STRUCTURAL GEOLOGY
IN THE BIRCH LAKE - UCHI LAKE
METAVOLCANIC-METASEDIMENTARY BELT
MITCHELL TOWNSHIP, ONTARIO

A Thesis

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Master of Science

by

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ABSTRACT

The Birch-Uchi Lake metavolcanic-metasedimentary belt is composed of rocks of early Precambrian age which are metamorphosed to the greenschist facies. In the study are granodiorite and diorite intrusions with highly assimilated, often sheared, contacts have intruded the metavolcanic sequence.

All rocks in the area have undergone at least two and possibly three periods of deformation. The effects of the oldest period can be observed as regional foliation referred to as S_1. S_1 was formed by dynamothermal metamorphism through the action of slip and cataclastic flow attendant with recrystallization. The present mineral assemblage, characteristic of Winkler's upper greenschist facies, resulted from this event. A second possible period of deformation developed a crenulation-cleavage (S_2) by flexural slip movements on the S_1 plane. These movements may have been a phase of the oldest deformation. The youngest period of deformation produced a second, imperfectly formed crenulation-cleavage (S_3) which is superimposed on S_1 and S_2. The S_3 plane formed by flexural slip on S_1. Minor recrystallization of quartz, kinking of tabular minerals, and rotational features exhibiting horizontal

movement are some effects produced in S_2 and S_3 formation.

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CHAPTER I

INTRODUCTION

General Statement

This study is a structural analysis of part of the Birch Lake - Uchi Lake metavolcanic-metasedimentary belt of Northwestern Ontario. The study area itself is underlain mainly by felsic metavolcanic rocks, minor metadiorite and a granodiorite intrusion. Folding in the rocks indicates that they have undergone more than one period of deformation. The objectives of the study are as follows:

(1) to identify the separate deformational events,

(2) to interpret the mechanism of deformation of each event,

(3) to establish the strain properties of each event,

(4) to determine the chronological sequence of deformational events,

(5) to relate the deformational events to metamorphism and granodiorite emplacement.

The procedures used to achieve the above objectives were as follows:

(1) mapping on a scale of 1 inch = 200 feet with

emphasis placed on orientations of geometrical elements,

(2) thin section study,

(3) geometrical analysis of orientation data.

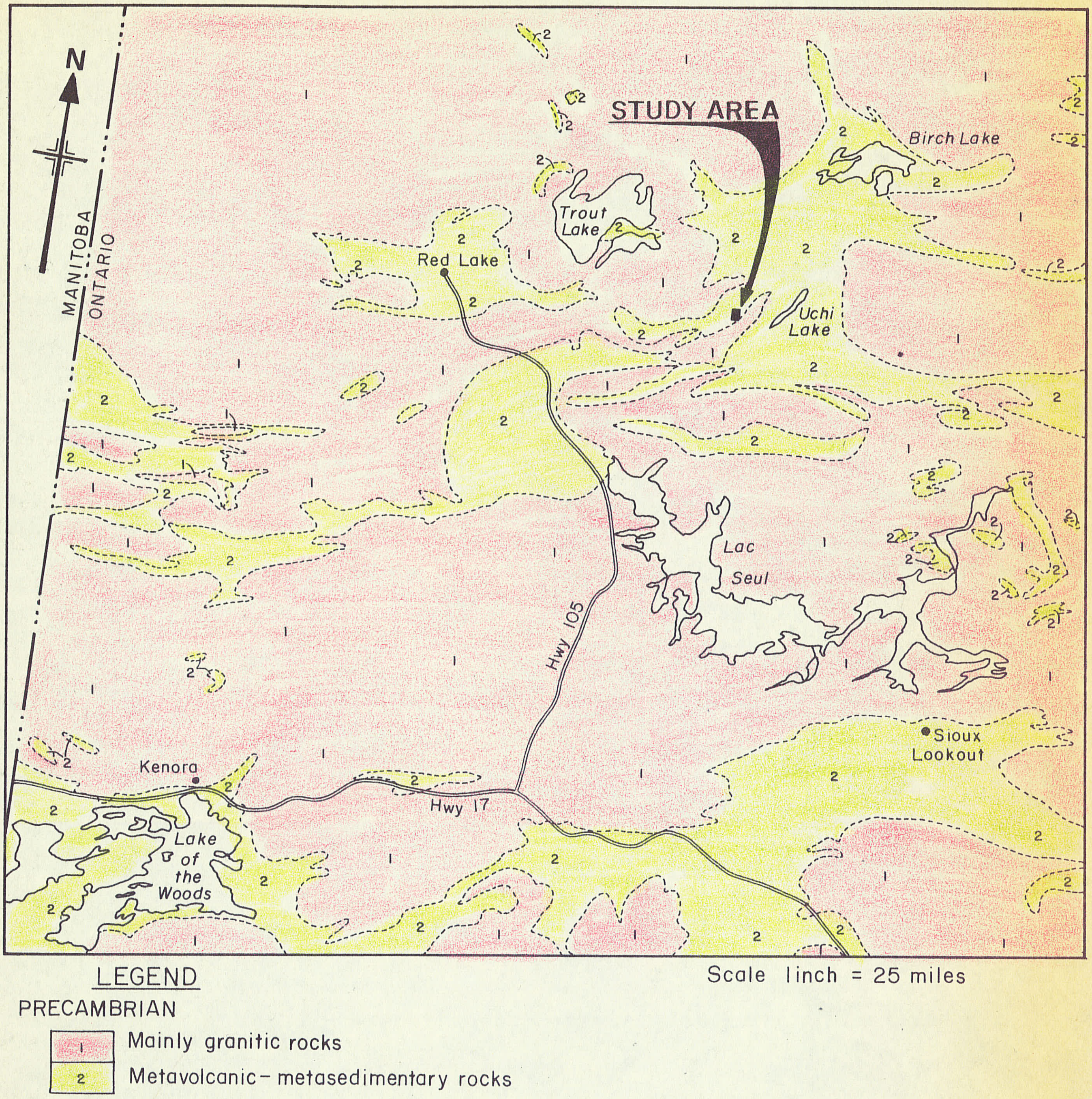
Location and Accessibility

The area in which the investigation was conducted is part of Mitchell Township, Ontario. The township is located 45 miles east of Red Lake, Ontario (Plate 1). Horseshoe Lake is located within the study area. A hydro line passes near the northwestern tip of the area and a new road has been completed recently along this line to the South Bay Mines property on Confederation Lake (Plate 2).

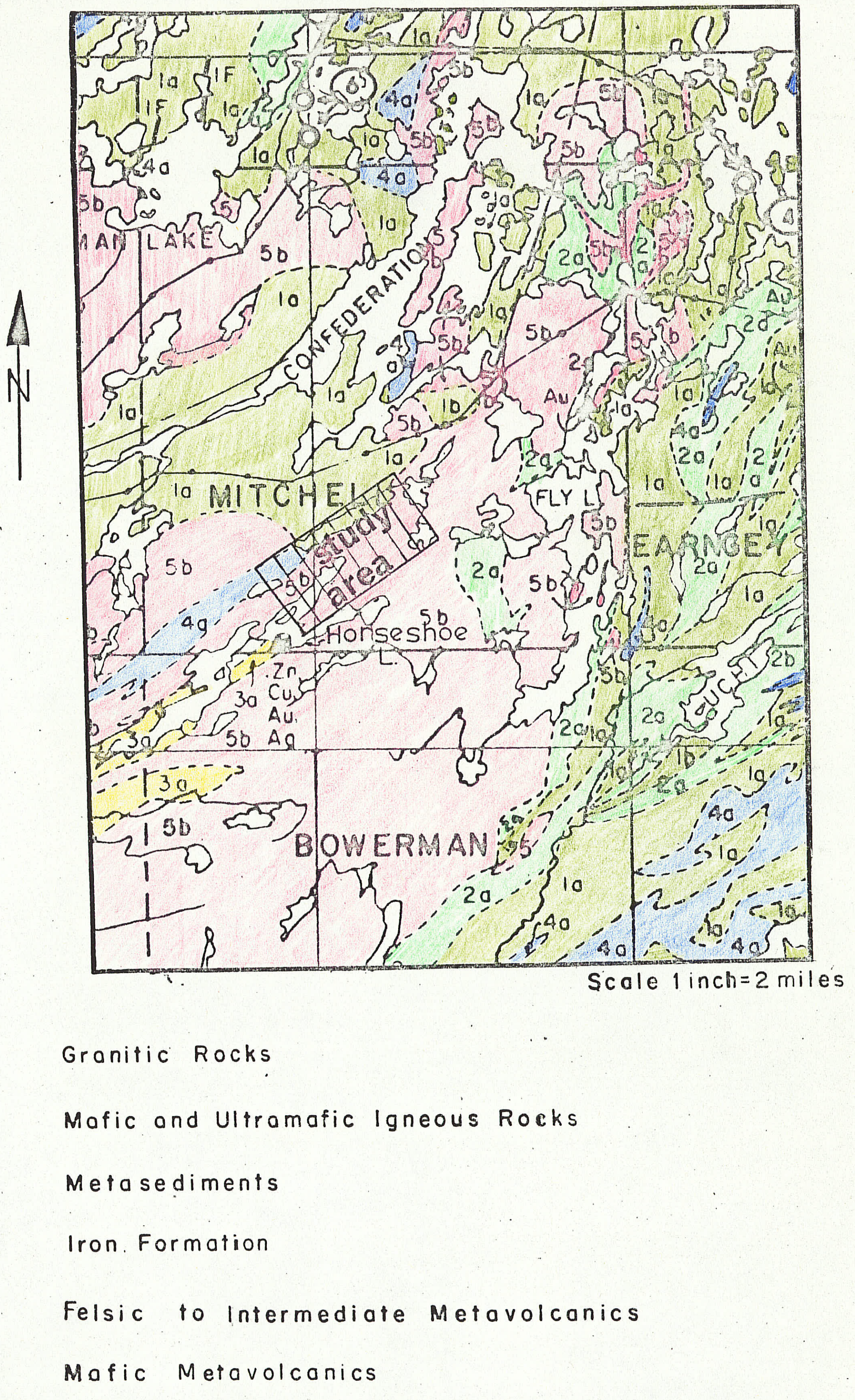
Previous Work

The area has been mapped previously by the Geological Survey of Canada. A G.S.C. compilation map, M 1200 A, on the Trout Lake area by J.A. Donaldson was published in 1964 on a scale of 1 inch = 4 miles. K.G. Fenwick mapped the area immediately southwest of the study area for the Ontario Department of Mines. The results of this work have been published on O.D.M. Preliminary maps P 350 and P 351 on a scale of 1 inch = 1320 feet. The general geology of part of Northwestern Ontario in which this investigation was conducted is shown in Plate 2.

PLATE 1



Location of study area near Uchi Lake, northwestern Ontario (Geology after ODM Map 2148).



General geologic compilation of a section of the Birch Lake-Uchi Lake metavolcanic-metasedimentary belt. The study area is outlined. (Modified after Ontario Department of Mines Preliminary Geologic Map No. P406).

Field Work

During the summer months of 1969 the author was employed by the Selco Exploration Company Limited to map their Arrow East and Arrow West grid areas along Horseshoe and Elbow Lakes. The Arrow East grid is the subject of this study. Mapping during 1969 was undertaken on a scale of 1 inch = 200 feet. The final geologic map with the grid location is shown in Plate 3 (in pocket).

Acknowledgements

The author wishes to express his gratitude to W.C. Brisbin who provided assistance and valuable criticism in all aspects of the study.

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Financial assistance for laboratory studies was provided through a grant to W.C. Brisbin from the Geological Survey of Canada.

CHAPTER II

GENERAL GEOLOGY

Introduction

The study area is located in the heart of the Superior province of the Canadian Shield. The Superior province consists of minor east-west trending Archean metavolcanic-metasedimentary belts interrupted by vast areas of plutonic granitic rocks. The study area itself comprises a portion of a belt of predominantly felsic meta-volcanic rocks which has been semi-concordantly intruded by a granodiorite pluton. The distribution of major rock types suggests the presence of a large fold structure with an amplitude of about 1.2 miles. The strike of the axial surface of the fold is northeast, parallel to the regional schistosity which has developed throughout the area.

The geological succession is summarized in the accompanying table of formations (Table I).

Stratigraphy

Previous mapping in the Birch-Uchi Lakes area of Ontario (Goodwin, 1967) places a synclinal axis immediately east of the study area. No reliable top determinations were

TABLE I

TABLE OF FORMATIONS

CENOZOIC

Recent	Silt, sand, organic deposits
Pleistocene	Clay, till, sand, boulders

Unconformity

PRECAMBRIAN

EARLY PRECAMBRIAN

Felsic Intrusive Rocks

Granodiorite, quartz sericite schist, quartz porphyry

Intrusive Contact

Metadiorite

Intrusive Contact

Metavolcanic Rocks

Mafic metavolcanic rocks

Mafic flows

Felsic metavolcanic rocks

Porphyritic biotitic flows and (or) tuffs, spherulitic flows and tuffs, tuff

Biotitic flows and (or) tuffs, spherulitic flows and tuffs, tuff

Sericitic flows and (or) tuffs, porphyritic pyroclastics, sheared flows and (or) tuffs found in the study area.

The mafic metavolcanic rocks (unit 4 on Plate 3) lie mainly to the northwest, outside the study area, although a small area of mafic flows is found in the core of the fold structure. The biotitic felsic metavolcanic rocks (units 2 and 3 on Plate 3) are found in the central portion. The sericitic felsic metavolcanic rocks (unit 1 on Plate 3) are found south of unit 2. Within the felsic volcanic group the main mass of granodiorite intruded along a specific contact.

Description of Rock Units

Sericitic Felsic Metavolcanic Rocks (Unit 1 on Plate 3)

Introduction

The sericitic felsic metavolcanic rocks are the southernmost unit in the study area. In general, they are represented by buff to pale green weathering quartz sericite schists although massive and porphyritic varieties are also present. Foliation is marked by the alignment of fine grained foliae of sericite. Their original nature is generally masked by metamorphism and the exact ratio of lavas to pyroclastics is indiscernible. One distinct porphyritic pyroclastic unit has the characteristics of an ignimbrite (Cooke, 1966).

