are:

Gneiss series

Megascopic features: The gneiss series is the most abundant unit, occuping about seventy-five percent of the area mapped. It is divided into two parts on the basis of color, composition, and texture (Plate III).

a) Quartz-potassium feldspar-biotite gneiss comprises about one-third of the total gneiss area.

b) Quartz-potassium feldspar gneiss comprises the remaining two-thirds of the area.

The quartz-potassium feldspar-biotite gneiss is darker in color, generally finer grained, and contains more biotite than the quartz-potassium feldspar gneiss. Each gneiss has a well developed mineral lineation accentuated by large pink feldspars sheathed in biotite. Foliation is obvious only in the quartz-potassium feldspar gneiss. The contact between the two gneisses is gradational; further complications such as faulting and cover preclude accurate location of the boundary.

Microscopic features: Petrographic analyses do not suggest any essential difference between the gneisses. It was hoped that petrographic examination would substantiate the megascopic observation that an increase in biotite content is responsible for the darker color of the quartz-potassium feldspar-biotite gneiss. However, the coarse texture of the gneisses as compared to the size of the thin sections precludes accurate quantitative estimation of the minerals present. Larger thin sections, two by two inches were useless for accurate quantitative determination because of biotite plucking.

The rock forming minerals of the gneiss, along with their approximate percentages are:

Potassium feldspar	45- 60
Quartz	25 - 35
Biotite	5 - 15
Plagioclase (albite and oligoclase ranging up to An_{26})	5 - 20

The potassium feldspar, primarily microcline and microcline perthite, with minor amounts of orthoclase, has two distinct occurrences in the gneiss.

1. Large, (3-11 mm: average about 6mm), generally cloudy, irregularly bounded grains that enclose grains of quartz, microcline, perthite, myrmekite, plagioclase, and to a lesser extent biotite. The included grains may occupy fifteen percent of the total cross sectional area of the feldspar.

2. Small ($<$ 1mm: average about $\frac{1}{2}$mm) more regularly bounded, clear, inclusionless, nearly equidimensional grains that occur in the groundmass along with other similarly-sized grains.

Quartz also has two distinct occurrences.

1. Large (1-3mm: average about $1\frac{1}{2}$mm), clear, elongate crystals that exhibit sutured boundaries and undulatory extinction. The elongate crystals generally exhibit a dimensional orientation resulting in the formation of bands of quartz crystals that are spatially related to the curvature of the

large potassium feldspar grains. Locally, areas of quartz segregation include fine specks of material that give the quartz a dusty appearance.

2. Small, (<1mm) nearly equidimensional, regularly bounded grains that form part of the groundmass between the large potassium feldspar crystals and the bands of large quartz crystals.

Brown biotite is one of the least abundant, but most conspicuous of the essential minerals. It occurs as parallel oriented flakes (<$\frac{1}{2}$mm) in elongated clusters: seldom does it occur as isolated crystals. From the pattern observed in thin section, it appears that the cleavage faces of biotite parallel the large potassium feldspar boundaries.

Biotite is seldom included by the large potassium feldspar crystals. However, biotite flakes, oriented with the cleavage, are found in large oligoclase crystals.

Plagioclase (albite and oligoclase ranging up to An_{26}) was determined by the method of Michel-Levy and by its relative indices of refraction. Plagioclase has two distinct occurrences.

1. It occurs with quartz as discrete grains of myrmekite. The myrmekite (<$\frac{1}{2}$mm) forms the groundmass along with small quartz and potassium feldspar grains. Myrmekite is also included within the large potassium feldspar grains.

2. A minor amount of the rock forming plagioclase has an occurrence similar to that of the large potassium feldspar crystals except that the plagioclase crystals never exceed a diameter of 4mm. The large plagioclase crystals differ from the potassium feldspar crystals by including biotite flakes which are parallel to the cleavage.

The accessory minerals of the gneiss are hornblende, zircon, sphene, apatite and garnet. The sphene and apatite are distributed throughout the groundmass. Green hornblende crystals (absorption: $Z>Y>X$), highly altered, are generally associated with biotite. Several hornblende crystals are hosts for quartz and zircon: the clear quartz blebs are aligned with the hornblende cleavage. Aggregates of small zircon crystals are generally associated with biotite or hornblende. Single crystals of zircon occur scattered throughout the groundmass within grains and between grain boundaries. No garnet was observed in thin section: however, an analysis of the heavy minerals (minerals with sp. Gr.$>$2.95) in an 830g. bulk sample of the gneiss contained seven grains of clear, colorless, tabular garnet with a few red colored inclusions. The red inclusions in reflected light are suggestive of hematite.

Amphibolites

Megascopic features. The amphibolite schists occur as distinct, linear units that vary in thickness from three to thirty feet. They are most abundant in the quartz-potassium feldspar-biotite gneiss. Some biotite rich schists occur in the quartz-potassium feldspar gneiss. Where observed the contact between the amphibolites and quartz-potassium feldspar-biotite gneiss is always sharp. However, a zone of gneiss richer in biotite than the quartz-potassium feldspar-biotite gneiss frequently accompanies the thicker amphibolites on the gneiss side of the contact. The following features are characteristic of the amphibolites.

1. They weather more rapidly than the gneiss.
2. Schistosity in the amphibolites is generally more conspicuous than in the surrounding gneiss.

3. Lineation is not conspicuously developed.

4. Large potassium feldspar grains are absent in the amphibolites.

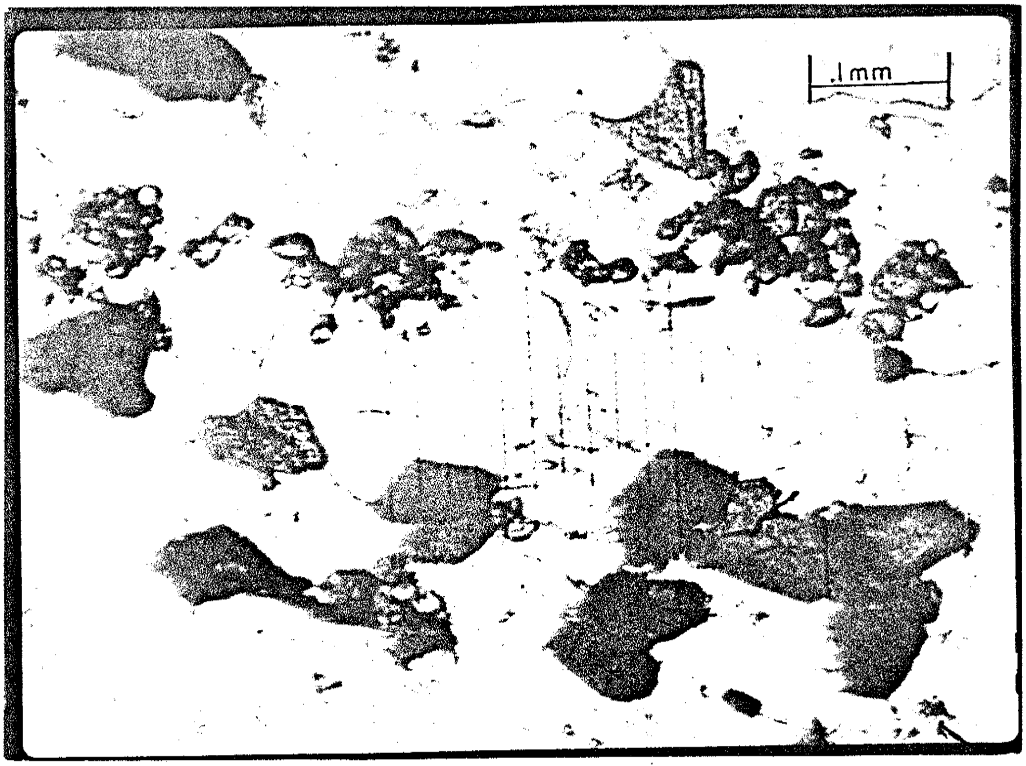
Microscopic features. A few of the darker amphibolites with hornblende as the most abundant constituent, showed neither a pronounced foliation nor a conspicuous lineation in the field. Because of the apparent absence of any structural features, two thin sections with different orientations were cut from the same sample. One section was cut parallel to the plane of assumed foliation: the second section was cut transverse to the attitude of lineation. The section cut in the plane of foliation showed an alignment of C axes of hornblende crystals which corresponds to the lineation in the gneiss. The section cut transverse to the lineation revealed a vague foliation which corresponds to the observed foliation in adjacent amphibolites. Amphibolites containing appreciable amounts of quartz manifest a conspicuous foliation because of the color variation.

The darker amphibolites that lack conspicuous megascopic structural features contain green hornblende (50 - 65%) and plagioclase (35 - 45%). The texture varies from a vaguely foliated and lineated nearly felty mass of hornblende and plagioclase to well foliated and lineated. The well developed foliation is expressed by alternating bands of oriented hornblende and unoriented plagioclase.

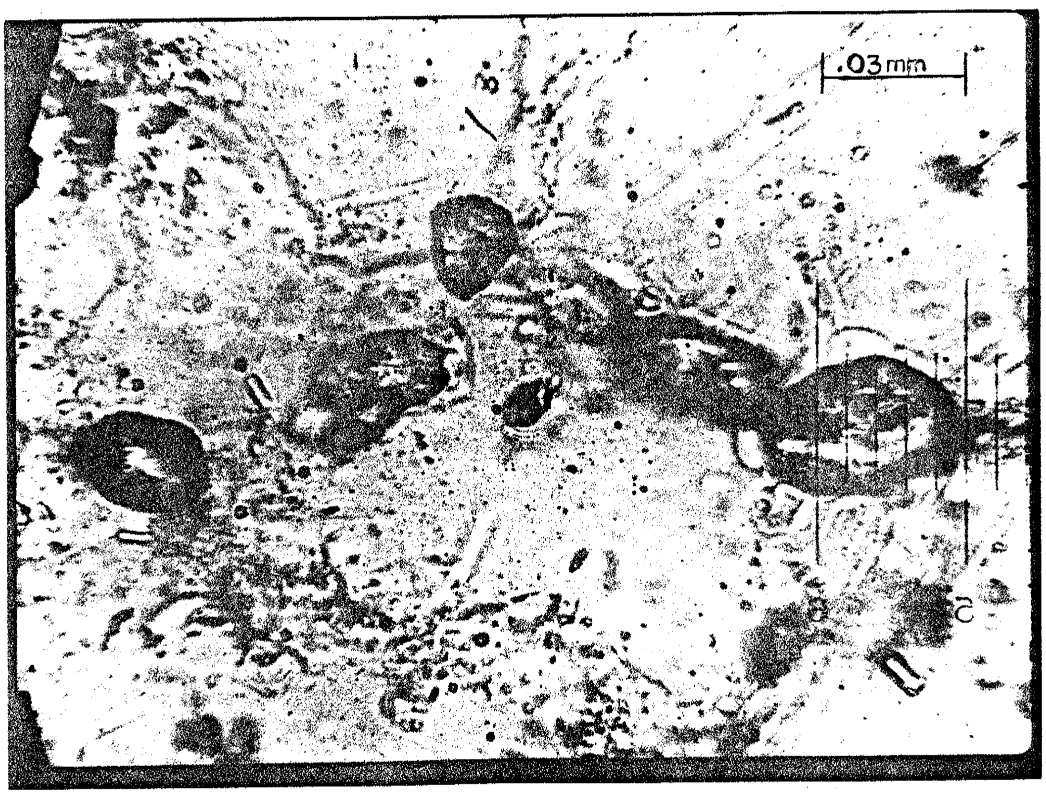
The hornblende, strongly pleochroic ($Z>Y>X$), is green and unweathered. A few hornblende crystals include clear, quartz blebs that have undulatory extinction. The plagioclase; consisting of albite, andesine, and oligoclase, has weathered into small grains of an unidentified amorphous appearing material. Some of the plagioclase crystals are peculiarly altered. The peripheries of many of the plagioclase crystals, about one fifth of their radius in thickness, are unaltered, clear, and twinned. From the clear, unaltered zone inward the crystals are uniformly and highly altered. In many of the plagioclase crystals, twinning is present in both the altered and unaltered part of the crystal. However, incases of intense alteration, the twinning ends abruptly at the altered-unaltered contact.

