TECTONIC EVOLUTION ENGLISH RIVER SUBPROVINCE

TECTONIC EVOLUTION
OF A PART OF THE
ENGLISH RIVER SUBPROVINCE
NORTHWESTERN ONTARIO

By

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Abstract

The English River Subprovince of Northwestern Ontario is an Archean gneissic terrain flanked by the greenstone-granite terrains of the Uchi and Wabigoon Subprovinces. Detailed and regional investigations have unravelled the complex question of the relative ages of rocks within these subprovinces.

Three tectonic rock assemblages have been defined. Tectonic assemblage I occupies the southern and central parts of the English River Subprovince and forms part of the English River Plutonic complex. This assemblage is dominated by severely deformed granitoid gneisses containing isoclinal D1 folds within the gneissic banding which are hence considered to be the oldest rock unit present (Cedar Lake gneisses).

Amphibolitic enclaves within the gneisses may represent an early supracrustal assemblage or a dyke swarm intruded into the gneisses. A subsequent tectonic event (D2) has produced isoclinal folds in both gneissic banding and amphibolite enclaves.

Strongly foliated tonalites and granodiorites of the Clay Lake Granitoid suite do not contain isoclinal (D2) folds and appear to have intruded the Cedar Lake gneisses and their associated amphibolites. This cannot be demonstrated

unequivocably however due to later deformation and the Clay Lake Granitoid Suite is hence included in Tectonic assemblage I.

Tectonic assemblage II underlies the northern part of the English River Subprovince and forms part of the English River Metasedimentary Migmatite Complex. The assemblage is dominated by garnet and cordierite bearing metasedimentary gneisses with a high proportion of granitoid leucosome. Metavolcanic rocks are restricted to a narrow belt at the southern margin of the complex.

It has been demonstrated elsewhere that rocks of tectonic assemblage II may be traced laterally into metasediments and metavolcanic rocks of the Uchi Subprovince with which they are partly coeval. A metaconglomerate at Perrault Lake contains clasts of foliated tonalite similar to rocks of the Clay Lake Granitoid Suite. Rocks of tectonic assemblage II have never been found as inclusions within rocks of tectonic assemblage I. This implies that tectonic assemblage II was deposited, at least in part, on a sialic basement of tectonic assemblage I.

The Twilight Gneisses of the Clay Lake area and pillow lavas and banded iron formation of the Cliff Lake area are correlated with rocks of Tectonic assemblage II. These rocks do not contain isoclinal (D2) folds but have been affected by a period of strong layer-normal compression (D3). The occurrence of Twilight gneisses in the cores of later domal structures, below rocks of tectonic assemblage I, indicates that the D3 event was associated with subhorizontal tectonics causing interleaving of "basement" and "cover".

The D3 deformation was the first event to affect rocks of tectonic assemblage II. It was accompanied by a high grade regional metamorphism producing upper amphibolite facies mineral assemblages over wide areas of the English River Subprovince. Granulitic mineral assemblage were produced in the Clay Lake area under conditions estimated to be in the range 650-750°C and 4.5 to 7.0 kb.

The D3 tectonic event was succeeded by intrusions of tectonic assemblage III which range from equigranular tonalites through porphyritic granodiorites to equigranular pink granites. These intrusions were emplaced throughout the English River Subprovince and are probably temporal equivalents of the "diapiric granitoid intrusions" of the Uchi and Wabigoon Subprovinces. The presence of both foliated and massive varieties of all compositions suggests that several phases of emplacement occurred. Trace element data suggests that the intrusive rocks were not generated from rocks compositionally similar to those of tectonic assemblage I.

Intrusion of tectonic assemblage III produced a variety of interfering minor structures in pre-existing rocks. Major dome and basin structures were produced in the Cedar-Clay Lakes area and the prevaling vertical attitude of pre-existing foliations was accomplished throughout the English River Subprovince at this time.

Major faulting at the southern boundary of the English River Subprovince appears to predate intrusions of tectonic assemblage III.

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CHAPTER I

INTRODUCTION

1-1. A REVIEW OF ARCHEAN TERRAINS

Areas of Archean rocks currently exposed on several continents contain two types of terrains with strikingly different tectonic and lithologic characteristics. One of the most intriguing problems of Archean geology, at the present time, concerns the relationships between the so-called "gneissic" terrains and the "greenstone-granite" terrains.

The more widely studied "greenstone-granite terrains consist essentially of volcanic and sedimentary supracrustal formations, metamorphosed to greenschist facies, which have been intruded by large granitoid plutons. The supracrustal formations are generally preserved as steeply dipping "greenstone belts" and are disposed marginally to the granitoid plutons in a manner which suggests that the latter were diapirically emplaced. The plutons are often internally complex, with regard to both fabric and composition. The bulk of the granitoid rocks are, however, tonalites or granodiorites.

Although the "gneissic" terrains are less well characterised they are known to be underlain by large volumes of granitoid gneisses and highly deformed and metamorphosed supracrustal rocks. They have also been extensively intruded by later granitoid plutons.

In the past few years a large number of research programs have produced a wealth of data on Archean gneissic terrains from throughout the world. Much of this scientific curiosity was aroused by the discovery, in Western Greenland, of gneissic rocks which are the oldest known rocks currently exposed at the surface of the earth (O.I.G.L. and McGregor 1971, Moorbath et al 1972). Numerous workers, including McGregor (1973) and Bridgewater et al (1973, 1975), have unravelled a tectonic history for the W. Greenland Archean gneisses which spans the time interval between 3.9 b.y. and 2.5 b.y. This history involves the development of at least two volcanogenic, supracrustal sequences and repeated intrusion and deformation of granitoid plutonic rocks. A similar crustal history has recently been suggested for Archean gneissic rocks of the Saglek Bay area, Labrador, by Bridgewater et al (1975) and Hurst et al (1975).

Archean gneissic terrains, in southern Africa, which possibly contain units predating the major volcanic supracrustal sequences, have been described from the Kaapvaal and Rhodesian Cratons. Stowe (1968, 1971, 1973) has described the "older tonalite gneiss complex" in Rhodesia which he suggests acted as a basement to the later, supracrustal Bulawayan and Shamvaian Groups. Part of this basement complex - the Gwenora migmatites - has recently been dated by Rb-Sr whole rocks methods at 2780 m.y. by Hawkesworth et al (1975). These authors also report ages of 2600-2700 m.y. for units from the Bulawayan supracrustal group and Stowe's original suggestions have therefore not been confirmed. However, Hawkesworth et al (1975) did obtain an age of approximately 3600 m.y. from the Mashaba area gneisses, indicating that this gneissic terrain is clearly older than the major Bulawayan supracrustal group.

Age relationships in the Kaapvaal Craton are far less clear. Hunter (1970, 1973, 1974) suggests that the "Ancient Gneiss Complex" in Swaziland predates development of the major, supracrustal Swaziland Sequence. Viljoen and Viljoen (1969) and Anhaeusser (1973), however, contend that the "Ancient gneiss complex" represents the roots of major greenstone belts that have been pervasively invaded by tonalitic magma. Whole rock Rb/Sr data from Hurley et al (1972) and Jahn and Shih (1974) indicate that the Onverwacht group volcanic rocks formed between 3500 m.y. and 3375 m.y. ago. Rb/Sr whole rock ages from the Ancient gneiss complex have a spread from 3395 m.y. to 3138 m.y.(Allsopp et al 1969). Clearly, the problem of age relationships has not yet been resolved satisfactorily in the Kaapvaal Craton.

A similar controversy currently surrounds the relationships between gneissic and supracrustal rock units exposed in the Archean Shield of India (Naha and Halyburton, 1974; Basu and Arora, 1976).

The Archean Superior Province of the Canadian Shield contains several subprovinces (Stockwell et al, 1970) or structural blocks (Wilson 1971) which are defined in terms of distinctive lithology, metamorphic grade and structural style. Boundaries between these subprovinces are usually recorded in the literature as being marked by major faults. The two major gneissic subprovinces in Western Ontario are the Quetico and English River which are separated by the intervening Wabigoon "greenstone-granite" subprovince.

At the time that the current research project was initiated, remarkably little was known about either the Quetico or English River subprovinces. In particular, the tectonic and temporal relationships between the subprovinces was a matter for considerable speculation. The two most popular hypotheses concerning these relationships were as follows:

(1) The gneissic terrains represent a sialic basement onto which the predominantly volcanic sequence of the greenstone terrains were deposited. The underlying gneissic terrains, in this model, served as a source region for the ubiquitous, diapiric granitoid bodies which invaded the greenstone terrains. Adjacent gneissic terrains served as partial provenance areas for the large volumes of greywacke type sediments which are commonly associated with the greenstone volcanics.

(2) The gneissic terrains represent sedimentary depositional areas which developed synchronously with the greenstone depositional areas. The gneissic terrains were

subsequently locations of both high heat flow (producing high metamorphic grade gneisses) and of massive injections of syntectonic and postectonic granitoid material.

In view of these controversial relationships throughout the world it is hardly surprising that a large number of models have been proposed to explain the tectonic development of Archean terrains. Excellent summaries of the various models are outlined by Anhaeusser (1973), Talbot (1973), Windley and Bridgewater (1971) and Windley (1973). A review of this literature raises the following questions:

(1) Were significant volumes of sialic crust present at the time of formation of the main supracrustal successions?

(2) If so, were they present as isolated protocontinents or as a thin, all enveloping, skin on which the supracrustal successions accummulated?

(3) Were Archean tectonic events dominated by density driven, vertical movements or did horizontal components - akin to present day plate tectonics - exert a controlling influence?

1-2. OBJECTIVES OF THE PRESENT STUDY

With a view to eventually resolving some of the problems outlined above, as they pertain to the Canadian Superior Province, a research program was initiated within the English River subprovince of the N.W. Ontario. The major objectives of the program were as follows:

(1) To determine a detailed structural, metamorphic and intrusive history for a small part of the subprovince.

(2) To present an interpretation and discussion of probable protoliths of the various rock types present within this small area through integration of field, petrographic and geochemical data.

(3) To clearly define the distribution and field relationships of rock types within a larger district of the subprovince. This district would preferably include all the tectonically important rock groups within an approximately north-south section.

(4) To integrate results from both the smaller area and the larger district into a coherent model for the tectonic evolution of the English River subprovince.

(5) To shed some light on the age relationships between the gneissic terrain of the English River subprovince and the adjacent "greenstone-granite" terrains of the Uchi and Wabigoon subprovinces.

Two factors dictated the choice of the English River subprovince as the focus of the research program. The Manitoba Department of Mines and the University of Manitoba published, in 1971, results of an integrated, regional investigation of the northern part of the subprovince in Manitoba (Project Pioneer - Manitoba Mines Branch publication

71-1). In addition, the Ontario Division of Mines were proposing to carry out a two year reconnaissance mapping program of the subprovince which would extend from the Manitoba border to longitude 92°00'W. (Operation Kenora - Ear Falls).

The Perrault Falls - Vermilion Bay district - which the author mapped in 1975 whilst attached to Operation Kenora-Ear Falls - covers an almost complete north-south section of the subprovince and includes the vast majority of the tectonically important rock groups. This district is described in detail in chapter 4 of this thesis.

The Cedar Lake area lies squarely within the Perrault Falls - Vermilion Bay district. The area provides excellent road and lake access and contains a reasonable proportion of rock outcrop. Structures indicated as "paragneiss domes" on O.D.M. compilation map 2175 provided further incentive for the choice of this area for detailed studies.

