

Structural Geology
of
Tustin and Bridges Townships
District of Kenora
Northwestern Ontario

A Thesis

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MAPS - (Back Pocket)

- MAP A. General geology of Tustin and Bridges Townships,
Scale 1" = 1/2 mile.
- MAP B. Structural trends from airphoto interpretation,
Tustin-Bridges area.

Abstract

The consolidated rocks of the Tustin-Bridges area are Precambrian in age. A thin mantle of Pleistocene and recent deposits covers about 60% of the area.

Volcanic and sedimentary rocks, regionally metamorphosed to the almandine amphibolite facies and intruded by sills, dikes, and irregular bodies of felsic, mafic, and ultramafic rocks, form an east-west trending belt that varies from 100 feet to 4 miles in width and dips steeply north. Rocks of the English River belt are in sharp intrusive contact with the north limit of the belt. A pluton and a complex batholith border the belt along its south limit; the contacts are migmatitic.

Four periods of deformation have been recognized within the metavolcanic-metasedimentary belt. Structures identified with the first deformational event are mainly obliterated by later structures and there is still some question as to the existence of this event. The second deformational event is characterized by the development of foliation and lineations. These structures were re-oriented, in the south part of the metavolcanic-metasedimentary belt, as a result of the third period of deformation. The re-orientation resulted in a concentric fold in the foliation, conical in form. The fourth period of deformation is characterized by brittle fracture in pegmatite bodies which were intruded contemporaneous with the previous

period of folding of the foliation.

Insufficient evidence precludes a kinematic interpretation of the first and fourth deformational events. The main strain mechanism during the second deformational event was cataclastic slip and recrystallization, and it is interpreted to be the result of the vertical emplacement of the English River belt by either intrusion or faulting. The operative mechanism during the third deformational event is one of flexural folding on foliation and is interpreted to be the result of the intrusion of either the Feist Lake pluton or the younger phases in the Crabclaw Lake batholith.

CHAPTER I

INTRODUCTION

GENERAL STATEMENT

The main objective of this investigation is to document and interpret the structural geology of the Tustin-Bridges area in Northwestern Ontario. The study encompasses the character and geometry of fabric elements on all scales, microscopic, mesoscopic and macroscopic. Collectively, these elements provide a record of the deformational history of the greenstone belt and form the basis for interpretation of the intrusive history.

LOCATION

The townships of Tustin and Bridges are located approximately 40 miles east of Kenora, Ontario. The Trans-Canada Highway, the main lines of the C.P.R., the Trans-Canada pipeline and the Hydro Electric transmission line pass through the area. Figure 1 shows the location of the map-area.

PREVIOUS WORK

A geological map of the Lake of the Woods area by Alexander Bell, published by the Geological Survey of Canada in 1881, shows a small belt of Huronian rocks in the vicinity of the map-area. The metavolcanic-metasedimentary rocks of this area have

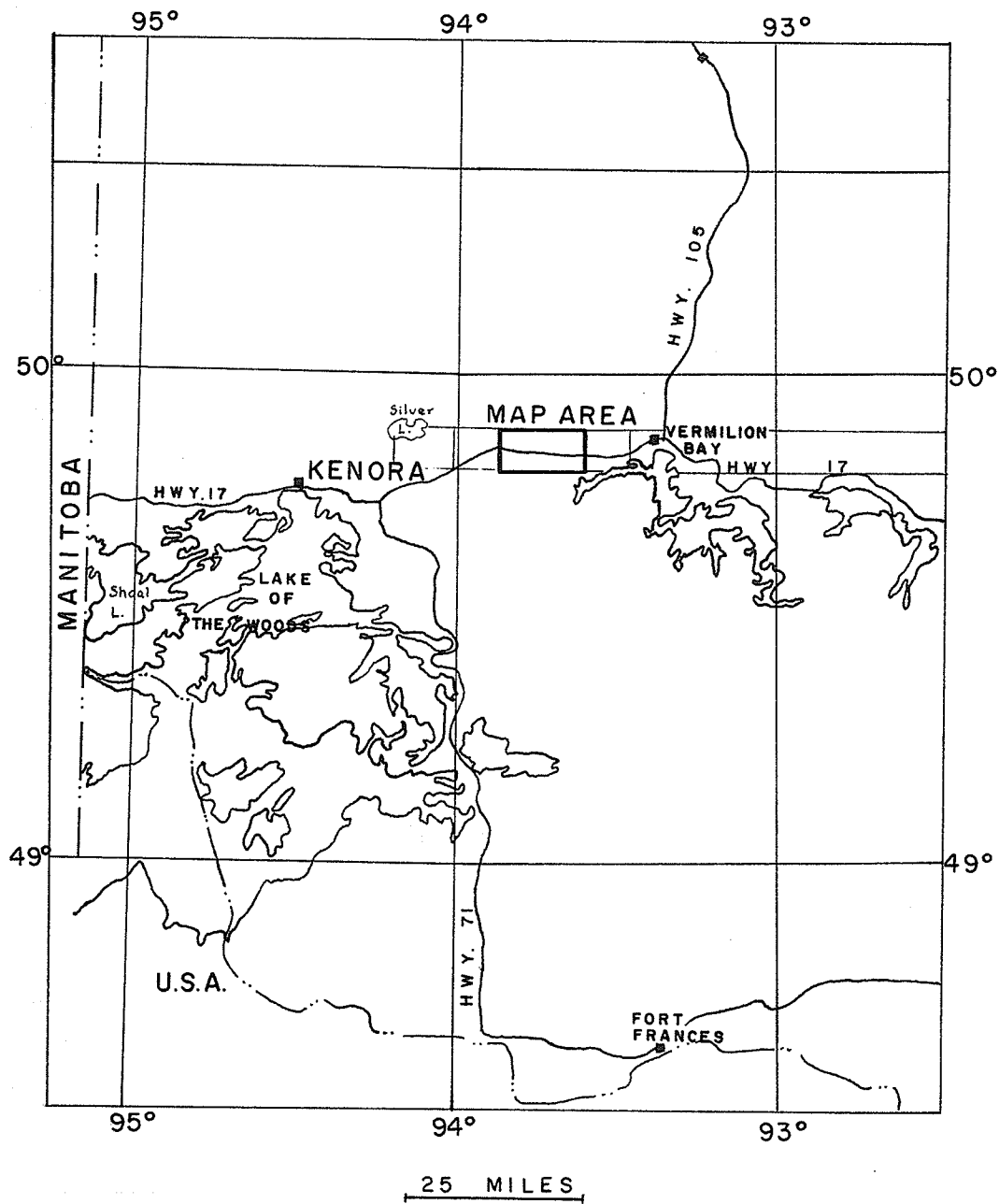


Figure 1 Key map showing the location of the map-area.

Scale - 25 miles to the inch.

been shown to be more extensive on the Kenora-Fort Frances Compilation Sheet, number 2115, published by the Ontario Department of Mines¹ in 1967.

FIELD WORK

The mapping project, which was conducted under the auspices of the Ontario Department of Mines, covered the townships of MacNicol, Tustin, Bridges and Docker. MacNicol and Tustin Townships were mapped during the 1967 field season and Bridges and Docker Townships were mapped during the 1968 field season.

Mapping was carried out by pace-and-compass traverses spaced at approximately one-quarter mile intervals. Shoreline mapping of major lakes supplemented the traverse survey. Topographic control was provided by vertical air photos on a scale of one-quarter mile to the inch.

ACKNOWLEDGEMENTS

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During the 1967 season, J. Power, J. Morin, M. Steeves and A. Higgins assisted in field work and during the 1968 season B. Stutsky, A. Garson, G. Rivers and N. Duke assisted in field work. Mr. Stutsky and Mr. Power worked independently and capably mapped about one-half of the area.

¹

Name changed to Ontario Department of Mines and Northern Affairs.

The author is also indebted to the Ontario Department of Mines for providing the financial assistance which made this study possible.

CHAPTER II

GENERAL GEOLOGY

INTRODUCTION

The consolidated rocks of the Tustin-Bridges area are of Precambrian age. Pleistocene clays, sands, and gravels form a thin cover over much of the bedrock.

The regional geologic setting of the area is portrayed best on map 2115, the Kenora-Fort Frances Compilation Sheet, published by the Ontario Department of Mines in 1967. The metavolcanic-metasedimentary-metagabbroic assemblage forms an east-trending belt of rocks that is bordered by a composite granitic batholith to the south and the English River belt to the north. (Map A and Map B, back pocket). The English River belt is a name given to one of the three structural subprovinces of the western part of the Superior province by C. H. Stockwell (1964, p. 1). The belt of metasedimentary and metavolcanic rocks varies in width from 100 feet to 4 miles. A reconnaissance survey has extended this belt east from Docker Township for 15 miles and westward to Silver Lake where it presumably joins with the major "greenstone" belt of the Kenora area.

The metamorphosed volcanic rocks consist mainly of mafic flows and intermediate pyroclastic rocks. These are interlayered with metamorphosed clastic sedimentary rocks.

Numerous dikes, sills and irregular bodies of felsic, mafic and ultramafic rocks intrude the metamorphic rocks.

Table I outlines the sequence of formations in the area. The petrology of the formations, their distribution and stratigraphic relationships, are presented in this chapter with sufficient detail necessary for structural interpretation. A more detailed account will occur in a forthcoming geological report to be published by the Ontario Department of Mines, (Pryslak, in press).

METAVOLCANIC-METASEDIMENTARY ASSEMBLAGE

Metavolcanic Rocks

The metavolcanic rocks form approximately 75% of the metavolcanic-metasedimentary sequence and are sub-divided into mafic metavolcanic and intermediate metavolcanic rocks.

(a) Mafic Metavolcanic Rocks

Mafic metavolcanic rocks occur mainly in the northern part of the metamorphic belt and are interlayered with metamorphosed clastic sedimentary and pyroclastic rocks.

The mafic metavolcanic rocks were derived predominantly from flows and minor tuffs of basaltic and andesitic composition and have been regionally metamorphosed to the almandine amphibolite facies. Amygdaloidal and pillow structures are generally

TABLE I - TABLE OF FORMATIONS

CENOZOIC

RECENT AND

PLEISTOCENE: clay, sand, and gravel.

UNCONFORMITY

PRECAMBRIAN

INTRUSIVE ROCKS

Late Felsic Intrusive Rocks

Pegmatite, pegmatitic granite, and aplite;
equigranular, biotite granite, quartz
monzonite, and granodiorite; porphyritic,
biotite granodiorite; migmatitic, biotite
granodiorite.

Granitic Rocks of the English River Belt

Equigranular, massive to gneissic, biotite
granodiorite, hornblende-biotite granodiorite;
porphyritic, foliated, biotite granodiorite.

INTRUSIVE CONTACT

Mafic and Ultramafic Intrusive Rocks

Metaquartz diorite, amphibolite, metaperido-
tite, metapyroxenite, metagabbro.

INTRUSIVE CONTACT

Early Felsic Intrusive Rocks

Quartz-feldspar porphyry.

INTRUSIVE CONTACT

METAVOLCANIC-METASEDIMENTARY ASSEMBLAGE

Metasedimentary Rocks

Metagreywacke; calc-silicate gneiss; iron
formation.

Intermediate to Felsic Metavolcanic Rocks

Undifferentiated schists; tuff, lapilli-tuff,
tuff-breccia.

Mafic to Intermediate Metavolcanic Rocks

Undifferentiated schists; pillowed flows;
tuff, lapilli-tuff, tuff-breccia.

highly distorted, but locally top determinations were obtained from the shape of the pillows and indicate that the top of the stratigraphic sequence faces south.

The rocks vary from massive to well foliated and are fine-to medium-grained. The color of the weathered surface varies from dark grey-green to black. A pronounced lineation is exhibited in the medium-grained varieties due to the parallel alignment of prismatic hornblende crystals in the plane of foliation. Hornblende and feldspar are dominant components. Pink to wine colored garnets, irregular in shape and ranging in size from 1 to 8 mm in diameter, may constitute up to 10% of the rock. The average composition, from the visual estimate of 4 thin sections, shows that the rocks are composed of about 60% hornblende and about 35% plagioclase (andesine), with quartz, epidote, magnetite, calcite, sphene and zircon constituting less than 5%. The microtexture is nematoblastic.

(b) Intermediate Metavolcanic Rocks

Metavolcanic rocks of intermediate composition occur mainly in the southern part of the metavolcanic-metasedimentary belt in Tustin Township. Smaller units occur interlayered with the mafic metavolcanic rocks to the north and the metasediments to the east.

The intermediate metavolcanic rocks are predominantly pyroclastic in origin and include metamorphosed pyroclastic breccia,

tuff-breccia and minor tuff and lapilli-tuff. In the field the distinction between metatuffs and metasedimentary rocks is difficult to make.

Fragment content in the pyroclastic rocks varies from 5% to 75%, with the average being 40% to 60%. The majority of fragments are deformed into three dimensional ellipsoids with the long and intermediate axes lying in the plane of foliation (Figure 2). Locally, sub-angular clasts are observed (Figure 3). Because of the distortion in the original shape of the fragments, it is often difficult to determine their original size. In the least deformed rocks (Figure 3), the fragments vary in diameter from about 1 to 40 cm. The most prominent fragments are felsic in composition and are embedded in a more mafic-rich matrix (Figure 2). Mafic fragments were observed at several localities (Figure 4).

In thin section the typical felsic fragment is fine-to medium-grained and composed of a mosaic of quartz and plagioclase (oligoclase-andesine) which constitutes approximately 92% of the fragment. Hornblende forms about 5% of the fragment and has a preferred orientation with the long axes of the crystals oriented approximately parallel to the long axes of the ellipsoidal fragments. Epidote, muscovite, biotite, calcite, sphene and magnetite constitute less than 3% of the fragment. The microtexture is cataclastic.



Figure 2 Typical metamorphosed intermediate tuff-breccia outcropping on the north side of Highway 17, 500 feet east of the Tustin-Bridges township line. Elongated felsic fragments are embedded in a more mafic-rich, foliated matrix. Narrow stringers of garnet-epidote-quartz occur along fracture planes and are shown on the overlay as solid areas.



Figure 3 Metamorphosed intermediate tuff-breccia, outcropping on the north side of Highway 17, at the Tustin-Bridges township line. The photo illustrates the compositional variation in the fragments and the complex nature of strain. Black spots are tar.



Figure 4 Highly deformed coarse pyroclastic rock outcropping on the small island at the northeast end of Bee Lake, Tustin Township. The exposure is a horizontal surface which is approximately perpendicular to foliation planes and lineations. Some mafic fragments are shown on the overlay as solid areas.

The matrix of the metamorphosed pyroclastic breccias, tuff-breccias and lapilli-tuffs is fine-to medium-grained and weathers dark grey to black in color. Foliation is generally well developed and is defined by the parallel alignment of planar biotite and the linear alignment of prismatic hornblende crystals. The foliation planes are approximately parallel to the edge of the nearest fragment.

The visual estimate of mineral components forming the matrix, from thin sections, is as follows: about 60% of the matrix is composed of a mosaic of quartz and plagioclase, about 35% is composed of hornblende and biotite, and less than 5% is formed by epidote, chlorite, calcite, sphene and magnetite. Although hornblende is the dominant mafic mineral, biotite may form 15% of the matrix.