The accessory minerals are quartz, biotite, and iron ore. The quartz occurs as small ($<$1/5mm) angular, clear grains with no orientation. The biotite occurs as aggregates of small flakes which are not oriented. Blotches of iron ore occur within and adjacent to the hornblende crystals. Magnetite was identified from the heavy mineral fraction of an amphibolite schist.

Some of the amphibolites that have gradational contacts with the gneiss contained essential quartz and are distinctly foliated and lineated. Microscopically, the essential minerals are: green hornblende (absorption: $Z>Y>X$)-15%, plagioclase feldspar (albite-andesine-oligoclase)-40%, and quartz-45%. Cross sections of small, euhedral, fresh, green hornblende crystals between layers of equidimensional quartz and plagioclase crystals impart a definite foliation to the rock. Locally, large ($2\frac{1}{2}$mm), dimensionally oriented, clear quartz grains with sutured boundaries accentuate the foliation. Accessory zircon, garnet (one grain) and iron ore, probably magnetite, occur. Zircon occurs in quartz grains and between grain boundaries. Stringers of zircons parallel or sub-parallel the foliation (Fig. 1, Plate I). The foliation is marked by the small, euhedral hornblende crystals that are oriented according to their maximum absorption. Many zircons that occur randomly and some that are sub-parallel to the foliation are sub-rounded to rounded (Fig. 2, Plate I).



Stringers of zircon grains sub-parallel to foliation Fig. 1



Rounded zircon grains Fig. 2

Quartz-potassium feldspar schists

Megascopic features: The quartz-potassium feldspar schists, like the amphibolite schists, occur as distinct linear units with a foliation and lineation that is generally well developed. However, the quartz-feldspar schists are thinner than the amphibolites, seldom exceeding two feet in thickness: a few reach a thickness of more than thirty feet. Locally, the quartz-feldspar schists grade laterally and vertically into the quartz-potassium feldspar gneiss. Gradational contacts are especially characteristic of the thicker schists and their limits can be denoted only approximately.

Microscopic features: The essential minerals of the quartz-potassium feldspar schists are quartz (60-80%) and potassium feldspar (40-20%). Bands of elongate quartz grains ($\frac{1}{2}$-1mm) alternate with bands of less obviously elongate feldspar crystals. Locally, however, the foliation is conspicuously expressed by alternating bands of large, irregularly bounded, sutured quartz grains and smaller, nearly equidimensional and equisized, more regularly bounded quartz and potassium feldspar grains.

Large (2-4mm) potassium feldspar grains in the quartz-potassium feldspar schists are sparse but their occurrence is similar to the occurrence of the large potassium feldspar grains in the gneiss.

Accessory biotite and zircon is also present. Isolated books of biotite, many of them unrecognizably weathered except for the external rectangular shape, conform to and accentuate the foliation.

Very small sub-rounded zircon grains occur disseminated throughout the thin section. Locally, stringers of zircon accentuate the foliation.

Quartz-potassium feldspar-biotite schists

A group of schists, very similar to the quartz-potassium feldspar schist, cluster about the central part of the mapped area. These schists are generally darker in color than the quartz-potassium feldspar schist: they have been called quartz-potassium feldspar-biotite schist. The quartz-potassium feldspar-biotite schist grades laterally and vertically into quartz-potassium feldspar schists; the amount of biotite being the critical factor. The quartz-potassium feldspar-biotite schists locally are thicker than the quartz-potassium feldspar schists. Nevertheless, the distinction between the two light colored schists is arbitrary and is made chiefly on the basis of color.

Epidosite

Megascopic features: Epidosite occurs in tabular, discontinuous, restricted outcrops and ranges in thickness from five to fifty feet. Although the areal distribution of epidosite is limited, it is easily recognized by its green color. Foliation is weakly developed in the epidosite: locally, where the epidosite grades into amphibolite schist, the foliation becomes more obvious. Variations in texture, color, and foliation are erratic, but locally pronounced.

Microscopic features: The patchy green color and variation in grain size observed in hand specimens is also evident in thin section. Two thin sections were examined and the "essential" minerals; epidote, quartz, and orthoclase vary from 80-55%, 45-7%, and 12-1% respectively. The epidote grains ($<$ 1/10mm) form a mosaic texture and, except for a few enclosed quartz grains, are separate from the other "essential" minerals. Most of the quartz occurs as larger ($\frac{1}{2}$mm) irregularly bounded, sutured grains in veinlets or patches. A few epidote grains are included in the larger quartz grains. The orthoclase is associated with the larger quartz grains, exhibits sutured boundaries, and is fresh and clear. No foliation or lineation is apparent in thin section.

Accessory minerals, biotite and chlorite, occur sporadically as disseminated grains. The chlorite is restricted to the patches of epidote.

Finer grained zones

Several patches of rock finer grained than the enclosing gneiss series occur in the quartz-potassium feldspar gneiss. The zones have gradational boundaries with the gneiss, appear to be unrelated to trends established in the schists, and include light and dark colored schists. Foliation in parts of the finer grained zones is better developed than in the surrounding gneiss: however, the reverse is also frequently observed. Compared with the gneiss series the features most characteristic of the finer grained zones are their irregular shape, smaller potassium feldspar crystals, and lighter color. Locally, highly schistose zones at the boundary serve to differentiate the gneiss from the finer grained zones.

Pegmatites

Pegmatite dikes from one inch to three feet thick occur throughout the area. A few lenticular pegmatites with a long axis from five inches (micropegmatites) to six feet were also observed.

Pegmatite dikes: The contacts between the pegmatite dikes and the gneiss are sharp, and the pegmatites may have many different orientations. Locally they split and include parts of the gneiss. The orientation of the internal structural features within the gneiss inclusions are identical with the orientation of the same features in the enclosing gneiss. A few pegmatite stringers one to three inches thick are very complexly folded. These are of very restricted occurrence and do not have a systematic pattern.

In many of the pegmatite dikes large, pink, euhedral to subhedral feldspars up to five inches long are in a matrix of irregularly seriate quartz crystals. No uniform zoning is observed in the pegmatite dikes, but they exhibit a crude zoning of pink feldspars at the walls with the center of the vein filled with quartz. Biotite occurs as a minor constituent.

A few dikelike bodies of massive quartz occur in the quartz-potassium feldspar-biotite gneiss.

Lenticular pegmatites: These consist of zonally arranged large pink feldspar and quartz crystals. Milky quartz comprises the central zone. Large, subhedral, pink feldspar crystals (from 1" to 10" in diameter depending on the diameter of the pegmatite) surround the central quartz zone. An outer zone of a mixture of quartz and pink feldspar imperceptibly grades into the gneiss. Two thin sections of a small (less than 5" diameter) lenticular pegmatite were analysed: the essential minerals are quartz and potassium feldspar. The potassium feldspar, microcline and microcline perthite, occurs as large, subhedral crystals including along its edges groundmass crystals of quartz and potassium feldspar. Quartz occurs as anhedral, large, clear crystals locally exhibiting undulatory extinction. Bands of elongate crystals of quartz pass through the large potassium feldspar crystals and the groundmass without interruption. The groundmass is composed of finer grained quartz and potassium feldspar. The groundmass potassium feldspar crystals and the large potassium feldspar crystals have been altered about the same amount. None of the groundmass potassium feldspar contains inclusions.