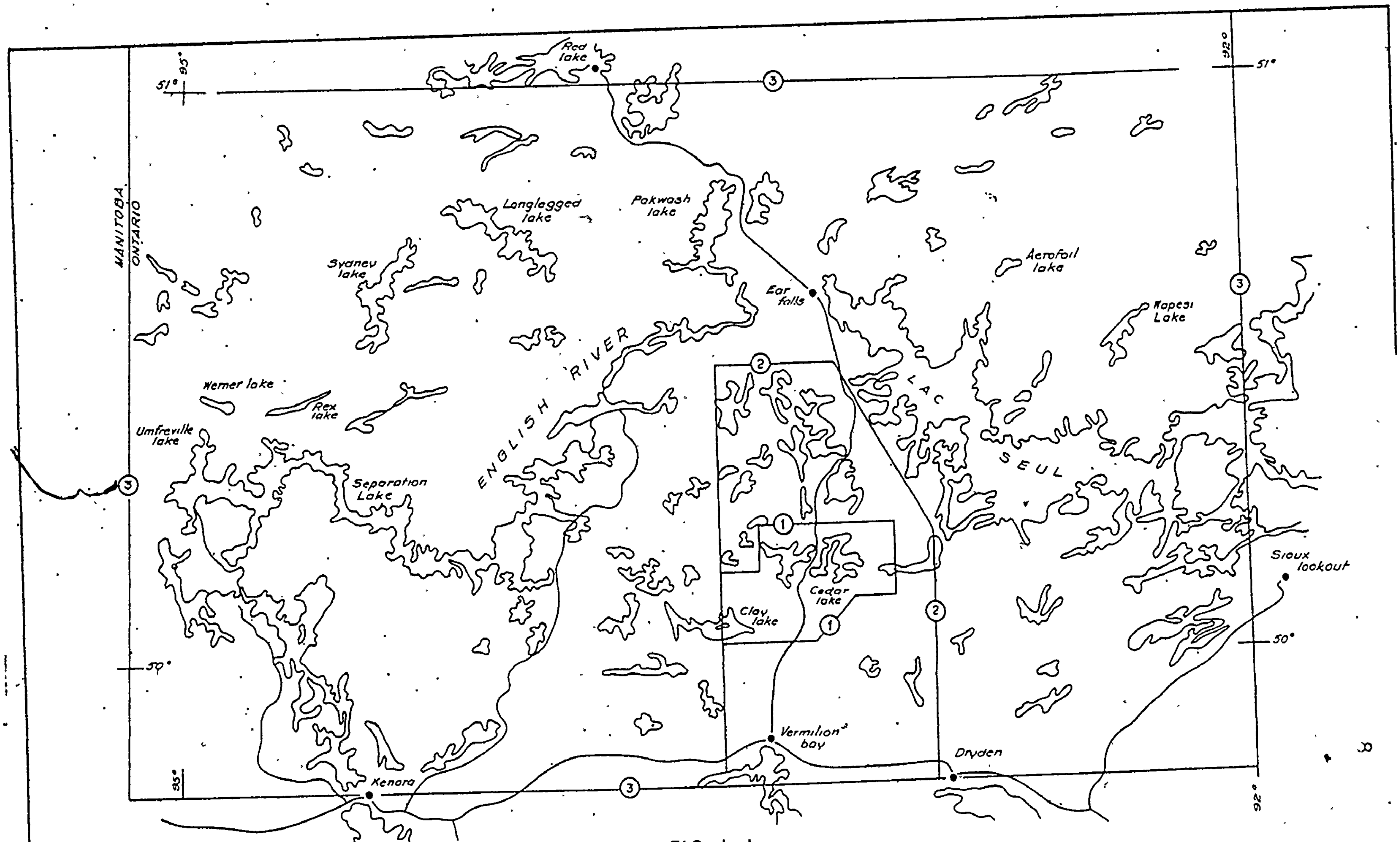


FIG. 1-1

LOCATION MAP SHOWING (1) Cedar lake - Clay lake area, (2) Vermilion Bay Distr. (3) Operation Kenora - Ear Falls

CHAPTER 2

PREVIOUS WORK AND REGIONAL SETTING

2-1 INTRODUCTION

Wilson and Brisbin introduced the term "English River Gneissic Belt" into the geological literature in 1963. Prior to this date there had been no systematic approach to geological investigations in N.W. Ontario and adjacent S.E. Manitoba. During the period 1968-1971 significant advances in both geological and geophysical understanding of southeastern Manitoba were made largely as a result of Project Pioneer, a co-operative undertaking of the Manitoba Mines Branch and the University of Manitoba.

Systematic reconnaissance geological mapping of the English River Subprovince in Ontario was initiated in 1974 by the Ontario Division of Mines. Operation Kenora-Sydney Lake (1974) covered a 5000 square mile area extending from the Manitoba-Ontario boundary to longitude 93°30'W and from latitudes 49°45'N to 50°55'N. In 1975 this program was continued to the east as Operation Kenora-Ear Falls, covering the area bounded by latitudes 49°45'N to 51°00'N and longitudes 93°30'N to 92°00'W.

Ongoing research projects with interest in western Superior Province geology are continuing at the Centre for Precambrian Studies of the University of Manitoba; Geotraverse Project of the University of Toronto and the Archean Crustal

Evolution Group of McMaster University. As a result of the large number of people now actively interested in this region much information has been acquired together with a certain confusion regarding terminology applied to the major geological and tectonic units.

Stockwell et al (in Douglas (Ed) 1970) initially subdivided the western Superior Province into tectonic "belts" or "subprovinces" (fig. 2-1). Stockwell et al use both the "belt" and the "subprovince" terminology in their text but use only the "belt" terminology on their map (fig. iv-1, p.46). Wilson (1971) introduced the concept of crustal "blocks" (fig.2-2) defined by both geological and geophysical criteria. Wilson's "blocks" appear to be geographically equivalent to Stockwell's "belts" but Wilson renamed some of the units and introduced the "Red Lake Block". Goodwin (1974) retained the "belt" terminology of Stockwell et al but introduced the "Uchi Volcanic-Plutonic Belt" - a unit broadly equivalent to Wilson's "Red Lake Block". The "subprovince" terminology and Goodwin's names for the various units have been used by Breaks et al (1974, 1975) and by the present author.

The English River Subprovince is thus broadly regarded as a tectonic entity which is crudely linear in form and lies approximately along latitude 50°N. It extends eastwards from the Paleozoic cover at Lake Winnipeg to the Paleozoic cover of the James Bay lowlands. The subprovince is approximately

80-110 km wide and is bordered to the north and south by the "greenstone-granite" terrains of the Uchi and Wabigoon subprovinces.

The boundaries of the English River Subprovince are poorly defined. Breaks et al (1974- 1975) place the northern boundary of the subprovince at the Sydney Lake Cataclastic Zone. The southern boundary of the subprovince is usually placed at the northern margin of the Tustin-Bridges metavolcanic belt. West of Kenora, however, and eastwards from Vermilion Bay the southern boundary has not been strictly defined.

Upon compilation of the data from Operation Kenora-Ear Falls it has become clear that the subprovince is dominated by metasedimentary migmatites in the north and by plutonic gneisses and granitoid intrusions in the south. Beakhouse (1975) has attempted to formalise this subdivision and proposes the name "Ear-Falls - Manigotagan gneiss belt" for the northern unit and the name "English River batholithic belt" for the southern unit. The two belts are separated by a discontinuous unit of metavolcanic rocks for which Beakhouse uses the name "English River metavolcanic rocks".

The use of the term "belt" for broad scale tectonic features is unfortunate. For instance, the "Ear Falls gneissic belt", although broadly continuous, is severely disrupted by a complex of intrusive rocks of igneous aspect. Furthermore, Beakhouse's terminology fails to emphasise the dominantly metasedimentary aspect of this unit. The current author prefers to use the name "English River metasedimentary migmatite complex" for the northern part of the English River Subprovince, and the term "English River plutonic complex" for the southern part. Retention of the belt terminology for the unit of metavolcanic rocks that separates the northern and southern complexes is recommended due to historical and scale considerations.

McRitchie (1971) has also subdivided the Manitoban portion of the English River Subprovince. A comparison of the nomenclature of the various tectonic subdivisions is presented in table 2-2 and figure 2-3 attempts to clarify the geographic distribution of the subdivisions.

In the following discussion of previous work the terminology of individual authors will be retained as far as possible. Subsequent chapters will employ the present author's terminology where appropriate.

2-2 GEOPHYSICAL STUDIES

The presence of a broad scale, high Bouguer gravity anomaly associated with the area of the English River Subprovince was first noted by Innes (1960), who associated the anomaly with the presence of denser, near surface rocks. Wilson and Brisbin (1963) suggested that the gravity anomaly was due to the elevation of the Mohorovicic Discontinuity and that the English River Subprovince was an elevated crustal block.

Hall and Hajnal (1969, 1973), and Hall (1971) have demonstrated the presence in N.W. Ontario and S.E. Manitoba of two crustal layers separated by the Intermediate or Riel Discontinuity (fig.2-4). The seismic data indicate the presence of a gently but significant downwarp in the surface of the Riel Discontinuity, (fig.2-5). Depths to the surface increase from 12 km close to the southern margin of the English River Subprovince to greater than 22 km in the vicinity of Pakwash Lake, close to the northern margin of the subprovince. A sympathetic upwarp is present within the surface of the Mohorovicic discontinuity; the depth to this surface decreases from 38 km in the south to 31 km in the north.

These changes in crustal structure are accompanied by a change in the surface rocks from dominantly granitoid gneisses and granitic intrusions in the south to dominantly metasedimentary gneisses and metavolcanic rocks in the north. It seems likely, therefore, that the high Bouguer anomaly associated with the northern English River Subprovince, is in part due to the elevation of the mantle and in part due to the presence of slightly denser surface rocks.

Kornik (1971) investigated aeromagnetic trends in N.W. Ontario and S.E. Manitoba. He distinguished a central E-W oriented zone of high magnetic intensity which is broadly equivalent to the southern plutonic complex of the English River Subprovince. This is flanked to the north by a zone of low magnetic intensity, with local intense highs, broadly equivalent to the English River metasedimentary migmatite complex and the Bird River - Separation Lake, and Rice Lake - Uchi Lake metavolcanic belts. In the south a similar zone coincides with the Kenora-Wabigoon metavolcanic belt. Similar aeromagnetic distinctions were also noted by McGrath and Hall (1969).

2-3 GEOLOGICAL STUDIES

Wilson (1971) has defined several crustal blocks in N.W. Ontario largely on the basis of aeromagnetic trends (fig. 2-2). Wilson's English River Block is bounded to the north by the Red Lake Block and to the south by the Kenora Block. The boundaries of these blocks were considered by Wilson to be late adjustment faults which separate areas of contrasting structural style and metamorphism. He suggested that the English River Block is composed almost entirely of sedimentary gneiss with interlayered granitic rocks and rare amphibolites. Wilson recognised the characteristic east-west trend of folds and commented on the presence of gneiss domes and basins in the southern part of the block. He also remarked that apparently rapid, gradational changes in lithologic and metamorphic facies took place in the vicinity of the block boundaries.

In view of the intensive ongoing research and mapping activities of many individuals and institutions it is difficult to make the distinction between previous and current work done within the subprovince. The following section, therefore, will attempt to synthesise the state of accumulated knowledge as of April 1976. The presentation of this synthesis is essential since a comprehensive account of this material is not presently available in the published literature. The summary will proceed geographically from north to south and will use the geologic subdivisions proposed by McRitchie (1971) as an initial basis. Since these subdivisions apply in a strict sense only to the Manitoba part of the subprovince, frequent "excursions" will be made into Ontario wherever geological correlations seem justified.

The Wanipigow River Plutonic Complex lies to the north of the Rice Lake greenstone belt. It consists essentially of quartz dioritic and granodioritic intrusive rocks with scattered gneissic phases and local "lit-par-lit" gneisses. The probable continuation of this unit in Ontario includes two large domal structures - the Sydney-Rainfall Lake Dome and the Longlegged Lake Dome (Breaks et al 1974). Interlayered amphibolite, biotitic quartzo-feldspathic gneiss and biotite trondhjemite gneiss form mantles to cores of foliated to gneissic, homogeneous to xenolithic trondhjemite. The domes are intruded by later stocks of biotite quartz-monzonite.