The contrast between the matrix and the fragments is generally well defined due to the compositional and textural differences given above. The foliation is more pronounced in the matrix than in the fragments, due to the higher proportion of aligned mafic platy and prismatic minerals in the matrix. The foliation in the matrix generally wraps around the fragments (Figure 2) but is penetrative in the fragments in highly deformed phases of the rocks (Figure 4). Microscopically, the contact between the elliptical-shaped fragments and the matrix varies from sharp to gradational over a width of several millimeters.

Metasedimentary Rocks

Metasedimentary rocks occur in the Game Lake area of Bridges Township. Minor amounts also are interlayered with the mafic and intermediate metavolcanic rocks. Some of these rocks may be volcanic in origin, but the high grade of metamorphism and pronounced deformation have obliterated original textures which would signify their true origin.

Metagreywacke predominates, but minor calc-silicate gneiss also is present.

(a) Metagreywacke

Rocks belonging to this group show considerable mineralogical variation. The following assemblages have been identified:¹

Biotite-quartz-feldspar schist

Hornblende-biotite-quartz-feldspar schist

Garnet-biotite-quartz-feldspar schist

Biotite-muscovite-quartz-feldspar schist

Muscovite-sillimanite-quartz-feldspar schist

Garnet-magnetite-quartz-feldspar schist

¹
The minerals in each assemblage are listed in order of increasing abundance (the composition of feldspars is discussed briefly below the list).

The metagreywackes are fine-to coarse-grained and weather light grey to rusty brown.

Biotite-quartz-feldspar schist and hornblende-biotite-quartz-feldspar schist predominate, but all assemblages are interlayered in most places.

Plagioclase (oligoclase) is dominant over K-feldspar in most assemblages; in those which bear sillimanite and where muscovite is more abundant than biotite, microcline and/or orthoclase are dominant over plagioclase. Minor minerals in most of the assemblages are epidote, calcite, chlorite, apatite, sericite and rare zircon and tourmaline.

Primary bedding is generally well preserved in the narrow units of metagreywacke that occur interlayered with the meta-volcanic rocks. The beds vary in thickness from 2 mm to about 20 cm. Bedding is poorly preserved in the metagreywacke sequence in the vicinity of Game Lake and where recognized the beds are greater than 2 feet in thickness.

Graded bedding was observed in fine bedded metagreywacke located north of Medicine Lake. Grain gradations suggest that stratigraphic tops face south.

Foliation, defined by the parallel alignment of planar biotite and muscovite, is well developed and coincides with bedding surfaces. Prismatic hornblende and aggregates of biotite

and muscovite have a linear orientation within the plane of foliation.

Calc-silicate Gneiss

Calc-silicate gneiss occurs as a single unit located in the center of Bridges Township, approximately 1000 feet north from Highway 17. The unit varies in width from 100 to 400 feet and has been traced over a length of two miles.

In outcrop, the rocks are banded, with green diopside-rich layers alternating with layers composed of black hornblende, biotite and feldspar. The layers vary from a fraction of an inch to several feet in width. Up to 5% disseminated sulfide minerals occur along the northern limit of this stratigraphic unit.

In thin section, diopside occurs as poikiloblastic augens with the inclusions consisting of quartz and microcline. Hornblende is subhedral and occurs in a mosaic of quartz, microcline and plagioclase. It is oriented with the long axis approximately parallel to the edges of the diopside metacrysts. The composition from the visual estimate of one thin section is: diopside 35%, hornblende 30%, microcline 5%, quartz and plagioclase 25% and epidote, muscovite, sphene, zircon and opaques constitute less than 2%.

EARLY FELSIC INTRUSIVE ROCKS

Only one early felsic intrusive unit has been recognized in the area. An east-trending dike of quartz-feldspar porphyry, 200 to 400 feet in width and 3 miles in length, occurs along the Bridges-Docker Township line just south of Cobble Lake. The quartz-feldspar porphyry dike has been regionally metamorphosed and predates the deformational event producing the regional foliation. It is in contact with mafic metavolcanic rocks to the south and with foliated amphibolite to the north. Locally, it contains inclusions of mafic metavolcanics and is intruded by later dikes of metagabbro.

Parallel orientation of planar biotite gives the quartz-feldspar porphyry a well developed foliation. The foliation in the mafic metavolcanic inclusions is parallel to the foliation surfaces in the host quartz-feldspar porphyry. Linear elements lie in the plane of foliation and consist of aggregates of mafic minerals and elongated quartz phenocrysts.

The average composition, from a visual estimate of two thin sections, is as follows: quartz phenocrysts 8%, feldspar phenocrysts 35%, biotite and chlorite make up about 5% of the ground-mass, and a fine-grained mosaic of quartz, plagioclase and microcline constitute the remainder of the matrix. The quartz phenocrysts are 3-dimensional ellipsoids composed of aggregate grains which exhibit undulatory extinction and have interlobate

grain boundaries. The feldspar phenocrysts are approximately round, varying in diameter from 1/2 mm to 8 mm, and are composed of either single crystals or aggregates of oligoclase. The microtexture of the quartz-feldspar porphyry is cataclastic and the matrix has been partially recrystallized.

MAFIC AND ULTRAMAFIC INTRUSIVE ROCKS

The metamorphosed volcanic and sedimentary rocks are intruded by dikes, sills and irregular bodies of mafic and ultramafic rocks. Except for an early mafic intrusion, mapped as amphibolite, all other intrusions post date regional metamorphism. The majority of these intrusive rocks occur along an east-west zone approximately one-half mile in width that extends from Gas Lake, at the western limit of Tustin Township, eastward through Lift, Medicine, Augite and Cobble Lakes. All mafic and ultramafic rocks have been intruded by later dikes of felsic rocks. Rocks of this group were sub-divided into the following types, starting with the oldest members: amphibolite, metaperidotite, metapyroxenite, and metagabbro. The prefix meta - to peridotite, pyroxenite and gabbro, in the text and maps A and B, implies alteration resulting from autometamorphism rather than regional metamorphism.

Amphibolite

The amphibolites are predominantly sill-like bodies and occur mainly within the mafic metavolcanic sequence. Some irregular shaped bodies are spatially related to the metabaggros

and the metapyroxenites.

The amphibolites weather black to dark grey, are medium-to coarse-grained and are massive to well foliated. It is difficult to distinguish the medium-grained well foliated types from the mafic metavolcanic rocks, and the coarse-grained massive to weakly foliated varieties from metagabbroic rocks.

The average composition of amphibolite, from a visual estimate of 3 thin sections, is as follows: hornblende 60%, plagioclase (andesine) 32%, and quartz 5%, with magnetite and sphene constituting less than 3%. Fine-to medium-grained plagioclase and quartz form an irregular mosaic. Quartz shows undulatory extinction and a few of the plagioclase crystals show minor deformation of the polysynthetic twin planes. Hornblende is subhedral and pleochroic from green to pale olive-green; it is fine-to medium-grained, nematoblastic and tends to be concentrated in lenses up to 1/4 inch in width. In the poorly foliated and massive varieties, the hornblende is medium-to coarse-grained, poikiloblastic and occurs in irregular clusters.

The metamorphic texture and mineralogical composition of the amphibolites suggest that they may be genetically related to the mafic metavolcanic rocks.

Metaperidotite

The metaperidotites are limited in areal extent and generally occur as small dikes or concordant elliptical bodies. The largest

body of metaperidotite that was observed in the field occurs on the group of small islands in the southeast part of Cobble Lake.

In the field the metaperidotites are readily recognized by their brown weathering. The weathered surface also is generally pitted and highly fractured. The pits vary in diameter up to 1/2 inch and in depth up to 1/4 inch.

Thin-section studies show that 5% of the metaperidotite is composed of relict olivine, with serpentine, tremolite and talc constituting the remainder of the rock in varying proportion. Magnetite and hematite may constitute up to 5% of the metaperidotite.

Table II gives the chemical composition of two metaperidotites.

Metapyroxenite

The metapyroxenites occur as small dikes and irregular bodies. They intrude the metaperidotites.

Metapyroxenites are dark green, coarse-grained rocks. They are generally massive, but locally are highly sheared.

In thin section, the massive varieties are composed of about 90% massive tremolite, pseudomorphic after clinopyroxene. Relict clinopyroxene, talc and magnetite make up the remainder. In the alteration of clinopyroxene to tremolite, the original textures are preserved in the massive rocks. The sheared varieties consist of a fine-grained felted mass of tremolite, talc and

Table II Chemical Analyses of Mafic and Ultramafic Rocks

Sample No.	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	FeO	MgO	CaO	Na ₂ O	K ₂ O	H ₂ O	CO ₂
A-108	38.70	3.59	-	4.76	30.35	3.20	.122	.01	8.32	-
P-107	39.60	3.39	11.87	6.32	23.40	6.06	.336	.08	6.26	-
A- 69	48.40	5.36	1.89	10.28	24.65	3.53	.109	.006	4.58	-
A-162	51.05	7.82	1.03	9.48	19.60	6.74	.401	.06	2.16	-
	P ₂ O ₅	S	Cr %	Cu ppm.	Zn ppm.	Pb ppm.	Co ppm.	Ni %		
A-108	.17	.034	.217	1	40	15	102	.11		
P-107	.25	.092	.128	243	78	33	160	.087		
A- 69	.13	.036	.155	26	76	15	112	.064		
A-162	.15	.003	.160	1	73	2	69	.024		

Location of Samples

A-108 Gas Lake, Tustin-MacNicol Township Line.
P-107 1/4 mile west of Windermere Lake, Tustin township.
A-69 200' north of Medicine Lake, Tustin township.
A-162 North shore of island in Lift Lake, Tustin township.

serpentine. Poikiloblastic metacrysts of hornblende, up to 6 mm in diameter, may constitute up to 5% of these rocks. The genetic origin of many of the sheared phases of rocks is uncertain.

Metagabbro

The metagabbros are spatially related to the metapyroxenites, metaperidotites and amphibolites. An outcrop of metagabbro, on the southeast shore of Bruin Lake, MacNicol Township, was found to contain inclusions of metaperidotite.

Metagabbroic rocks are typically porphyritic with 1 mm to 6 mm black hornblende phenocrysts embedded in a very fine-grained, light grey groundmass. The outcrops are generally massive in character but grade into weakly foliated phases.

In thin section pale green, subhedral hornblende phenocrysts constitute 65% of the rock. Irregular patches of original clinopyroxene occur in the cores of many phenocrysts but constitute less than 10% of the rock. The groundmass is composed of 30% plagioclase (andesine to sodic labradorite), 3% euhedral epidote and 2% magnetite and sphene. Minor cataclastic texture is observed in a few thin sections.

FELSIC INTRUSIVE ROCKS

Spatially, the felsic intrusive rocks may be sub-divided into four groups (Map A, back pocket):

1) the English River belt, which occupies the area north of the metavolcanic-metasedimentary belt;

2) the Feist Lake pluton, which lies in the southwestern part of the map-area;

3) the Crabclaw Lake batholith which lies in the southeastern part of the map-area; and

4) felsic intrusive rocks within the greenstone belt.

The chronological relationship between the first three major groups has not been established; they are separated from one another by the metavolcanic-metasedimentary rocks. Rocks belonging to the fourth group may be genetically related to one, two or all three of the other groups. The relative ages of the intrusive rocks will be discussed in Chapter VII.

English River Belt

Gneissic granodiorite occurs in the northern part of the map-area and forms part of a regional sequence of rocks that are collectively known as the English River belt.

The rocks are grey to pinkish-grey and range from foliated-porphyritic to granoblastic-gneissose. Amphibolite inclusions are common, they may be massive or foliated. The host granitic material shows laminar flow structure around both types of inclusions.

The foliated inclusions are fine-to medium-grained and are

generally tabular in shape. Their occurrence is restricted to the area of the contact between the gneiss belt and the metamorphic belt. The long axes of the inclusions are approximately parallel to the contact but the vertical length of the inclusions is not known.

The massive inclusions are medium-to coarse-grained and are highly irregular to lensoid in shape. A very weak foliation is observed in a few places, particularly near the edges of the inclusions. The massive inclusions occur throughout the gneissic granodiorite but appear to be concentrated in outcrops adjacent to lineaments characterized by topographic depressions, particularly in the area east of Linklater Lake (Map B).

The gneissic rocks near the contact with the metavolcanic rocks, in the vicinity north of Cobble Lake, are sheared and highly hematitized over a width of about 200 feet. The structure has not been observed west of Balmain Lake.

The average composition of the porphyritic gneisses, from a visual estimate of six thin sections, is as follows: oligoclase about 60%, microcline about 15%, quartz about 15%, biotite about 8%, with rare hornblende, chlorite, apatite, sphene, zircon, magnetite and ilmenite. The phenocrysts consist mainly of oligoclase but a few are microcline. A cataclastic texture is prevalent in the rocks along the contact with the greenstone belt in the area north of Cobble Lake. Biotite is "smeared out" and largely altered to chlorite.

In the equigranular, hornblende-bearing gneisses, the mafic mineral component varies from 5% to 35% with the average being about 15%. The equigranular biotite granodiorite contains about 5% biotite. In both units, the texture is interlocking granular.

For a more comprehensive study of the English River belt, the reader is referred to Dwibedi (1967).

Feist Lake Granodiorite

The Feist Lake pluton consists of a light pink to greyish-pink, medium-to coarse-grained massive biotite granodiorite, with a hybrid zone several hundred feet to one mile in width adjacent to the host metamorphic rocks. Inclusions of foliated host rock depicting flow structures are aligned sub-parallel to the contact. Pink pegmatite dikes are a common occurrence in the hybrid zone.

The average composition of the granodiorite, from a visual estimate of 3 thin sections, is: plagioclase (oligoclase) about 60%, microcline about 15%, quartz about 15%, biotite about 8% and magnetite, sphene and zircon constitute less than 3%. The microtexture is approximately equigranular-interlocking. Myrmekitic texture is extensively developed in some thin sections.

Crabclaw Lake Batholith

The Crabclaw Lake batholith is a complex intrusive body with at least four different compositional phases. The contact between the metavolcanic-metasedimentary rocks and the granitic rocks constituting the batholith is migmatitic. The contact between phases within the batholith ranges from sharp to migmatitic.

The predominant phase is a white-weathering biotite granodiorite with varying amounts of foliated mafic to felsic inclusions. The host granitic material is gneissic to massive with the layered types showing laminar flow structure around the inclusions.

Minor phases within the batholith are a grey, foliated biotite granodiorite and a "quartz-eye" granite. The former occurs along Highway 17, south of Game Lake and covers an area less than one square mile. It contains pink granodiorite and pegmatite dikes. The "quartz-eye" granite occurs south of Stewart Lake; its area is also less than one square mile. The "quartz-eyes" are irregular in shape and are up to 8 mm in diameter. Contact relationships between the "quartz-eye" phase and other granite phases are obscure. Microtextures in the "quartz-eye" granite are approximately equigranular and interlocking. The lack of cataclastic textures in these units and the flow structure around inclusions implies that the foliation

probably developed during emplacement.

The youngest phase, a pink, massive, coarse-grained granite, intrudes all other granitic phases of the batholith except pegmatite. The average composition, from a visual estimate of one thin section, is: microcline about 60%, plagioclase (oligoclase) about 18%, quartz about 15%, biotite about 5% and magnetite, sericite, chlorite, zircon and apatite constitute less than 2%. The microtexture is semi-porphyritic and interlocking.

Felsic Igneous Rocks Intruding the Greenstone Belt

Pegmatite dikes are the predominant igneous rocks intruding the metavolcanic-metasedimentary-metagabbro belt, these dikes are approximately concordant. White and pink varieties were identified in the field. The white pegmatite is restricted to the northern part of the belt while the pink variety occurs mainly in the southern part of the belt.