Porphyritic Sericitic Pyroclastic Unit (Unit 1a on Plate 3)

The porphyritic sericitic pyroclastic unit is well exposed in the study area. This rock type is volcanic in origin and is interpreted as an ash flow or ignimbrite (Cooke, 1966). In places this unit is 200 feet thick.

Texturally, relict phenocrysts of quartz and plagioclase feldspar are set in an aphanitic granoblastic groundmass of quartz, plagioclase, and very minor potassium feldspar. Plagioclase phenocrysts An_3 - An_7 are subhedral to euhedral and up to 5 mm in length. Rounded quartz phenocrysts are 3 - 4 mm in diameter. Sericite imparts a schistose appearance to the rock.

The rocks of the porphyritic pyroclastic unit are very siliceous and probably approach rhyolite in composition. The total quartz content is about 40% with quartz phenocrysts comprising about 20% of this total. The content of plagioclase phenocrysts varies randomly from 15% to 40%. The potassium feldspar content of the groundmass is difficult to determine accurately but staining tests confirm at least 1%. Sericite, which may account for most of the original potassium feldspar, constitutes about 10% of the total rock.

The porphyritic pyroclastic unit contains numerous ignimbritic structures. Pyroclastic fragments are present in the form of wispy discontinuous mafic lenses composed in part of a dark chloritic mineral. Subhedral plagioclase phenocrysts are present in the chloritic lenses. Also contained in the pyroclastic unit are fine-grained siliceous fragments which weather lighter in color than the surrounding matrix and which average about 6 inches long. The long and intermediate axes of both types of fragments are parallel to the regional foliation. The chloritic and siliceous fragments constitute about 5% of the pyroclastic unit.

Slight compositional differences in the pyroclastic unit result in indistinct outlines of possible angular pyroclastic fragments. Metamorphism and possible welding of the unit at the time of deposition has masked the fragmental appearance to some degree.

The indistinct fragment outlines and the random nature of the plagioclase phenocryst content within the unit suggests an ignimbritic origin for the porphyry. Cooke (1966) describes similar structures referred to as 'discoids' in recent ignimbrites in the Great Basin region of North America. He believes these structures to be fragments and compaction structures which have undergone deuteric alteration.

Massive to Sheared Sericitic Flows and/or Tuffs (Units 1b and 1c on Plate 3)

The massive and sheared sericitic flows and/or tuffs consist of a groundmass of interlocking fine-grained quartz, plagioclase, and possibly potassium feldspar containing rounded relict quartz phenocrysts. Foliation is marked by an alignment of greenish sericite grains. These metavolcanics probably approach a rhyolite in composition.

The total quartz content may exceed 40% with quartz phenocrysts constituting up to 10% of some rocks. Plagioclase phenocrysts (albite), where not destroyed, are present in amounts less than 5%. Sericite constitutes from 10% to 50% of the rock depending on the degree of alteration of potassium feldspar. Zircon is found occasionally as knee-shaped twins.

Generally, the quartz sericite schists have no recognizable relict features which might assist in deciphering the genesis of the rocks. The same applies to the massive units which occur near the nose of the fold in the SW corner of the area. The presence of a few fine tuffaceous units and the texture and composition of the rocks strongly suggests that they are volcanic in origin.

Biotitic Felsic Metavolcanic Rocks (Units 2 and 3 on Plate 3)

The biotitic felsic metavolcanic rocks in the central part of the area have been metamorphosed to quartz biotite plagioclase schists. Although texture, composition, and a few relict structures suggests that these rocks are volcanic in origin, the ratio of lava to pyroclastic material is undiscernable.

Thin section study shows that units 2 and 3 are composed of fine grained granoblastic quartz, plagioclase, and minor potassium feldspar. Aligned biotite and minor sericite produce a distinct foliation. Recrystallized clear quartz 'eyes' with an internal mosaic texture are interpreted as relict quartz phenocrysts. Subhedral relict plagioclase phenocrysts are present occasionally along with anhedral calcite, euhedral magnetite grains and subhedral porphyroblasts of garnet. Chlorite is present in minor amounts and may crosscut or parallel the aligned biotite grains.

The biotitic felsic metavolcanic rocks are too fine grained to obtain exact percentages of quartz and feldspar. Two broad units are distinguished. The rocks of unit 3 are estimated to contain up to 10% relict quartz phenocrysts; the rocks of unit 2 contain no quartz phenocrysts. Relict plagioclase phenocrysts may constitute as much as 3% of some rocks. The biotite content is estimated to vary from 5% to 15% while calcite, an alteration product of the plagioclase feldspars, may constitute as much as 8% of some rocks. Probable almandine garnet and magnetite exceed 10% by volume in a few horizons which are tuffaceous in origin. Riebeckite in prismatic poikiloblastic crystals is rare.

Primary features are poorly preserved in units 2 and 3 owing to the degree of metamorphism. Only a few pyroclastic features provide clues to the mode of formation. Bedding in the tuffaceous material is observed in a few places (Plate 4). Structures with a spherulitic appearance are common and similar to some recent pyroclastic accretionary lapilli (Moore and Peck, 1962). Thin units of these suspected accretionary lapilli interlayered with known tuffaceous beds support the idea of a pyroclastic origin for at least part of the felsic biotite schist unit.

Mafic Metavolcanic Rocks (Unit 4 on Plate 3)

Minor amounts of mafic metavolcanics, probably originally flows, are observed on Horseshoe Lake. These weather dark green and exhibit a well developed foliation. Thin section studies indicate they are now principally composed of chlorite, epidote, and actinolite with minor calcite and quartz.

Metadiorite (Unit 5 on Plate 3)

Metadiorite occurs along the narrow lake north of Horseshoe Lake and has probably been intruded into the metavolcanic sequence. Zenoliths of metadiorite found in the granodiorite body attest to a pre-granodiorite emplacement.

In two thin sections studied, the metadiorites are composed of up to 40% amphibole, plagioclase totally altered to epidote, quartz, and calcite, and about 10% biotite. The amphibole is of two types, a blue green variety which is later than and replaces a fibrous colorless variety, probably tremolite.

PLATE 4

Photograph of preserved bedding in felsic tuff.
Plane of outcrop is horizontal.

Felsic Intrusive Rocks (Unit 6 on Plate 3)

The large felsic intrusive body found mainly in the NW portion of the area is composed of massive recrystallized granodiorite. Mylonite zones of quartz-sericite schist are developed within the body and along the contacts with felsic metavolcanic rocks. Where the granodiorite is in contact with felsic volcanic rocks either a sheared quartz-sericite schist or a granitic quartz porphyry is found.

Massive granodiorite

Massive granodiorite is medium-grained and has a hypautomorphic recrystallized texture. Anhedral to euhedral grains of microcline and plagioclase feldspar along with anhedral recrystallized grains of quartz form an interlocking texture. Graphic intergrowths of quartz and potassium feldspar are common.

The potassium feldspars form the largest crystals and comprise 15% by volume. Plagioclase (oligoclase) and quartz constitute about 35% by volume while the aligned tabular minerals, biotite and sericite, make up less than 10% of the rock.

Sheared granodiorite

A gradational hybrid zone marks the contact between granodiorite and the felsic metavolcanic rocks. The contact is often marked by a shear zone up to 150 feet thick, in which case, the intrusive body has been transformed to a quartz-sericite schist which contains minor amounts of chlorite and biotite. The schist developed from the granodiorite closely resembles the quartz-sericite schist of volcanic origin. At the contact of the two, the small 2 mm blue quartz eyes of the metavolcanic schists contrast with the large sugary white augens of the granitic schist which are up to 1 cm in length. The same sugary augens are seen in the shear zones within the main granodiorite body where the sericite schist is obviously of granodiorite origin.

Metamorphism

The mineral assemblages of the different rock types indicate they have been metamorphosed to the upper greenschist facies (Winkler, 1965). The minerals correspond to Winkler's quartz-albite-epidote-almandine subfacies which is the highest temperature subfacies in the greenschist facies. Typical mineral assemblages in the area are as follows:

(1) felsic metavolcanic rocks

(a) albite (An_5) + quartz + biotite + chlorite + sericite ± calcite ± potassic feldspar

(b) albite ($An_?$) + quartz + biotite + almandine garnet + chlorite + sericite + calcite

(c) albite (An_3 - An_7) + quartz + sericite + chlorite ± biotite ± calcite ± rebeckite

(2) mafic metavolcanic rocks

(a) albite ($An_?$) + chlorite + epidote + calcite + actinolite ± quartz

(3) metadiorite

(a) plagioclase ($An_?$) + epidote + blue green hornblende + actinolite + calcite ± quartz + biotite

Almandine garnets first make their appearance in the quartz-albite-epidote-almandine (B 1.3) subfacies of greenschist metamorphism. The plagioclase associated with calcite bearing minerals should be of albite composition. Unfortunately, the only plagioclase compositions attainable were in felsic metavolcanic rocks and these proved to be albite. The potassium feldspars of felsic metavolcanic rocks were converted to sericite and quartz.

The plagioclase of the metadiorite and mafic metavolcanics is altered to quartz, calcite, and epidote suggesting the metadiorite contained a fairly calcic plagioclase (Roubault, 1963).

One difference between lower greenschist and upper greenschist rocks may be the replacement of actinolite by hornblende (Winkler, 1965). Such a situation occurs within the metadiorite where fibrous actinolite, which probably replaced original pyroxene, has been itself replaced by blue green amphibole, probably hornblende.

Some pale green highly pleochroic chlorite in biotitic felsic metavolcanic rocks crosscuts the aligned biotite and has developed after the main metamorphic event.

CHAPTER III

MAJOR STRUCTURAL FEATURES

Layering (S_0) and Folds in Layering

Description

In this study relict bedding or layering is referred to as S_0 . Layering is recognizable on a mesoscopic and a megascopic scale. On the mesoscopic scale it occurs as beds in the few tuffaceous units; and on the megascopic scale it is recognized by the contacts of major rock units.

The position of the S_0 contacts delineates a large fold structure in the map area (Plate 3). The nose of the fold is best portrayed by the contact between the two biotitic felsic volcanic units (units 2 and 3). A sill-like intrusion of granodiorite can be traced around the nose of the fold structure.

Geometry of the Major Fold in S_0

The geometry of the major fold is unknown except for the strike of the axial surface which is approximately north-east. Although mesoscopic layering occurs infrequently, it is parallel to the axial surface where exposed. No mesoscopic layering was observed in the hinge area of the fold.

Regional Foliation (S_1)

Description of S_1

General Statement

A prominent foliation (S_1) occurs in all rock types of the study area. For the most part, this foliation has a near vertical dip and strikes northeast and is characterized by the planar alignment of tabular minerals. The following is a discussion of the characteristics of S_1 and evidence of its tectonic origin.

Sericitic Felsic Metavolcanic Rocks

(a) Porphyritic pyroclastic unit

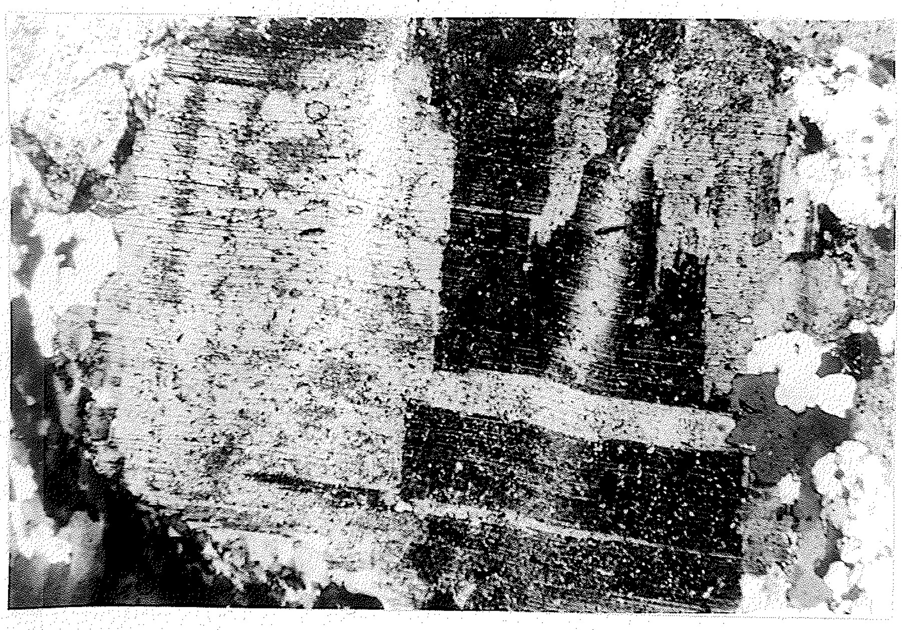
The porphyritic sericitic pyroclastic unit (unit 1a, Plate 3) acted as one of the more brittle units during the formation of S_1; nevertheless, it still has a pervasive regional foliation. This foliation is observed best in both horizontal and vertical thin sections cut perpendicular to S_1. The character of the foliation texture is cataclastic.

The S_1 planes in this sericitic pyroclastic unit are marked by aligned sericite and biotite which occur as poorly defined tabular concentrations and constitute 5% to 10% of the rock. These micaceous minerals curve around the quartz phenocrysts. Almost all the quartz phenocrysts occur as crushed mosaic textured aggregates. The long and intermediate dimensions of the aggregates lie in the planes of the regional foliation. The development of S was apparently simultaneous with slight rolling, crushing, breaking apart, and recrystallization of the quartz phenocrysts. Some phenocrysts have separated into smaller pieces leaving a trail of fine grained granulated quartz between them.

The plagioclase phenocrysts appear to have been more brittle and less susceptible to recrystallization than quartz. The feldspars are often twinned and deformation of twinning is useful in identifying relative movements (Plates 5 and 6). Deformation of twinning suggests failure by slippage. A few of the individual feldspar lathes remain relatively undeformed, with only minor granulation having taken place around crystal edges. Most of the feldspars display evidence of deformation in the form of crushing, slight rolling, and small kinks in twinning. Some phenocrysts have been broken and crushed producing a trail of smaller pieces. Twinning in each of the broken pieces of an individual crystal may be aligned so that a semicircle is formed by rolling and movement along slip planes.