The Rice Lake greenstone belt contains a basal unit of basic volcanic rocks with thin sedimentary horizons. This is overlain by a thick sequence of acid and intermediate, fragmental volcanic rocks which is succeeded by a sedimentary unit containing impure quartzite, greywacke, slate and conglomerate.

The boundary between the Uchi Subprovince and the English River Subprovince in Ontario is placed by Breaks et al (1974) along the Sydney Lake cataclastic zone and its northern off shoot, the Longlegged Lake - Pakwash Lake cataclastic zone. The cataclastic zone varies between 0.5 and 1.5 km in width, and contains mylonites with vertical foliation and local pseudotachylite. At Pakwash Lake the northern cataclastic zone juxtaposes an unmigmatised greywacke-pelite assemblage to the north with a metasedimentary migmatite assemblage to the south. Similar cataclastic zones separate the Rice Lake greenstone belt from the Manigotagan gneissic belt in Manitoba.

Within the Manigotagon gneissic belt McRitchie and Weber (1971) have defined a complex sequence of metamorphism and deformation affecting metasediments and metasedimentary migmatites (paragneisses). The earliest deformation event (D1) produced isoclinal folds in compositional layering and was accompanied by a major metamorphic event (M1). A pattern of increasing metamorphic grade southwards is accompanied by anatexis of the metasedimentary protolith. The sequence of metamorphic zones recognised is based upon the first appearance of the following minerals: (i) chlorite, (ii) biotite, (iii) almandine, (iv) andalusite, (v) sillimanite and orthoclase, (vi) sillimanite and cordierite. The characteristic plutonic phase associated with zone (vi) is an authochthonous, synkinematic grey tonalitic or granodioritic gneiss.

The second deformation (D2) produced intrafolial, similar, asymmetric, Z and S folds with regionally shallow plunges. The dominant regional foliation was produced during this event. The geothermal gradient established during M1 persisted through the M2 metamorphic event producing a general matrix coarsening. Large, intrusive bodies of quartz monzonite and granodiorite of the Turtle-Tooth Lakes suites were intruded late in the D2, M2 tectonothermal event. The D3 deformational event is associated with a variety of fold styles which are dominantly concentric but locally disharmonic, similar or kinklike and are associated with the development of incipient strain slip cleavage. The D4 event is responsible for major curvilinear fracture and mylonite zones which separate the gneissic belt from the Rice Lake greenstone belt.

Early reconnaissance mapping in Ontario by Bruce (1924) and Derry (1930) included parts of the English River metasedimentary migmatite complex. Carlson (1957) mapped the Werner Lake - Rex Lake area adjacent to the Manitoba-Ontario boundary. He describes metasediments, tonalites, mafic intrusives and granites from this area. Williamson and Hudec (1958) and Hudec (1965) have mapped areas northeast of Lac Seul. These authors defined a group of older migmatitic paragneisses intruded by two ages of granitic rocks. The older intrusives are invariably white coloured, biotite granodiorites containing variable proportions of paragneissic inclusions. The younger intrusives are pink, aplitic to pegmatitic granites. Breaks et al (1974, 1975) report a regional metamorphic event in the English River metasedimentary migmatite complex with the widespread development of almandine, cordierite and sillimanite. The more advanced stages of metamorphism are characterised by the anatectic development of medium to coarse grained, white, granitoid diatexite (Mehnert 1968). Numerous stocks, dikes and sills of massive, leucocratic pink quartz monzonite intrude the metasedimentary migmatites.

Morin (1970) and Morin and Turnock (1975) have studied the petrology of a clotty granite at Perrault Falls - the southern margin of the English River metasedimentary migmatite complex adjacent to the Red Lake highway. Mafic clots of green biotite, quartz, sillimanite and cordierite and contained in an equigranular pink granite matrix which also contains disseminated garnet and sillimanite. The granite has intrusive contact relationships with the surrounding biotite - cordierite gneiss. The authors suggest that the clots may be refractory relicts of paragneiss inclusions which were partially melted.

The Pine Falls plutonic complex outcrops south of the Manigotagan gneiss belt in Manitoba. It is described by McRitchie (1971) as an undifferentiated complex containing an abundance of metasomatised porphyroblastic phases. Towards the east at Black River the complex includes quartz monzonites which have undergone complete anatexis and been reintruded into the Manigotagan gneisses. Large, homogeneous quartz-diorite plutons are present and in places foliated quartz-diorite may be seen intruding rocks of the Bird River greenstone belt.

J.F. Davies conducted geological mapping during the period 1952-1958 within the Bird River greenstone belt, the Lac du Bonnet Pluton and the Winnipeg River plutonic complex. The Bird River greenstone belt contains basic volcanic rocks overlain by impure quartzites, arkoses, slate and chart. This succession is intruded by the Bird River sill which is a layered and differentiated sequence ranging from granophyric gabbro through anorthositic gabbro to metapyroxenite and metaperidotite. The Bird River sill and associated Cu-Ni sulphide deposits have been described by Karup-Moller and Brummer (1971). At Booster and Ryerson Lakes conglomerates containing tonalite clasts are associated with quartzo-feldspathic greywackes and quartzites. The metamorphic grade appears to increase to the northeast (Butrenchuk 1970) towards the Manigotagan gneissic belt.

A discontinuous metavolcanic belt in Ontario occurs at the southern margin of the English River metasedimentary migmatite complex. The thickest section (greater than 2 km) occurs at Separation Lake and thins rapidly both east and west.

Massive to foliated, mafic to intermediate banded amphibolites with poorly preserved pillows are associated with minor felsic to intermediate tuff and lapilli tuff. The unit is discontinuously present to Oak Lake where a conglomerate containing mafic and felsic metavolcanic fragments has been reported. Possible continuations of this belt at Wabaskang and Perrault Lakes will be described in a subsequent chapter.

The Lac du Bonnet pluton outcrops over an area in excess of 2500 sq km in Manitoba, south of the Rice Lake greenstone belt. McRitchie (1971) considers the body to be a flat, sheet like, intrusion dipping steeply to the northwest. The dominant phase is a homogeneous, equigranular, unfoliated, pink quartz monzonite. Locally, large xenoliths are present which McRitchie considers to be equivalents of the Bird River greenstone belt. Large, irregular plutonic bodies which are compositionally similar to the Lac du Bonnet pluton occur throughout the Ontario portion of the English River plutonic complex. These bodies are regarded by Breaks et al (1974, 1975) as being very late in the tectonic sequence and contain xenoliths of both granitoid gneiss and metasedimentary gneiss.

The Winnipeg River plutonic complex in southeastern Manitoba contains discontinuously banded, biotite and hornblende bearing quartz dioritic and granodioritic gneisses with skialithic, anatectic phases. Dips are generally shallow to the west-northwest. A broad zone of compositionally similar gneissic rocks outcrops in the southern part of the English River plutonic complex in Ontario. In the Kenora district, these gneisses are the subject of a detailed research program currently being undertaken by C.F. Gower of McMaster University. The granitoid gneisses extend across almost the entire width of the complex in the Cedar Lake and Lac Seul regions, north of Dryden.

Numerous granitoid bodies intrude the gneisses throughout the English River and Winnipeg River plutonic complexes. McRitchie (1971) describes a southwards transition in Manitoba from granitoid gneisses through porphyroblastic (k feldspar) gneisses to massive, homogeneous porphyroblastic quartz monzonite and granodiorite. The latter phases have been referred to by Farquharson and Clark (1971) as the Whiteshell porphyritic granodiorite. A similar body of massive porphyritic granodiorite of batholithic dimensions occupies the central axis of the plutonic complex in Ontario, where it clearly intrudes the gneissic rocks.

Foliated, equigranular quartz diorite and tonalite to granodiorite plutons also intrude the gneissic rocks but apparently predate intrusion of the porphyritic plutons. This group of intrusions includes the tonalitic Rennie Batholith in Manitoba (McRitchie 1971) and the Dalles tonalite/granodiorite in the Kenora District of Ontario (Gower 1975). Also included in this group are the quartz diorites of the High Lake - Rush Bay area, lying to the west of Kenora, which were mapped by Davies (1965).

For the sake of completion it is necessary to mention two further studies undertaken as University theses. Dwibedi (1966) undertook a reconnaissance petrologic and geochemical study of the English River Subprovince west of the Red Lake Highway. Jones (1973) completed a petrologic study of samples taken from the Red Lake Highway. He defined, in broad terms, an increasing grade of metamorphism culminating in the centre of the English River Subprovince with granulitic mineral assemblages near Cliff Lake. Both of these studies were carried out prior to the completion of regional mapping.

2-4 RADIOMETRIC AGE DETERMINATIONS

In recent years the possibility of a "pre-Kenoran" event being present in rocks of the western Superior Province has led to an increasing number of radiometric age dating studies. The earliest study was done by Purdy and York (1965) who analysed 9 samples of granites and gneisses collected along a 125 mile traverse of Highway 105 from Vermilion Bay to Red Lake. The samples were taken from several rock groups which are now known to represent distinct geological events within the Wabigoon, English River and Uchi subprovinces. The samples however produced a surprisingly good Rb-Sr "isochron" defining an age of 2.45 b.y. $\pm$ 0.10 b.y. (Rb^{87} = 1.39×10^{-11} yr^{-1}). Purdy and York concluded that the Kenoran "orogeny" is clearly the dominant feature within this region.

Subsequent radiometric studies have been concentrated mainly in the Manitoba part of the region since geological data for Ontario was, until very recently, very sparsely distributed. In the following discussion the studies have been arranged in a geographic order proceeding from north to south across the Western Superior Province. All Rb-Sr data reported hereafter has been based, by the original authors, on an Rb^{87} decay constant of $1.39 \times 10^{-11} yr^{-1}$.

Krogh et al (1975) report U-Pb zircon ages of 2.9 b.y. from a gneiss of problematic origin within the Berens River Block (north of the Uchi-Red Lake - Rice Lake greenstone terrain). Ermanovics (1975) reports that Rb-Sr whole rock ages on post-kinematic, massive quartz monzonite from the Berens River Block "vary from 2.7 to 2.6 b.y.". A U-Pb zircon study of the same rocks yielded an age of 2715 m.y. (Krogh et al 1975).

Turek and Peterman (1968) obtained an Rb-Sr metamorphic age of 2550 ± 80 m.y. from phyllites of the Rice Lake Group. Ages of emplacement of gold-quartz veins in Rice Lake metavolcanic rocks were recorded as 2720 ± 158 m.y. Turek and Peterman (1971) report a metamorphic Rb-Sr age of 2555 ± 70 m.y. from a quartz diorite body intruding the Rice Lake greenstones. Mylonites from the north and south boundaries of the Rice Lake belt yielded ages of 2345 ± 100 m.y.

Within the Manigotagan gneissic belt Turek and Peterman

(1971) obtained an Rb-Sr age of 2735±55 m.y. and initial Sr 87/Sr 86 ratio of 0.7019±0.0008 from a late tectonic quartz monzonite intrusion at Black Lake. They also record an Rb-Sr metamorphic age of 2530 m.y. from a sample of biotite from a paragneiss. Ermanovics (1975) reports a U-Pb zircon concordia age of 2690±10 m.y. from a sample of hybrid paragneiss from the Manigotagan gneissic belt. Ermanovics states - "The significance of this age is unknown but may represent a reset zircon age".

Penner and Clark (1971) have obtained an Rb-Sr isochron age of 2650±35 m.y. and an initial Sr 87/Sr 86 ratio of 0.7015±0.0015, from metavolcanic rocks of the Bird River greenstone belt. The age is considered by these authors to be a minimum age for the extrusion of the volcanic rocks as these rocks may be susceptible to having their ages reset during subsequent metamorphism. The same authors analysed samples of grey, gneissic quartz diorite and granodiorite from the Pine Falls plutonic complex. An age of 2640±135 m.y. and an initial Sr 87/Sr 86 ratio of 0.7014±0.0021 were obtained.