The age relationship between the two varieties of pegmatite has not been established. Mineralogical evidence suggests that several ages of pink pegmatite may also occur. Coarse muscovite and tourmaline is common in the pink pegmatites in the northern part of the belt, but have not been observed elsewhere. Similarly, many pegmatites in the south are radio-active, unlike the pink pegmatites in the northern part of the belt.

A white weathering, coarse-grained, porphyritic granodiorite outcrops along the north shore of Cobble Lake with dikes extending

westward into Augite and Lift lakes. Small pink garnets and weak radio-activity are common characteristics of the granodiorite and the white pegmatite, implying a genetic relationship.

The mesoscopic fabric of all pegmatites and the granodiorite varies from massive to highly fractured. Cataclastic textures were observed in two thin sections of the pegmatites.

CHAPTER III

METAMORPHISM

INTRODUCTION

All the volcanic and sedimentary rocks and some of the early intrusive rocks have been regionally metamorphosed. Retrograde metamorphism has modified some of the effects of regional metamorphism. The metamorphic mineral assemblages have been described in Chapter II. The present chapter will summarize the data already given and present additional information related to metamorphism.

REGIONAL METAMORPHISM

The metavolcanic-metasedimentary belt of rocks has been regionally metamorphosed to the almandine amphibolite facies. The composition of plagioclase in the mafic metavolcanic rocks is An ³⁰⁻⁴²; in the metasedimentary and intermediate pyroclastic rocks the plagioclase composition is An ¹³⁻³²; in the amphibolites the plagioclase composition is An ³³⁻⁴⁷. Mineral assemblages containing sillimanite are not widespread and data is insufficient to establish the subfacies of regional metamorphism. Some of the typical mineral assemblages are illustrated in Figures 5, 6, 7 and 10.

Regional metamorphism can be classified more specifically



Figure 5 Photomicrograph (50-x), mafic metavolcanic, specimen 67-3-A-47, (see Map A for location). Hornblende exhibits a preferred crystallographic orientation except for the euhedral porphyroblast. Epidote is concentrated along the margin of the porphyroblast.

Legend: E.....Epidote.
H.....Hornblende.
Mag....Magnetite.
P.....Plagioclase.

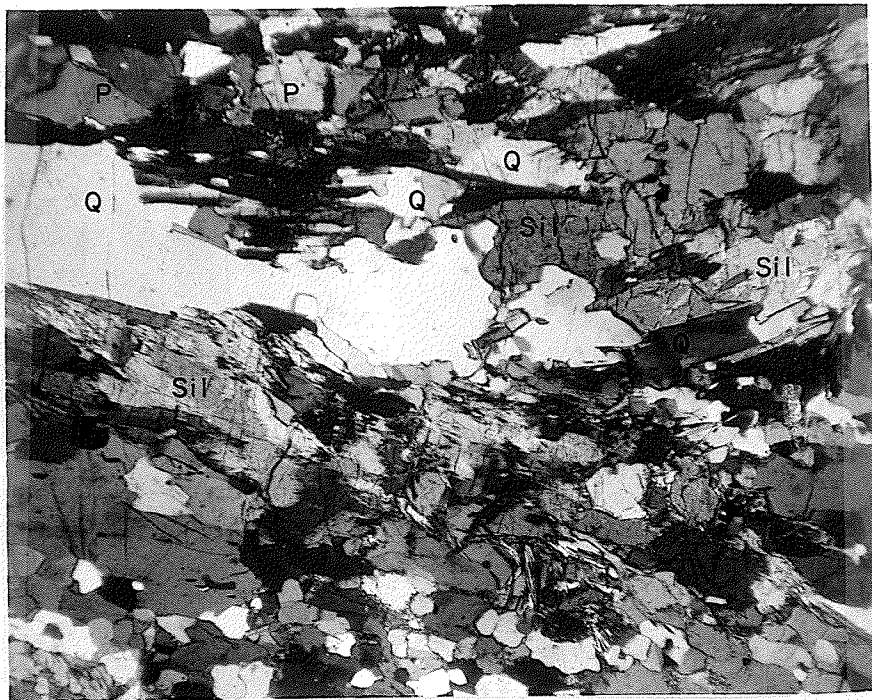


Figure 6 Photomicrograph (50-x),
sillimanite-quartz-feldspar schist,
specimen 67-3-A-88, (see Map A for location).

Legend: P.....Plagioclase.
Q.....Quartz.
Sil....Sillimanite.



Figure 7 Photomicrograph (50-x).
Hornblende-pyroxene gneiss, specimen 67-3-A-1,
(see Map A for location).
Two twinned and poikiloblastic metacrysts of
diopside are embedded in a matrix composed of
plagioclase, microcline and hornblende.

Legend: H.....Hornblende.
P.....Plagioclase.
Px.....Pyroxene.

as regional dynamothermal metamorphism (as defined by Winkler, 1967). Textures indicate that both deformation and recrystallization were important mechanisms in the development of the fabric of the metamorphosed rocks.

The effects of deformation are noted in thin sections by: (1) cataclastic textures in the pyroclastic rocks (Figures 9 and 10), and the quartz-feldspar porphyry (Figure 8); (2) the undulatory extinction of quartz and plagioclase in all but the fine-grained portions of the metavolcanic-metasedimentary rocks.

Recrystallization in the metamorphosed rocks is evident from: (1) the preferred orientation of subhedral, biotite and hornblende; (2) the mosaic pattern formed by quartz and feldspar grains.

The grain size in the metamorphic rocks varies. The mafic metavolcanic rocks, the intermediate meta-tuffaceous rocks and the metasedimentary rocks are fine-to medium-grained, approximately equigranular (Figures 5 and 6); the intermediate meta-tuff breccias are very fine-to medium-grained, inequigranular (Figures 9 and 10). Recrystallization of the very fine-grained felsic portions has produced polygonal-shaped grains.

The textures and orientation of the minerals as observed on a microscopic scale indicates that recrystallization took place as the rocks were undergoing strain. Minor post-tectonic recrystallization is evident by the presence of hornblende

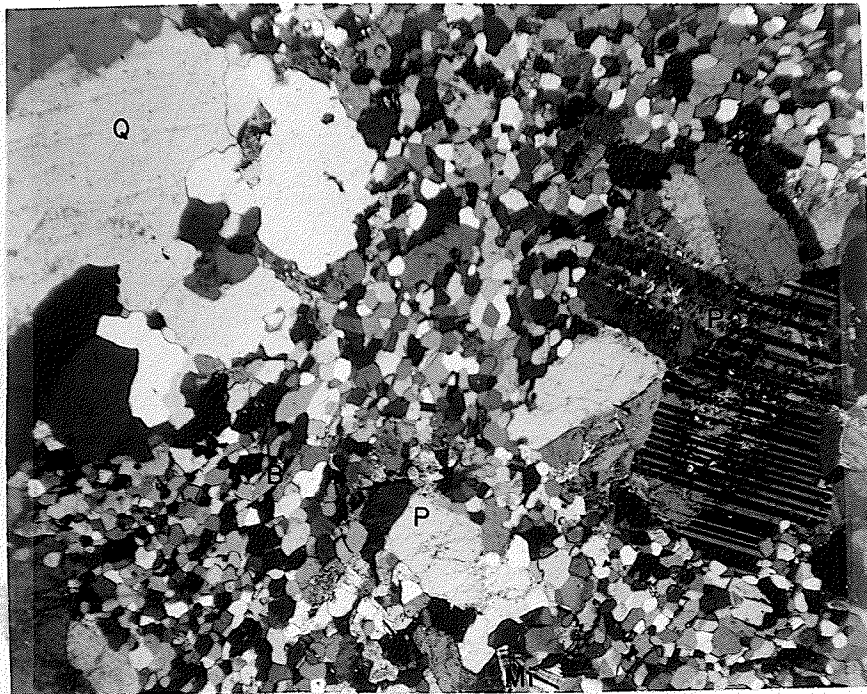


Figure 8 Photomicrograph (50-x),
quartz-feldspar porphyry, specimen 67-3-P-64.

Legend: B.....Biotite.
Mi.....Microcline.
P.....Plagioclase.
Q.....Quartz.

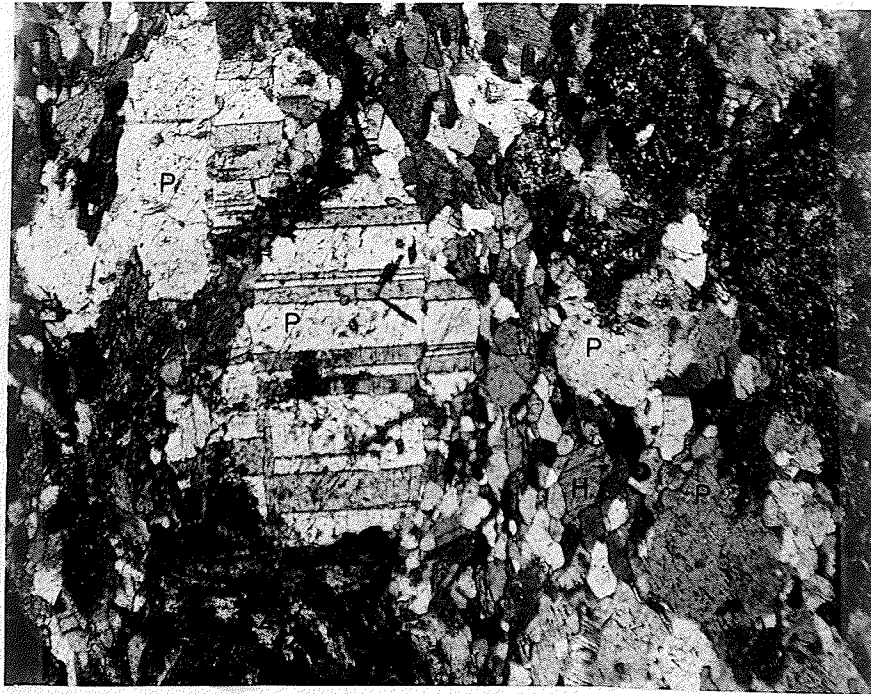


Figure 9 Photomicrograph (50-x),
cataclastic texture in lapilli-tuff,
specimen 67-3-A-72.

Legend: C.....Chlorite.
H.....Hornblende.
P.....Plagioclase.
Z.....Zoisite.



Figure 10 Photomicrograph (50-x), metalapilli-tuff, specimen 67-3-P-37. Two textural domains occur with the coarser-grained domain representing a fragment and the fine-grained portions representing the matrix.

Legend: B.....Biotite.
M.....Muscovite.
P.....Plagioclase.
T.....Tourmaline.

porphyroblasts in the mafic metavolcanic rocks (Figure 5), and muscovite porphyroblasts in the intermediate meta-lapilli-tuff (Figure 10).

RETROGRADE METAMORPHISM

Evidence for minor retrograde metamorphism was noted in some of the thin sections. Sillimanite is partially altered to muscovite, and biotite is partially altered to chlorite. There is no evidence indicating whether the retrograde metamorphism is the result of a separate period of metamorphism or is related to the end stages of the period of regional dynamothermal metamorphism.

CHAPTER IV

STRUCTURAL ELEMENTS

INTRODUCTION

This chapter presents a description of the structural elements of: (a) the metavolcanic-metasedimentary rocks; (b) the granitic rocks. They are mostly microscopic and mesoscopic, some macroscopic.

STRUCTURAL ELEMENTS OF THE METAMORPHIC ROCKS

Bedding

Bedding is better developed in metasedimentary and meta-tuffaceous rocks than in the mafic metavolcanic rocks and the intermediate metatuff-breccias. The metasedimentary rocks outcropping to the north of Medicine, Lift, Augite and Cobble lakes are well bedded in comparison to the metasedimentary rocks in the vicinity of Game and Kimber lakes. Bedding in the former group is characterized by alternating felsic and more mafic-rich layers. The felsic layers range from approximately 1/8 inch to 4 inches in width; the more mafic-rich layers are generally less than 2 inches in width. Beds in the latter group are generally greater than 2 feet in thickness, although locally they may be finely bedded (Figure 11).

Approximately elliptical structures with siliceous cores and distinct light grey colored rims about one inch in width, were observed in metasedimentary rocks on the north shore of Kimber Lake. These structures range in size from 3 to 12 inches by 6 to 24 inches. Although bedding shows some distortion in the vicinity of each structure, the bedding planes pass through the structures rather than wrap around them suggesting that the structures are accretionary and not boulders or the product of metamorphic processes. These structures are illustrated in Figure 11.

Foliation

Foliation is the dominant structural element of the metavolcanic-metasedimentary rocks. The regional orientation of the foliation is approximately parallel to the contacts with the major batholiths, but locally it is transected by the intrusive rocks.

The foliation is in the form of a penetrative schistosity resulting from the parallel alignment of tabular biotite and muscovite and the linear alignment of prismatic hornblende. Where primary layering is preserved, the foliation and layering are almost always parallel.

The development of foliation in the metavolcanic-metasedimentary rocks varies from strongly schistose to moderately well foliated. Generally, the structure is best developed in the rocks near the



Figure 11 Finely bedded metamorphosed clastic sedimentary rocks with an accretionary structure, located on the north shore of Kimber Lake, Bridges Township. Dark spots are lichen.

contacts with the major felsic intrusive bodies that lie south of the metamorphic belt and also along narrow linear zones within the greenstone belt. Foliation is strongly developed in the matrix of the metatuff-breccia and "wraps" around the deformed fragments as illustrated in Figure 2. However, where the deformation is more extreme, as portrayed in Figure 4, the foliation becomes penetrative within the fragments as well as within the matrix. The result is that mafic fragments become indistinguishable from the matrix and the outline of the felsic fragments becomes difficult to recognize.

Single Mineral Lineations

Field studies indicate that prismatic hornblende occurs with the long axes aligned within the foliation planes. These lineations are best observed in the felsic fragments of the intermediate metatuff-breccia. The hornblende is aligned approximately parallel to the long axes of the fragments.

Microscopically, the mineral lineations are generally aggregates of hornblende or hornblende and biotite and are discussed further in the following section.

Aggregate Mineral Lineations

Mafic minerals, predominantly hornblende and biotite, commonly occur as elongate tabular aggregates with their long axes aligned along the foliation planes. These lineations are

best observed in the metamorphosed sedimentary and intermediate pyroclastic rocks. The aggregates of mafic minerals vary from less than 1 mm to 2 mm in width and from 1/2 mm to 20 mm in length. In the metatuff-breccia, aggregate mineral lineations are approximately parallel to the long edges of the deformed felsic fragments.

The aggregate mineral lineations are related to the development of foliation and are interpreted to represent the direction of tectonic transport or extensive strain.

Fragment Lineations

Deformed volcanic fragments constitute lineations in the rocks of the Tustin-Bridges area.

Most fragments are deformed into triaxial ellipsoids with their long and intermediate axes in the plane of the foliation. The short dimensions of the fragments vary in length from a fraction of an inch to 6 inches, the intermediate axes vary in length from about 1 inch to 15 inches, and the long axes vary in length from about 3 to 30 inches. Measurement of the long axes dimensions is difficult, for the long dimensions have approximately vertical orientation and rock exposures parallel to the axes are not common. Orientation of the long dimensions of deformed fragments is parallel to single mineral lineations and aggregate mineral lineations.

Minor Folds

The axes of minor folds in the area constitute a lineation. The folds are traced by deformation of bedding and foliation surfaces.