Thin sections of the porphyritic pyroclastic unit exhibit the same textural features in both horizontal and vertical thin sections. In the vertical sections, a slight dimensional elongation of the quartz aggregates in S_1 is the only notable difference (Plate 7).

PLATE 5

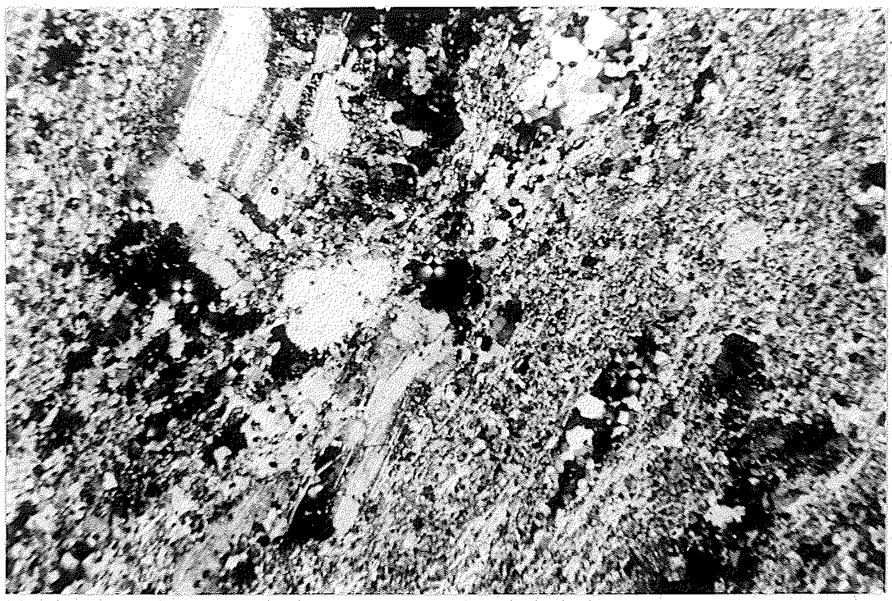


Photomicrograph (X80, X-nicols) of deformed plagioclase twinning. Carlsbad and pericline twinning are kinked. View is horizontal section taken from porphyritic pyroclastic.

PLATE 6

Photomicrograph (X20, X-nicols) of porphyritic pyroclastic unit. Note mosaic quartz aggregates granulated edges of feldspar, deformed twinning, and an interlocking granoblastic matrix. View is horizontal.

PLATE 7



Photomicrograph (X20, X-nicols) of vertical section of porphyritic pyroclastic perpendicular to the regional foliation. Sericite accentuates the S_1 plane along with the dimensional elongation of mosaic textured quartz lenses. Same sample as PLATE 6.

(b) Quartz sericite schists

The quartz sericite schists display excellent development of S_1 due to the alignment of sericite flakes. Quartz aggregates have developed a mosaic texture and their long dimension is parallel to S_1. Large feldspar grains exhibit a cataclastic texture. Rotational features are indicated by rotated minerals which leave 'debris' trails of sericite to mark their former position (Plates 8 and 9).

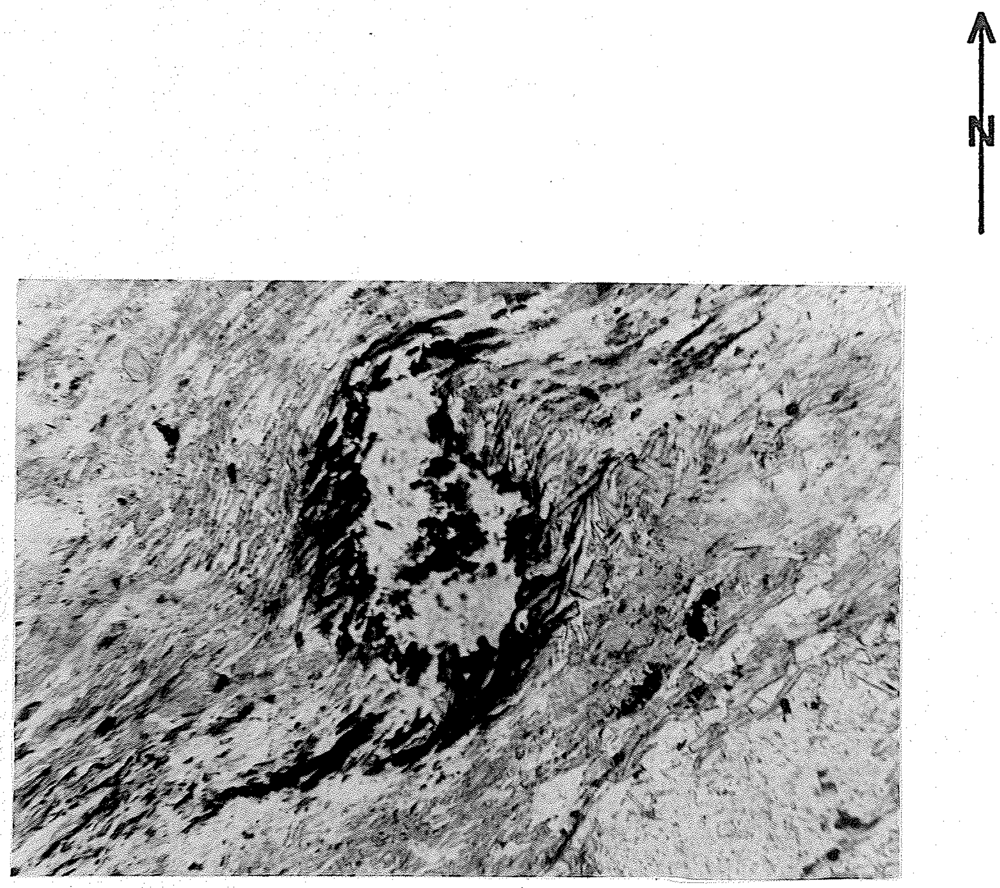
Biotitic Felsic Metavolcanic Rocks

The penetrative regional foliation (S_1) within units 2 and 3 is accentuated by the alignment of biotite and sericite. Relationships of the aligned tabular minerals with small quartz and plagioclase phenocrysts and porphyroblasts of garnet give clues as to the nature of the foliation.

The biotitic felsic metavolcanic rocks contain relict small blue quartz phenocrysts some of which remain subspherical and seemingly undeformed; others are crushed and recrystallized into lensoid aggregates with a granoblastic interlocking texture. Strain shadows in the quartz grains are common.

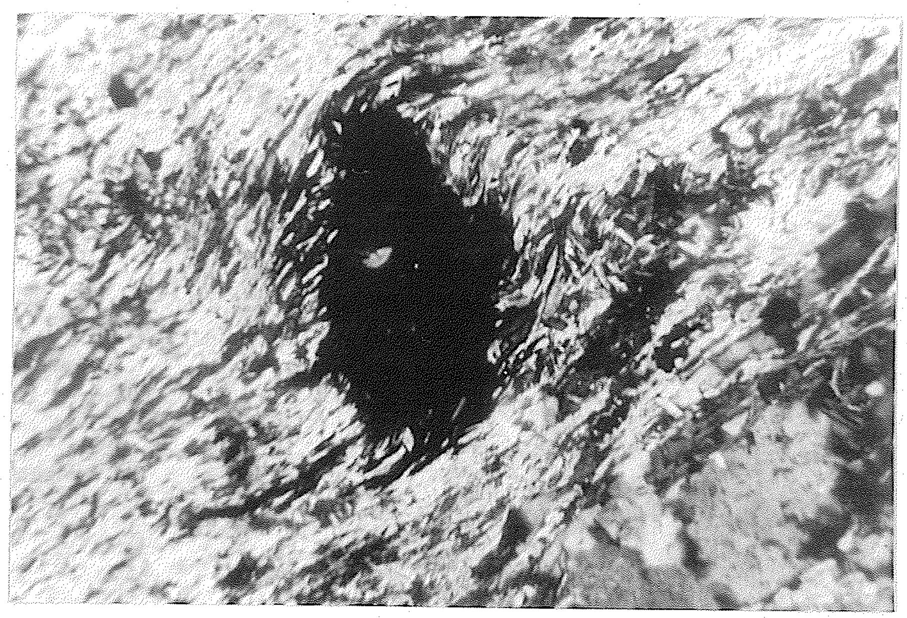
Most plagioclase phenocrysts are also crushed and broken and the crushed aggregate deformed into lensoid shapes. However, some plagioclase phenocrysts retain a fairly coarse grain size.

PLATE 8



Photomicrograph (X80, plane light) demonstrating the rotational phenomenon of a hematite pseudomorph. Rotation trails follow the S_1 plane. View is horizontal.

PLATE 9



Photomicrograph (X80, X-nicols) showing the same phenomenon as PLATE 8.

Garnets within units 2 and 3 provide evidence concerning development of S_1. A few garnets appear to be rolled; however, the majority are flattened perpendicular to and dimensionally elongated within S_1. A distinct fracture pattern perpendicular to the direction of regional foliation is present in each porphyroblast. Inclusions within the garnets are aligned in rows parallel to S_1 (Plates 10 and 11). As noted previously, chlorite develops in the shadow zone of the garnets and randomly crosscuts the biotite. Another generation of chlorite is aligned with the biotite along S_1 and probably formed with the development of S_1.

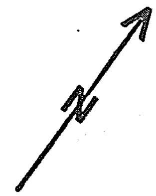
Metadiorite

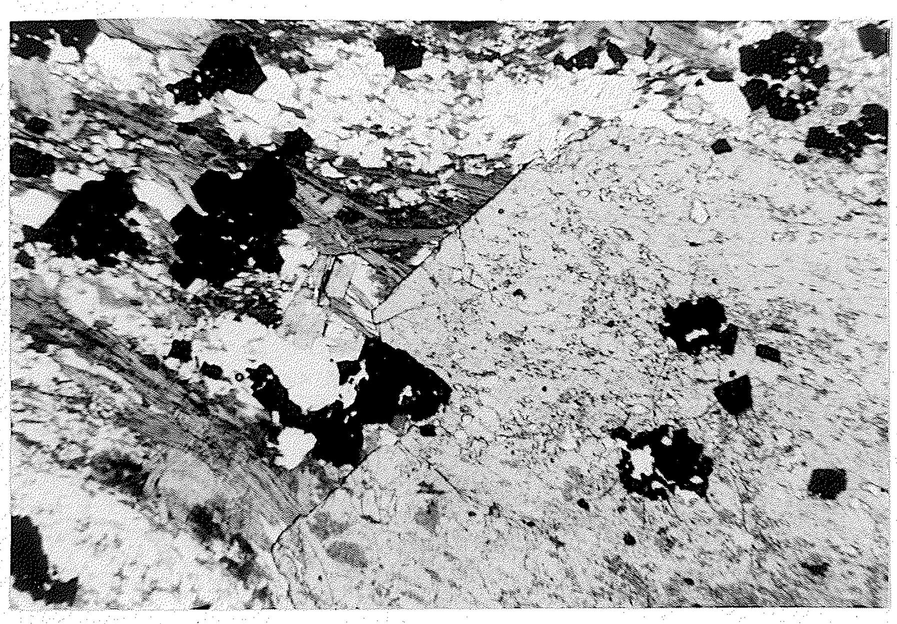
Evidence of S_1 formation in the diorites is found in a number of shear zones of chlorite-epidote schist within the main diorite body. As stated before, the diorite was emplaced prior to the granodiorite which itself has been affected by the same forces which developed S_1.

Granodiorite

The granodiorite is characterized by northeast trending shear zones displaying well developed foliation; however, between these zones the foliation is less distinct or absent. Shear zone thicknesses vary from a few feet to tens of feet and the zones are often curviplanar (Plate 12). Contacts are gradational and the gradation consists of a

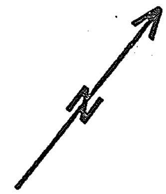
PLATE 10

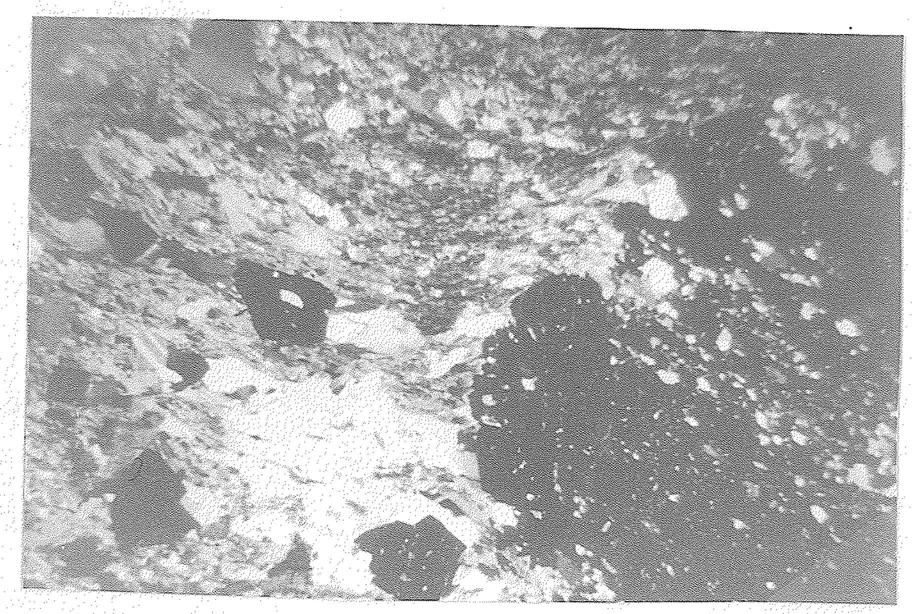




Photomicrograph (X20, plane light) of garnet crystal. Euhedral faces are developed where in contact with green chlorite. View is horizontal.

PLATE 11





Photomicrograph (X20, X-nicols) showing aligned inclusions within the garnet. Calcite develops as an alteration product at the ends of the elongate garnets. The S_1 plane is accentuated by aligned biotite.

PLATE 12

Photograph of small shear zone in granodiorite. Left lateral movement is indicated by curved fractures. Plane of photo is horizontal.

change from granodiorite with a slight mortar structure to a quartz sericite schist. Intermediate stages include recrystallized granodiorite with interlocking and mosaic textures and slightly sheared granodiorite with aligned biotite, sericite, and chlorite.