Penner and Clark (1971) also report an age of 2495±130 m.y. and initial Sr 87/Sr 86 ratio of 0.7088±0.0068 for the Lac du Bonnet pluton. Farquharson (1975) has recently revised this data based on incorporation of three additional samples which controlled the previous isochron. The revised results are: age 2680±91 m.y., and initial Sr 87/Sr 86 ratio of 0.6998±.0032.

Farquharson and Clark (1971) have obtained Rb-Sr ages for various plutonic phases from the Winnipeg River plutonic complex. Eight samples of pink, gneissic to massive granodiorite from south of the Winnipeg River yielded an age of 2644$\pm$50 m.y. with an initial Sr 87/Sr 86 ratio of 0.7001 $\pm$0.0014. The Whiteshell porphyritic granodiorite, a large unfoliated body of unknown dimensions which contains inclusions of gneissic pink granodiorite, yielded on an age of 2610$\pm$113 m.y. and initial Sr 87/Sr 86 ratio of 0.7071$\pm$0.0038 from a total of seven samples. Four of these samples taken independently yield an age of 2594$\pm$9 m.y. with an initial Sr 87/Sr 86 ratio of 0.7098$\pm$0.0004. Farquharson and Clark (1971) suggest that the discrepancy reflects some geological variation, such as variable initial ratio.

Four samples of grey to pink, foliated, porphyritic granodiorite from the margin of the Rennie Batholith yielded an isochron age of 2603$\pm$320 m.y. with an initial Sr 87/Sr86 ratio of 0.7009$\pm$0.0031. The high error is a consequence of the small spread of Rb/Sr values and a low mean Rb/Sr ratio.

The Caddy Lake quartz monzonite is described by Farquharson and Clark (1971) as a medium grained, light grey muscovitic, garnetiferous rock which appears to comprise two parts: (a) faintly foliated gneiss with difuse compositional banding, which is intruded by (b) light grey to pinkish, massive quartz monzonite and pegmatite. The unit yields an age of 2556$\pm$12 m.y. and an initial ratio of 0.7087$\pm$0.0015.

Krogh et al. (1975) have analysed zircons from the Lac Seul region of the English River Subprovince in Ontario. The isotopic results indicate that tonalitic gneisses in this region have a minimum age of 3008±12 m.y. The data also indicate that these zircons have been modified by a later metamorphism. The authors conclude, by the use of assumed trajectories, that a probable age for the gneisses in excess of 3043±35 m.y. is indicated.

In summary therefore (Fig.2-6) the U-Pb zircon studies suggest the following history:

1. A period of zircon crystallisation ca 3060 m.y. to 2900 m.y. represented, at present, only in tonalitic gneisses of the Berens River Block and the Lac Seul area.

2. A period of metamorphism, migmatisation and granite intrusion at approx. 2690 m.y. in the Manigotagan paragneisses and the Lac Seul area.

3. Intrusion of pegmatitic granite ca. 2580 m.y. in the Lac Seul area.

In contrast, Rb-Sr ages greater than 2735 m.y. are absent and the data suggest the following history:

1. An event ca. 2725 m.y. recorded in the crystallisation of the Berens River quartz monzonite, the Black Lake quartz monzonite (Manigotagan gneissic belt) and gold-quartz veins intruding the Rice Lake greenstones.

2. Intrusion of the Lac Du Bonnet pluton at 2690 m.y.

3. An event ca. 2650 m.y. representing possible metamorphism of the Bird River greenstone sequence and recorded in the Pine Falls gneissic quartz-diorite and foliated to gneissic granodiorites from south of the Winnipeg River.

4. An event ca. 2600 m.y. recorded by the Whiteshell porphyritic granodiorite and the foliated, porphyritic margin of the Rennie Batholith.

5. An event ca. 2550 m.y. recording metamorphism in the Rice Lake greenstone belt and the Manigotagan gneissic belt. This event is also represented by the Caddy Lake quartz-monzonite and by intrusion of massive quartz-diorite plutons in the Rice Lake belt.

6. Mylonite formation at the margins of the Rice Lake greenstone belt ca. 2345 m.y.

If taken at face value, the Rb/Sr isotopic data records an almost continuous spectrum of igneous and metamorphic activity occurring over a time span of approximately 175 m.y. from 2550 m.y. to 2725 m.y. Such a conclusion immediately invites comparison with the Mesozoic batholith of Central California (Evernden and Kistler 1970, Kistler and Peterman 1973). Five major epochs of granitic intrusion in Central California occurred at approximately 30 m.y. intervals over a total time span in excess of 130 m.y. It is entirely possible, therefore, that, within the English River and adjacent subprovinces, igneous intrusions of similar fabric and composition were emplaced at different times.

Significantly, U/Pb isotopic studies record a period of zircon crystallisation in excess of 3.0 b.y. old. These older ages are confined, to date, to tonalitic rocks but are recorded from geographically widespread locations. This is strong evidence in favour of the existence of a sialic nucleus (or nucleii) in N.W. Ontario prior to 3.0 b.y. ago. The apparent time gap between the 3.0 b.y. event and the 2.7 b.y. event may represent the current paucity of U/Pb data or may in fact be geologically significant. Clearly there is a great need for more isotopic data which must be firmly based on the geological information which is now becoming available.

2-5 SUMMARY

Compilation of previous and current work provides a reasonably clear overview of the English River Subprovince. The northern part of the English River Subprovince is referred to as the English River metasedimentary migmatite complex. It is associated with a high Bouguer anomaly and a zone of low magnetic intensity containing local intense magnetic highs. The crustal structure beneath this complex includes a significant downwarp of the Riel discontinuity and a sympathetic upward in the Mohorovicic discontinuity. upwarp

High grade metasedimentary gneisses of the northern complex are locally gradational into lower grade, greywacke type, metasediments and metavolcanic rocks of the Uchi Subprovince. Elsewhere, the northern boundary of the subprovince is marked by a distinctive zone of mylonitisation. The mylonitisation appears to post date intrusion of a complex suite of granitoid rocks and has been tentatively assigned an age of 2345 m.y. The southern margin of the complex of metasedimentary gneisses is marked by a discontinuous belt of metavolcanic rocks which may be basal to the metasedimentary sequence.

The southern part of the English River Subprovince is referred to as the English River plutonic complex. Severely deformed granitoid gneisses which underlie the southern and central parts of the complex may be equivalent in age to tonalitic rocks elsewhere which have yielded U/Pb zircon ages in excess of 3.0 b.y. At least 50% of the total area of the complex is underlain by intrusive granitoid rocks. These range in composition from quartz-diorites to granites and have fabrics which range from strongly foliated to massive. Rb/Sr isotopic studies suggest these rocks were intruded throughout the time span 2725 m.y. to 2550 m.y.

The southern boundary of the English River Subprovince is generally recorded in the literature as a major fault. Previous studies indicate that the boundary served as a locus for granitoid intrusion both during and after the faulting event.

Table 2-1 Subdivision of the English River Subprovince

	McRitchie (1971)	Beakhouse (1974)	Current author	
North				
1.	Wanipigow River plutonic complex			
2.	Rice Lake greenstone belt		Uchi Subprovince	
3.	Manigotagan gneissic belt	Ear Falls - Manigotagan gneiss belt	English River metasedimentary migmatite complex	
4.	Pine Falls plutonic complex			English River Sub-Province
5.	Bird River greenstone belt	English River metavolcanic rocks	Separation Lake-Oak Lake greenstone belt	
6.	Lac du Bonnet pluton			
7.	Winnipeg River plutonic complex	English River batholithic belt	English River plutonic complex	
South			Wabigoon Subprovince	

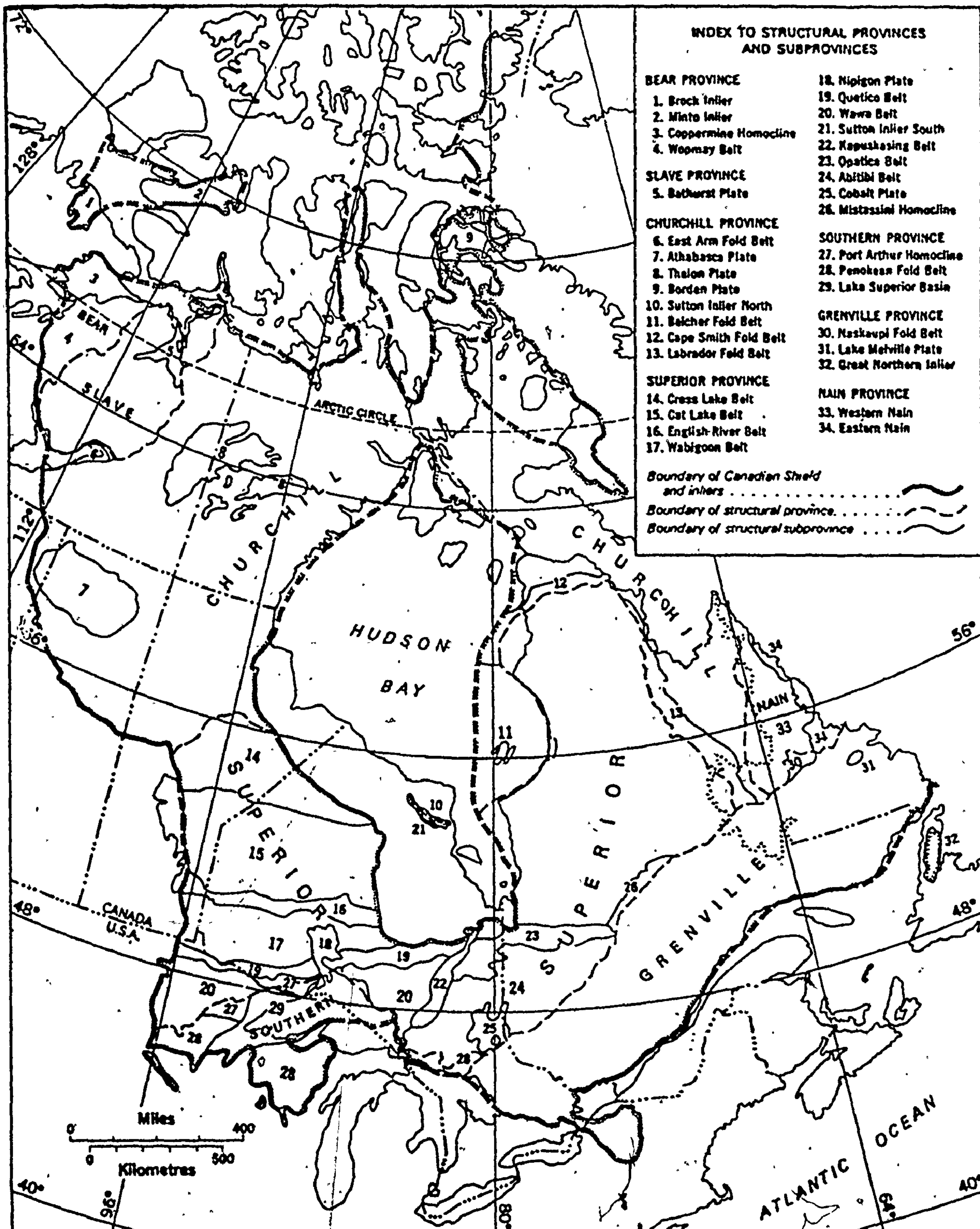


Figure 2-1 Geological subdivision of the Superior Province (from Stockwell et al. 1970)