Minor folds in bedding are restricted to the band of metasedimentary rocks in the vicinity of Medicine and Cobble lakes. In the field, the bedding surfaces were observed to coincide with foliation surfaces. However, one thin section of a minor fold, cut perpendicular to the axial trace of the fold, shows that foliation transects bedding in the hinge area. The fold, marked by the bedding surfaces, is older than the foliation.

Minor fold structures marked by deformation of foliation surfaces are not numerous in the metamorphosed rocks but have a widespread distribution. Most minor folds display a right-handed asymmetry in plan view, but disharmonic folds are present also.

MINOR STRUCTURAL ELEMENTS OF THE GRANITIC ROCKS

English River Belt

The English River belt consists predominantly of a gneissic granodiorite, which is commonly porphyritic, and minor phases of massive granodiorite which occur as regionally conformable bands from a fraction of an inch to three thousand feet in thickness.

Foliation is the dominant structural element of the gneissic granodiorite. It is defined by the sub-parallel arrangement of planar biotite, approximately conformable to compositional layering. The long axes of hornblende crystals lie in the plane of foliation but do not show a linear orientation. Gneissosity is characterized by laminar flow structure which envelops the mafic inclusions that occur within these rocks.

Feist Lake Pluton

The Feist Lake granodiorite is generally massive in character, except for the peripheral hybrid zone adjacent to the belt of metamorphosed host rocks.

Foliation in the Feist Lake pluton is restricted to the hybrid zone. Inclusions of foliated host rocks vary in size from small lenticular streaks to large tabular blocks up to several tens of feet in width. The larger inclusions are relatively undeformed, with the long axes oriented in a plane approximately parallel to the contact of the metamorphic belt. The smaller inclusions generally have been highly assimilated by the host granodiorite and give the rocks a layered structure. Biotite shows an arrangement sub-parallel to the layering, and hornblende in several places has a linear alignment in the plane of foliation. The foliation characteristically wraps around the inclusions.

Crabclaw Lakes Batholith

The Crabclaw Lakes intrusive complex consists of massive, migmatitic and gneissic phases. Migmatitic rocks, consisting of an intrusive component with inclusions of host rocks, have varying characteristics; inclusions may be angular to rounded in shape and in sharp contact with the intrusive phase, or they may be highly deformed and assimilated with the intrusive phase giving the rock a gneissic texture. The development of foliation appears to be determined by the degree of assimilation of the inclusion by the granitic phase. In the gneissic phases tabular biotite is aligned in a sub-parallel manner, conformably with the mineralogical layering, and wraps around inclusions.

Granitic Rocks Intruding the Metamorphic Belt

Numerous pegmatite and aplite dikes, sills and irregular bodies intrude the host rocks and are most numerous near the south limit of the metamorphic belt. All pegmatites and aplites are massive in character but some are highly fractured. Mesoscopically, the fractures are randomly oriented and discontinuous. On a microscopic scale the pegmatites are characterized by cataclastic textures.

MACROSCOPIC STRUCTURES

Faults, Lineaments and Shears

No major faults were recognized in the field but many shear zones have been interpreted to represent fault structures.

Numerous shear zones occur throughout the area, particularly in the metavolcanic-metasedimentary rocks. The shears are generally parallel to the foliation in the rocks but have been observed to transect the foliation at angles of up to 15 degrees, indicating that the foliation developed earlier than the shear zones.

The shear zones vary from several inches to about 20 feet in width and occasionally can be traced discontinuously for several miles along strike. The shear zones grade into normal foliated rocks. Veins composed of quartz, epidote, garnet and carbonate commonly occur along the center of narrow shears. (See Figure 2).

Several prominent lineaments which may be faults occur within the metamorphosed belt. One occurs along the south shore of Cobble, Augite, Lift and Medicine lakes. A second, less distinct lineament, occurs about 1/2 mile south of the one mentioned above. The second lineament follows the mafic metavolcanic-metasedimentary contact. Less prominent lineaments occur throughout the belt and are believed to represent faults.

Lineaments which may not be faults occur in all rocks of the Tustin-Bridges area. Many occur in the dominantly granitic terrains and are believed to reflect the variation in composition of the rocks, particularly as determined by an increase in the amount of metavolcanic-metasedimentary inclusions. The arcuate lineaments in the area east of Linklater Lake reflects lineaments of this type (Map A). Lineaments coincident with remnants of metasedimentary rocks occur in the southeast part of Bridges Township.

Map B (in back pocket) represents a compilation of lineaments in the Tustin-Bridges and adjoining areas.

Major Fold Structures

Primary structures normally used in determining the stratigraphic order for a sequence of rocks are generally lacking in the area. Graded bedding in metasedimentary rocks located north of the Medicine Lake, and pillow structures located one thousand feet south from the west portion of Medicine Lake, indicate that the stratigraphic top for the north part of the metamorphic belt is in a southward direction. The total belt is considered to be a homoclinal sequence but this conclusion is only speculative; because of the high degree of metamorphism, the top determinations that were obtained in the south part of the belt are not considered reliable.

A major fold structure, marked by foliation surfaces in the metamorphic belt occurs south of Highway 17 in the Lacourse Lake area, Tustin Township. The foliation in the metavolcanic-metasedimentary rocks has been re-oriented approximately parallel to the contact of the nearest pluton. The geometry and kinematics of this fold will be discussed in the following chapters.

CHAPTER V

GEOMETRY OF STRUCTURAL ELEMENTS

INTRODUCTION

This chapter describes the geometric relationships of the structural elements within the rocks of the metamorphic belt and the intrusive rocks. The description is based on field observations, thin-section studies and orientation diagrams.

The map-area was divided into five major sub-areas (Figure 12), one for each of the three batholiths and two for the metavolcanic-metasedimentary belt. In the latter, one sub-area consists of structural elements with relative homogenous orientation, and the second sub-area structural elements display heterogenous orientation. Two structural domains were outlined within the second sub-area with each domain representing the limbs of a major fold structure.

A statistical approach was used in obtaining the orientation data. Using a transparent overlay with a 1/4 mile grid pattern (i.e. one inch), the orientation of structural elements was obtained for each 1/16 square-mile area, providing a reading was taken within that area during field mapping. If more than one reading was available the one nearest to the center of the area was used. Data were plotted on the lower hemisphere of the Schmidt equal-area projection and contoured.

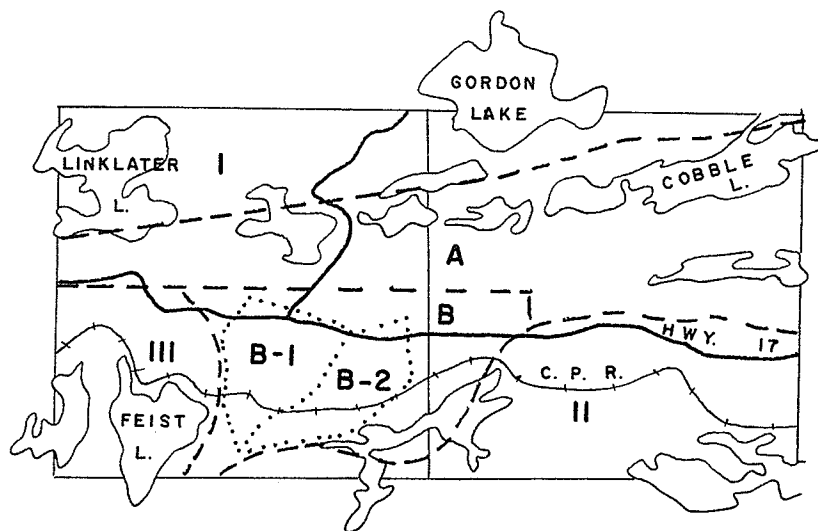


Figure 12 Map-area showing division of sub-areas (heavy dashed lines) and structural domains (dotted lines).

- | | |
|--------------|--|
| Sub-area I | English River belt. |
| Sub-area II | Crabclaw lake batholith. |
| Sub-area III | Feist Lake batholith. |
| Sub-area A | Metavolcanic-metasedimentary belt, north part. |
| Sub-area B | Metavolcanic-metasedimentary belt, south part. |
| Domain B-1 | West limb of fold structure. |
| Domain B-2 | East limb of fold structure. |

GEOMETRY OF THE STRUCTURAL ELEMENTS IN THE METAMORPHIC ROCKS

Sub-areas A and B

Foliation and lineations are the dominant structural elements of the metamorphosed volcanic and sedimentary rocks. Although bedding is preserved locally, its distribution is not uniform. Foliation surfaces are conformable to bedding surfaces and therefore, orientation diagrams for bedding were not constructed. Mineral and clast lineations were originally plotted separately, however they revealed similar distribution patterns and consequently they were combined.

Figures 13a and 13b show the distribution of foliation surfaces and lineations in sub-areas A and B, respectively. The foliation surfaces in sub-area A reveal a relatively homogeneous orientation with the poles plotting as a maxima to a plane trending $N78^{\circ}E$ and dipping $72^{\circ}N$. The orientation of foliation in sub-area B indicates the presence of a strike variation from NW through EW to NE with dips generally in a northerly direction. The variation is the result of the development of a major fold structure and will be discussed in the next section.

The most frequent lineation plunge for sub-area A is $42^{\circ}N\ 10^{\circ}E$. The lineation concentration in sub-area B is less well defined. The variation in sub-area B is largely attributed to the effect of the fold structure.

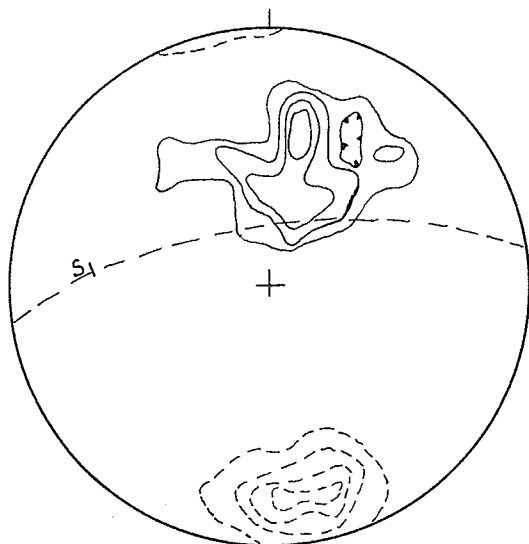


Figure 13a. Sub-area A; equal-area projection of 45 lineations contoured (solid lines) at 3, 6, 9 and 12% per 1% area; and 271 poles to foliation contoured (dashed lines) at 4, 8, 12 and 14% per 1% area.

S_1 is the mean attitude of foliation surfaces for sub-area A (i.e. great circle at right angles to maxima concentration of foliation poles).

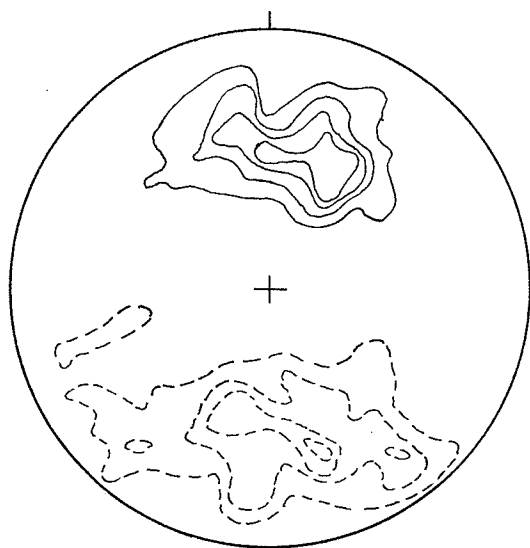


Figure 13b. Sub-area B; equal-area projection of 102 lineations contoured (solid lines) at 3, 6, 9 and 12% per 1% area; and 167 poles to foliation contoured (dashed lines) at 2, 4, 6 and 8% per 1% area.

Explanation of the contoured plots of lineations and poles to foliation (Figures 13a, 13b, 14a, 14b) reveals that the mean lineation position seldom plots exactly on the mean foliation plane. This relationship is more apparent than real, for field and thin-section observations indicate that lineations lie in the plane of foliation. The discrepancy is attributed mainly to measurement error.

Minor fold structures marked by deformation of foliation surfaces plunge $48^{\circ}\text{N}50^{\circ}\text{E}$ in sub-area A (Figure 14a). 21 folds had a Z-asymmetry and 10 folds were disharmonic in style. Both types illustrated similar distribution patterns and therefore, were combined in Figure 14a. The maximum concentration is $48^{\circ}\text{N } 50^{\circ}\text{E}$, an orientation which is close to lying in the foliation. The axial lines of minor folds in sub-area B and their corresponding asymmetry is given in Figure 14b. The orientation of minor folds in sub-area B (Figure 14a) have a greater spread than the minor folds in sub-area A (Figure 14b).

Domains B-1 and B-2

Foliation surfaces and lineations in sub-area B have a greater variation in orientation than in sub-area A (Compare Figure 13a with 13b). This variation in orientation can be attributed to the large fold structure in sub-area B which has re-oriented the foliation (Map A). The disappearance of this fold to the north in sub-area A suggests that the two sub-areas

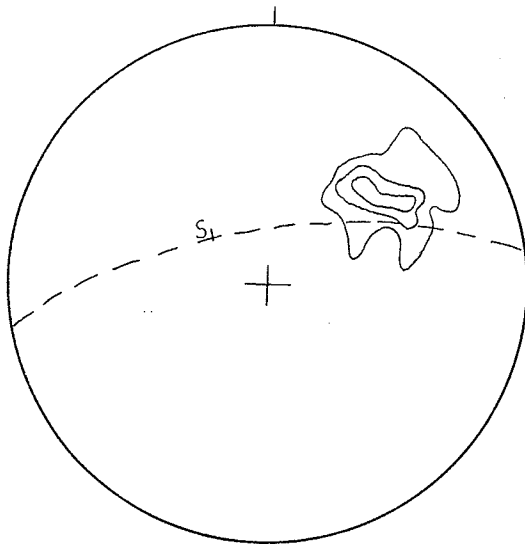


Figure 14a. Sub-area A; equal-area projection of 31 minor fold axes contoured at 6, 9 and 12% per 1% area. S_1 is the mean attitude of foliation surfaces for sub-area A (figure 13a).

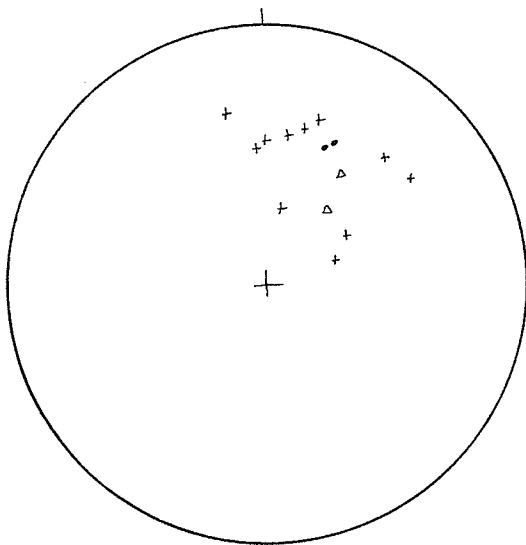


Figure 14b. Sub-area B; equal-area projection of minor fold axes.

- + , Z-shaped folds.
- . , S-shaped folds.
- Δ , disharmonic folds.

are separated by a detachment zone, south of which the foliation has been folded. An accurate location for the detachment zone has not been established and the displacement probably occurred along several sub-parallel faults (Map A and Map B). The character of the fold and presence of the foliation as a structural anisotropy point to a flexural type of folding in which foliation has been active. The geometry and style of their fold were interpreted from the following analysis.