The schist within the intensely sheared zones in the granodiorite is classified as a blastomylonite. Deformation is extreme. The quartz within the zones is in the form of large augens (Plate 13). The texture portrayed in the shears is in part cataclastic; many non-crushed and recrystallized lenses of quartz are present also. Absence of strain shadows within the quartz may indicate a near complete post tectonic recrystallization of the quartz (Turner and Weiss, 1963). The S_1 direction is expressed by aligned sericite and biotite which may curve around the quartz aggregates. The aggregates are ellipsoidal with their long and intermediate dimensions parallel to the foliation planes and the short dimensions perpendicular to the foliation (S_1). The ends of the quartz aggregates are frayed as if they have been corroded.

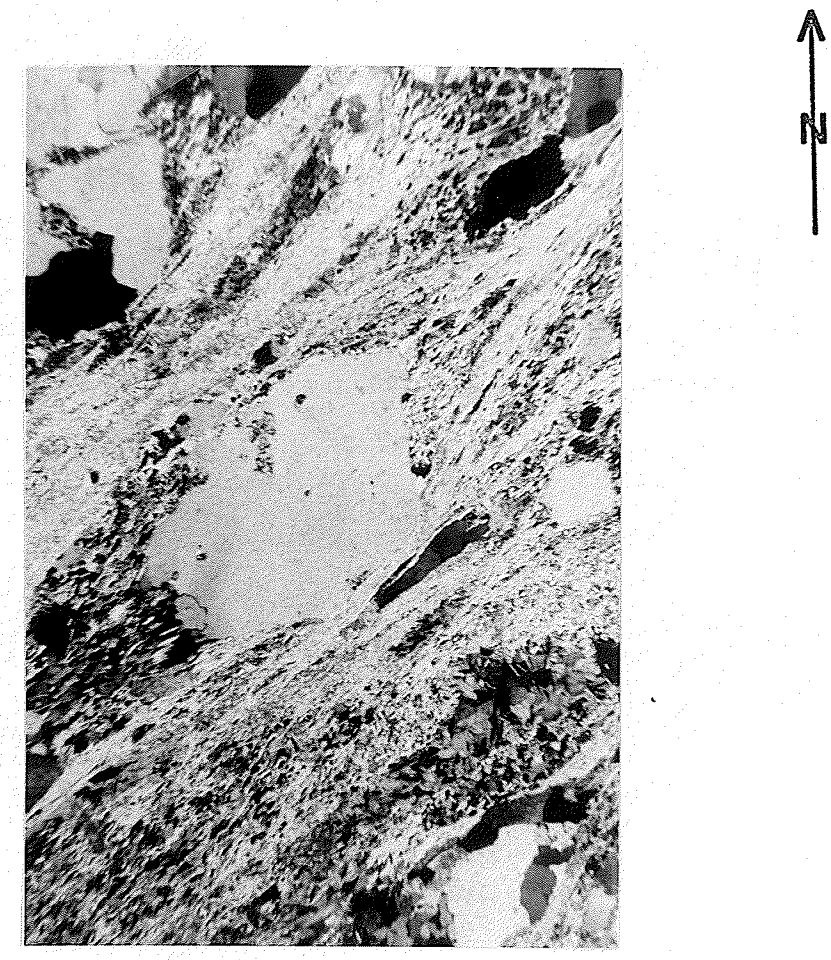
Horizontal and vertical thin sections of sheared granodiorite cut perpendicular to the regional foliation exhibit the same phenomena (Plates 14 and 15). The quartz aggregates are of similar dimensions in both views.

Proceeding away from the shear zones into more massive granodiorite, foliation development is not so

PLATE 13

Photomicrograph of a sheared granodiorite now classified as a blastomylonite (X40, X-nicols). Absence of strain shadows may indicate complete recrystallization of quartz. Foliation direction is N 65°E.

PLATE 14



Photomicrograph (X20, X-nicols) of sheared granodiorite. Cataclastic and recrystallization textures are common. View is horizontal and perpendicular to the regional foliation.

PLATE 15

Photomicrograph (X20, X-nicols) of sheared granodiorite. Same features shown as in PLATE 14. View is vertical and perpendicular to the regional foliation.

obvious due to the minor amount of sericite and biotite. Where there are tabular minerals there is a faint alignment of these minerals in the northeast direction (Plate 16). Quartz aggregates exhibit an interlocking texture. No dimensional orientation of the quartz grains is noted in the massive portions of the granodiorite; however, as the shear zones are approached, quartz aggregates become tabular and aligned in the S_1 direction.

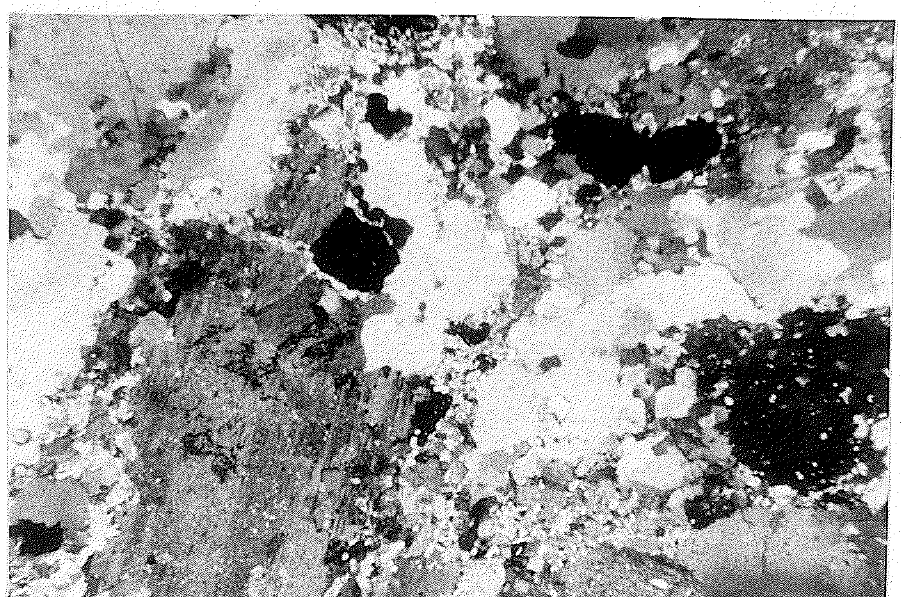
Relationship Between S_1, Ptygmatic Folds and Boudinage

Ptygmatic folding and boudinage within the study area are related to S_1 development. Ptygmatic folding of quartz veins is a common feature in the volcanic rocks and in shear zones in granodiorite (Plate 17). Boudinage features are restricted to the few layered tuffaceous units.

The attitude of the axial surface of the ptygmatically folded quartz veins is everywhere the same as the attitude of S_1. No consistent plunge of fold axis within one small sector of the area could be ascertained by measurements. This implies that the quartz veins had considerable variation in attitude prior to ptygmatic fold development. The limbs of the ptygmatic folds are parallel to S_1 and show boudinage effects.

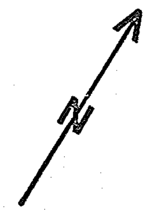
Ptygmatic folds are a good indicator of the relative susceptibility of the rock units to deformation and S_1 development (Kuenen, 1967). Ptygmatically folded quartz with the shortest wavelength and greatest amplitude are

PLATE 16



Photomicrograph (X20, X-nicols) of recrystallized granodiorite with interlocking and mosaic texture. Complete recrystallization at least along grain boundaries is inferred. View is horizontal with north toward top of photo.

PLATE 17



Photograph of a large quartz ptygma in a quartz sericite schist mylonite zone. Plane of photo is horizontal.

found in the highly schistose rocks while greater wavelengths and smaller amplitudes occur in the more massive less schistose rocks (Plate 18).

Boudinage in bedding is also related to S_1 development. Competent beds in a less competent matrix have resulted in boudinage bedding structures (Plate 19). The boudins are dimensionally orientated with their long and intermediate axes in the S_1 plane. Both ptygmatic folds and boudinage are consistent with compressive strain perpendicular to S_1 and extensive strain parallel to S_1.

Geometry of S_1

The regional foliation direction remains relatively constant throughout the study area. The strike is the same as the axial plane direction of the major fold in layering. The direction of the S_1 surface varies between N 50° E and N 80° E (Plate 20). The dip is usually vertical or steeply dipping to the northeast.

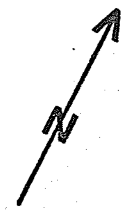
Mechanism of Formation and Style of Strain Forming S_1

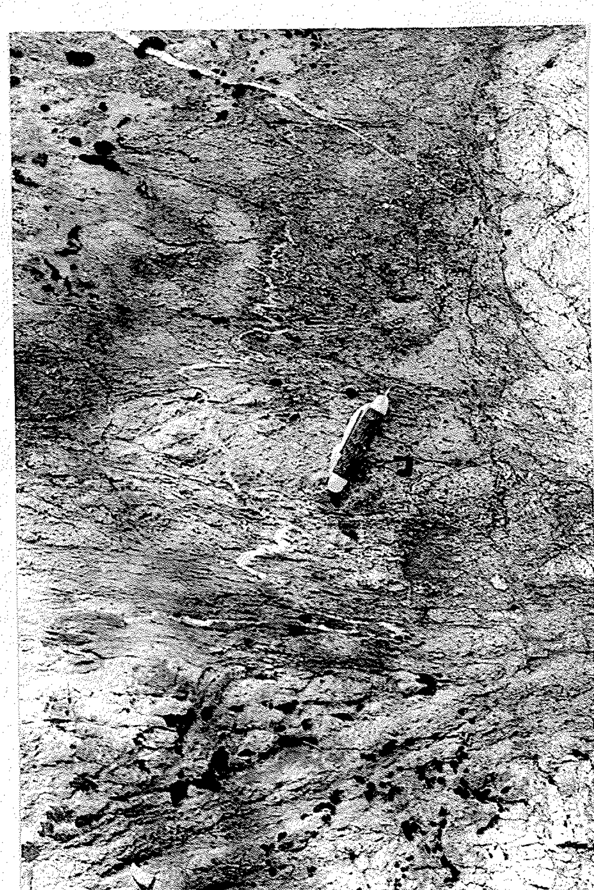
Style of Strain Forming S_1

The style or type of strain which led to the development of S_1 can be inferred from the character of rotational fabrics, ptygmatic folds, boudinage, and lensoid aggregates of minerals.

The ptygmatic folds and boudinage suggest a pure

PLATE 18



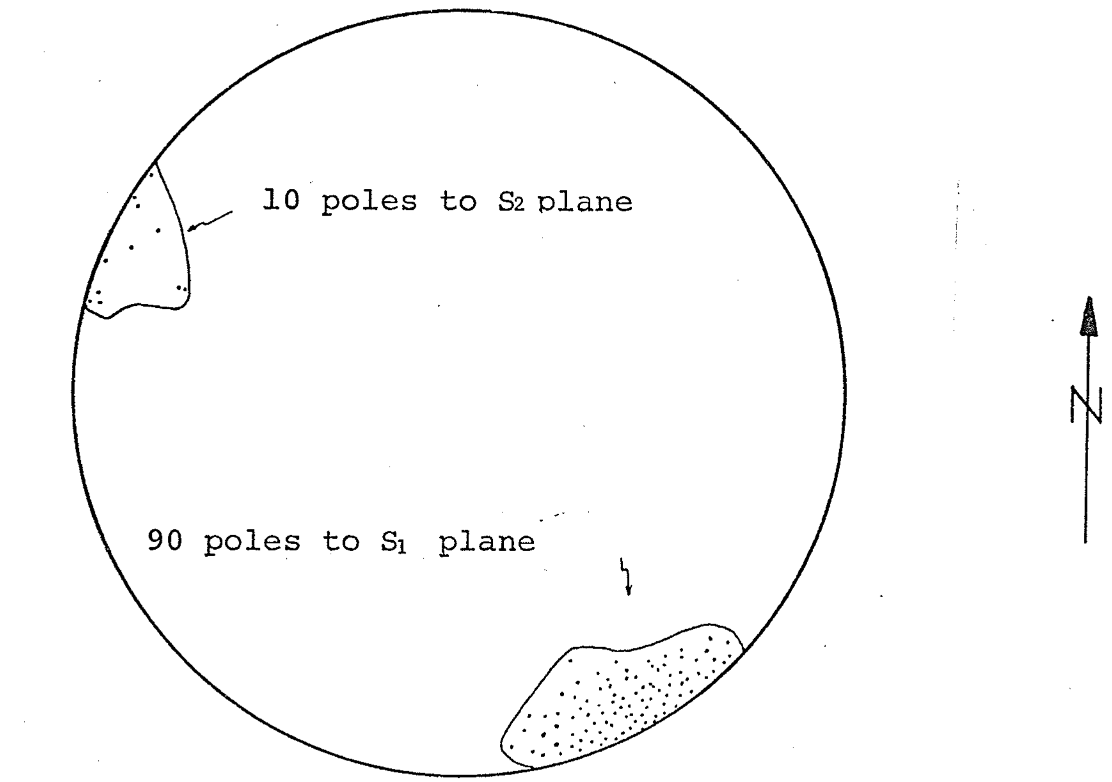


Photograph of granitic boudin in a quartz biotite plagioclase schist. Ptygmatically folded quartz vein passing through the schist and the granitic boudin has a shorter wavelength and greater amplitude in the schist. Plane of photo is horizontal.