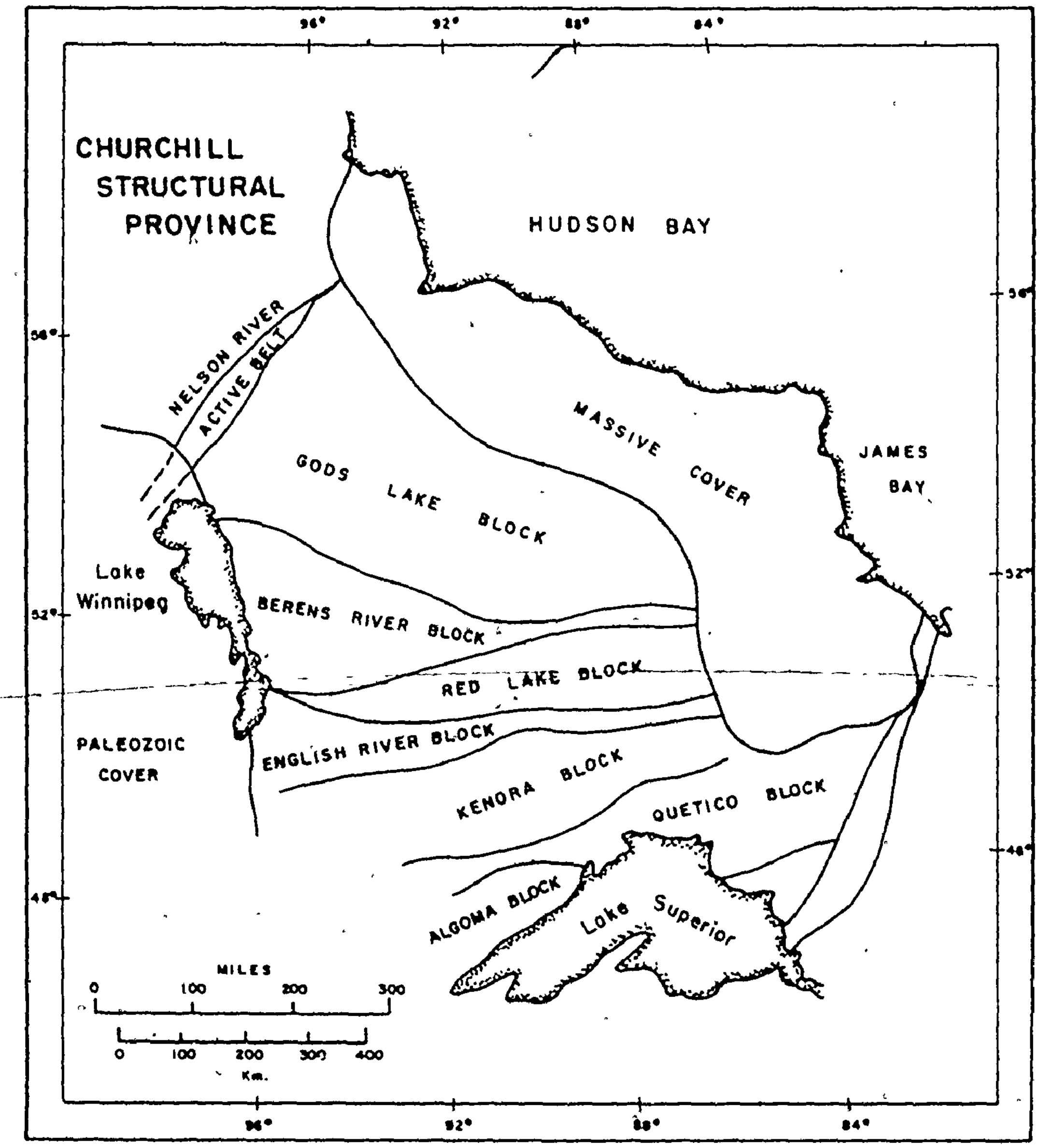


Figure 2-2 Structural Blocks In The Western Superior Province (from Wilson 1971)

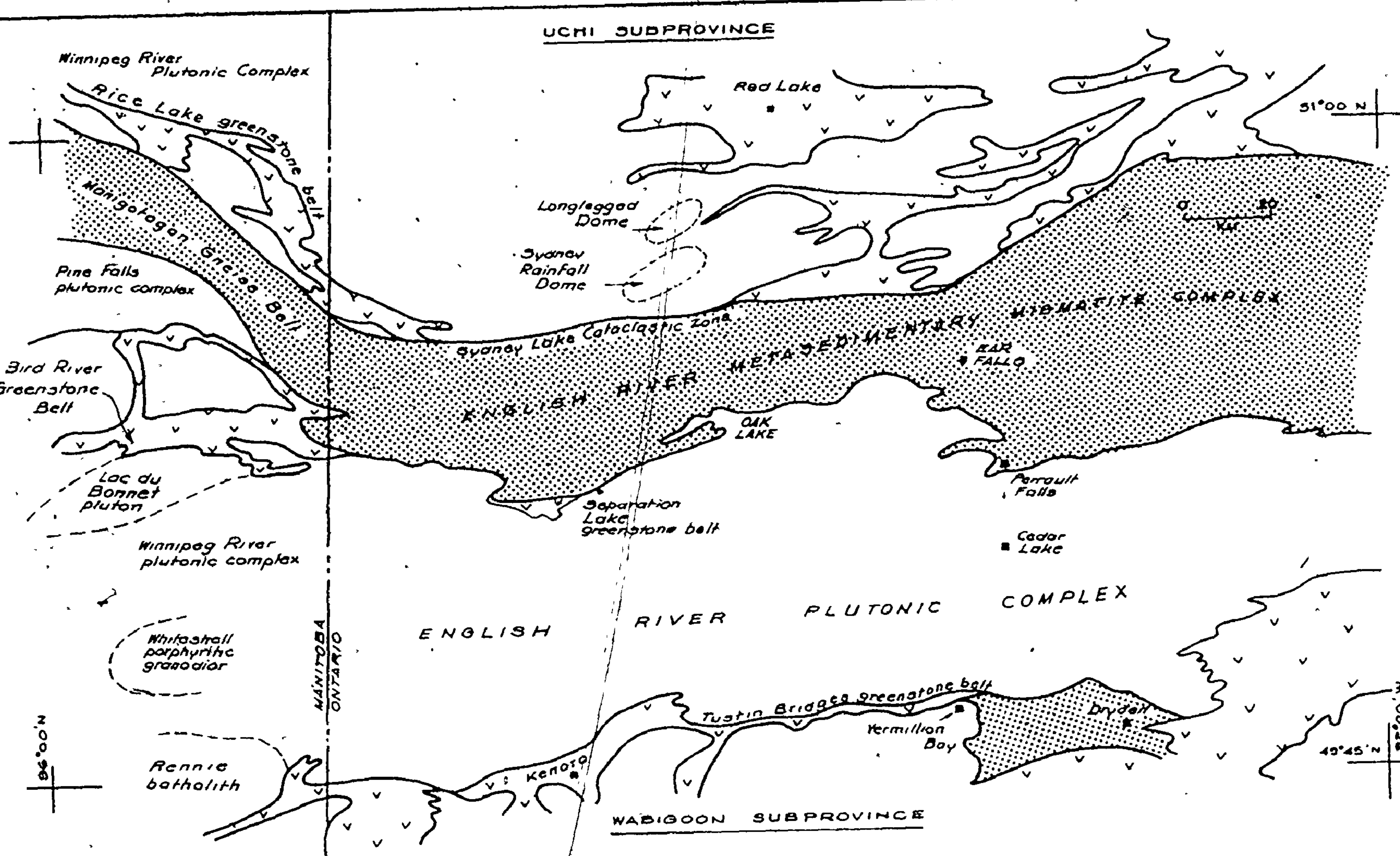

UCHI SUBPROVINCE
Winnipeg River Plutonic Complex
Rice Lake greenstone belt
Manigotagan Gneiss Belt
Pine Falls plutonic complex
Bird River Greenstone Belt
Lac du Bonnet pluton
Winnipeg River plutonic complex
Whiteshell porphyritic granodior
Rennie batholith
MANITOBA
ONTARIO
Red Lake
Longlegged Dome
Sydney Rainfall Dome
Sydney Lake Cataclastic Zone
ENGLISH RIVER METASEDIMENTARY MIGMATITE COMPLEX
EAR FALLS
OAK LAKE
Separation Lake greenstone belt
Perrault Falls
Cedar Lake
ENGLISH RIVER PLUTONIC COMPLEX
Tustin Bridges greenstone belt
Vermillion Bay
Dryden
Kenora
WABIGOON SUBPROVINCE
51°00 N
49°45 N
96°00 W
92°00 W
0
20
KM

Figure 2-3

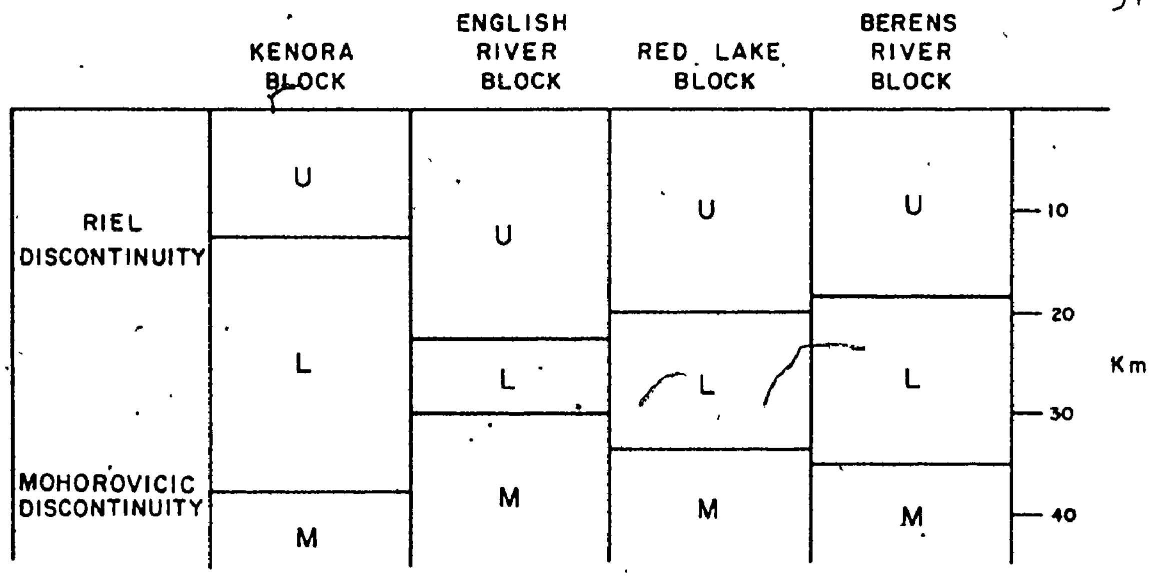


Figure 2-4a Crustal Structure in the Western Superior Province
From data in Wilson (1971)
U - Upper Crust , L - Lower Crust , M - Mantle