The structural domains B-1 and B-2 were outlined so each would enclose approximately one limb of the fold structure. Figure 15a and 15b illustrate the orientation of foliation surfaces and lineations in domains B-1 and B-2, respectively. Furthermore these figures show the amount of re-orientation during folding. The synoptic diagrams (Figures 16a and 16b) show the data from these domains plotted together and provide a basis for the interpretation of the fold geometry. Either one of two types of folds are consistent with the data:

(a) cylindroidal fold (Figure 16a), and conical fold (Figure 16b).

(a) Cylindroidal Fold Interpretation

Figure 16a shows the orientation of early lineations and foliation with the interpretation for a cylindroidal fold.

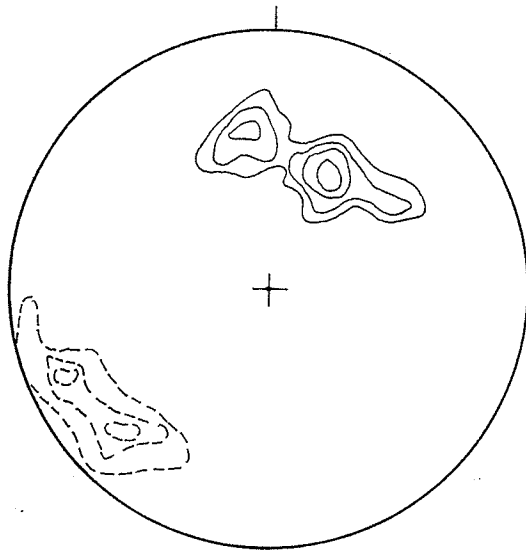


Figure 15a. Domain B-1; equal-area projection of 21 lineations contoured (solid lines) at 5, 10, 20 and 40% per 1% area; and 31 poles to foliation contoured (dashed lines) at 3, 10 and 15% per 1% area.

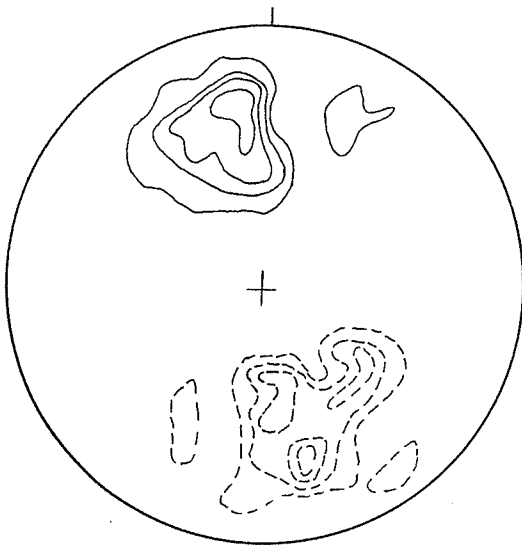


Figure 15b. Domain B-2; equal-area projection of 34 lineations contoured (solid lines) at 3, 6, 9 and 12% per 1% area; and 40 poles to foliation contoured (dashed lines) at 3, 6, 9 and 12% per 1% area.

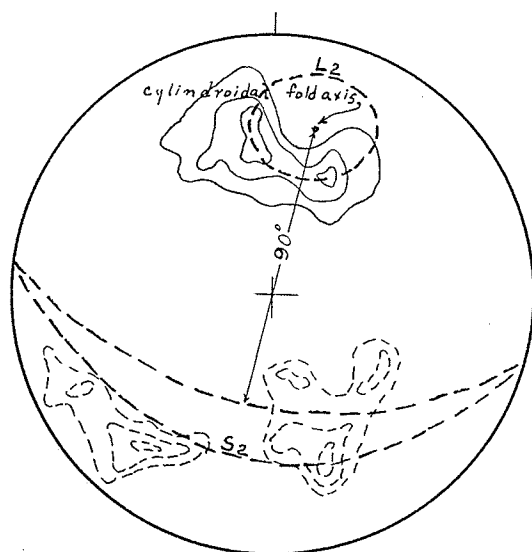


Figure 16a. Synoptic diagram of domains B-1 and B-2. Lineations are contoured (solid lines) at 5, 10 and 15% per 1% area, and poles to foliation are contoured (light dashed lines) at 2, 4, 6 and 8% per 1% area. The heavy dashed lines illustrate the interpretation for a cylindroidal fold.

L_2 is a small circle representing the re-orientation of early lineations. S_2 is the best fit great circle along which foliation poles have been re-oriented by cylindroidal folding.

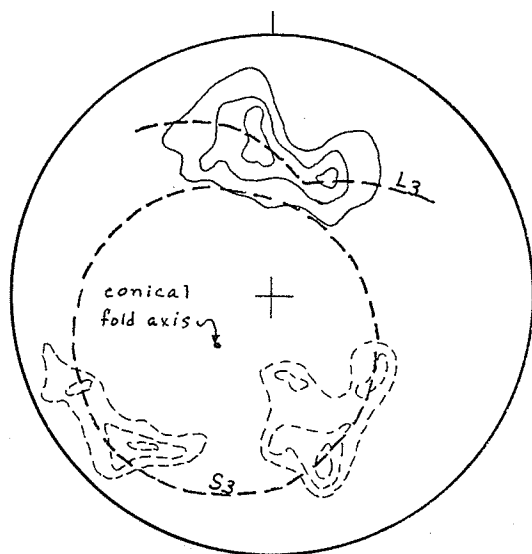


Figure 16b. Synoptic diagram of domains B-1 and B-2. Lineations are contoured (solid lines) at 5, 10 and 15% per 1% area, and poles to foliation are contoured (light dashed lines) at 2, 4, 6 and 8% per 1% area. The heavy dashed lines illustrate the interpretation for a conical fold.

L_3 is part of a complex spiral curve along which early lineations have been re-oriented.

S_3 is a best fit small circle along which early foliation poles have been re-oriented by conical folding.

Weiss (1966) states that:

"The geometry of rotation of earlier linear structures by later folding depends on the kinematics of the late folding." (p. 105).

For a cylindroidal fold the projection of lineations follows a small circle. A best-fit small circle was constructed for the distribution of lineations. The geometric center of this small circle, as determined on a Wulff stereographic projection, represents the axis of the fold around which the pre-folding lineations have been dispersed in a conical pattern. The axis plunges $34^{\circ}\text{N } 13^{\circ}\text{E}$. If cylincrical folding has taken place the poles to foliation should follow a great circle distribution at right angles to this axis. The actual plots show that the foliation poles are 105° to the fold axis. This disagreement is probably a result of the measurement error discussed previously.

(b) Conical Fold Interpretation

The same data, interpreted for a conical fold, is illustrated in Figure 16b.

Whitten (1966) states that:

"in a π diagram for conical folds the S-poles fall on a small circle (rather than a great circle, as is the case for cylindroidal folds)" (p. 63).

At the same time the lineations are:

"folded into complex spiral curves the form of which depends on the style of the fold, on the cone angle and on the orientation of the early lineations on the fold." (Stauffer, 1964, abs.).

A small circle was constructed to pass through three points of maximum concentration for the poles to foliation surfaces. The geometric center of this circle represents the fold axis which plunges 68° S 48° W. Providing that the lineations had a constant orientation prior to folding, the angle between the early lineations and the dip direction would change regularly across the fold for equal changes in fold arc. A sharp break in the curve occurs where the early lineations and the dip of foliation are parallel. This break should fall on the small circle representing the position of foliation poles folded conically, but in this case the break falls 16° outside the circle. This discrepancy may be due to the measurement error which produced the difference between the plunge of lineations and the dip of foliation planes.

Comparison of the two interpretations indicates that there is little to choose between them; both fit the data almost to the same degree. A conical fold is favored by the author because the poles to foliation follow a small circle distribution better than a great circle.

ORIENTATION OF FOLIATION IN THE BATHOLITHS

Foliation is the dominant structural element in all three granitic batholiths. Figures 17a, b and c show the plot of poles to foliation for the English River belt (sub-area I), the Crabclaw Lake batholith (sub-area II) and the Feist Lake pluton (sub-area III), respectively.

The foliation in the rocks of the English River belt is relatively consistent, trending $N80^{\circ} E$ and dipping vertically.

Two maximum areas of concentration for the poles to foliation occur in the Crabclaw Lake batholith. The rocks in the north part of the batholith trends $N65^{\circ} E$ and dip $65^{\circ} NE$ while the rocks in the south part trend east-west and dip $82^{\circ} S$.

The distribution of foliation surfaces in the Feist Lake pluton reflect the intrusive nature of the granitic body to the metamorphic belt.

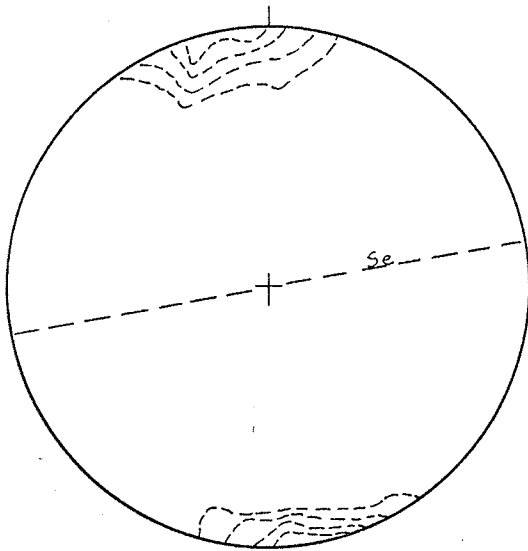


Figure 17a. Sub-area I;
(English River Gneisses) equal-area
projection of 136 poles to foliation
contoured at 4, 8, 12 and 16%
per 1% area. Se is the plane of
foliation at right angles to the
maximum concentration of foliation
poles.

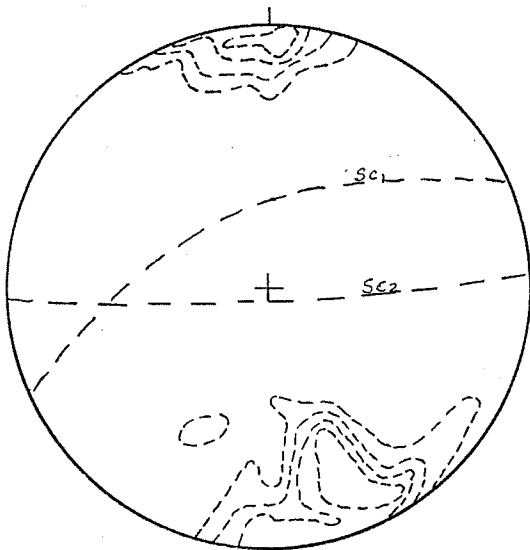


Figure 17b. Sub-area II;
(Crabclaw Lake Granite) equal-area
projection of 112 poles to foliation
contoured at 2, 4, 6 and 8%
per 1% area. Sc_1 and Sc_2 are
foliation planes at right angles to
the two areas representing maximum
concentration of foliation poles.

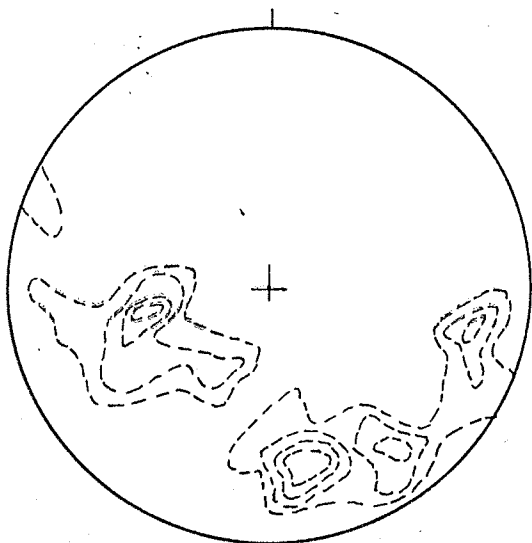


Figure 17c. Sub-area III;
(Feist Lake Granite) equal-area
projection of 42 poles to foliation
contoured at 2, 4, 6 and 8% per
1% area.

CHAPTER VI

INTERPRETATION OF STRUCTURAL HISTORY

INTRODUCTION

Four deformational events have been recognized in the rocks of the map-area; evidence for these events is from field investigations, microscopic studies and the geometric analysis of structural elements. This chapter presents the pertinent evidence for deformational history along with a quantitative strain analysis for each deformational event. The tectonic history of the Tustin-Bridges area is summarized in Table III.

The interpretation of the structural history is based primarily on: (a) the identification of the regional foliation as tectonic in origin; (b) the recognition of structural events that predated the foliation development; and (c) the identification of deformational events that post dated the development of foliation.

FIRST PERIOD OF DEFORMATION - D_1

Evidence for D_1

The evidence for D_1 is in the form of planar biotite arranged in a sub-parallel manner transecting the bedding and

Table III - Tectonic History of the Tustin-Bridges Area.

Deformational Period	Surfaces Deformed	Fold Style and Geometry	Mechanism	Structures Developed
D ₁	Bedding	unknown	unknown	some minor folds
D ₂	Bedding	unknown	cataclastic slip and recrystallization	tectonic foliation, mineral and fragment lineations, Cobble Lake break
D ₃	Foliation Bedding	-concentric in foliation, -conical or cylindroidal?	flexural slip on foliation surfaces	major and minor folds, detachment zone
D ₄			brittle fracture	mesoscopic fractures and mortar textures

axial plane of a minor fold structure, indicating that the deformation of bedding occurred prior to the development of foliation.

Although minor and major structural elements resulting from D_1 have not been recognized in the field studies, this evidence was determined from the study of a single thin section of a minor fold structure in a bedded metasedimentary rock, located two miles east from Cobble Lake (Docker Township). The evidence for this event is not strong and future work may negate this interpretation. If bedding was deformed prior to foliation development, the deformation may have been a consequence of: (1) the early stages of the major deformational period during which foliation was developed, or (2) to an early period of deformation not related to the above-mentioned one. The latter interpretation is consistent with the structural history of other greenstone belts of the Superior Province (Brisbin, 1969).

Strain Analysis of D_1

The general lack of mesoscopic and megascopic structural elements, related to D_1 , precludes an interpretation of strain. Any fabric related to D_1 , if it took place, has been obliterated by later events so that it is not possible to draw conclusions on the mechanism of deformation. The single minor fold structure that was studied in thin section appears to be concentric

but transecting foliation distorts the original symmetry of the fold.

SECOND PERIOD OF DEFORMATION - D_2

Evidence For D_2

Evidence for D_2 is obtained from the microscopic and mesoscopic textural and structural characteristics and the orientation of foliation surfaces, mineral lineations and fragment lineations. D_2 is synchronous with regional metamorphism.

The preferred orientation of mineral grains, which define secondary foliation and lineation structures, results from deformation and recrystallization, evidence for which was given in Chapter III. Briefly stated, evidence for deformation is indicated by undulatory extinction in quartz and plagioclase and by cataclastic textures, particularly in the metatuff-breccias. Recrystallization under stress is evident in the parallel alignment of undeformed biotite and muscovite and the linear alignment of hornblende crystals.

The regional orientation of foliation in the metamorphic belt is approximately parallel to the contact of the nearest batholith. Foliation and mineral and fragment lineations, in the north part of the metamorphic belt (sub-area A, Figure 12) have a uniform orientation (Figure 13a) whereas, in the south

part of the belt (sub-area B) the same structural elements have been re-oriented (Figure 13b). This re-orientation is a result of a later deformational event (D_3) and will be discussed later. The orientation of the secondary structural elements in sub-area A probably have not been altered greatly since their development.