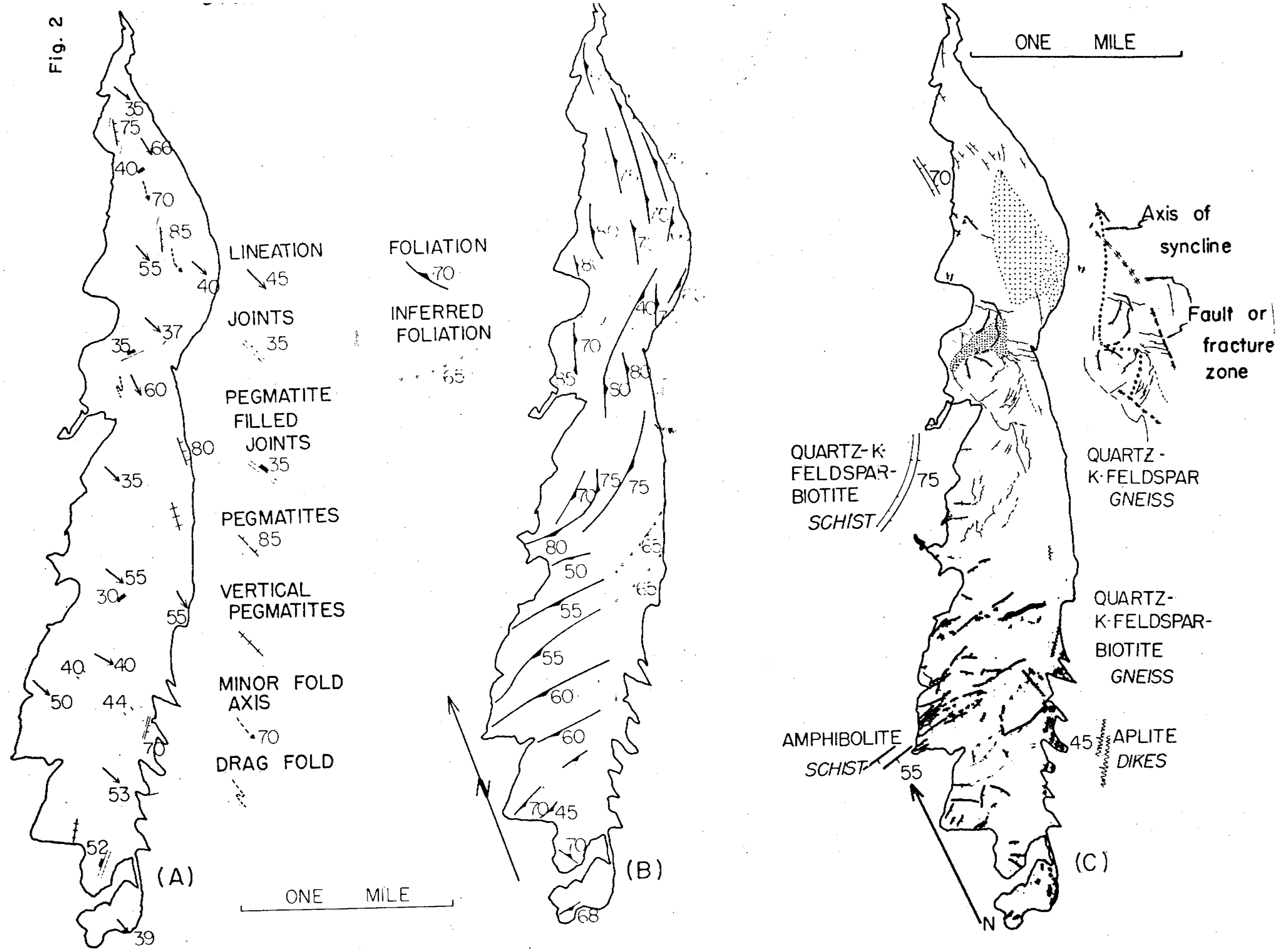
Aplite dikes

The aplite dikes have two types of occurrence.

1. Aplite stringers occur within or associated with the pegmatites. Frequently, these aplite stringers occupy the center of the pegmatite. In these occurrences the aplites, like the associated pegmatites are split and include undisturbed gneiss.

2. The most prominent aplite occurrence is in the quartz-potassium feldspar-biotite gneiss. In this rock the aplites, from 2' - 12' thick, maintain a strike similar to the strike of the East Joyita fault but are broken by transverse faults dipping steeply to the south. Bifurcation of these aplites is not common. Locally stringers of pegmatite occur within the aplite or at the contact of the aplite with gneiss.

Fig. 2


LINEATION
JOINTS
PEGMATITE FILLED JOINTS
PEGMATITES
VERTICAL PEGMATITES
MINOR FOLD AXIS
DRAG FOLD
FOLIATION
INFERRED FOLIATION
ONE MILE
(A)
(B)
(C)
N
Axis of syncline
Fault or fracture zone
QUARTZ-K-FELDSPAR-BIOTITE SCHIST
QUARTZ-K-FELDSPAR GNEISS
QUARTZ-K-FELDSPAR-BIOTITE GNEISS
AMPHIBOLITE SCHIST
APLITE DIKES

STRUCTURAL FEATURES

Lineation, schistosity, bedding, faults, fracture zones, joints and associated pegmatites are the principal structural elements in the area investigated.

Lineation

Lineation is the most obvious structural feature (Fig. 2-A). It occurs in every mapped unit except the pegmatite and aplite dikes. Frequently accentuated by large pink potassium feldspar crystals, the measured lineation is conspicuous in all units except the amphibolite and epidosite. It is measurable in the amphibolite and epidosite schists but the striking color variation caused by the large pink potassium feldspars is absent.

The lineation measured is a mineral lineation. In the gneiss and light colored schists large pink potassium feldspars sheathed in biotite, produce the lineation. In the amphibolite schists it is due to the orientation of the long dimension of the hornblende crystals. The cause of the lineation is not evident in thin sections of the epidosite. Where foliation and lineation occur together, the lineation is measured in the plane of foliation. The attitude of the mineral lineation is uniform, and similar to the attitude of observed fold axes.

Schistosity and bedding

In the gneiss complex bedding and schistosity are closely related. The recorded schistosity measurements were obtained largely from the schists. Schistosity is also locally well developed in the northern part of the quartz-potassium feldspar gneiss. Measurements of schistosity in the quartz-potassium feldspar-biotite gneiss could be made only in the biotite rich zones adjacent to some of the amphibolite schists.

Relic beds were distinguished from the enclosing gneiss by a combination of two or more of the following.

1. Grain size. The amphibolites and the quartzo-felspathic schists are finer grained than the gneiss series.

2. Outcrop pattern. The quartzo-felspathic schists form small folds in the otherwise homogeneous gneiss series. Also, prominences of quartzo-felspathic schists and notches of amphibolite schist have resulted from differential weathering.

3. Color. The amphibolite schists are darker than the gneiss series.

Schistosity-bedding relationships are:

1. In the quartz-potassium feldspar-biotite gneiss and in the northern part of the quartz-potassium feldspar gneiss, the attitude of the schistosity is nearly parallel to the attitude of the beds. Both the schistosity and the bedding dip more steeply in the northern part than in the southern part of the mapped area.

2. In the southern part of the quartz-potassium feldspar gneiss large parts of the beds and the coincident schistosity have been deformed. The deformation produced broken beds of schist (Plate III), locally disturbed the schistosity (Plate V), and resulted in a broad warping which changed the strike of the foliation from a northerly to an easterly direction (Fig. 2-B).

3. In the central part of the quartz-potassium feldspar gneiss and on the noses of small folds, the schistosity cuts across the trend of the bedding.

The quartz-potassium feldspar schists in the northern part of the quartz-potassium feldspar gneiss trend uniformly about north-south and dip steeply east: the amphibolite schists in the quartz-potassium feldspar-biotite gneiss trend uniformly about east-west and dip moderately steeply to the south. The configuration of beds in the central and southern parts of the quartz-potassium feldspar gneiss (Plate III) is suggestive of either and anticline or a syncline. Because of drag fold relationships (Plate IV) and the observed relationship between the direction of plunge of other small folds and the plunge of the mineral lineation (Plate IV), the structure is considered to be a deformed southeastward plunging syncline.

Faults and fracture zones

In this study, fracture zones were distinguished from faults on the basis of movement. If obvious movement is shown by offset of schists, pegmatites, aplites or other faults, the plane of movement is denoted as a fault. If movement along apparently crushed zones is imperceptible, or if little movement is localized along closely spaced, sub-parallel irregular planes, the zone is denoted as a fracture zone.

Most of the faults (Fig. 1-B) are transverse to the trend of the gneiss complex, local in extent, and dip steeply to the south. A few are parallel to or sub-parallel to the contact of the gneiss complex. Some of the faults contain calcite, barite, fluorite, and galena; however, most of the faults are either barren or contain only a coating of iron oxides. Silicification is largely restricted to the East Joyita fault. Because of the relative homogeneity of the gneiss complex most of the faults are difficult to trace unless crosscutting relationships with dikes or bedding is observed.

Joints and associated pegmatites

One joint orientation, striking nearly east-west and dipping from 30 - 35 degrees to the northwest is present. Another possible orientation, weakly expressed, strikes north-northeast and dips steeply to the east. Joint planes of the east-west orientation are regular, can be traced locally for hundreds of feet and frequently contain pegmatites about five inches thick. The spacing of the east-west orientation is variable; however, some of the canyon walls are well jointed with the spacing seldom exceeding four feet. The joint planes of north-northeast orientation are irregular and discontinuous.

The pegmatites also occur with two orientations. The east-west striking, northwest dipping orientation is the same as the more prominent joint orientation. Seldom was an east-west joint orientation measured without the observation that one or more of the joints was occupied by a pegmatite. The pegmatite generally occupied the joint along its entire strike. Locally however, the pegmatite outcrop is discontinuous while its host joint continues.

The other pegmatite orientation strikes north-northeast, dips steeply either east or west, or vertically; but is less prominent than the east-west orientation. No pegmatites of the north-northeast orientation were observed with the north-northeast joint orientation.

PETROFABRIC ANALYSIS

Six non-selective point diagrams of the C crystallographic axis of quartz were prepared with the aid of the Leitz five-axis universal stage and the lower hemisphere of the Schmidt equal-area projection net. By means of the Schmidt method, (Fairbairn, 1949, p. 285 and Billings, 1954, p. 111) density diagrams were prepared from the point diagrams. The relative densities of each diagram are expressed in percentages. The author elected to study the orientation of quartz for the following reasons.

1. After completion of the field work it became evident that the amphibolites, the quartz-potassium feldspar schists, the quartz-potassium feldspar-biotite schists, and the gneiss series were of tectonic significance. The number and size of quartz grains in each of these rocks is sufficiently large for fabric analyses.

2. Many well defined anisotropic quartz fabric diagrams have been prepared from areas that have undergone low grade metamorphism. Field evidence from the gneiss complex indicates that metamorphism was followed by a period of structural deformation (broad warping) without recrystallization. The axis of structural deformation is in the southern part of the quartz-potassium feldspar gneiss. If the conclusion drawn from the field evidence is incorrect, quartz fabric diagrams prepared from rocks on either side of the axis of structural deformation should reflect this.

The petrofabric study of the gneiss complex is not sufficiently exhaustive to be considered as a separate phase of the investigation. It was undertaken merely to supplement megascopic observations and the results shall be discussed with that in mind.

Each fabric diagram is oriented with respect to a megascopic lineation or foliation. One fabric diagram is oriented geographically (Fig. 3-A).

Cloos (1946, p. 5) in a discussion of fabric data defines three co-ordinate axes a, b, and c: "b is the direction of the fold axis...; a is perpendicular to b in the movement plane; (Sander, 1936, p. 302) and c is perpendicular to the ab plane, thus also (to) the cleavage plane." (The material in quotes except for the parenthesis (to) is taken from E. Cloos (1946, p. 5).

In the gneiss complex the attitude of the megascopic mineral lineation is in accord with the attitude of the axes of observed folds. Because of the observed relationship between the mineral lineation and the fold axes, the terminology of Sander is adopted in this paper: i.e., b denotes the megascopic mineral lineation or the fold axis; ab is the foliation plane; c is perpendicular to ab. Only those axes which are observable megascopically, or those which can be inferred from megascopic data are noted on the fabric diagrams.

Figure 3

(A) The only diagram that is oriented geographically is shown in Figure 3-A. The section from which Figure 3-A was prepared was cut "tangent" to the crest of a small fold and oriented parallel to the fold axis, the b axis. The fold is in quartz-potassium feldspar schist. Figure 3-A shows two maxima and two incomplete girdles. Maximum I is a shallow plunging lineation bearing about 40 degrees from the b axis. Maximum II is a lineation in the ac plane. The intersection of the girdles may account for Maximum II.