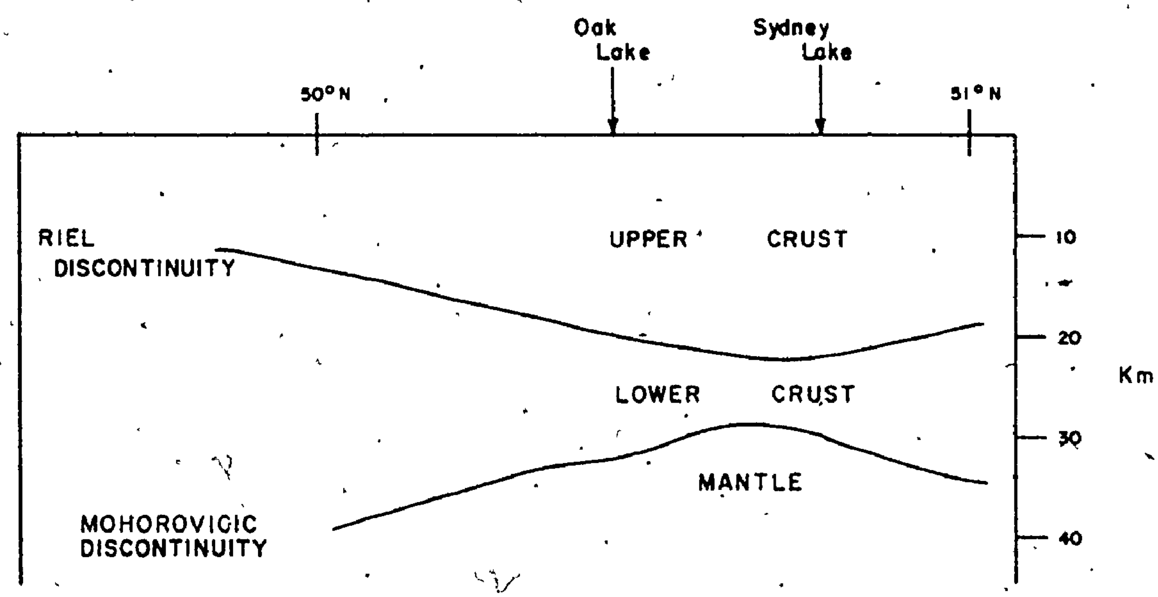


Figure 2-4b Crustal Structure at longitude 94° W across the English River Subprovince
From data in Hall & Hajnal (1973)
Vertical exaggeration X 2

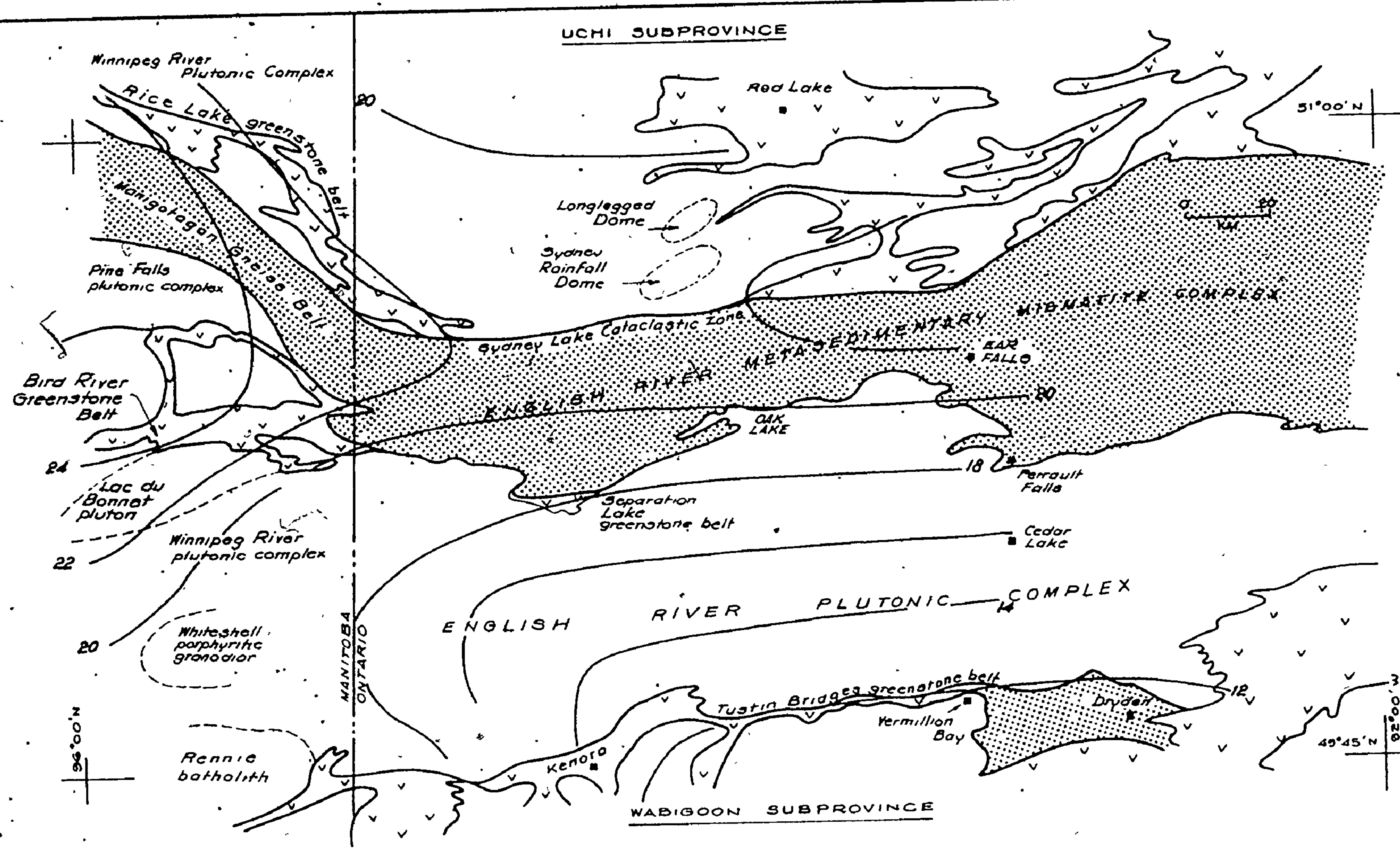


Figure 2-5a

Depth (Km) To The Riel Discontinuity – Redrawn From Hall And Hajnal (1973)

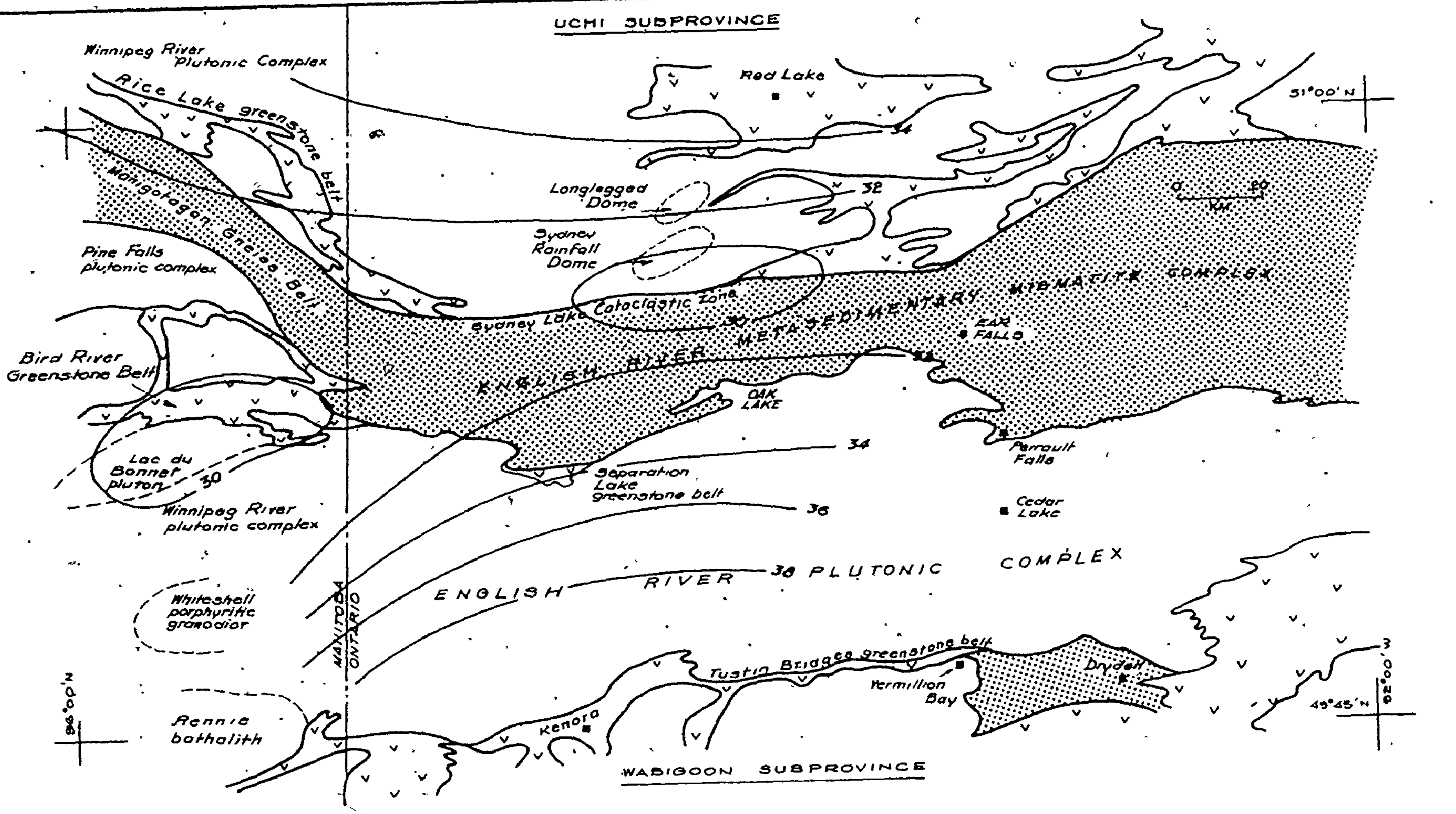


Figure 2-5b

Depth (Km) To The Mohorovicic Discontinuity – Redrawn From Hall And Hajnal (1973)