Strain Analysis of D_2

Field evidence, thin-section studies and measurement of fragment dimensions indicate that the main strain during D_2 was accomplished by cataclastic slip and recrystallization and that layering behaved passively. Mineral and fragment lineations indicate that the direction of maximum extensive strain was approximately vertical and that the maximum compressive strain was approximately horizontal and perpendicular to foliation planes.

Whole rock strain is best portrayed in the metatuff-breccias. Figure 10 shows the regional variation in the ratio of fragment dimensions and probably depicts variation in the degree of strain. The average ratio for the area is 1:7:15. Each figure is the average of 5 to 10 readings taken on felsic fragments which predominate in the unit. Complete ratios were not determinable at some localities because of the nature of the exposures; at these localities minimum:intermediate ratios are shown. Near the contact with the granitic masses, the fragments exhibit a higher

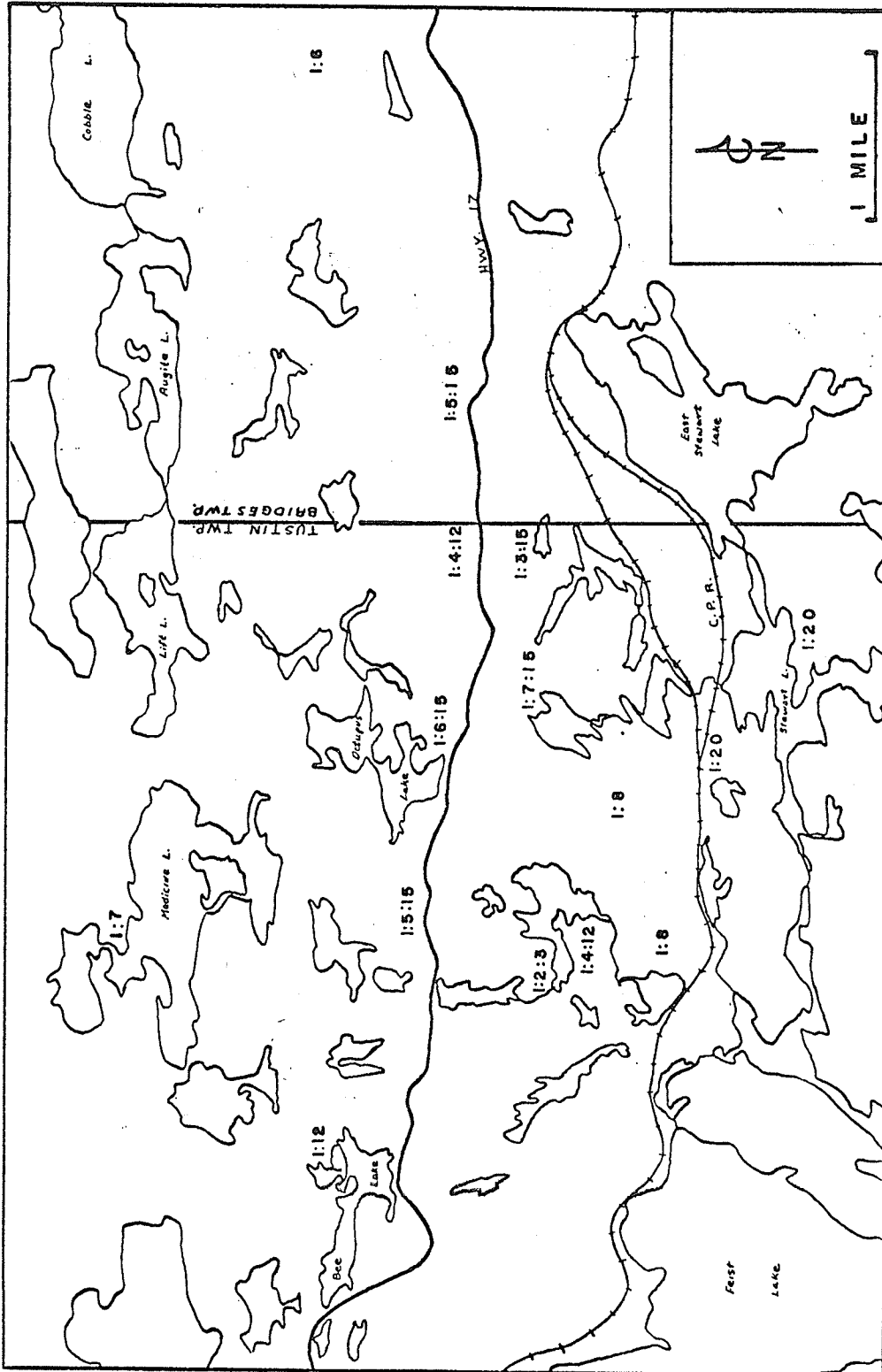


Figure 18. The ratio of fragment dimensions as determined from field measurements. Each ratio represents 5 to 10 readings. The dimension of the long axis is not readily measured at all localities.

Legend: 1:5:15 is minimum : intermediate to maximum.
 1:5 is minimum : intermediate.

degree of deformation.

Variation in the present deformed shape of the fragments depends upon several factors: (1) the original shape of the fragments; (2) the ductility contrast between the fragment and the matrix; (3) fragments of different composition have different competency; (4) variation in the amount of deformation.

Where bedding occurs, foliation generally is parallel to this anisotropy. Figure 18 illustrates the variation in the development of foliation in bedded metatuff and metalapillituff. The area of maximum fragment deformation coincides with the area of best developed foliation. Foliation in the massive metatuff is poorly developed. Therefore, deformed fragments can be used only as a partial measure to indicate whole rock strain.

"As lineations, however, the elongate deformed fragments may be used to identify the direction of flow or slip during passive deformation"
(Brisbin, 1968, abs.).

THIRD PERIOD OF DEFORMATION - D_3

Evidence For D_3

The main evidence for D_3 is obtained from; (1) the re-orientation of foliation and mineral and fragment lineations that were developed during D_2 ; (2) the intrusive relationship

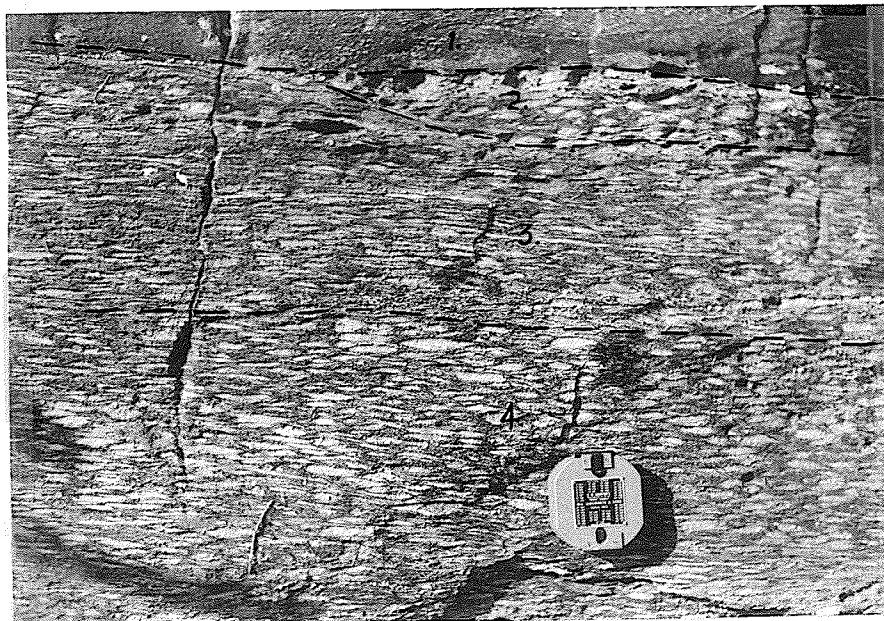


Figure 19 Vertical view of a bedded tuff-lapilli tuff, Medicine Lake area. The photo is approximately perpendicular to the foliation surfaces and the long axis of the clasts. Four strain domains are outlined;

1. Mafic tuff, weakly foliated.
- 2, 3 & 4. Lithic lapilli-tuff with the average ratio of short to intermediate axis from 10 reading per domain being, 1:4.2, 1:10 and 1:6.5, respectively.

and regional distribution of pegmatites.

The secondary structural elements, that were developed as a result of D_2 , have a uniform orientation in sub-area A but show a re-orientation in sub-area B (Compare Figures 13a and 13b) due to D_3 . The re-orientation resulted in a concentric fold in the foliation, which is considered to be conical in form (Figure 16b). The folded foliation in sub-area B is separated from the rocks to the north (i.e. sub-area A), that were relatively unaffected by D_3 , by a series of sub-parallel faults forming a detachment zone.

The shape and distribution of pegmatites provides further evidence for D_3 . The pegmatites may show considerable variation in shape but are generally tabular to lensoid. Although they crosscut foliation locally, they are approximately conformable to foliation on a regional scale. The regional distribution of pegmatites can be readily explained as a natural consequence to flexural folding of foliation. Space is provided by the folding process. Whitten (1966) states:

"during flexural folding arcuate 'spaces' commonly develop between successive competent layers; as deformation proceeds such potential 'spaces' become filled with incompetent material that migrates plastically, or with precipitates of the more mobile constituents."

Strain Analysis of D_3

D_3 resulted in the development of a major fold structure. The operative mechanism, with foliation surfaces active, is one of flexural folding. The fold structure was developed in the southern part of the metamorphic belt and D_3 did not appreciably affect the rocks in the northern part of the belt. The two different parts of the metamorphic belt represent different strain domains and are separated by a detachment zone. The geometry of foliation and lineations, that were developed during D_2 , indicate that these structures were re-oriented into a conical fold.

Pegmatites, quartz-epidote-garnet veins and shears, mark zones of dilation and slip which, along with foliation planes, were kinematically active during D_3 .

FOURTH PERIOD OF DEFORMATION - D_4

Evidence For D_4

D_4 is characterized by brittle deformation in the form of discontinuous fractures of various orientation and is most prevalent in the felsic igneous rocks intruding the metavolcanic-metasedimentary-metagabbroic rocks. Thin sections of these rocks commonly reveal mortar textures.

There is no evidence to indicate whether or not D_4 is a separate period of deformation or is related to the end stages

of D_3 . Deformation of the metavolcanic-metasedimentary belt during D_3 was probably in the brittle domain.

Strain Analysis of D_4

Unlike joints, which in a particular exposure are generally restricted to two or three directions and crosscut all lithologic units, the fractures in the late felsic igneous rocks that intrude the metamorphic belt, particularly the pegmatites, are discontinuous and randomly oriented.

CHAPTER VII

RELATIONSHIP BETWEEN DEFORMATIONAL HISTORY AND INTRUSIVE HISTORY

INTRODUCTION

Numerous felsic, mafic and ultramafic bodies intrude the metavolcanic-metasedimentary sequence, and three large granitic igneous masses are in contact with the host metamorphic belt. The relative ages of these granitic masses, as well as the other intrusive rocks in the area, can be deduced partially by (1) the presence or absence of structural features attributable to the deformational events and by (2) the contact relationships between the granitic masses with other intrusive units.

The age relationship between the deformational events and the intrusive history is summarized in Table IV. Specific evidence is presented in the following section.

QUARTZ-FELDSPAR PORPHYRY

The quartz-feldspar porphyry, located immediately south of Cobble Lake, has a tabular-shape and is concordant with the metavolcanic rocks. Contact relationships with the host mafic metavolcanic rocks and the amphibolite rocks were not observed in the field.

The quartz-feldspar porphyry has been regionally metamorphosed and therefore, is pre-D₂. The age relationship of this

rock with exact time is unknown.

AMPHIBOLITE

The amphibolite rocks occur as sills within the mafic metavolcanic rocks and as irregular shaped bodies spatially related to the metagabbros, metapyroxenites and metaperidotites. They have been regionally metamorphosed and therefore are pre-D₂. Petrological data indicates that they may be genetically related to the mafic metavolcanic rocks; if this interpretation is correct the amphibolites may be pre-D₁.

ENGLISH RIVER GNEISS BELT

Rocks of the English River belt exhibit intrusive relationships with the metamorphic belt and there is evidence to indicate that vertical emplacement of the gneissic belt was contemporaneous with metamorphism of the volcanic-sedimentary sequence.

Massive mafic inclusions are common in the gneissic granodiorite and have a widespread distribution. Inclusions of metavolcanic rocks are also present but are restricted to an area of approximately several hundred feet in width along the contact of the English River Belt and the metamorphic belt. The massive inclusions, if derived from the greenstone belt, indicate that the gneissic granodiorite was emplaced prior to or contemporaneous with regional metamorphism of the metavolcanic-

TABLE IV - AGE RELATIONSHIPS BETWEEN INTRUSIVE
HISTORY AND THE DEFORMATIONAL HISTORY
OF THE GREENSTONE BELT.

INTRUSIONS	DEFORMATIONAL EVENTS ¹
Quartz-feldspar porphyry	Pre-D ₂ .
Metagabbro (amphibolite)	Pre-D ₂ ; possibly pre-D ₁ .
Gneissic granodiorite (English River Belt)	Syntectonic with D ₂ (?)
Metaperidotite	Post-D ₂ .
Metapyroxenite	Post-D ₂ .
Metagabbro	Post-D ₂ .
Crabclaw Lake Complex:	
1) Foliated biotite granodiorite	Pre-D ₂ (?)
2) 'Quartz-eye' granodiorite	Post-D ₂ (?)
3) Migmatitic granodiorite, quartz-monzonite	Post-D ₂ .
4) Granite, pink pegmatite	Post-D ₂ ; possibly syntectonic with D ₃ .
Cobble Lake granodiorite, white pegmatite	Post-D ₂ .
Biotite granodiorite (Feist Lake Pluton), pink pegmatite	Syntectonic with D ₃ .

¹D₂ is identified as synchronous with regional metamorphism of the greenstone belt.

D₃ is identified as synchronous with the flexural folding of foliation in the south part of the belt.

metasedimentary belt. The foliated inclusions and their restricted distribution indicate that the metavolcanic-metasedimentary belt had suffered metamorphism and deformation prior to final consolidation of the gneisses. Emplacement of the English River belt, during D_2 , is consistent with the orientation of lineations and foliation in the north part of the metamorphic belt. The foliation in the English River rocks (sub-area I) is approximately parallel to foliation in sub-area A (Compare Figure 17a with 13a). The discrepancy in the dips is attributed to the gradual decrease in the dip of foliation in the metavolcanic-metasedimentary rocks away from the contact with the gneissic belt. The development of flow foliation in the gneissic rocks was probably contemporaneous with the development of tectonic foliation in the metavolcanic-metasedimentary sequence. No fabric data was obtained to indicate what the mode of emplacement may have been for the English River belt. However, a vertical emplacement is suggested from refraction seismology studies by Hall and Hajnal (1969). These studies indicate that the English River belt is suggestive of blocks with sharp flexures or possibly faults at the margins.

MAFIC AND ULTRAMAFIC INTRUSIVE ROCKS

Mafic and ultramafic rocks intrude the metavolcanic-metasedimentary sequence but have not been regionally metamorphosed to the amphibolite facies and therefore, have been interpreted

as post-D₂. Alteration of these rocks is attributed to auto-metamorphism. Intrusive relationships among the members indicate that the order of intrusion from oldest to youngest was; meta-peridotite, metapyroxenite, and metagabbro. All three members are intruded by pegmatite dikes.