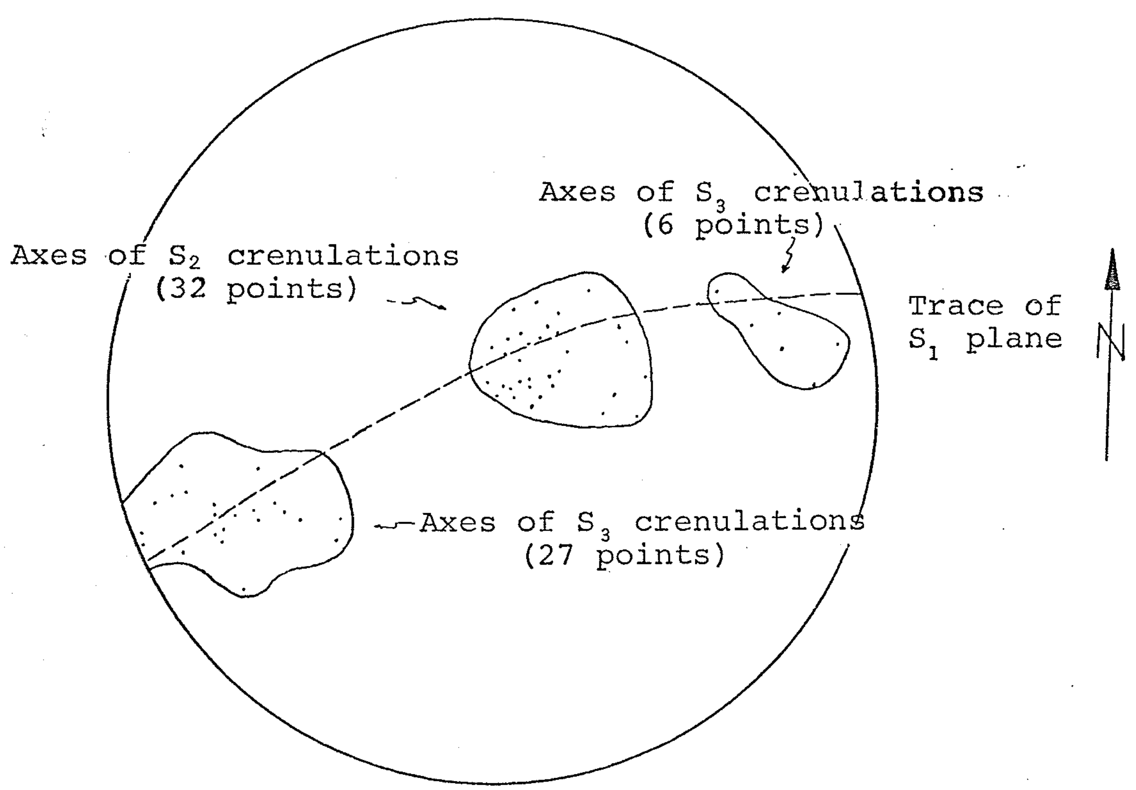
PLATE 19

Boudinage structures in a bedded tuff found on south limb of major fold. Plane of photo is vertical.

Plate 20



A. Poles to the S_1 and S_2 planes (Wulff net-lower hemisphere).



B. Orientation of S_2 and S_3 crenulations (Wulff net-lower hemisphere).

shear component of strain. Compressive strain has taken place in a direction perpendicular to the foliation (S_1) along with extensive strain parallel to S_1. Field observation of the orientation of elongated mineral aggregates, boudins and ptygmatic folds suggest that maximum extensive strain was close to vertical during the development of S_1. Rolled porphyroblasts and relict plagioclase phenocrysts suggest horizontal movement or slip on S_1. These data are contradicting and introduce the possibility that the fabric elements suggesting horizontal slip are related instead to the development of a later cleavage, S_2.

Mechanism Forming S_1

Textural relationships involving the planar alignment of tabular minerals, crushed ellipsoidal aggregates of quartz along foliation planes, the transition from a massive granodiorite to a blastomylonite and the general interlocking and recrystallized grains of quartz and feldspar, indicate that cataclastic flow attendant with recrystallization were the important mechanisms involved in the formation of S_1. These processes provide evidence that the S_1 surfaces were formed tectonically. Granulation and recrystallization have destroyed large feldspar grains in all rocks except the porphyritic pyroclastic unit (unit 1a). Large quartz grains generally have undergone a complete granulation and recrystallization, although some rigid quartz bodies have survived the deformation and retained their original form. The extreme case of cataclastic flow occurs within the shear zones of the granodiorite. Here, feldspars are completely destroyed. Along with the cataclastic flow process biotite and sericite were developed parallel to S_1.

Crenulation - Cleavage (S_2)

General Statement

Two sets of crenulation-cleavage occur within the study area. One set, S_2, strikes in a northerly direction and dips vertically. The S_2 cleavage is characterized by crenulations on S_1 which pitch to the northeast at a large angle on the S_1 plane. The other set, S_3, which is discussed in a later section, has an undetermined strike. The S_3 cleavage is characterized by crenulations on S_1 which are orientated close to the strike direction of S_1. The S_3 set of crenulations is found to be younger in age than the S_2 set.

Description of S_2

The S_2 crenulation-cleavage is found often in highly sheared schistose rocks which have a well developed foliation (S_1) and an abundance of tabular minerals. In these rocks, S_2 forms a closely spaced cleavage which trends north across the S_1 plane (Plate 20). This direction is uniform throughout the study area. The intersection of S_2

and S_1 is characterized by crenulations, the axes of which pitch at a high angle to the northeast in the S_1 plane (Plate 21).

The development of crenulations which lead to S_2 depends on the content of micaceous minerals within the rock. Where quartz and feldspar content is greater than 50%, microfolding is not well developed.

Where the crenulations are present quartz grains and veinlets are often kinked (Plate 22). Quartz usually does not exhibit a dimensional orientation in the direction of S_2. However, some vein quartz in sericitic metavolcanic rocks is dimensionally orientated with the long and intermediate axis parallel to S_2 (Plate 23).

Fine layering parallel to the S_1 plane also undergoes a crenulation development. A refraction phenomena occurs when the resulting S_2 cleavage passes from dark chloritic layers into sericitic layers (Plate 24). Larger scale kinks in the S_1 plane are present also (Plates 25 and 26).

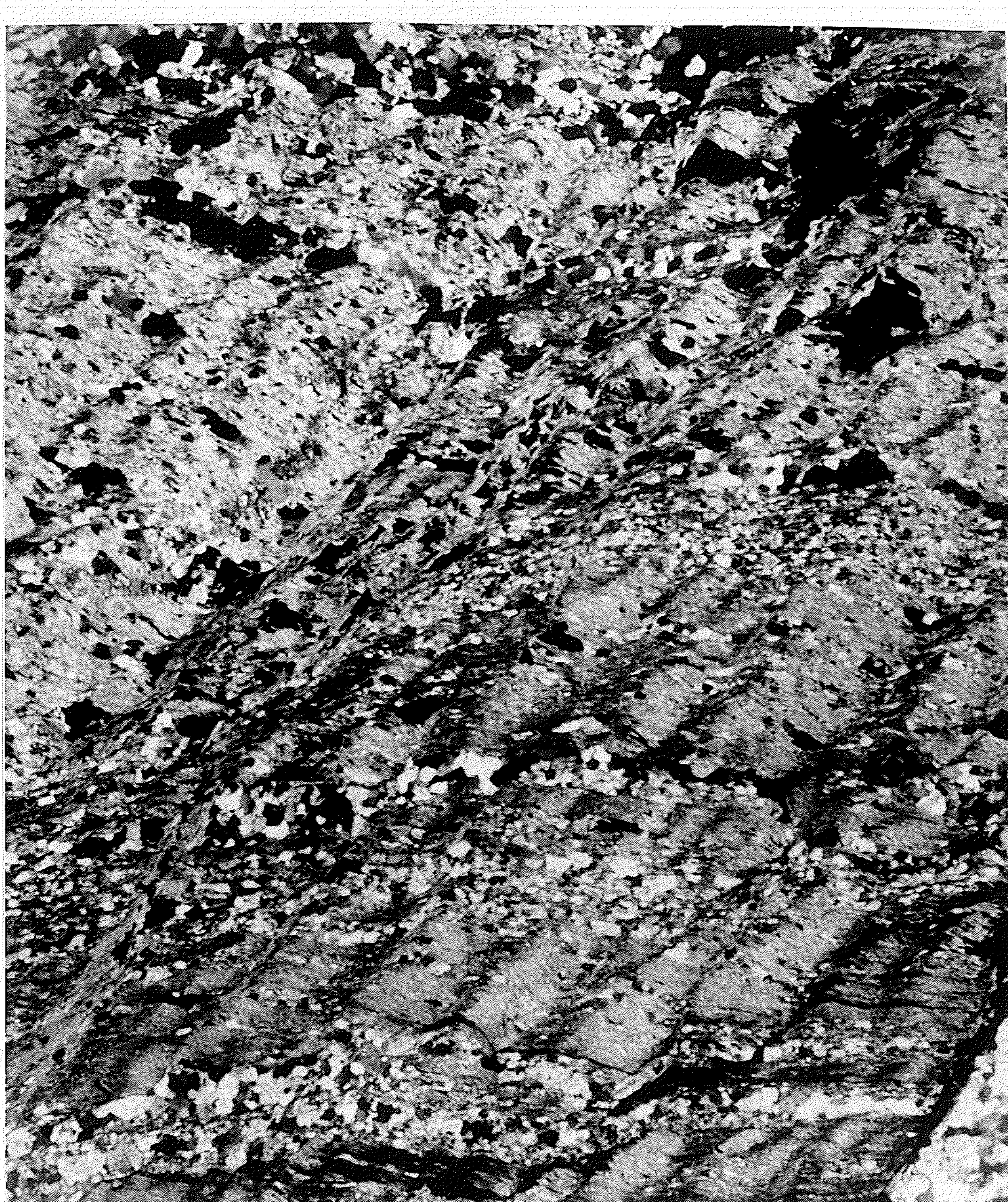
Geometry of S_2

The S_2 crenulation-cleavage generally strikes from true north to N 30°E and dips steeply to the northeast. It cuts across the S_1 direction at a fairly constant angle throughout the area. The axes of the S_2 crenulations are plotted in Plate 20.

PLATE 21

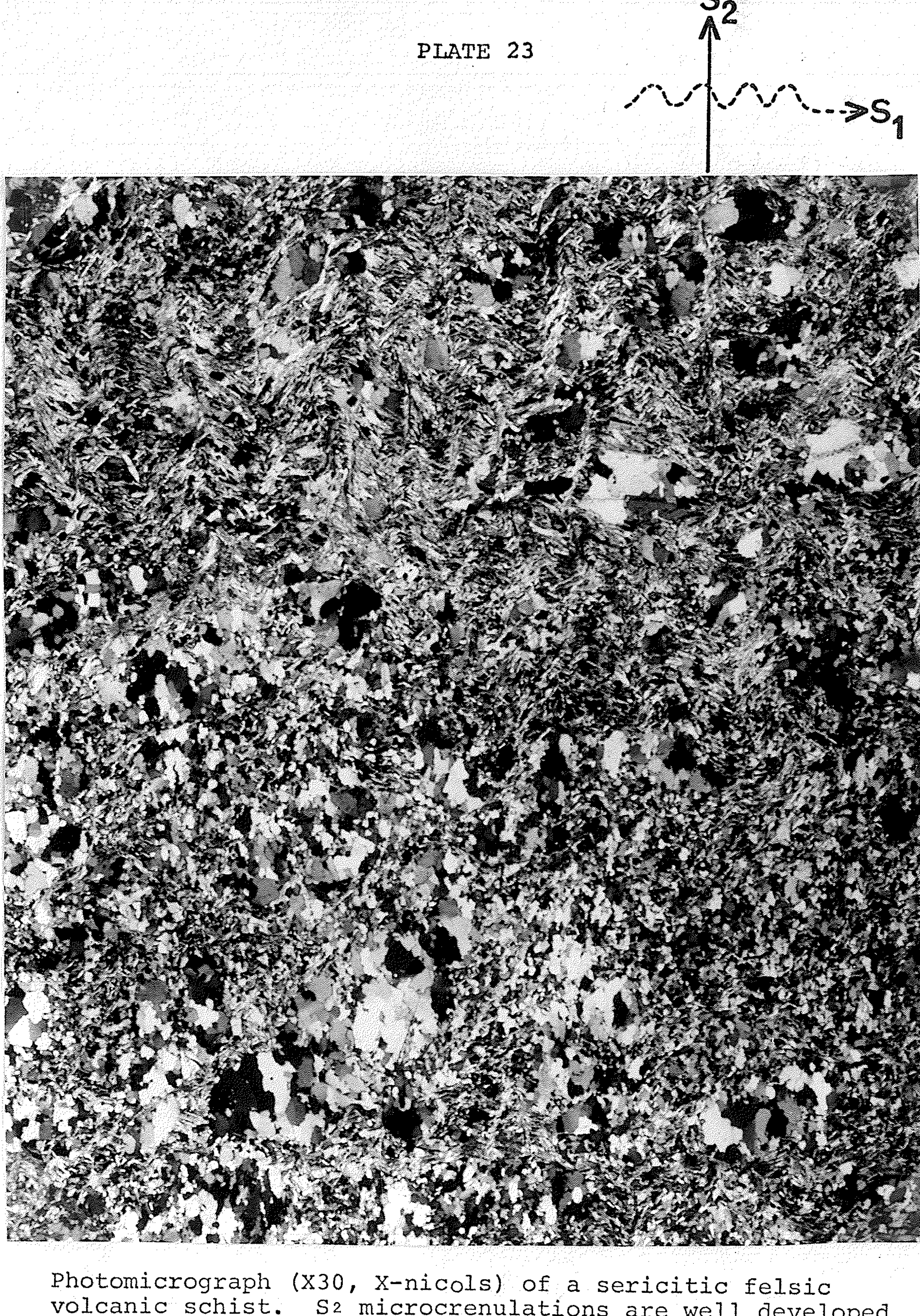
Photograph of crenulation-cleavage (S_2). Rock is a sheared granodiorite. Plane of photo is horizontal.

PLATE 22



Photomicrograph (X-nicols) of a sericitic felsic meta-volcanic rock. Asymmetric crenulations develop the crenulation-cleavage S_2. View is horizontal and north is toward top of photo.