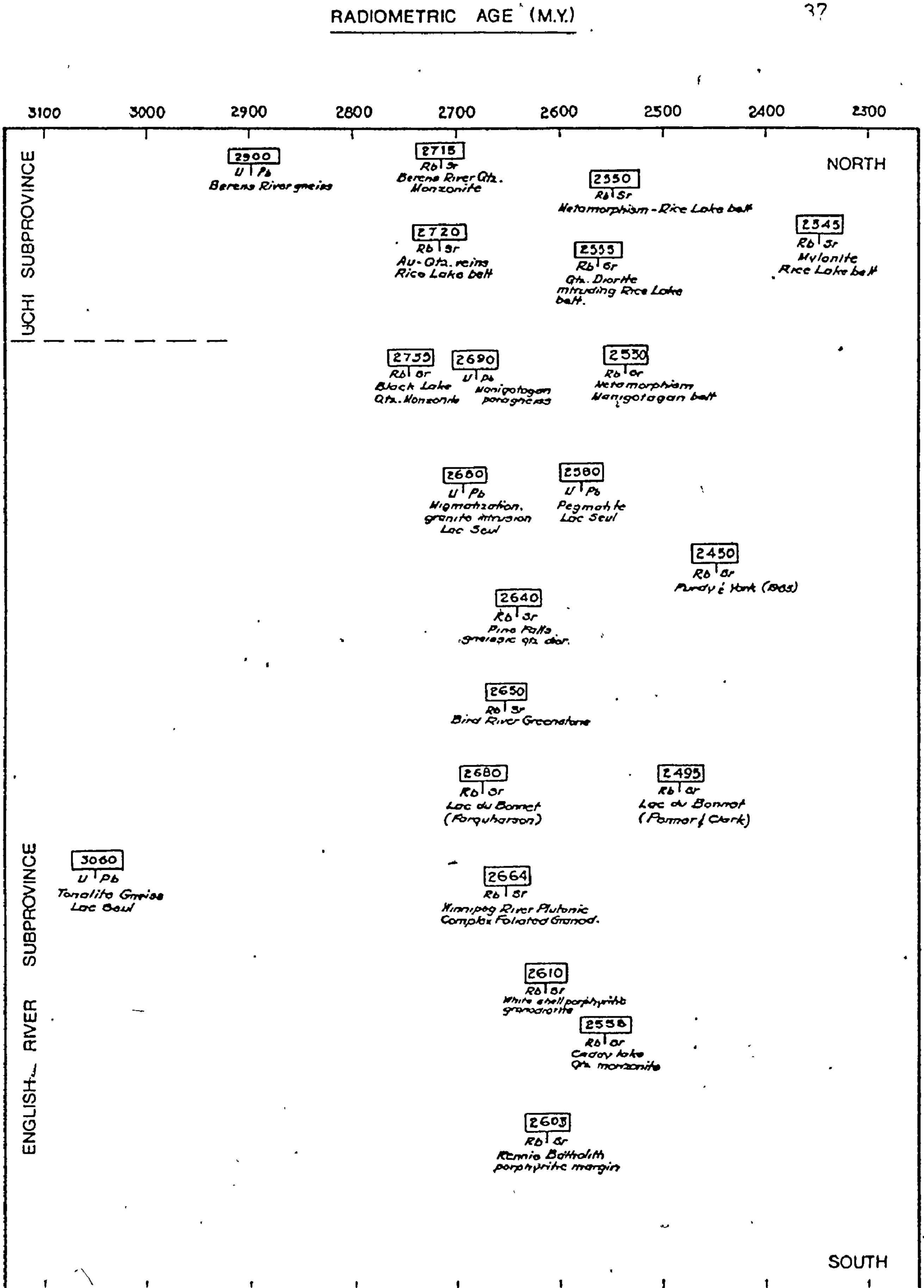


FIGURE 2-6 RADIOMETRIC AGES

CHAPTER 3

GEOLOGY OF THE CEDAR LAKE-CLAY LAKE AREA

3-1 LOCATION AND ACCESS

The Cedar Lake - Clay Lake area lies astride the Red Lake highway, approximately 40 km north of Vermilion Bay, N.W. Ontario between latitudes 50°00'N and 50°15'N, longitudes 93°00'W and 93°30'W. Excellent road access to the area is available by use of the Red Lake Highway, the Camp Robinson - Ord Lake logging road, the Cliff Lake logging road and the Redbluff Lake logging road. These roads service numerous lakes which give access to plentiful lakeshore outcrops. Rock exposure away from lakeshores and roads are just barely adequate. Most of the area is covered by dense second generation timber and low bush following logging operations conducted several tens of years ago.

3-2 DISTRIBUTION AND DEFINITION OF UNITS

The distribution of major geological units within the area (fig.3-1) is controlled by the major structural features present. Three major domal structures - the Cedar Dome, Mystery Dome and Twilight Dome - are individually elongate in a NW-SE direction and their culminations define a NE-SW trend. The domes are defined by orientation of gneissosity and lithologic units within the gneissic rocks. Late tectonic, granitic intrusive bodies are broadly conformable to the major structures but are locally discordant.

Strongly banded, severely deformed granitoid gneisses - hereafter referred to as the Cedar Lake gneisses - are the dominant lithology within the Cedar Dome. Severely disrupted mafic enclaves of unbanded amphibolite and more continuous enclaves of mafic tonalitic gneiss are abundant in this unit. Cedar Lake gneisses are also present along the northwest and southeast margins of the area and underlie a large basinal structure northwest of the Mystery and Twilight Domes.

The central portions of the Mystery and Twilight Domes are underlain by strongly banded, garnetiferous, biotite rich, gneisses which will be referred to as the Twilight gneisses. Strongly foliated, locally gneissic, granitoid rocks which occupy the flanking regions of the Twilight and Mystery domes will be called the Clay Lake granitoid suite. This suite contains a variety of interbanded granitoid rocks of dominantly tonalitic and granodioritic composition. The compositional banding is on a large enough scale to allow mapping of distinct phases in some parts of the area.

The outer parts of the northeast and southeast limbs of the Mystery Dome are underlain by a complex unit of interbanded mafic and felsic rock types. The unit contains both banded and unbanded amphibolites, hornblende-biotite gneisses, strongly foliated granitoid rocks and granitoid gneisses. The latter two rock types are believed to be representatives of the Clay Lake granitoid suite and the Cedar Lake gneisses. This unit of rocks will be called the Transitional Sequence.

At Trail Lake, on the northeast limb of the Mystery Dome, a very distinctive unit of quartzo-feldspathic gneisses occurs in association with amphibolites. The gneiss is composed of abundant leucotonalitic veins separated by thin, mafic schlieren. Both veins and schlieren are strongly deformed. The unit has been named the Trail Lake Series.

Late tectonic, granitoid intrusive rocks are broadly concordant to the major structures. A large, sheet like body of porphyritic granodiorite and pink granite separates the Cedar Dome in the north from the Mystery and Twilight Domes in the south. This body will be called, here, the Cliff Lake porphyritic granodiorite. A projection of this body extends northwards around the Cedar Dome and eventually merges into the marginal phase of the Thaddeus Lake Pluton in the east. To the south, a thin projection of the body provides continuity into the porphyritic granodiorite south of Clay Lake. Westwards, the Cliff Lake porphyritic granodiorite merges into a similar body of almost batholithic proportions (Breaks et al, 1974).

In the northwest corner of the area, elongate, concordant bodies of foliated tonalite-granodiorite intrude the Cedar Lake gneisses.

3-3 DESCRIPTION OF UNITS

(i) Cedar Lake gneisses

The Cedar Lake gneisses are a strongly heterolithological unit (Plate 3-1). The dominant components of this unit are strongly banded, severely foliated tonalitic and granodioritic gneisses. Compositional banding is discontinuous, with widths varying from a few millimetres up to several metres. The contacts between wider bands may be either sharp or gradational over a few centimetres. The most obvious banding is defined largely by the percentage of mafic minerals present, with dominant biotite being rarely accompanied by hornblende. Greyish white leucotonalite and more mafic biotite tonalite are interbanded with pink leucogranite on a scale of 1-4cm. Colour index of individual bands is in the range 5-20 but very thin biotite rich schlieren may be considerably more mafic. Mafic schlieren are commonly associated with the margins of pink coloured leucocratic bands having granitic compositions. Such bands rarely exceed 3 cm in width and are extremely discontinuous or lensoid.

Grain size and textural characteristics accentuate the compositional banding. The more mafic, tonalitic bands are strongly foliated, finer grained (0.5 - 1.0mm), and have allotriomorphic textures. Foliation is defined by parallel alignment of biotite and by elongation of anhedral quartz and plagioclase. Lensoid quartz grains exhibiting strong mosaic extinction in thin section are common. Leucotonalitic bands tend to be coarser grained (1-2mm) and not so obviously foliated. In thin section, however, anhedral plagioclase and quartz are aligned within a foliation defined by parallel orientation of biotite. Thin leucotonalite units, having sharp contacts, have been deformed into isoclinal, rootless folds within the compositional banding. It is suspected that these units represent very early veins injected into the protolith of the gneisses. Pink leucogranite bands are even coarser grained (1-4mm) and less severely deformed by tight to isoclinal folds.

The compositional banding or gneissosity of this unit is enhanced by the presence of mildly discordant leucogranite veins. The veins vary from 1-15 cms thick and have been tightly folded along with the compositional banding. A foliation has been developed in the veins, parallel to that of the host, but discordances of 5-10° between vein and compositional banding are still present. These veins are distinguished on structural grounds from less severely deformed or undeformed leucogranite veins which have been ubiquitously injected into the gneisses.

Sampling of the gneisses is made extremely difficult by the presence of the small scale compositional banding and numerous injected granitic phases. The latter were successfully avoided during sampling but all samples collected contained some form of compositional banding. This is reflected in the wide range of modal compositions plotted on figure 3-2a. The dominantly granodiorite composition is a function of the intimate interbanding of tonalitic and granitic bands.

Plagioclase is strongly twinned, unzoned, frequently antiperthitic and has oligoclase compositions ranging from An_{22}-An_{30}. Potassic feldspar is present in the form of perthitic microcline exhibiting a strong cross-hatched twinning. Magnetite, apatite, sphene and zircon are common accessory minerals.

(ii) Amphibolite enclaves in Cedar Lake gneiss

Amphibolite enclaves are an essential component of the Cedar Lake gneiss as defined in this work. The enclaves range in size from small fragments less than 20 cm in length up to mappable units 50 metres wide and 1 km in length. The most abundant enclaves are composed of unbanded, medium grained amphibolite and are on the order of 2 metres long and 1 metre wide. They are, in fact, boudins elongated in the gneissosity and often exhibit cuspate extremities. Trains of boudins are often semicontinuous within the gneissosity. Thin, bleached reaction rims with biotite replacing hornblende are common. Thin leucotonalite veins are frequently present within amphibolite boudins and these are often folded or boudinaged in the present gneissosity plane.

The most common type of amphibolite occurring as small enclaves contains between 35% and 45% plagioclase of andesine composition (An_{33-38}) and 35-50% hornblende. These two minerals form a granoblastic, equigranular, polygonal texture with grain size in the range of 0.5 - 1.0mm. Diopsidic clinopyroxene, usually present at the 10-20% level, may be found within the groundmass or may form weakly poikiloblastic crystals up to 2 mm in length. In some samples, elongation of hornblende and, to a lesser extent, plagioclase produces a marked linear fabric, parallel to elongation of diopside poikiloblasts. Minor quartz and biotite are frequently present and magnetite, accompanied by accessory sphene may constitute up to 5% of the total.

Other amphibolitic enclaves are characterised by the presence of small lenses (3mm x 2cm) of plagioclase accompanied by minor quartz. The lenses are flattened in the gneissosity plane and are parallel to a very weak compositional banding which is outlined by horizons containing biotite. Ultramafic rock types are also rarely present as small enclaves in the gneiss. This type usually consists of a granoblastic intergrowth of diopside and lesser hornblende with minor plagioclase. Thin, hornblende rich rims are common adjacent to the leucotonalite component of the host gneisses.

Larger, more continuous, amphibolitic units are also present in the Cedar Lake gneisses. These units may be up to 50 metres wide and can be traced in intermittent outcrops for distances of up to 1 km. These units are generally unbanded, commonly lineated rather than foliated and are composed dominantly of granoblastic intergrowths of hornblende and plagioclase. The units are frequently injected by thin, leucotonalitic veins and in places these may produce an agmatitic morphology.

One of these units, exposed on the northwest arm of Cliff Lake contains coarse megacrysts of plagioclase. The megacrysts occur both as single euhedral crystals with irregular margins (1.5cm x 0.7cm) and as clusters of similar size containing four or five intergrown, subhedral crystals. The texture is similar to a glomeroporphyritic texture. The megacrysts are labradoritic (An_{55-60}) and contain inclusions of anhedral to subhedral hornblende (0.1 - 0.3mm) aligned parallel to the 'c' crystallographic axis. A thin rim of finer grained plagioclase (1.0mm grain size) of andesine composition (An_{34}) surrounds the megacrysts. The groundmass is a granoblastic intergrowth of approximately equal proportions of hornblende and plagioclase (An_{30}) with a marked alignment of hornblende parallel to the alignment of the megacrysts.

Marginal relationships between these amphibolite units and the host gneisses are unknown due to lack of exposure. The present author suspects, however, that they represent dikes originally intrusive into the protolith of the gneisses. The time of emplacement of these units relative to the complex deformational history of the gneisses is problematical and will be discussed in section 3-4 of this chapter.

Amphibolitic units exhibiting a strong compositional banding are also associated with the Cedar Lake gneisses. These units are suspected to be of volcanic extrusive origin and will be described in section 3-3 (vii) of this chapter.

(iii) Mafic tonalitic gneiss units in Cedar Lake gneiss

Weakly banded, strongly foliated, relatively mafic, hornblende-biotite gneisses occur as thin units 50-100 metres wide and traceable for up to 2 km along strike. The units have gradational boundaries extending over several metres with the Cedar Lake gneisses. The units exhibit a weak banding defined by variation in grain size and mafic mineral content which is amplified by the presence of concordant leucotonalite veins. Compositionally, the rocks consist of an equigranular (1-2 mm), foliated, granoblastic, interlobate intergrowth of plagioclase An_{30} (50-60%), quartz (25-35%), biotite (8-17%) and hornblende (0-5%). Magnetite, apatite, sphene and zircon occur as accessory minerals. Massive amphibolite enclaves are frequently associated with the hornblende-biotite gneisses and occur as boudins 1-2 metres in length.