CRABCLAW LAKE BATHOLITH

At least four intrusive units have been identified within this igneous complex. The oldest phase is a foliated, grey biotite granodiorite, which forms only a minor portion of the total biotite granodiorite unit. There is no evidence that links the oldest unit with any of the deformational events within the metamorphic belt. All of the other members of this complex contain inclusions of metavolcanic-metasedimentary rocks and therefore, are interpreted to be post-D₂. Pink granite, pink pegmatitic granite and pegmatite are the youngest intrusive rocks in this complex, and although their intrusion may have been responsible for the folded foliation in the metamorphic belt (D₃) this has not yet been definitely established.

FEIST LAKE PLUTON

The Feist Lake Pluton is interpreted as a piercement structure. The linear alignment of metavolcanic inclusions, located at the periphery of the pluton, and the lineations produced by primary feldspar phenocrysts in the vicinity of Bee Lake, are

attributed to a flow mechanism during vertical piercement emplacement.

Inclusions of metagabbro occur in this pluton in the area between Feist Lake and Windermere Lake. The folded foliation in the metavolcanic-metasedimentary belt may have developed in response to the intrusion of this pluton as well as to the emplacement of the Crabclaw Lake batholith.

FELSIC IGNEOUS ROCKS INTRUDING THE GREENSTONE BELT

(a) Cobble Lake Granodiorite and White Pegmatite

White pegmatite dikes in the vicinity of Augite and Cobble lakes are spatially and petrologically related to the granodiorite in the Cobble Lake area. Both the pegmatite and the granodiorite, contain inclusions of metamorphosed volcanic, sedimentary and gabbroic rocks and therefore, were intruded post- D_2 and are younger than the metagabbroic rocks.

(b) Pink Pegmatite

Pink pegmatite dikes have a widespread occurrence within the metamorphic belt but are most common: (1) along the contact between the rocks of the metamorphic belt and the granitic rocks to the south; and (2) within the metavolcanic-metasedimentary rocks in that part of the metamorphic belt that was folded during D_3 .

The regional distribution of pegmatites within the major fold structure indicates that they were intruded into 'spaces' that were developed as a result of flexural folding on foliation (D_3). Consequently, the pegmatites are probably syn- D_3 and may be related to the intrusion of the Feist Lake granodiorite or to the intrusion of the younger phases in the Crabclaw Lake batholith.

CHAPTER VIII

SUMMARY

Volcanic and sedimentary rocks, regionally metamorphosed to the almandine amphibolite facies, form an east-west trending belt extending from the southeast shore of Silver Lake, Jackman Township, to the vicinity of Sanford Township. The belt varies in width from 100 feet to 4 miles; foliation within the belt dips approximately vertical in the northern part of the belt but varies from 10 degrees to 75 degrees north in the southern part of the belt.

The belt is bordered to the north by the English River belt. The contact between these belts is sharp. The trend of the southern limit of the metamorphic belt is variable and is bordered by the Feist Lake pluton and the Crabclaw Lake batholith. The contact between the granitic rocks and the metamorphic rocks is migmatitic.

A sill of quartz-feldspar porphyry, and minor dikes and sills of mafic rocks (mapped as amphibolite) were intruded into the volcanic-sedimentary sequence early in their history and prior to regional metamorphism or deformation.

Field and thin-section studies indicate that the rocks of the metamorphic belt have suffered four periods of deformation.

1. Structures related to the first period of deformation are mainly obliterated by later deformational events.

2. The second period of deformation accompanied regional metamorphism of the volcanic-sedimentary sequence to the almandine amphibolite facies. Foliation and mineral lineations were developed as a result of cataclastic slip and recrystallization. Fragments were deformed into ellipsoids with the long and intermediate axes aligned in the plane of foliation. The direction of tectonic transport, defined by the lineations, was approximately vertical. The mechanism of deformation is interpreted to be the vertical emplacement of the English River belt. Minor amounts of felsic, mafic and ultramafic rocks were intruded into the volcanic-sedimentary sequence post-regional metamorphism of the belt.

3. The third period of deformation resulted in the re-orientation of structural elements that were developed during the second period of deformation. This event produced a fold in the foliation in the southern part of the metamorphic belt. A statistical study of the geometry of this fold and re-oriented lineations indicates that the fold may be conical in form. The northern part of the belt was not greatly affected by the strain of the third deformation event and the area is separated from the south part of the belt by a series of sub-parallel faults. The mechanism responsible for deformation is interpreted as the

vertical emplacement of either the Feist Lake pluton or the younger phases of the Crabclaw Lake batholith, or possibly both.

The fourth period of deformation is represented by the brittle fracture in pegmatites that were intruded as semi-concordant bodies in the metavolcanic-metasedimentary rocks during the third deformational event. Evidence is insufficient to interpret a mechanism for the fourth deformational event.

List of References

Brisbin, W. C.

- 1969: Deformation of Sedimentary and Volcanic
Fragments During Passive Folding. Abstract.

Davies, J. C., and Pryslak, A. P.

- 1967: Geological Compilation Sheet 2115, Kenora-
Fort Francis Sheet; Ontario Dept. of Mines.

Donath, F. A., and Parker, R. B.

- 1964: Folds and Folding; Geol. Soc. Am. Bull.,
v. 75, p. 45-62.

Dwibedi, K.

- 1966: Petrology of the English River Gneissic Belt,
northwestern Ontario and southwestern Manitoba;
unpublished Ph.D thesis, University of Manitoba.

Hall, D. H. and Hajnal, Z.

- 1969: Crustal Structures of Northwestern Ontario;
Refraction Seismology; C.J.E.S., v. 6, No. 1,
p. 81-100.

Pryslak, A. P. (in press)

- Geology of the Tustin-Bridges Area; Ontario
Dept. of Mines and Northern Affairs.

Ramsay, J. G.

1967: Folding and Fracturing of Rocks; New York,
McGraw Hill, 568p.

Stauffer, M. R.

1964: The Geometry of Conical Folds, New Zealand;
Journal of Geology and Geophysics, v. 7,
No. 2, p. 340-347.

Stockwell, C. H.

1964: Fourth report on structural provinces, orogenies,
and time-classification of rocks of the Canadian
Precambrian Shield; Geol. Surv. Can., paper
64-17 (part II), p. 1-21.

Turner, F. J., and Verhoogen, J.

1960: Igneous and Metamorphic Petrology; New York,
McGraw Hill, 694p.

Weiss, L. E.

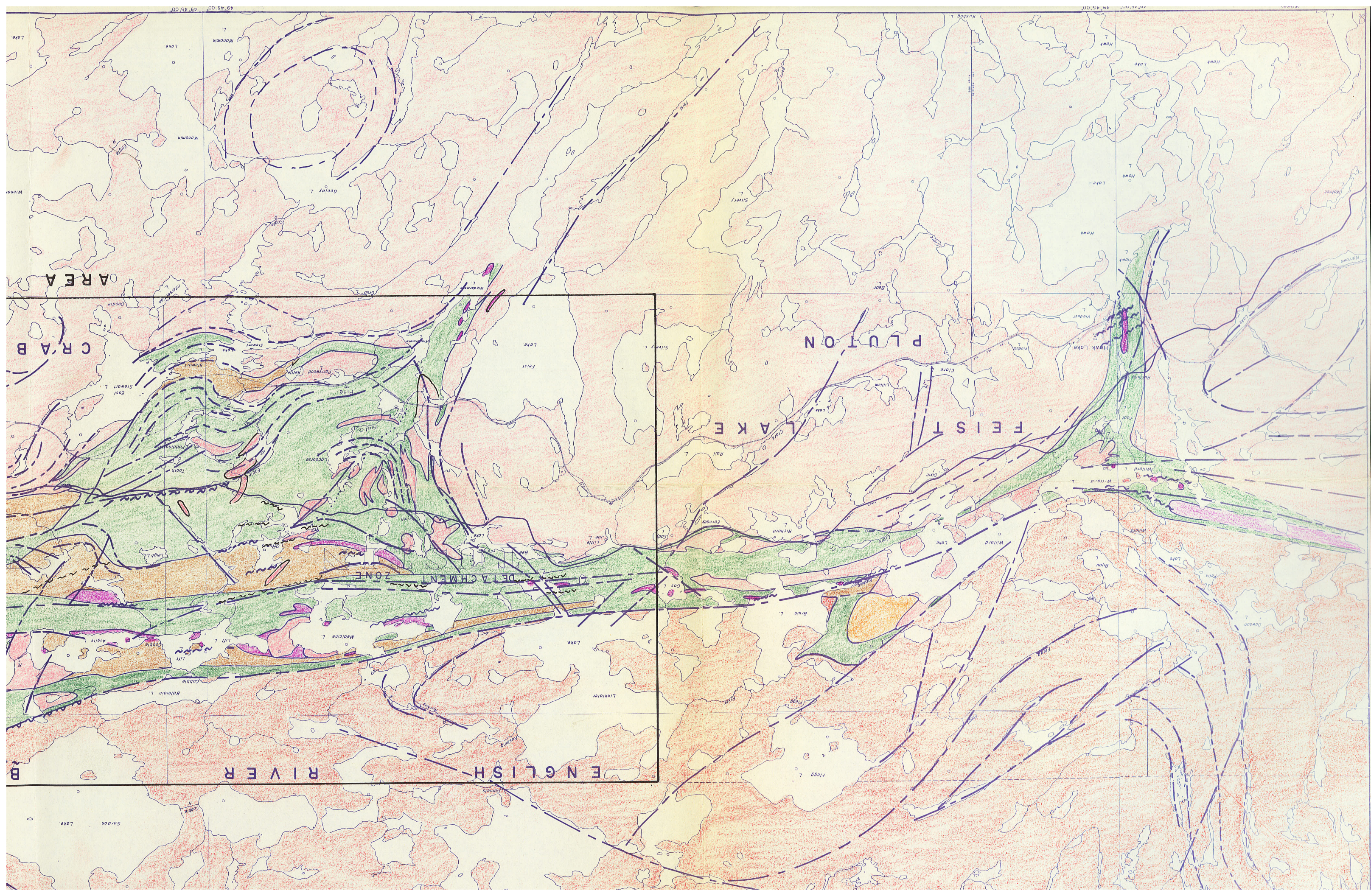
1959: Geometry of Superposed Folding; Geol. Soc. Am.
Bull., v. 70, p. 91-106.

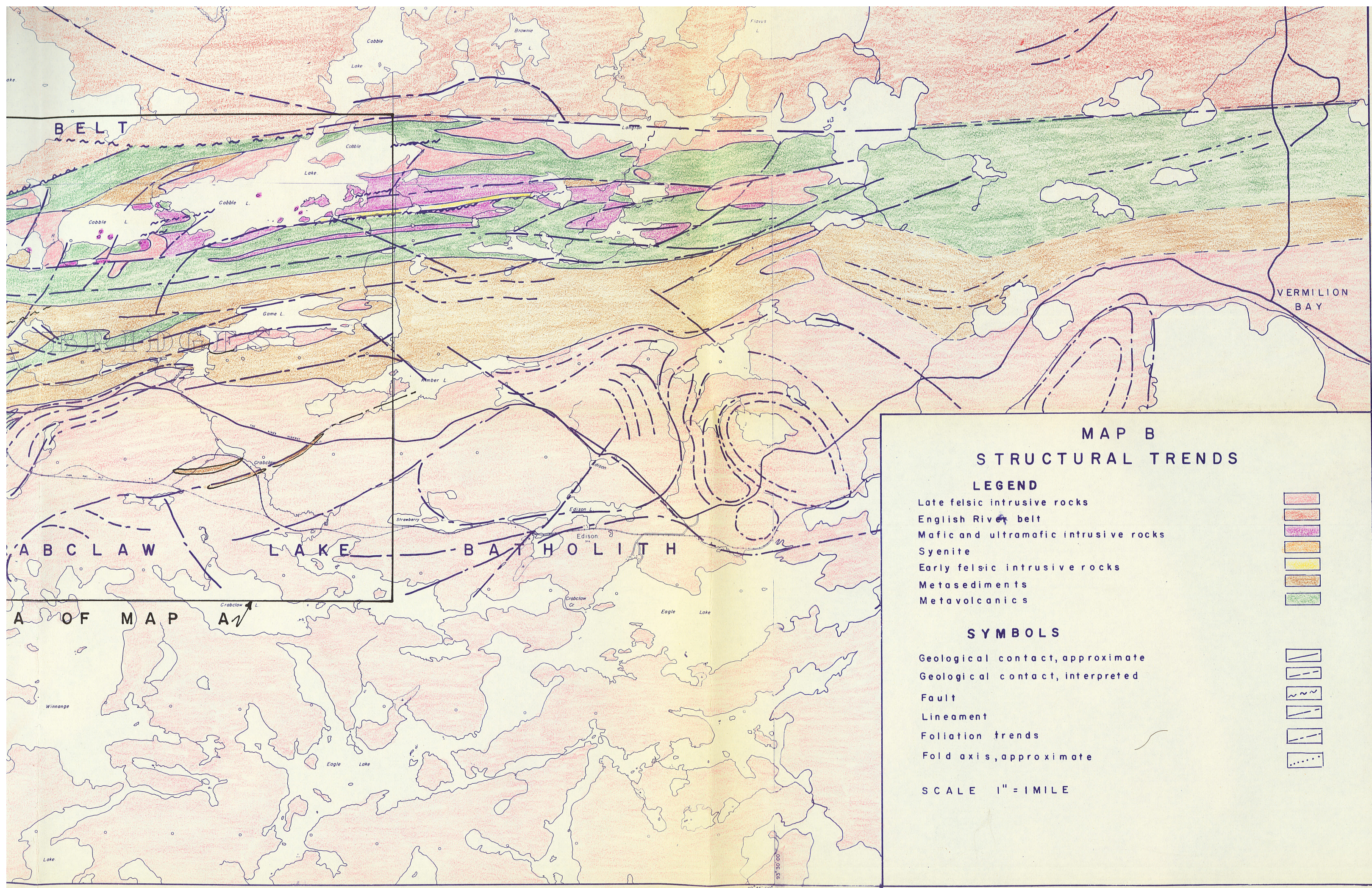
Whitten, E. H.