PLATE 23

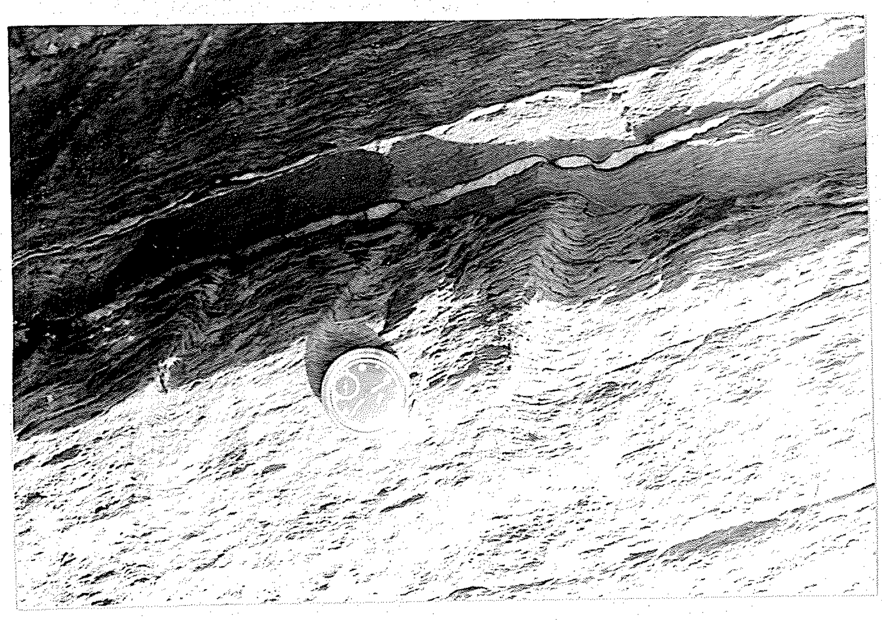


Photomicrograph (X30, X-nicols) of a sericitic felsic volcanic schist. S_2 microcrenulations are well developed where quartz is not so abundant. In the quartz rich zones a dimensional recrystallization of quartz in the S_2 direction results. North is toward top of photo.

PLATE 24

Photomicrograph (X80, X-nicols) demonstrating refraction phenomenon as asymmetric S_2 crenulations pass from a dark chloritic layer to a sericitic layer. Rock is a quartz-sericite-chlorite schist. View is horizontal.

PLATE 25



Photograph of volcanic schist. The S_2 crenulations are present on the near vertical face (S_1). Plane of photo is horizontal.

PLATE 26

Photograph exhibiting same phenomenon as PLATE 25.
The S_2 crenulation-cleavage is well developed.
Plane of photo is horizontal.

Asymmetry of S_2 Crenulations

S_2 crenulations have a definite S asymmetry looking down the crenulation axes. The movement producing the microfolds was in a horizontal direction, suggesting that the rotational fabrics discussed in the mechanism of deformation producing S_1 may be a consequence of the same S_2 movements.

Mechanism of Formation of S_2

The folding of S_1 to produce crenulations resulting in the development of S_2 indicates that S_2 is a tectonically formed cleavage. S_1 was the active plane of movement. Rotational movements involving flexural slip movement on S_1 resulted in microcrenulations at regularly spaced intervals, and as a consequence, crenulation-cleavage was formed.

Crenulation-cleavage (S_3)

General Statement

The occurrence of a third cleavage, S_3, is rare. This cleavage has an origin similar to that of S_2 and is revealed by the presence of near horizontally pitching crenulations on S_1.

Description of S_3

The S_3 cleavage, although not as perfectly developed as the S_2 cleavage, has many of the same characteristics and appears to have developed in a similar fashion. Microcrenulations on S_1 have led to the reorientation of S_1 to produce an imperfect crenulation-cleavage. Some rocks are characterized by both S_2 and S_3 cleavages (Plates 27 and 28) in which case interference of microcrenulations occurs (Plate 29).

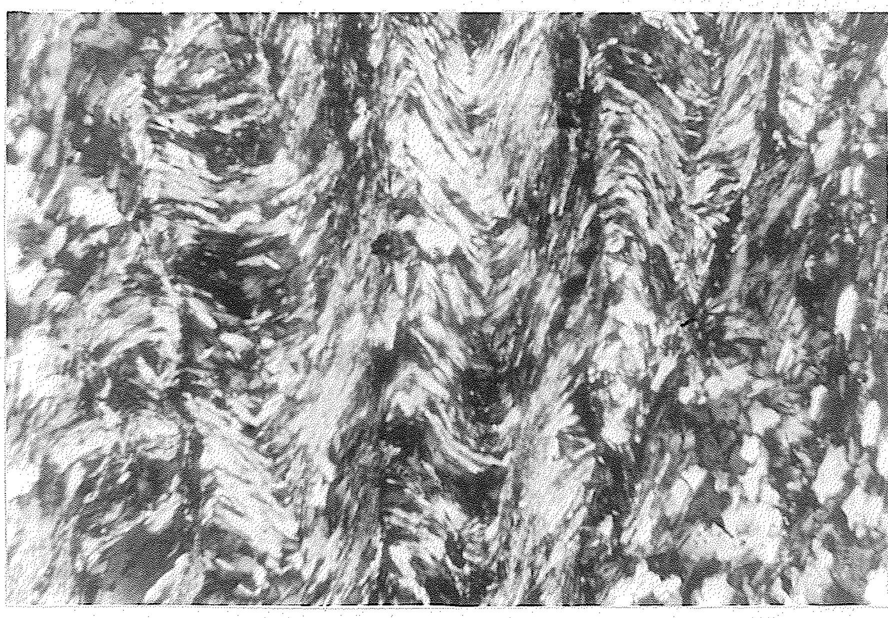
Geometry and Asymmetry of S

The orientation of the S_3 cleavage is difficult to determine because of its poor development. Analysis of thin sections reveals that the dip is close to horizontal. Visible S_3 crenulations on the S_1 plane have a shallow plunge in contrast to the steep plunge of S_2 crenulations (Plate 20). No consistent symmetry or asymmetry of S_3 crenulations could be ascertained.

Mechanism of Formation of S_3

The S_3 cleavage developed in the same fashion as the S_2 cleavage. The character of the microfolds again suggest that S_3 is a crenulation-cleavage resulting from flexural slip movements on S_1. In contrast to the horizontal slip on S_1 required to produce S_2 crenulations the slip which resulted in S_3 crenulations was close to vertical; consequently the two crenulations are of different ages. The relative age can be ascertained in rocks containing

PLATE 27



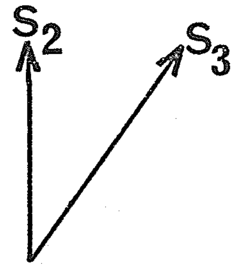
Photomicrograph (X20, X-nicols) of crenulation-cleavage S_2. View is horizontal.

PLATE 28

Photomicrograph (X20, X-nicols) showing imperfectly developed S_3 cleavage in felsic metavolcanic schist. View is vertical cut perpendicular to S_1 plane. Same specimen as PLATE 27.

both (Plate 29); where S_3 crenulations are observed to produce a reorientation of S_2 crenulations.

PLATE 29



Photomicrograph (X15) showing two deformational events in a metavolcanic schist. S_3 crenulations crosscut S_2 crenulations. Plane of photo is a vertical view on the S_1 plane.

CHAPTER IV

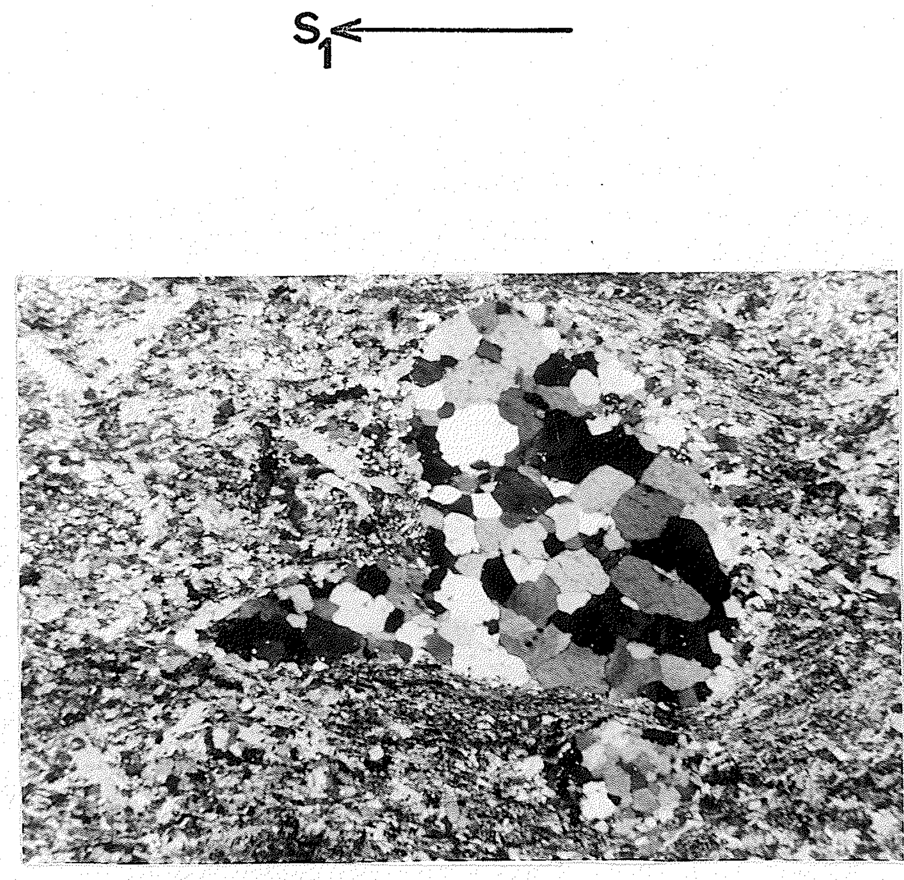
MINOR STRUCTURAL FEATURES

Quartz Lenses

Lenses of white sugary quartz up to one-half inch in length are present in the biotitic felsic metavolcanic rocks. These lenses are quite different from the clear blue quartz of phenocrysts and aggregates of quartz in mylonite zones. In thin section they are composed of a fine grained mosaic of quartz and may represent amydaloidal filling in volcanic rocks.

The quartz lenses tend to show a preferred orientation in thin section. In the vertical view cut perpendicular to S_1, the lenses are orientated with their long dimension along the S_1 plane. In the horizontal view perpendicular to S_1 the preferred orientation of the long dimension along the S_1 plane. In the horizontal view perpendicular to S_1 the preferred orientation of the long dimension is usually at an angle to the direction of S_1. The angle between S_1 and the long dimension of the quartz lenses in the horizontal view near the nose of the major fold in bedding is about 60 (Plate 30). Farther out on the limbs of the fold this angle diminishes and the quartz lenses are more elongate or

PLATE 30



Photomicrograph (X20, X-nicols) of a quartz lens in a metavolcanic schist. The main dimensional orientation of the quartz lense is 60° off the S_1 direction. A wedge of quartz does follow the S_1 direction. View is horizontal.

stretched in the horizontal view (Plate 31).

An insight into the process forming the present orientation of the quartz lenses is the presence of sigmoidal-shaped quartz lenses near the nose of the major fold (Plate 32). One whole lens , after being extended, rolled, and recrystallized has separated into two sigmoidal-shaped smaller lenses connected by a thin quartz trail. The sigmoidal lense appears to signify a horizontal movement on S_1. This movement could be attendant with development of S_1 or with crenulation of S_1 to produce S_2 .

Jointing

The metavolcanic rocks generally have a regular system of joints while the granodiorite has an irregular joint system.

Two main joint sets are present in the metavolcanic rocks. The first set is near horizontal while the second set strikes between 160° and 190° and dips almost vertically. En echelon tension joints are present also but their occurrence is limited. Usually they are associated with the second set of joints (Plate 33).

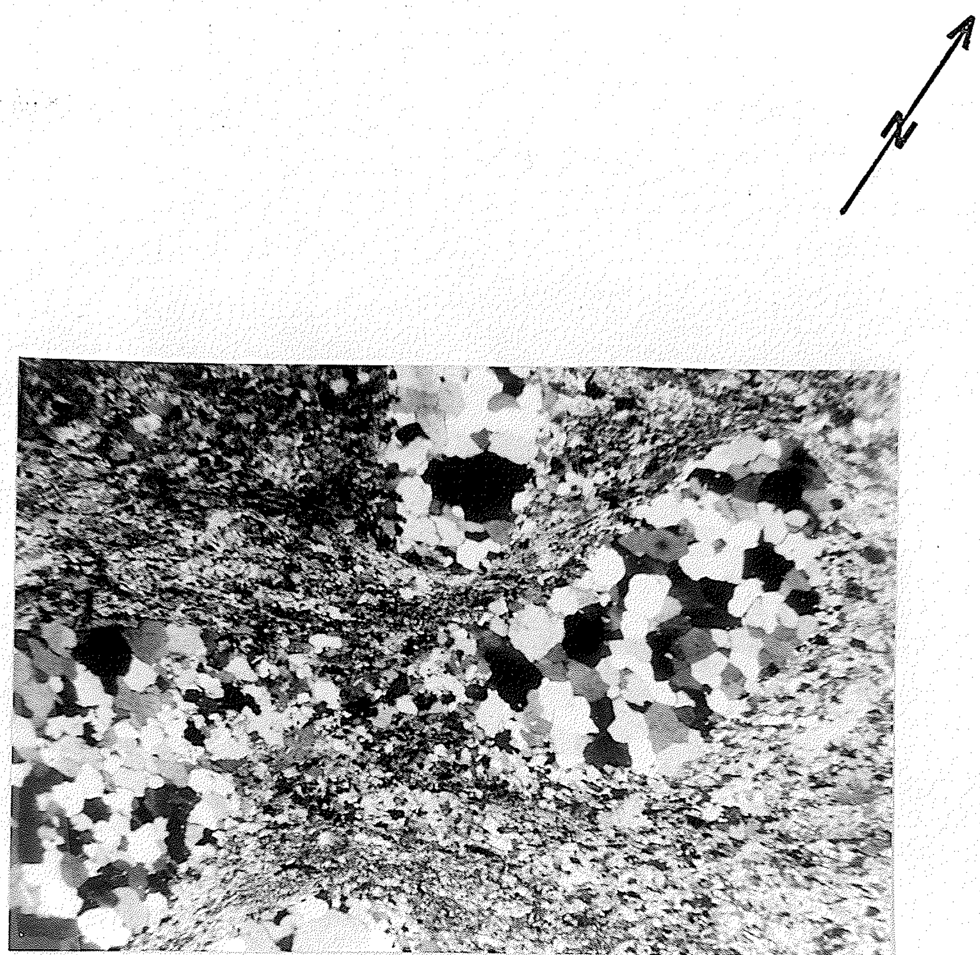
The granodiorite intrusion has undergone intense jointing and fracturing. Joints in the granodiorite have variable strikes but two main joint directions are sub-parallel to the main joint sets in the metavolcanic rocks.