(B) This diagram was prepared from a section cut parallel to the plane of observed foliation in a quartz-potassium feldspar schist. Two maxima and an incomplete girdle are present. Maximum I is a lineation in the ab plane, the plane of the girdle. Maximum II is in or nearly in the ab plane and strikes nearly perpendicular to Maximum I.

Figure 4

(A) This diagram taken from a quartz-plagioclase-hornblende schist shows a girdle in the ac plane and a maximum slightly off the girdle.

(B) This section is taken in the plane of foliation from a biotite rich zone in the quartz-potassium feldspar-biotite gneiss. Several maxima within an incomplete girdle in the ab plane are shown. Some of the maxima cluster about the north and south ends of the b axis.

Figure 5

(A) This section is taken perpendicular to the lineation in the quartz-potassium feldspar gneiss. Three maxima are present within a girdle in the ac plane. Maxima I and II are lineations nearly perpendicular to each other. Maximum III is slightly within the periphery of the girdle.

(B) This diagram is taken from the quartz-potassium feldspar gneiss perpendicular to the lineation. Two lineation maxima are present which strike nearly at right angles to each other.

Fig. 3

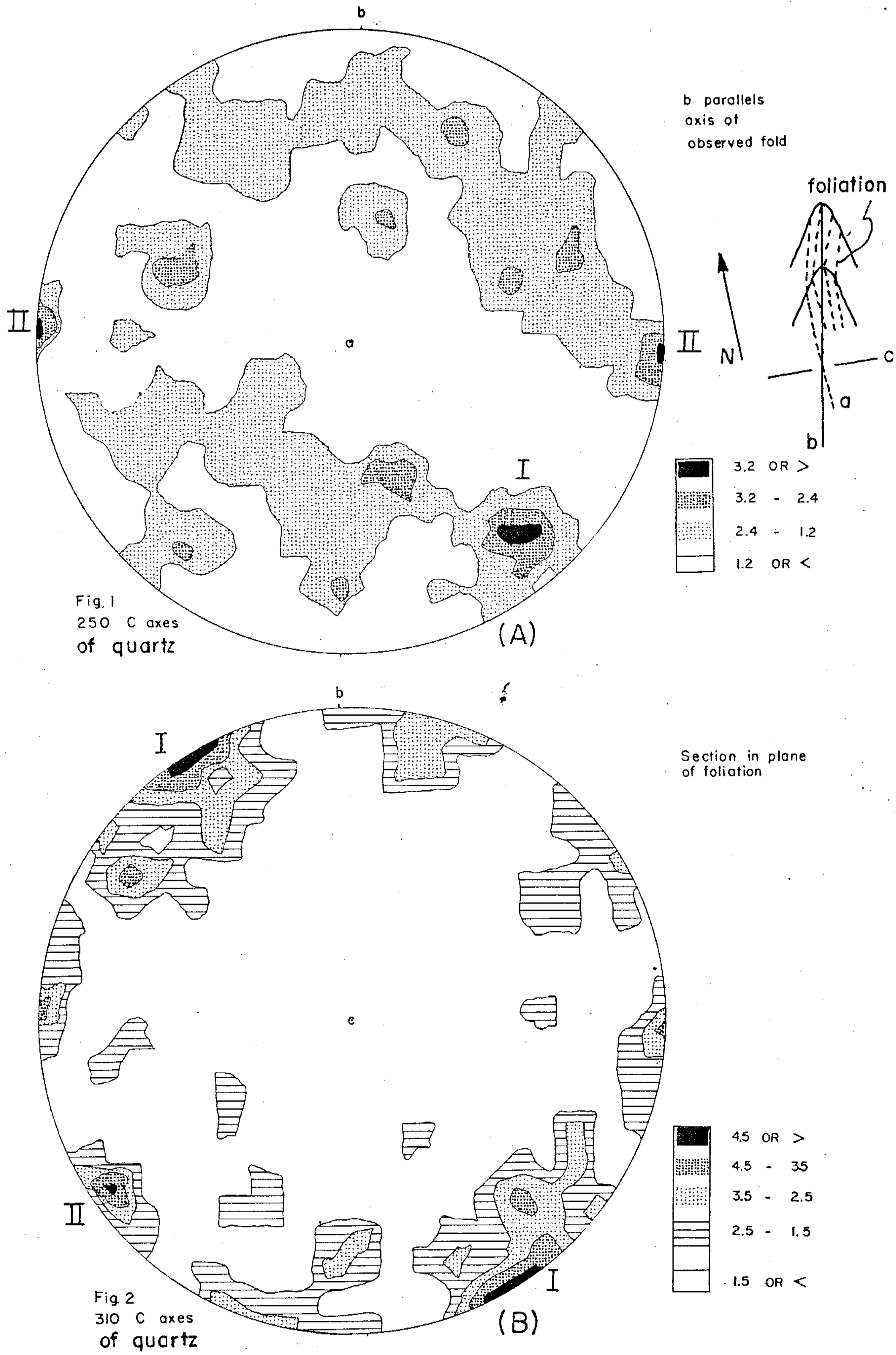
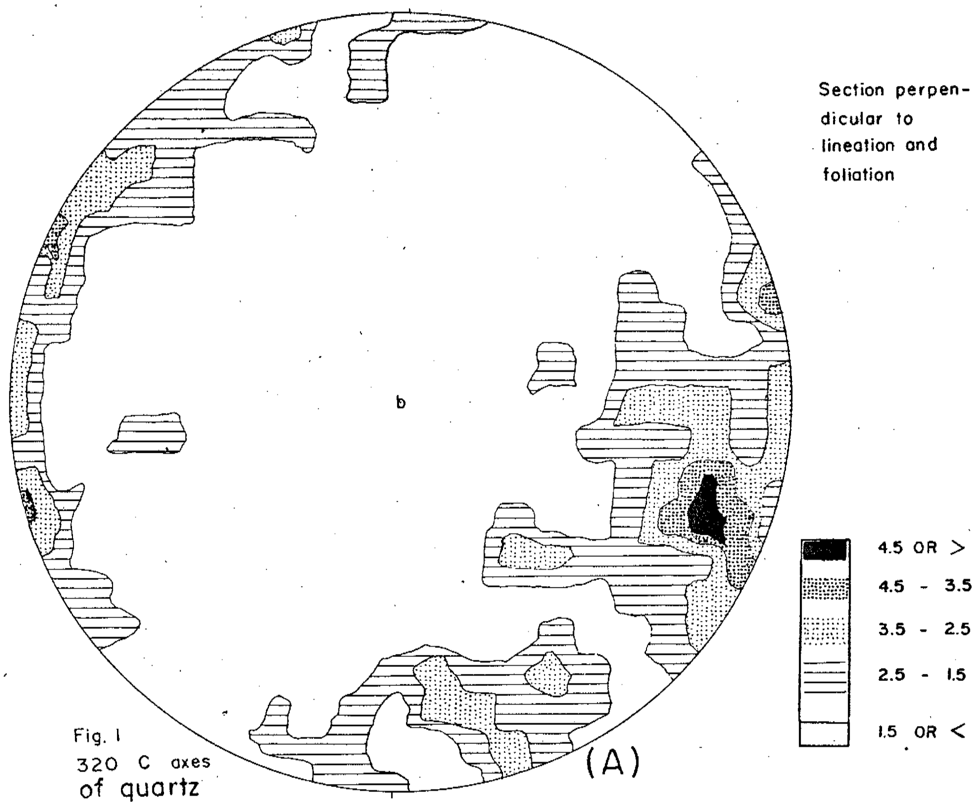
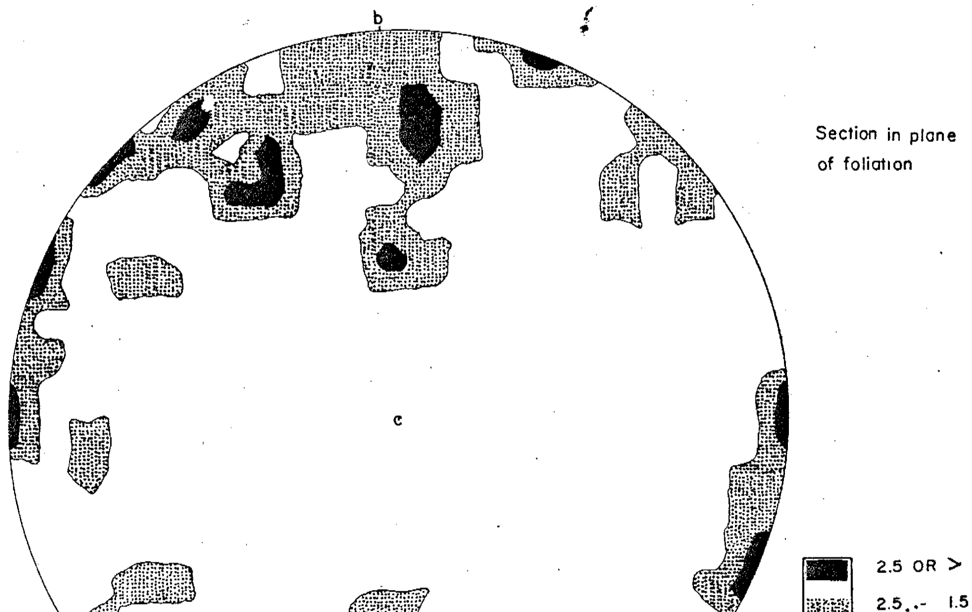

b
a
II
II
I
Fig. 1
250 C axes
of quartz
(A)
b parallels
axis of
observed fold
foliation
N
c
a
b
3.2 OR >
3.2 - 2.4
2.4 - 1.2
1.2 OR <
b
c
I
I
II
Fig. 2
310 C axes
of quartz
(B)
Section in plane
of foliation
4.5 OR >
4.5 - 3.5
3.5 - 2.5
2.5 - 1.5
1.5 OR <