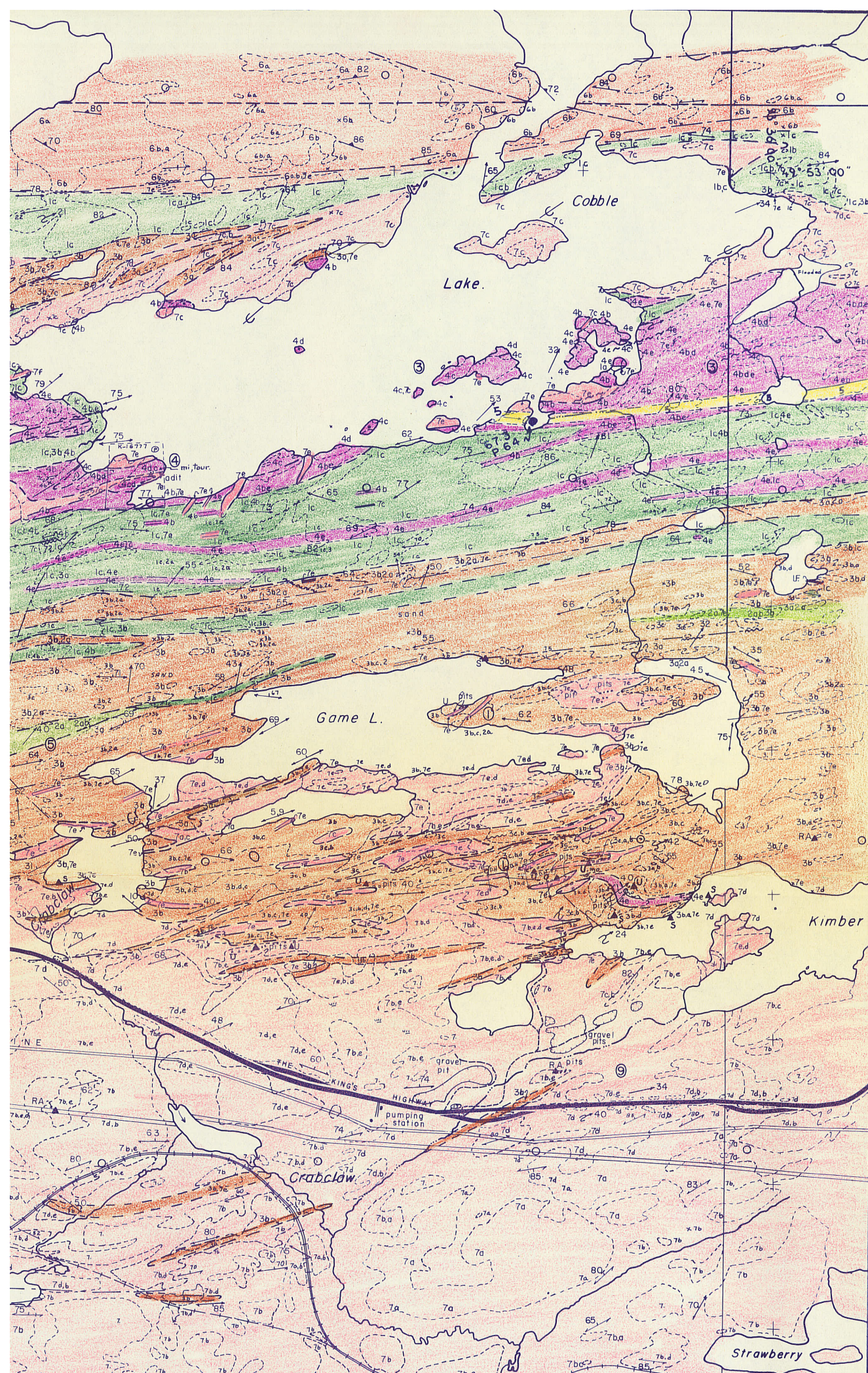
1966: Structural Geology of Folded Rocks; Chicago,
Rand McNally and Co., 663p.

Winkler, H. G. F.

1967: Petrogenesis of Metamorphic Rocks; Springer-
Verlag, New York Inc., 237p.







LEGEND

CENOZOIC

RECENT

Lake, stream, and swamp deposits

PLEISTOCENE

Sand, gravel, and clay deposits

UNCONFORMITY

PRECAMBRIAN

7 GRANITIC ROCKS

7 Undifferentiated

7a. Biotite granite

7b. Equigranular, biotite-quartz monzonite, biotite granodiorite, hornblende-biotite granodiorite

7c. Porphyritic biotite granodiorite

7d. Migmatite

7e. Pink pegmatite, pegmatitic granite, aplite

7f. White pegmatite

6 GRANITIC ROCKS OF THE ENGLISH RIVER BELT

6 Undifferentiated

6a. Equigranular, gneissic, biotite granodiorite, hornblende-biotite granodiorite

6b. Porphyritic, massive to foliated, biotite granodiorite

6c. Equigranular, massive to foliated, biotite-quartz monzonite, biotite granodiorite

INTRUSIVE CONTACT

5 EARLY FELSIC INTRUSIVE ROCKS

5 Quartz-feldspar porphyry

INTRUSIVE CONTACT

4 METAMORPHOSED MAFIC AND ULTRAMAFIC ROCKS

4 Undifferentiated

4a. Quartz diorite

4b. Gabbro

4c. Peridotite

4d. Amphibolite

INTRUSIVE CONTACT

3 METASEDIMENTS

3 Undifferentiated

3a. Muscovite-bearing metagreywacke

3b. Biotite-bearing metagreywacke

3c. Hornblende-bearing metagreywacke

3d. Garnetiferous metagreywacke

3e. Calc-silicate gneiss

2 INTERMEDIATE METAVOLCANICS

2 Undifferentiated

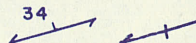
2a. Tuff, lapilli-tuff, tuff-breccia

SYMBOLS

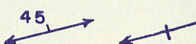
Bedding (inclined, vertical)



Foliation (inclined, vertical)



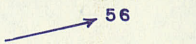
Schistosity (inclined, vertical)



Gneissosity (inclined, vertical)



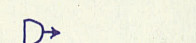
Lineation with plunge



Glacial striae



Tops from pillow shapes



Tops from graded bedding



Area of bedrock outcrop



Small bedrock outcrop



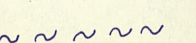
Geological boundary



Lineament



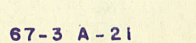
Fault



Drill hole



Thin section location

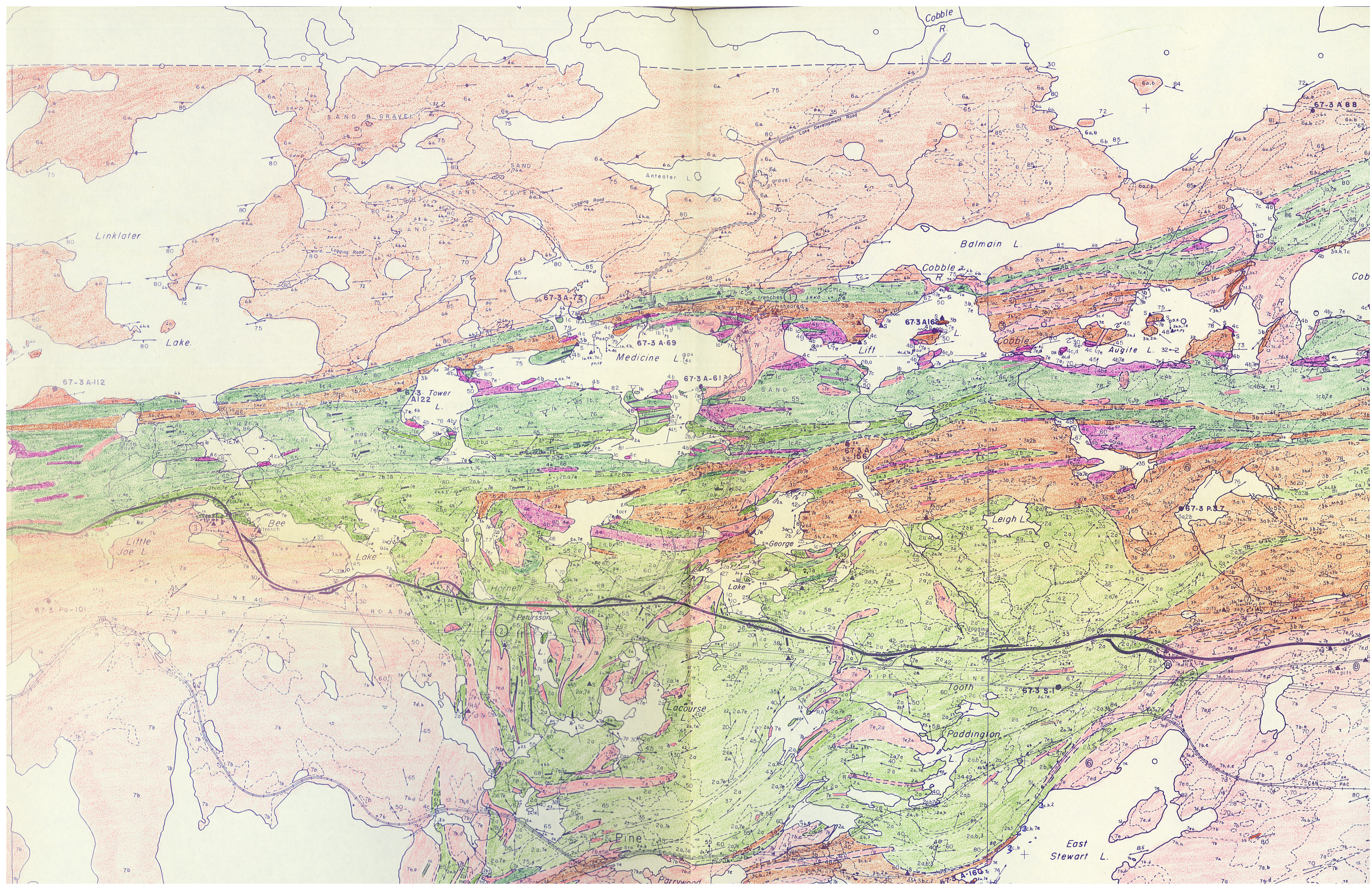


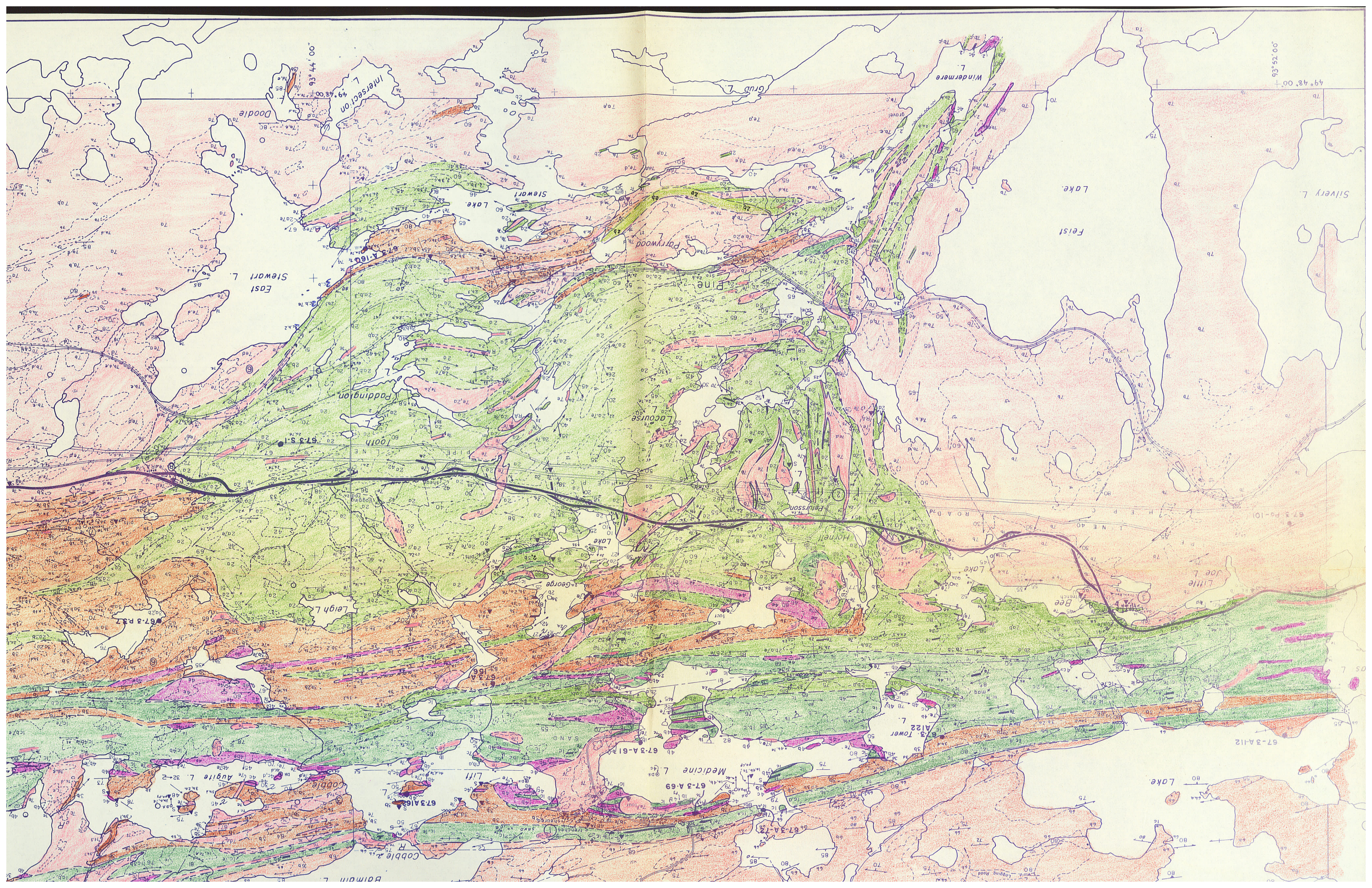
Drag fold with plunge



MAP A

GEOLOGY OF







PRECAMBRIAN

- 7 GRANITIC ROCKS
 - 7 Undifferentiated
 - 7a. Biotite granite
 - 7b. Equigranular, biotite-quartz monzonite, biotite granodiorite, hornblende-biotite granodiorite
 - 7c. Porphyritic biotite granodiorite
 - 7d. Migmatite
 - 7e. Pink pegmatite, pegmatitic granite, aplite
 - 7f. White pegmatite

- 6 GRANITIC ROCKS OF THE ENGLISH RIVER BELT
 - 6 Undifferentiated
 - 6a. Equigranular, gneissic, biotite granodiorite, hornblende-biotite granodiorite
 - 6b. Porphyritic, massive to foliated, biotite granodiorite
 - 6c. Equigranular, massive to foliated, biotite-quartz monzonite, biotite granodiorite

- 5 EARLY FELSIC INTRUSIVE ROCKS
 - 5 Quartz-feldspar porphyry

- 4 METAMORPHOSED MAFIC AND ULTRAMAFIC ROCKS
 - 4 Undifferentiated
 - 4a. Quartz diorite
 - 4b. Gabbro
 - 4c. Peridotite
 - 4d. Amphibolite

- 3 METASEDIMENTS
 - 3 Undifferentiated
 - 3a. Muscovite-bearing metagreywacke
 - 3b. Biotite-bearing metagreywacke
 - 3c. Hornblende-bearing metagreywacke
 - 3d. Garnetiferous metagreywacke
 - 3e. Calc-silicate gneiss

- 2 INTERMEDIATE METAVOLCANICS
 - 2 Undifferentiated
 - 2a. Tuff, lapilli-tuff, tuff-breccia
 - 2b. Hornblende-biotite-quartz-feldspar schists (possibly metasedimentary in part)

- 1 MAFIC METAVOLCANICS
 - 1 Undifferentiated
 - 1a. Tuff, lapilli-tuff, tuff-breccia
 - 1b. Pillowed flows
 - 1c. Hornblende-plagioclase schists; biotite-hornblende-plagioclase schists; garnet-hornblende-plagioclase schists (possibly metasedimentary in part).

- Gneissosity (inclined, vertical)
- Lination with plunge
- Glacial striae
- Tops from pillow shapes
- Tops from graded bedding
- Area of bedrock outcrop
- Small bedrock outcrop
- Geological boundary
- Lineament
- Fault
- Drill hole
- Thin section location
- Drag fold with plunge

MAP A GEOLOGY OF TUSTIN AND BRIDGES TOWNSHIPS DISTRICT OF KENORA

Scale: 1" = 1/2 mile