The joint systems cut and postdate the development

PLATE 31

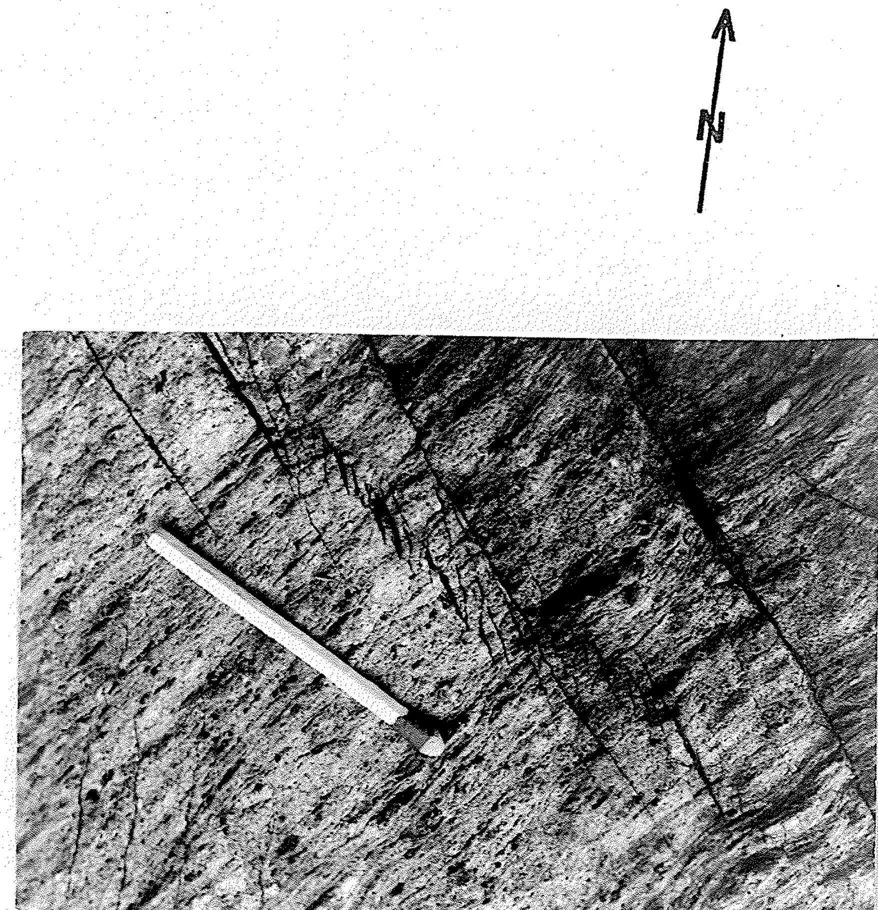
Photomicrograph (X20, X-nicols) of quartz lenses in a metavolcanic schist. The dimensional orientation of the quartz lenses is 15° off the regional foliation direction. The lenses are more elongate than those found near the nose of the major fold. View is horizontal.

PLATE 32



Photomicrograph (X20, X-nicols) showing two sigmoidally-shaped quartz lenses connected by a thin quartz trail. The two lenses were broken apart by extension, rolling, and then recrystallized. View is horizontal.

PLATE 33



Photograph of en echelon tension joints. Plane of photo is horizontal.

of S_1. However, their relationship to the development of cleavages S_2 and S_3 is not clear. One main joint direction is subparallel to S_2 and its development may be related to that of S_2.

CHAPTER V

STRUCTURAL AND METAMORPHIC SYNTHESIS

The study area shows evidence of three major tectonic planes, S_1, S_2, and S_3. This leads to the recognition of three tectonic events, D_1, D_2, D_3. However, there is a possibility that the D_1 and D_2 events could be linked and represent the same phase of deformation.

The oldest recognizable tectonic event, D_1, resulted in the development of S_1, a tectonic foliation produced by pure shear and possibly simple shear movements. The development of S_1 was attendant with the development of the present mineral assemblages, the alignment of tabular minerals, and the granulation extension and recrystallization effects. Cataclastic flow and recrystallization phenomena were predominant; the metamorphism was dynamothermal in character (Turner and Verhoogen, 1960). The long and intermediate axes of extensive strain lay in S_1, the direction of greatest compressive strain was perpendicular to the S_1 plane, and the direction of greatest extensive strain was close to vertical.

The S_2 tectonic plane is a crenulation-cleavage developed by a flexural slip mechanism on S_1. Movement producing the crenulations is interpreted to have been horizontal, as opposed to the near vertical direction of maximum extensive strain in S_1 development. S_2 is thought to be unrelated to the development of S_1.

S_3 is definitely a later tectonic plane. This is indicated by cross folding (Plate 29) and the different movement direction during D_3. This direction is perpendicular to the crenulation axes and therefore horizontal.

The intrusion of the granodiorite and diorite pre-date the development of S_1, because both rock types exhibit the same foliation (S_1). The effects of the granodiorite and diorite intrusions upon the rocks of the area are unknown.

The age of the major folding of the S_0 planes in the area poses a problem which at present is unresolved. One possibility is that the fold is produced by the same mechanism which developed S_1. The fold would then be a similar fold (Ramsay, 1967) where bedding has no effect on slip surfaces. Evidence for this is the fact that the strike of S_1 is coincident with the strike of the axial plane of the fold. This evidence, while suggestive, is not conclusive. The fold must be considered therefore as either pre- or syn- S_1 development.

CHAPTER VI

SUMMARY

This structural study of part of the Birch Lake - Uchi Lake metavolcanic-metasedimentary belt in Northwestern Ontario has led to the following conclusions:

(1) Three major tectonic planes have been identified. These are the S_1, S_2 and S_3 planes. This leads to recognition of three deformational events although S_1 and S_2 could belong to the same phase of deformation.

(2) The oldest recognizable event produced the penetrative regional foliation (S_1) by dynamothermal metamorphism. Operative processes were cataclastic flow and recrystallization. A pure shear type of strain has been identified as characteristic of this event. The direction of maximum extensive strain appears to be near vertical. A simple shear strain is also present, however, it is likely related to a later deformational event. The resulting foliation (S_1) has a constant northeast strike direction and dips vertically or steeply northeast.

(3) The next recognizble event led to the development of a crenulation-cleavage which crosscuts the S_1 plane. The mechanism of formation was flexural slip on an active S_1 plane. Micro-crenulations on S_1 were developed and tabular minerals were asymmetrically kinked. Movement was in a horizontal direction and evidence suggests that S_2 is a distinct deformational event unrelated to the development of S_1. The S_2 cleavage strikes between N 10° W and N 20° E and also dips vertically.

(4) The youngest recognizable tectonic event led to the development of a second crenulation-cleavage (S_3). Both S_1 and S_2 are crosscut by S_3. The S_3 cleavage also formed as a result of a flexural slip mechanism on S_1. The exact attitudes of the S_3 planes are unknown but they are close to horizontal.

(5) All rocks in the area predated the development of S_1.

(6) The whole assemblage of rocks was metamorphosed to the upper greenschist facies at the time of S_1 development. The events leading to S_2 and S_3 deformed already existing tabular minerals.

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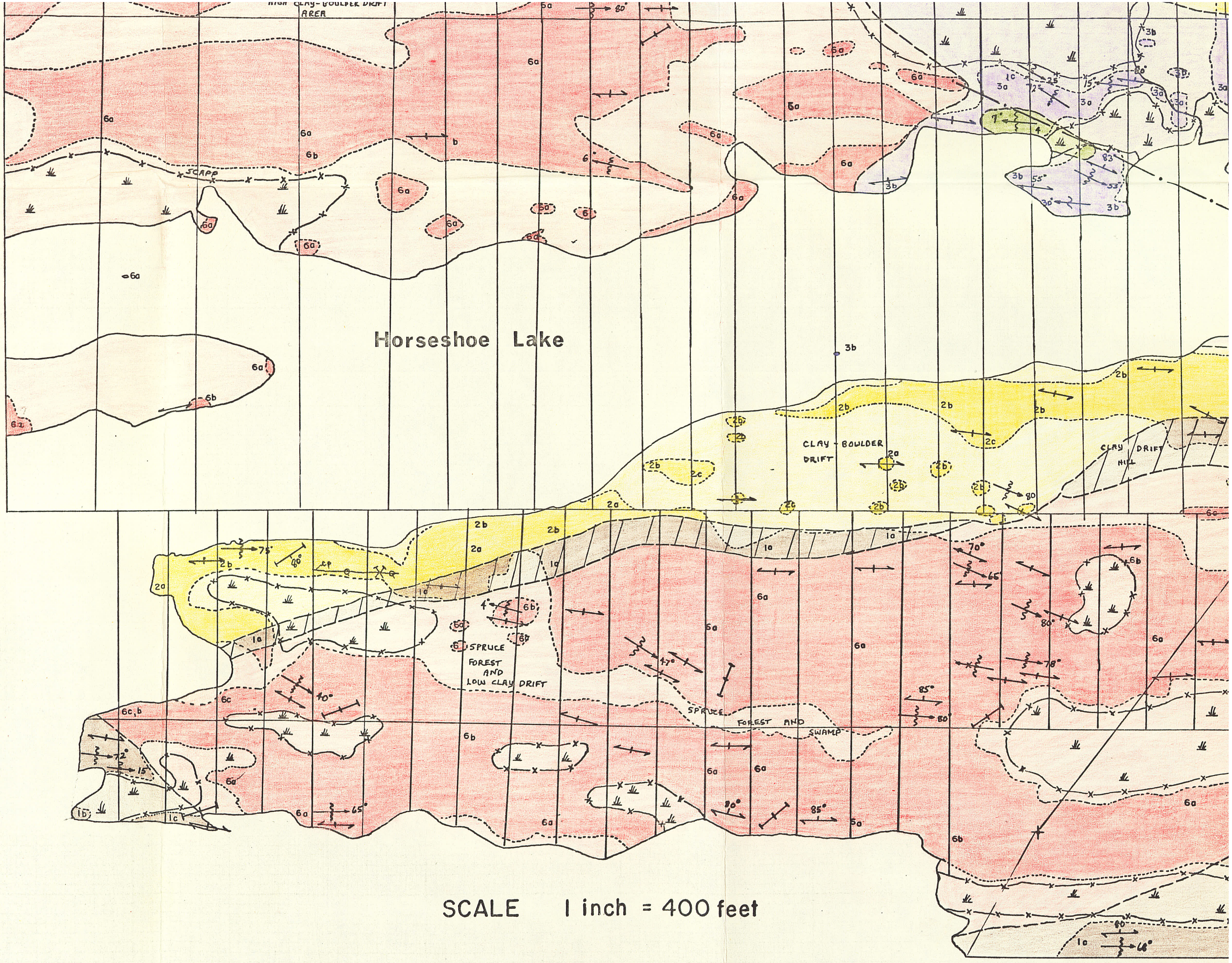
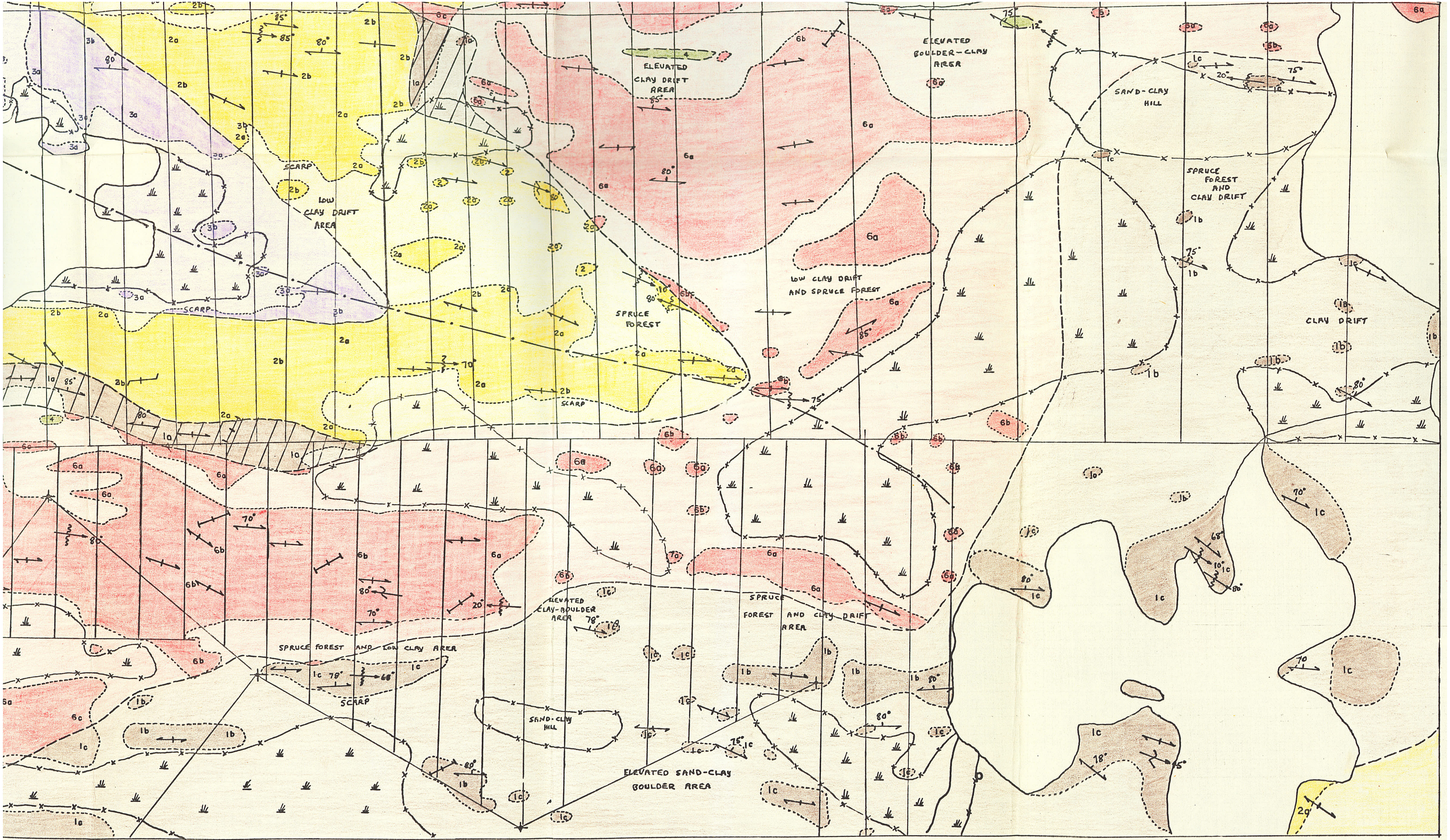
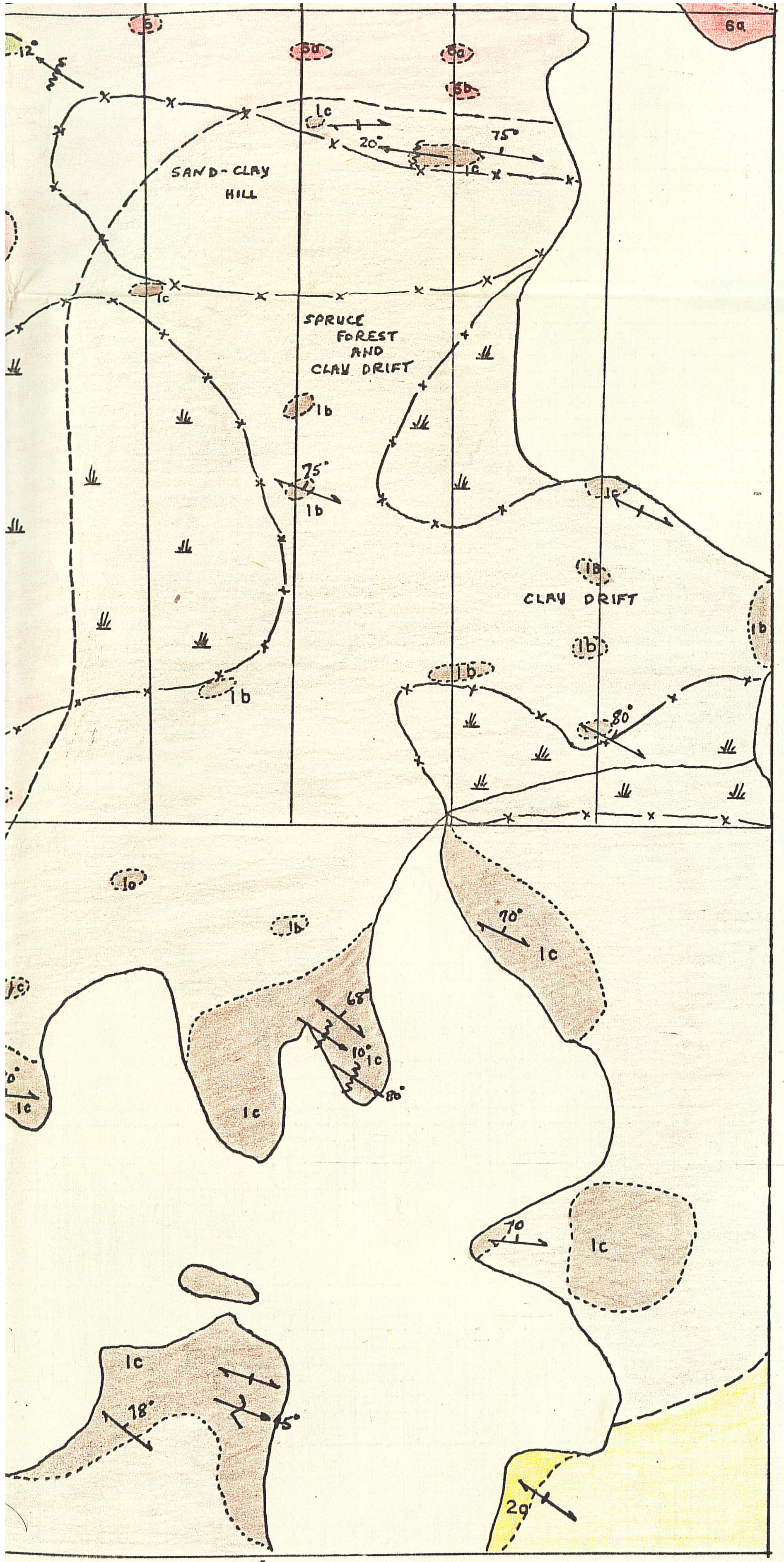