Fig. 4



Section perpendicular to lineation and foliation

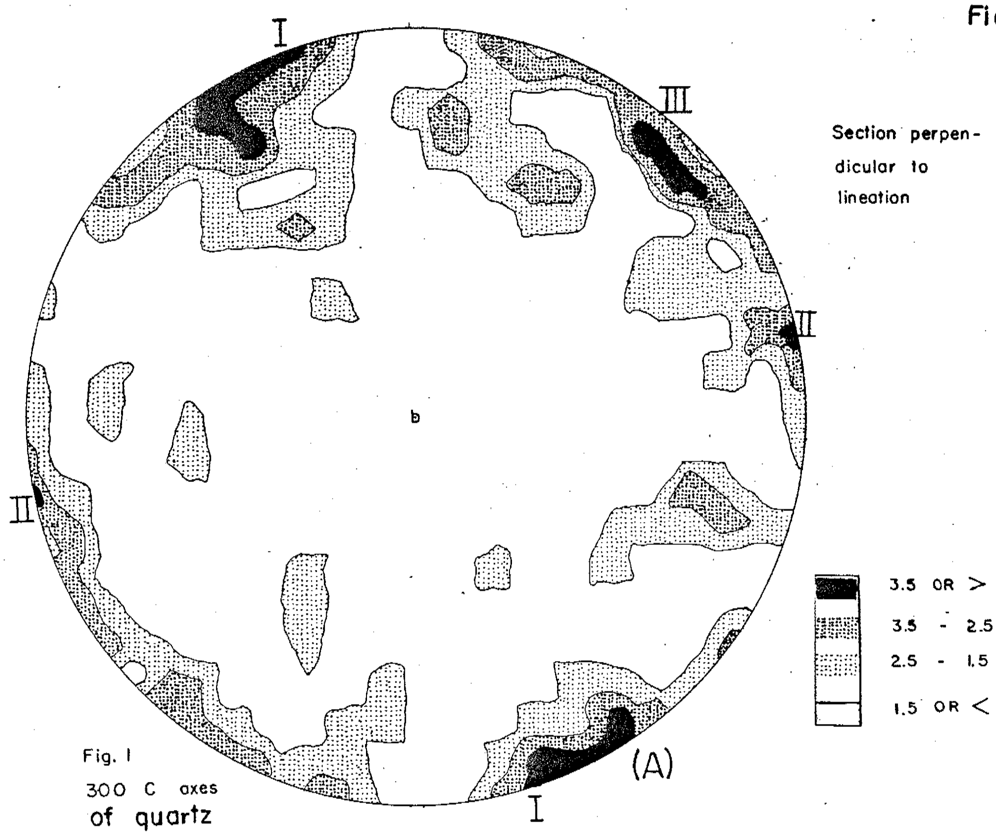
Fig. 1
320 C axes of quartz



Section in plane of foliation

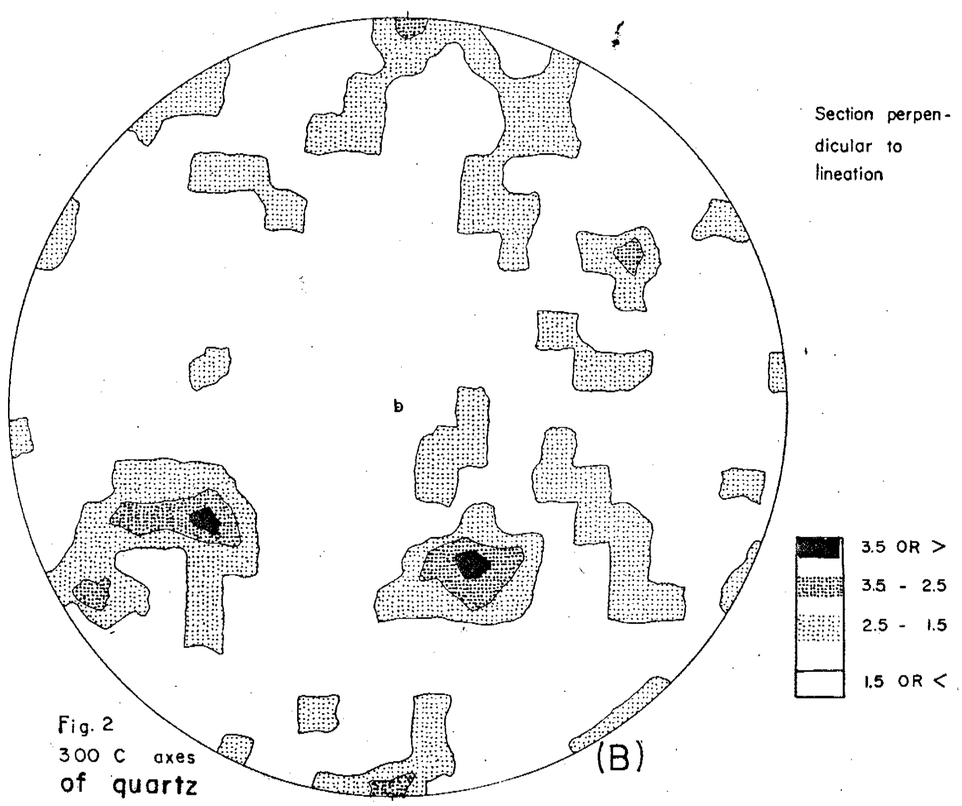
Fig. 2
300 C axes of quartz

Fig. 5



Section perpendicular to lineation

Fig. 1
300 C axes of quartz



Section perpendicular to lineation

Fig. 2
300 C axes of quartz

ECONOMIC FEATURES

Lindgren, Graton, and Gordon (1910, p. 240) and Lasky (1932, p. 55) have investigated the possible economic significance of the Cu, Pb, F, and Ba mineralization present in the Precambrian gneiss complex. The observations of the author pertinent to the Cu, Pb, F, and Ba were not sufficiently detailed to warrant any additions to the observations made by the earlier workers.

An occurrence of beryl in a pegmatite was reported in 1961 (Radcliffe, M., personal communication). An examination of the "discovery pegmatite" with a heavy liquid of specific gravity equal to 2.70 (Sp. Gr. quartz is 2.65; Sp. Gr. of beryl is 2.75-2.80) revealed no beryl. The examination of many other pegmatites with the heavy liquid also revealed no beryl; consequently, no additional work was done.

The examination for beryl was carried out in the following manner. Several samples of quartz (each sample in excess of 5g.) were obtained from a pegmatite. Each sample was crushed (the crushed material ranging in size from powder to 1mm) and poured into a bottle of heavy liquid.

It has been pointed out that several percent of beryl might go undetected by this method because of intimate mixing with quartz. This may be true. However, the pegmatites, in the refractory gneiss host rock, average less than one foot in thickness. Therefore several percent of beryl would not constitute ore under present day conditions.

INTERPRETATION

The coarse texture of the gneiss series, the uniform simple composition that prevails in the gneiss series, the presence of quartz-feldspar and amphibolite schists, and the megascopic and microscopic structure pattern that is present in the gneiss complex is suggestive of large scale, penetrative, dynamic metamorphism; i.e., regional metamorphism. The presence of large potassium feldspar metacrysts within gneissic terrane (Ramberg, 1952, p. 238) and the presence of myrmekite (Williams, Turner, and Gilbert, 1958, p. 235) are indirectly suggestive of regional metamorphism. Much of the potassium feldspar within the gneiss complex is attributed to late stage metasomatic activity for the following reasons.

1. The large amount of potassium feldspar (45-60% of the gneiss series) present.
2. The textural relationship. Large potassium feldspars filled with inclusions and generally sheathed in biotite do not exhibit cataclastic effects. This suggests that introduction of the potassium feldspar occurred late in metamorphism.

The uniformly oriented, steeply dipping schists; the locally transverse but generally coincident relation of the schistosity to the bedding; the similarity between the orientation of the mineral lineation and the axes of observed folds can best be explained as results of isoclinal folding.

Deformation in the form of a broad warping has been superimposed upon the regionally developed structure. The deformation is indicated by the broken bedding and coincident schistosity in the southern part of the quartz-potassium feldspar gneiss, the location of the axis of deformation.

Microscopic fabrics of rocks in the vicinity of, and south of the axis of deformation are not markedly different. This is supporting evidence that the second stage of deformation occurred without recrystallization.

Most of the rocks in the gneiss complex contain essential potassium feldspar. The ratio of authigenic to introduced feldspar is not known. Therefore, the following statements about source rocks and metamorphic facies are conjectural.

The gneiss series represents quartzo-feldspathic schists derived from arenaceous sediments or siliceous igneous rocks. The light colored schists (the quartz-potassium feldspar and the quartz-potassium feldspar-biotite schists) are quartzo-feldspathic schists. Rounded zircons and zircon stringers parallel to the foliation within the light colored schists suggests that they were derived from arenaceous sediments. Amphibolites may originate from basic igneous rocks or from impure calcareous sediments. Stringers of zircon that parallel the foliation and rounded zircons (Fig. 1 and Fig. 2, Plate 1), and the hornblende-plagioclase ratio (Williams, Turner, and Gilbert, p. 243) suggest derivation from impure calcareous sediments, some of which may have been basic tuffaceous sediments. Evidence suggesting introduction of material was not observed in the amphibolites. For this reason the amphibolites represent the actual metamorphic conditions better than any other rock in the gneiss complex. Hence, a moderate-to-high grade of metamorphism typical of the amphibolite facies is assigned to the gneiss complex.

One strong joint orientation and perhaps a second, less pronounced orientation are present. Two orientations of pegmatite are also present;

a strong permatite orientation within the strong joint orientation; a weaker pegmatite orientation which may be correlated with the weak joint orientation. The joints and associated pegmatites maintain a constant attitude throughout the gneiss complex regardless of the attitude of earlier structural patterns. Joint development therefore postdates the second stage of deformation. The pegmatites and aplites are confined to the gneiss complex. Faulting, the last structural event within the gneiss complex has offset the pegmatites and aplites.

A good correlation exists between the microscopic fabric and fabric observed in the field.

The following correlations between the microscopic fabric and the megascopic fabric are possible.

1. Lineation parallel or subparallel to b, a megascopic mineral lineation which coincides with the áxes of observed folds. This is shown by maximum I (Fig. 3-B) and perhaps by the clustering of maxima around the b axis of Fig. 4-B.
2. Foliation in the ab plane. This is shown by the girdles of Fig. 3-B and Fig. 4-B. The ab girdles correspond to the foliation measured in the field.
3. Lineation within the plane of foliation. In the field where lineation and foliation were observed together, the lineation was always within the plane of foliation. Fig. 3-B shows this relationship very well. In Fig. 4-B, this relationship exists but is not well developed.

A well developed microscopic fabric with no megascopic equivalent is present. This is the ac girdle (Fig. 4-A, Fig. 5-A). To account for the ac girdle, three explanations have been advanced based on b as the axis of rotation (Fairbairn, 1939; p. 1489; 1949, p. 122; Turner, 1948, p. 259). These are:

1. Rotation of grains.

2. Rotation of strain axes.

3. Formation of micro-flexure folds.

There is no evidence that any of the three processes above were operative. The author therefore suggests a fourth possibility: the development of a post-deformation growth fabric within ac fractures. There is no evidence for the fourth possibility either. However, ac fractures (tension joints) are probably more characteristic of isoclinal folds than either 1., 2., or 3., above. The fabric shown in Fig. 3-B cannot be related to any microscopic or megascopic structural pattern. Maximum II is perhaps a growth lineation resulting from the intersection of the two inclined girdles. The origin of the girdles is not known. The relation of the fabric shown in Fig. 5-B to any observed structural pattern is unknown. However, most of the orientations that comprise this fabric were recorded from quartz grains which occur as inclusions within the large potassium feldspar crystals. Perhaps the growth of the potassium feldspar metacrysts disturbed an earlier deformation fabric.

SUMMARY AND CONCLUSIONS

The investigation of the Precambrian gneiss complex was undertaken to determine: (1) its igneous or metamorphic history and (2) its structural history.

The rocks are metamorphic. The data suggests a metasedimentary history for the following reasons.

1. The attitudes, spatial distribution, and composition of the schist layers suggest that the schists are metasediments.

2. The lateral gradation of quartz-potassium feldspar schist into amphibolite schist; the local lateral and vertical gradation of quartz-potassium feldspar schist into quartz-potassium feldspar-biotite schist; and the local gradational contacts of the schists with the gneiss series all suggest a metasedimentary history.

3. Zircon stringers which parallel the foliation are indicative of relic bedding. Because of the refractory nature of zircon, rounded zircon grains in metamorphic rocks are considered to be evidence that the rock is a metasediment.

4. The composition and texture of the gneiss series, quartz-potassium feldspar schists, quartz-potassium feldspar-biotite schists, amphibolites and epidosite can be explained by regional metamorphism of arenaceous, impure calcareous or basic volcanic sediments that have been selectively felspathized.

The structural history may be summarized as follows.

1. Sedimentation: deposition of arenaceous, impure calcareous, or basic volcanic sediments (Fig. 6-A).

2. Regional metamorphism and deformation producing isoclinal folding which resulted in the formation of axial plane cleavage (foliation) and a b lineation (Fig. 6-B). Simultaneous development of schistosity within axial plane cleavage.

3. Deformation (broad warping) which disrupted the structure pattern of the earlier regional deformation (Fig. 6-C).

4. Alkali felspathization which may have occurred later than the regional deformation but earlier, during or later than the second deformation.

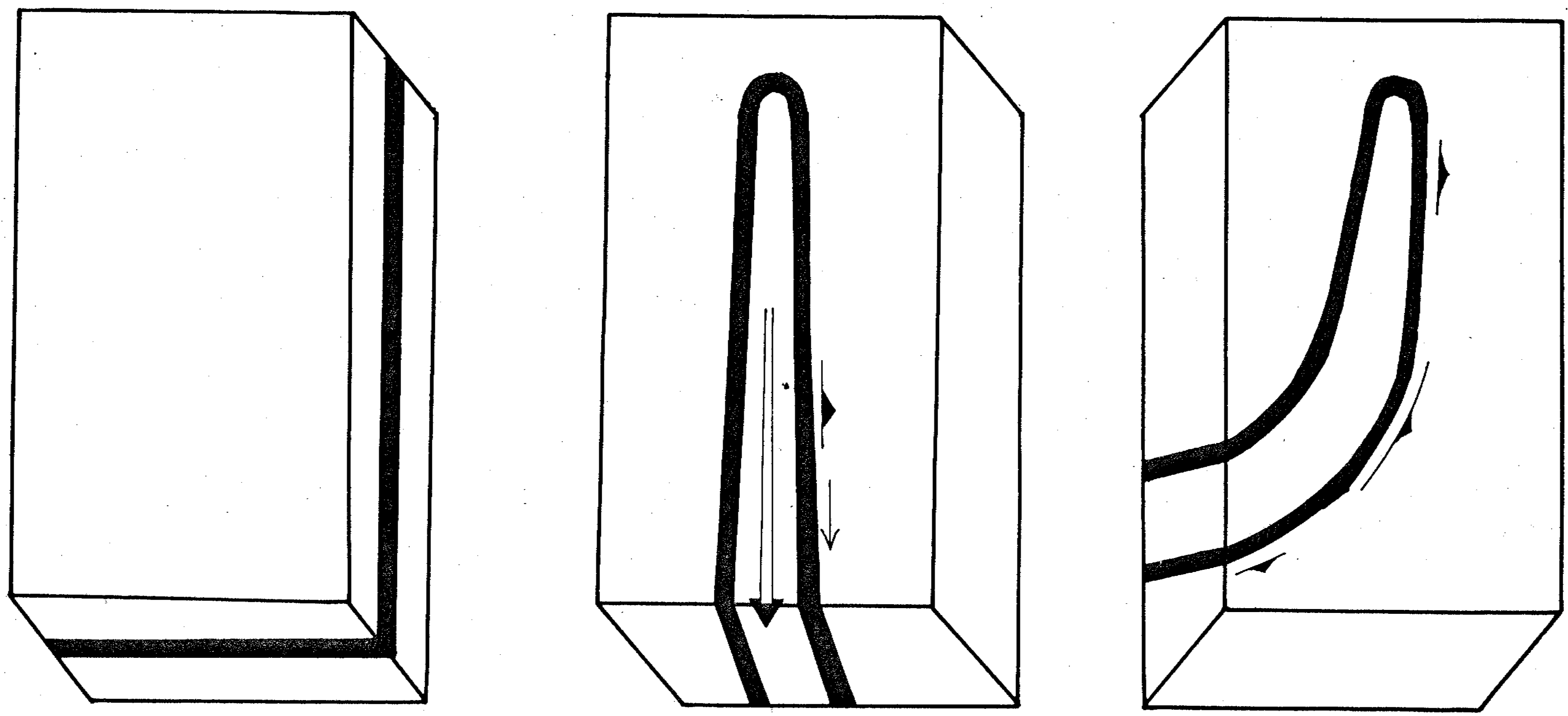
5. Jointing which because of its uniform orientation throughout the area occurred later than either deformation.

6. Pegmatitization and probably the formation of aplite dikes.

7. Faulting and fracturing which may be temporally related to the jointing and pegmatitization or may be occurring at the present time.

Figure 6

PRECAMBRIAN STRUCTURAL HISTORY



(A) SEDIMENTATION

(B) REGIONAL METAMORPHISM RESULTING IN:
- ISOCLINAL FOLDING
- SCHISTOSITY

(C) DEFORMATION OF REGIONAL STRUCTURE

REFERENCES

Billings, M. P., (1954) Structural Geology; New York, Prentice Hall, Inc., 514 p.

Cloos, E., (1946) Lineation; A Critical Review and Annotated Bibliography; Memoir 18, Geol. Soc. of America.

Fairbairn, H. W., (1939) Quartz Orientation in Tectonites; Bull. Geol. Soc. of America, v. 50, p. 1475.

______________, (1949) Structural Petrology of Deformed Rocks; Cambridge, Mass., Addison Wesley Press Inc., 344 p.

Lasky, S. G., (1932) The Ore Deposits of Socorro County, New Mexico, NMBMMR, Bull. 8., Socorro, New Mexico.

Lindgren, W., Graton, L. C., & Gordon, C. H., (1910) The Ore Deposits of New Mexico, U. S. Geol. Surv. Prof. Paper 68.

Ramberg, H., (1952) The Origin of Metamorphic & Metasomatic Rocks; University of Chicago Press, 317 p.

Turner, F. J., (1948) Evolution of the Metamorphic Rocks; Geol. Soc. of America, Mem. 30.

Wilpolt, R. H., MacAlpin, A. J., Bates, R. L., Vorbe, G.; (1946, Rev. 1954) Geologic Map and Stratigraphic Sections of Paleozoic Rocks of Joyita Hills, Los Pinos Mountains, and Northern Chupadera Mesa, Valencia, Torrance, and Socorro Counties, New Mexico. U. S. Geol. Surv. Oil and Gas Investigations Preliminary Map. 61

Williams, Turner, and Gilbert, (1958) Petrography; San Francisco, W. H. Freeman & Co., 406 p.

This thesis is accepted on behalf of the faculty of the Institute by the following committee:

Max E. Willard

A. J. Budding

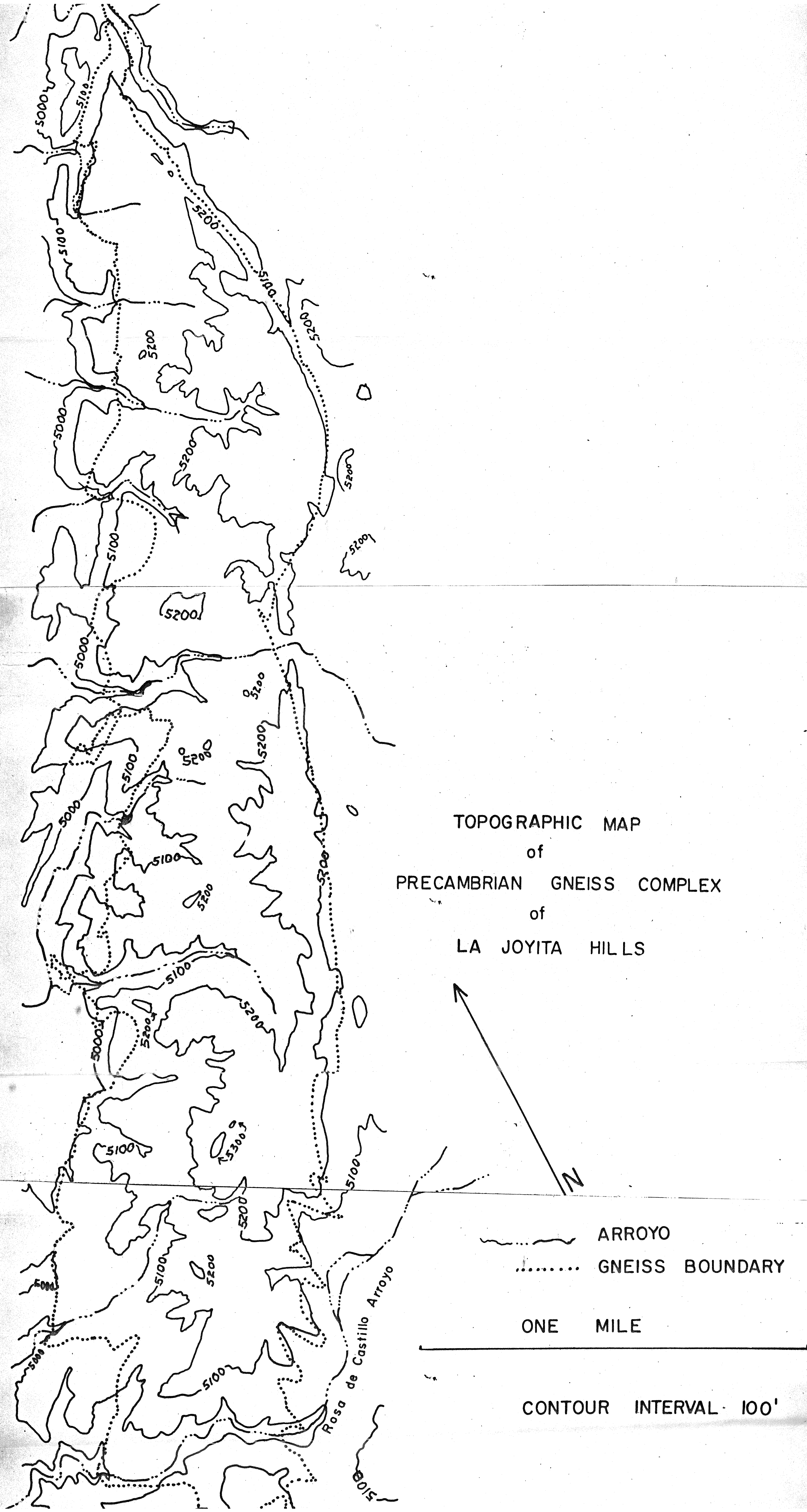
Clay T. Smith

Marvin W. Wilkening

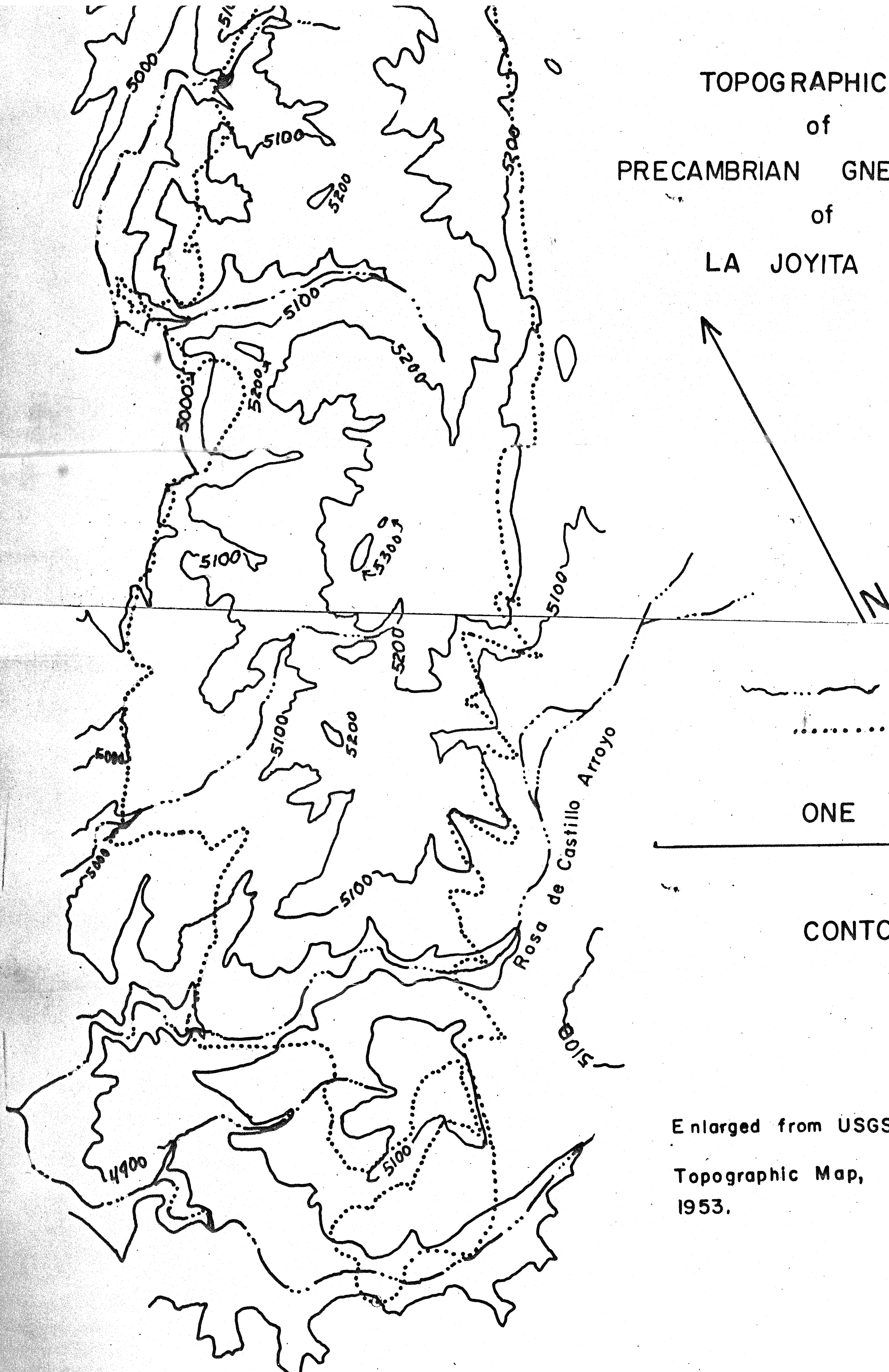
____

Dexter H. Reynolds

Date: August 14, 1962


TOPOGRAPHIC MAP
of
PRECAMBRIAN GNEISS COMPLEX
of
LA JOYITA HILLS
N
ARROYO
GNEISS BOUNDARY
ONE MILE
CONTOUR INTERVAL 100'
Rosa de Castillo Arroyo