SCALE 1 inch = 400 feet



by V. J. Sopuck

PLATE 3



by V. J. Sopuck

4 Mafic flows

3 Porphyritic Biotitic Felsic Metavolcanic Rocks
- 3a Massive flows and (or) tuffs
- 3b Spherulitic flows and (or) tuffs
- 3c Tuffs

2 Biotitic Felsic Metavolcanic Rocks
- 2a Massive flows and (or) tuffs
- 2b Spherulitic flows and (or) tuffs
- 2c Tuffs

1 Sericitic Felsic Metavolcanic Rocks
- 1a Porphyritic pyroclastic
- 1b Massive flows and (or) tuffs
- 1c Sheared flows and (or) tuffs

1a Quartz-feldspar porphyry

SYMBOLS

Outcrop areas

Topographic boundary

Schistosity (vertical, inclined)

Pitches of crenulations on schistosity planes (vertical, horizontal, inclined)

Crenulation-cleavage (vertical, inclined)

Axial plane trace of ptygmatic folds (vertical and inclined plunge of fold axis)

Bedding (vertical and inclined)

Geological contact

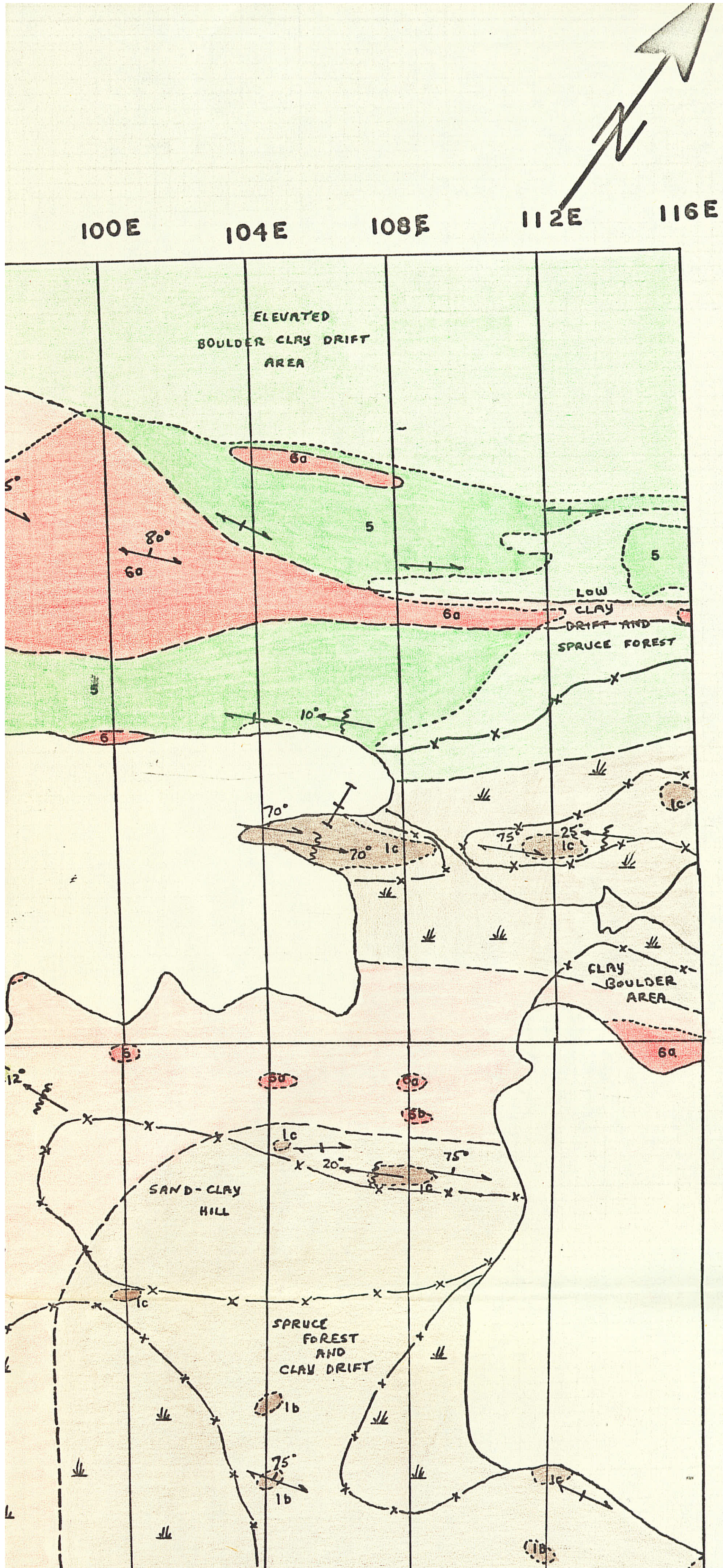
Axial plane trace

Swamp and spruce forest

Claim post

Trench

cp Chalcopyrite showing



LEGEND

CENOZOIC

PLEISTOCENE — Clay, till, sand, boulders

UNCONFORMITY

PRECAMBRIAN

6 — Felsic Intrusive Rocks
- 6a Massive granodiorite
- 6b Sheared granodiorite (quartz sericite schist)
- 6c Contact porphyry

INTRUSIVE CONTACT

5 — Mafic Intrusive Rocks
- 5 Diorite

INTRUSIVE CONTACT

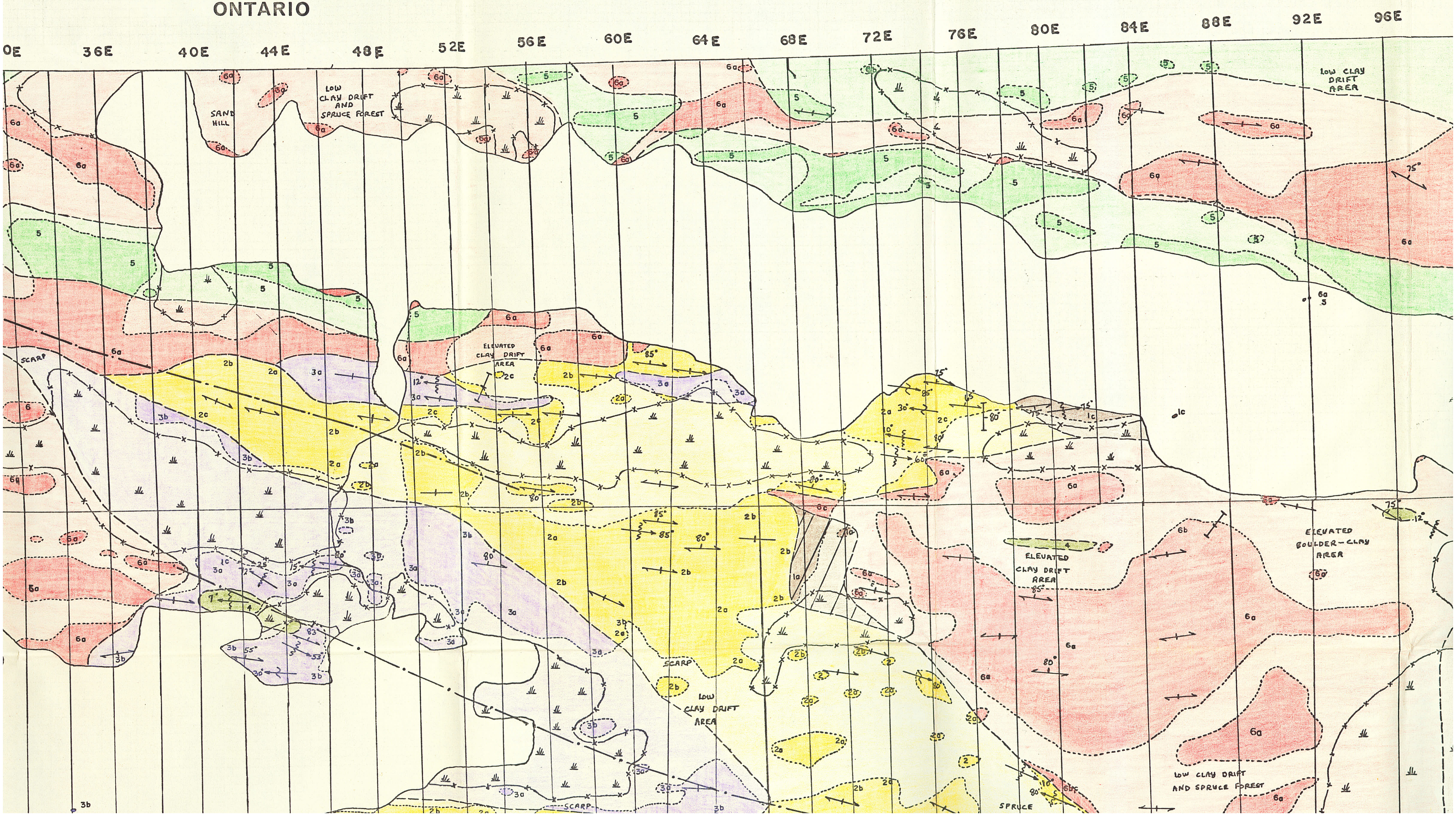
4 — Mafic Metavolcanic Rocks
- 4 Mafic flows

3 — Porphyritic Biotitic Felsic Metavolcanic Rocks
- 3a Massive flows and (or) tuffs
- 3b Spherulitic flows and (or) tuffs
- 3c Tuffs

2 — Biotitic Felsic Metavolcanic Rocks
- 2a Massive flows and (or) tuffs
- 2b Spherulitic flows and (or) tuffs
- 2c Tuffs

1 — Sericitic Felsic Metavolcanic Rocks
- 1a Porphyritic pyroclastic
- 1b Massive flows and (or) tuffs

GEOLOGY OF HORSESHOE LAKE AREA
MITCHELL TOWNSHIP
ONTARIO



GEOLOGY OF HORSESHOE LAKE
MITCHELL TOWNSHIP
ONTARIO