TOPOGRAPHIC MAP
of
PRECAMBRIAN GNEISS COMPLEX
of
LA JOYITA HILLS



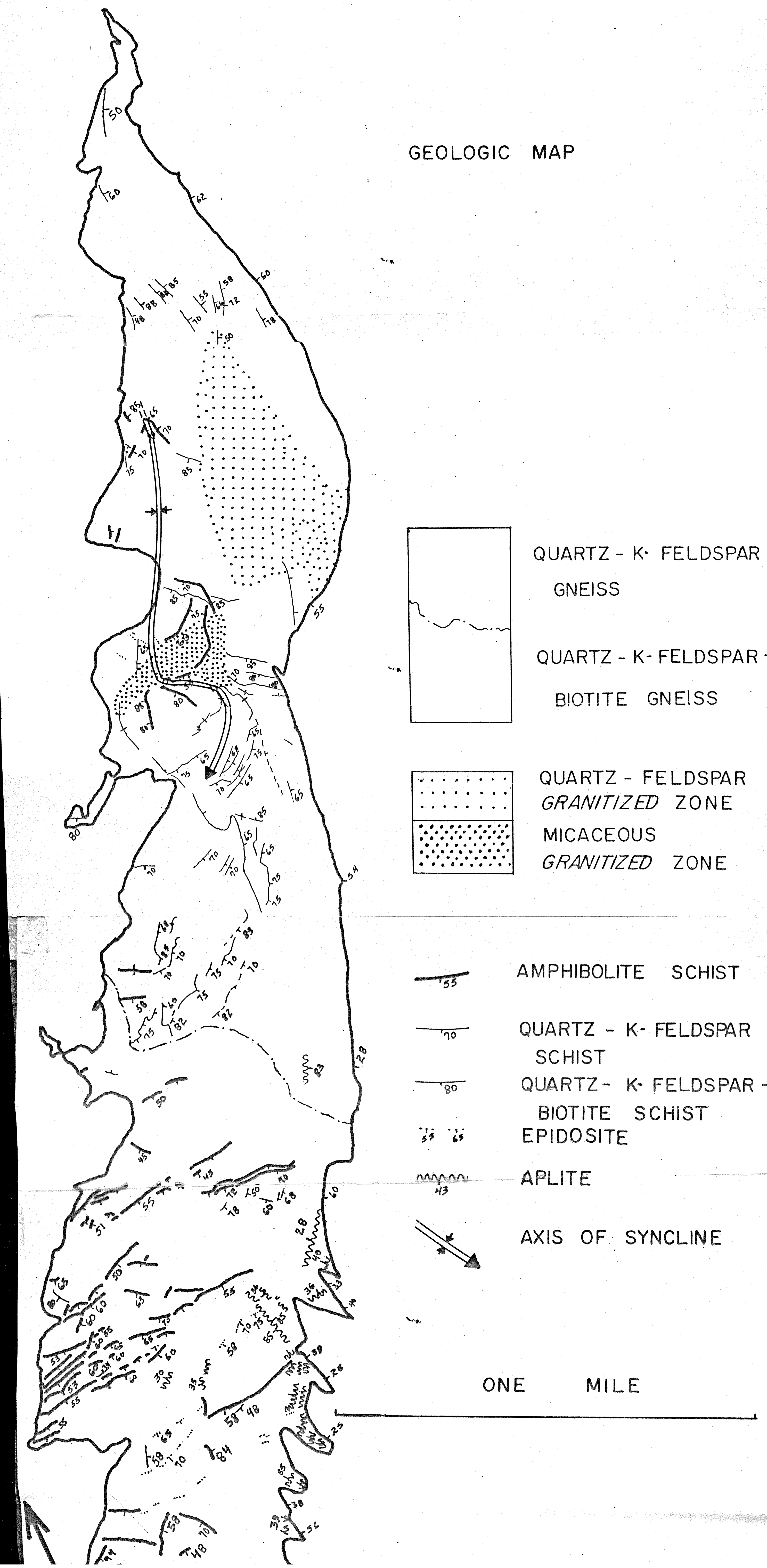
ARROYO

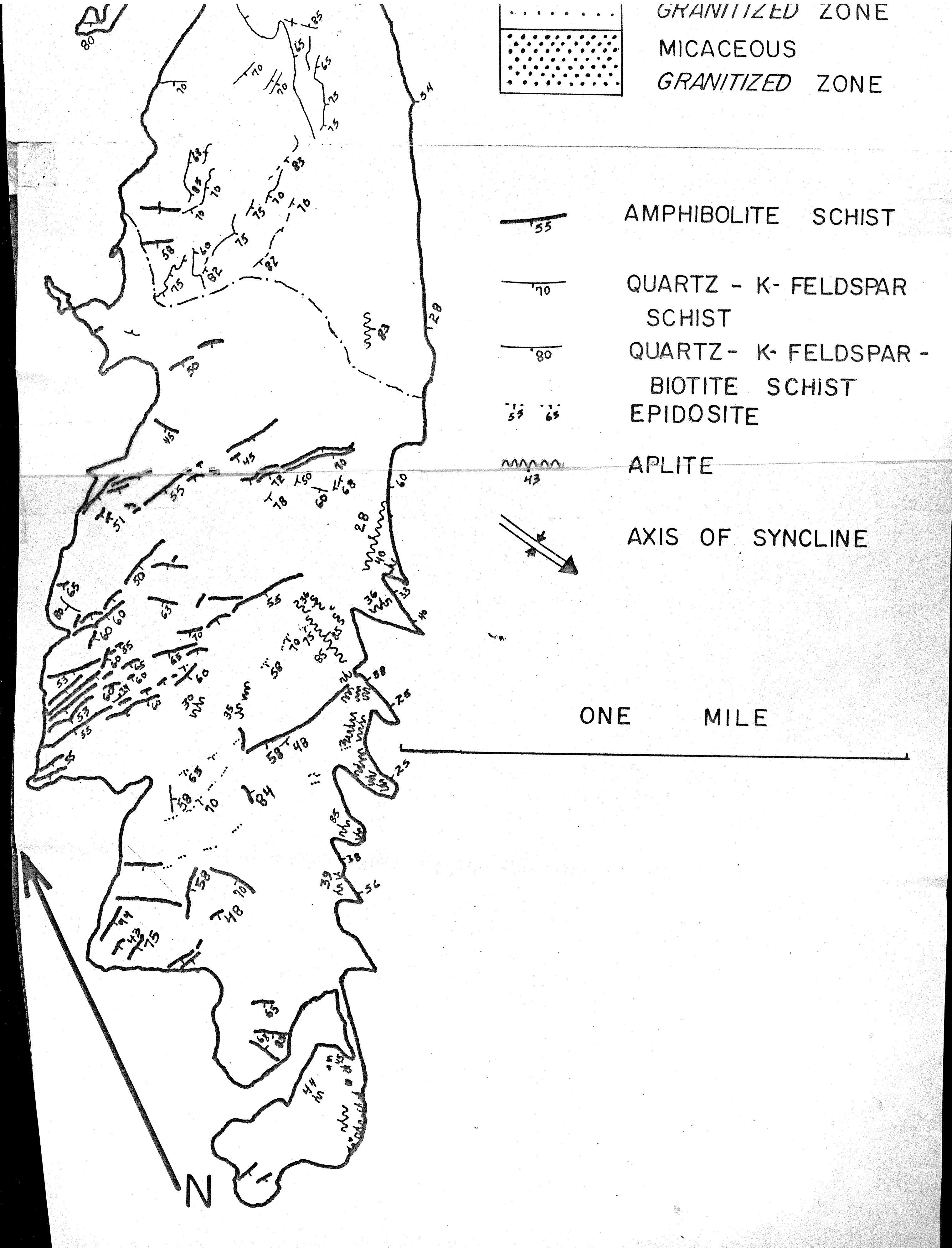
GNEISS BOUNDARY

ONE MILE

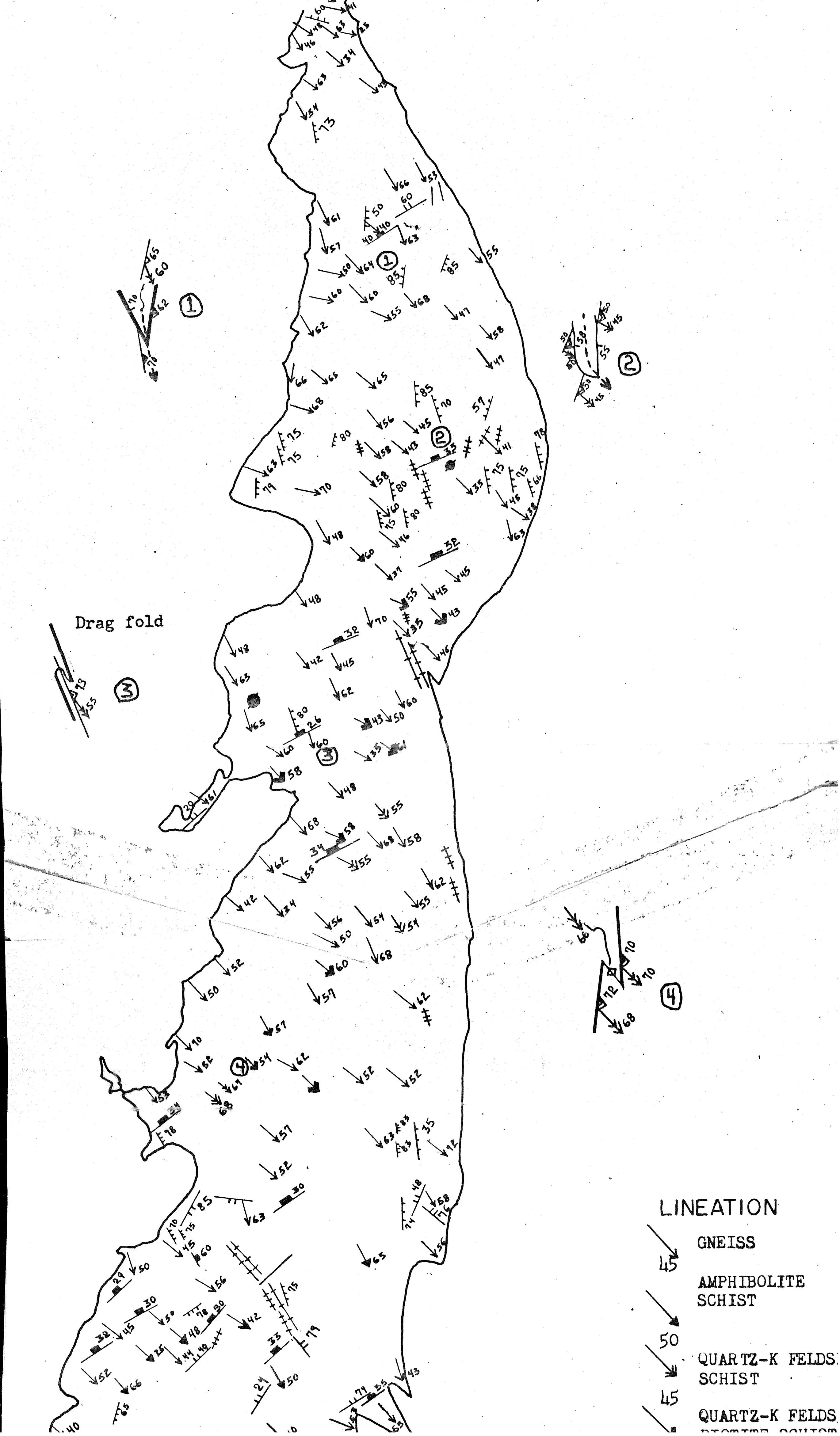
CONTOUR INTERVAL 100'

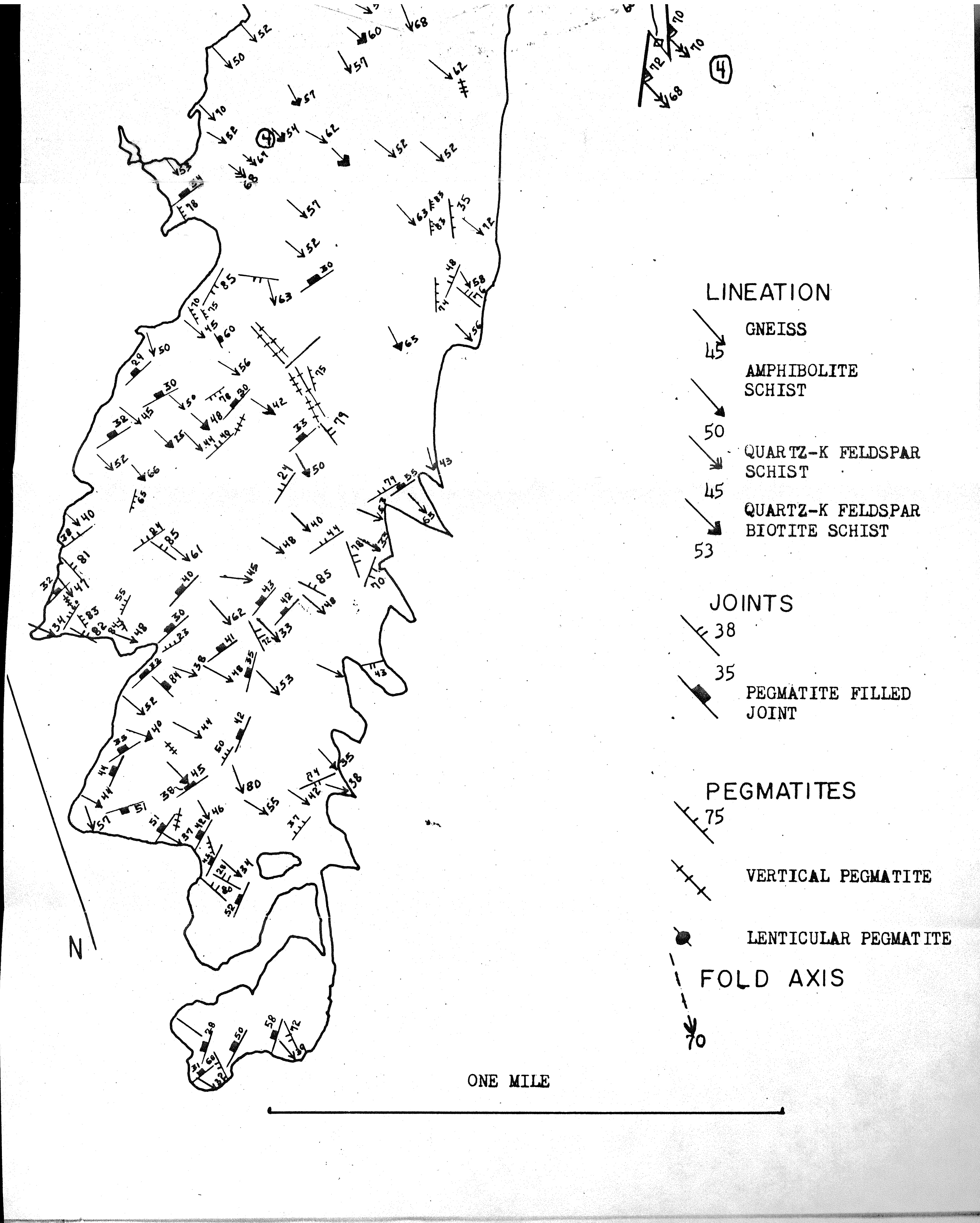
Enlarged from USGS
Topographic Map,
1953.


GEOLOGIC MAP
QUARTZ - K- FELDSPAR GNEISS
QUARTZ - K- FELDSPAR - BIOTITE GNEISS
QUARTZ - FELDSPAR GRANITIZED ZONE
MICACEOUS GRANITIZED ZONE
AMPHIBOLITE SCHIST
QUARTZ - K- FELDSPAR SCHIST
QUARTZ - K- FELDSPAR - BIOTITE SCHIST
EPIDOSITE
APLITE
AXIS OF SYNCLINE
ONE MILE


GRANITIZED ZONE
MICACEOUS GRANITIZED ZONE
AMPHIBOLITE SCHIST
QUARTZ - K- FELDSPAR SCHIST
QUARTZ- K- FELDSPAR - BIOTITE SCHIST
EPIDOSITE
APLITE
AXIS OF SYNCLINE
ONE MILE
N

DATA MAP OF LINEATION, FOLDS PEGMATITES & JOINTS





N
LINEATION
GNEISS
AMPHIBOLITE SCHIST
QUARTZ-K FELDSPAR SCHIST
QUARTZ-K FELDSPAR BIOTITE SCHIST
JOINTS
PEGMATITE FILLED JOINT
PEGMATITES
VERTICAL PEGMATITE
LENTICULAR PEGMATITE
FOLD AXIS
ONE MILE