(iv) Clay Lake granitoid suite

Strongly foliated, locally gneissic, biotite tonalite and biotite granodiorite are interlayered on a scale of 5-15 metres at Clay Lake. The two rock types have intergradational boundaries and both have medium to coarse grained (1 - 3mm) equigranular, allotriomorphic, interlobate, foliated textures.

The tonalitic rocks typically have a greasy grey-green coloration and contain up to 15% mafic minerals. Biotite is accompanied by minor orthopyroxene with hornblende or clinopyroxene. Plagioclase (An_{28-35}) is commonly strongly antiperthitic. Granodioritic rocks have a pinkish coloration due to the presence of up to 15% microcline. Mafic contents of the granodiorites (approx. 8-10%) are somewhat lower than those of the tonalites and biotite is generally the only ferromagnesian silicate present. Thin, concordant leucotonalite veins are sparsely present and these often exhibit mild boudinage.

When traced northeastwards into the Mystery Dome area the Clay Lake granitoid rocks undergo a change of character. The essential compositional characteristics remain unchanged but the rocks are more severely foliated and locally develop a compositional banding. In addition, two texturally distinctive rock types form locally mappable units which are broadly concordant.

The first is a coarser grained, moderately foliated biotite tonalite which characteristically contains small lenticular amphibolitic enclaves. Grain size is in the range 2-4mm and biotite (10-15%) is accompanied by minor amounts of orthopyroxene which is variably replaced by a fine grained, brown, serpentinous material. These units may contain rare poikiloblastic megacrysts of microcline.

The second distinctive rock type is a strongly foliated medium grained, bluish-grey coloured tonalite or granodiorite. This type typically contains small, equant, pink garnet crystals disseminated throughout the rock. Highly discontinuous compositional banding is present on a millimetre scale and is accentuated by strongly boudinaged concordant leucotonalite veins. Augen shaped microcline megacrysts are locally present, have maximum dimensions up to 10 mm and are surrounded by diffuse haloes of fine grained plagioclase. Occasionally the microcline megacrysts have sigmoidal shapes (Plate 3-2) which strongly suggests that they represent original phenocrysts which were present prior to the deformation event which produced the foliation. Modal analyses of the Clay Lake granitoid suite are presented in figure 3- 2 .

(v) Amphibolite enclaves in Clay Lake granitoid suite

Amphibolite enclaves within the Clay Lake granitoid suite are generally not abundant, rarely exceeding 2% of the total rock in individual outcrops. Locally, however, concordant units up to 20 metres wide of unbanded, lineated amphibolite are present. These units have a fine grained, granoblastic, lineated, polygonal to interlobate texture of intergrown plagioclase, hornblende and clinopyroxene. Plagioclase compositions range widely from An_{36} to An_{52}. The amphibolite units are injected by leucotonalite veins, especially along the margins. In the immediate vicinity of some of the amphibolite units the granitoid host has an increased mafic content and hornblende becomes an important constituent.

In view of the concordant relationships between amphibolite units and granitoid host rocks the time relationships of these units are uncertain. The presence of small, lenticular enclaves of amphibolite within the Clay Lake granitoid rocks suggests however that the granitoid rocks intruded amphibolites in their original configuration.

(vi) Mafic tonalitic gneiss units in Clay Lake granitoid suite

Slightly more mafic-rich tonalitic gneiss forms broadly mappable, concordant units within the Clay Lake granitoid suite. The units vary from a few metres to upwards of 200 metres thick and are most abundant in the western limb of the Mystery Dome. These well banded rocks are medium grained, have granoblastic, foliated, interlobate textures and generally contain slightly more than 20% mafic minerals. Biotite is the dominant mafic mineral and is always accompanied by orthopyroxene and occasionally by hornblende. Banding is defined by grain size and variation in mafic content. The less mafic units bear a strong resemblance to tonalitic varieties of the Clay Lake granitoid suite. Minor pink garnet is often present in thin leucotonalite veins which are concordant to foliation and compositional banding.

(vii) Banded amphibolites

Banded amphibolitic rocks believed to be of volcanic extrusive origins occur in six geologic settings.

(a) As rare enclaves within the Clay Lake granitoid suite
(b) As enclaves within the Cedar Lake gneisses
(c) As enclaves in the Cliff Lake porphyritic granodiorite
(d) As a major part of the Trail Lake series
(e) As an integral part of the Transitional sequence
(f) As minor units in the Twilight gneisses.

Occurrences within settings (d), (e) and (f) will be discussed for convenience in subsequent sections.

Banded amphibolites within the Clay Lake granitoid suite are confined to two locations; one at Redbluff Lake, the other at Mystery Lake. At both locations the banded amphibolites occur as a unit 10-20 metres thick, the Redbluff Lake occurrence being traceable in intermittent outcrops along strike for approximately one kilometre. The rocks are banded on a scale of 1-4 cm, the banding being defined by variations in the ratio of hornblende to diopside. The banding is continuous along strike for distances in excess of 15 metres and is accentuated by thin (2cm), concordant leucotonalitic lenses and veins. Both the banding and leucotonalitic veins have been boudinaged and occasional tight folds with class 1B or 2 morphology (Ramsay 1967) are present. Small enclaves of banded amphibolite are present in rocks of the Clay Lake granitoid suite at the margins of the larger amphibolite unit.

Banded amphibolites within the Cedar Lake gneiss occur as elongate units 50-150 metres wide and up to 1.5 km in length. The banding is once again defined by variations in the ratio of hornblende to clinopyroxene and minor biotite may also be present. The strongly banded horizons are interlayered with less obviously banded, more homogenous units 10-15 metres thick. The latter have a weakly defined compositional banding on a scale of 0.5 to 2.0 metres and frequently contain lensoid pods of coarse grained clinopyroxene and/or epidote. The pods are generally in the order of 20 cm in length and may represent boudins of a formally more continuous horizon.
The occurrence north of Cedar Lake includes a 1 metre thick siliceous, magnetite rich unit which could represent a former banded iron formation.

The relationships between these units and the Cedar Lake gneisses are not at all clear due to the generally poor quality and distribution of outcrop. The units are, however, structurally concordant with the gneisses and contain leuco-tonalite veins which may have been derived from the gneisses. Such veins appear to increase in quantity towards the margins of the amphibolite units, but actual marginal relationships have never been observed.

Amphibolite enclaves within the Cliff Lake porphyritic granodiorite are relatively abundant. Part of a very large enclave outcrops on highway 105 at Cliff Lake, over a distance of some 800 metres perpendicular to strike. Compositional banding and foliation dips southerly at approximately 50° and the sequence is on the order of 600 metres thick. Several massive units each approximately 130 metres thick are interlayered with strongly banded units on the order of 10-15 metres thick.

The most northerly banded unit contains abundant contorted "pods" of coarse grained epidote, clinopyroxene and plagioclase. The northernmost massive unit is rather more mafic than the others, has finer grained margins and a coarser grained central portion. This unit may therefore represent an originally intrusive sill. The central massive units are medium to coarse grained throughout and contain numerous clots and distorted stringers of epidote. A roughly elliptical feature that may represent an original lava tube (Plate 3-3) is also present in one of the central units. The feature is 2 metres by 1 metre in horizontal section and extends down dip for at least 5 metres. Concentric zoning within the feature is defined by small lensoid blebs of plagioclase concentration. A pillowed flow unit approximately 45 metres thick occurs at the southern end of the continuous outcrop. The pillows are readily recognisable despite moderate flattening but are not sufficiently well preserved to indicate the facing direction of the sequence (Plate 3-4).

A large number of smaller amphibolite enclaves are present within the Cliff Lake porphyritic granodiorite between Cliff and Cedar Lakes. The vast majority of these enclaves contain a strong compositional banding defined by relative concentration of hornblende and clinopyroxene. In this respect they are identical to the banded horizons within the volcanic succession described above and remarkably similar to banded amphibolite units within the Cedar Lake gneisses.

A second occurrence of banded amphibolites of almost certain volcanic-extrusive origin outcrops at the southern margin of the Cliff Lake porphyritic granodiorite, on highway 105, 1.0 km northeast of Trail Lake. Here, a 180 metre thick unit of amphibolites contains a 3-5 metre thick zone of banded iron formation at its southern end (Plate 3-5). The iron formation consists of 5 mm thick interlaminations of magnetite and fine grained quartz. It is structurally underlain by a 2 metre thick, rusty weathering amphibolite with a brecciated appearance which may possibly represent a flow top breccia. The remaining members of this sequence are either massive or compositionally banded amphibolites. One unit contains thin streaks of fine grained plagioclase and quartz, which may represent flattened amygdales, in a fine grained, hornblende rich matrix. The amphibolitic sequence has been traced for approximately 1.5 km along strike.

It is unfortunate that both of the amphibolite sequences with clearly extrusive volcanic protoliths are contained entirely within the Cliff Lake porphyritic granodiorite. As a result it has not been possible to observe the field relationships between these units and the Cedar Lake gneisses.

(viii) The Trail Lake Series

A heterolithologic sequence of interbanded, quartzo-feldspathic gneisses and amphibolites outcrops at Trail Lake. The sequence is approximately 500 metres wide and extends roughly 8 km along strike at the southern margin of the Cliff Lake porphyritic granodiorite.

The gneissic part of this sequence is composed of a parallel array of thin quartzo-feldspathic stringers and 1-2 cm wide veins separated by more mafic bands and schlieren. The leucocratic parts of the gneiss are dominantly leuco-tonalitic in composition, with grain size in the range 2-4 mm. Mafic clusters of orthopyroxene and biotite are frequently found within the thicker veins. The mafic portion of the rock is highly variable in both composition and texture. Throughout most of the sequence it consists of a medium to fine grained (0.5-1.5mm) foliated, interlobate intergrowth of equal proportions of quartz and plagioclase (An_{36}), accompanied by 20-25% mafic minerals. The mafic constituents are always biotite, orthopyroxene and magnetite but the relative proportions vary widely throughout the outcrop. Locally, much more basic compositions are present with 50% plagioclase (An_{36}), 20% biotite and 30% pyroxene. Fine scale compositional banding may be present defined by relative proportions of orthopyroxene and clinopyroxene.

Deformation of this strongly veined unit has produced small scale tight to isoclinal upright folds about subhorizontal axes. The numerous small scale folds are evident on subvertical surfaces as a strong rodding or mullion structure which is characteristic of the Trail Lake series.

Strongly lineated, orthopyroxene and clinopyroxene bearing amphibolites within the Trail Lake sequence include both banded and unbanded varieties. In thin sections the amphibolites have an equigranular, fine grained (0.5-1.0mm) granoblastic, polygonal texture with strong preferred orientation of mafic minerals. The amphibolites are injected by discordant, pegmatitic leucogranite veins which often produce a marked bleached reaction rim in the host.

(ix) <u>The Transitional sequence</u>

The Transitional sequence is a convenient name for a complexly interbanded unit of various lithological rock types that outcrops on the northeast and southeast limbs of the Mystery Dome. The sequence is essentially an interbanding of amphibolitic units, strongly foliated granitoid units similar to the Clay Lake granitoid suite and granitoid gneiss units similar to the Cedar Lake gneisses. Units similar to the Clay Lake granitoid suite dominate this sequence in the northeastly limb of the dome. In the southeasterly limb of the dome, however, the sequence is dominated by units similar to the Cedar Lake gneisses.

In the northeasterly dipping limb of the Mystery Dome, amphibolitic and granitoid units are interlayered on all scales from 1 metre to 30 metres. Massive unbanded amphibolite units are either strongly boudinaged or agmatised by a network of leucotonalitic veins. Strongly banded, pyroxene bearing amphibolites and banded, mafic, pyroxene-biotite gneisses with thin, concordant leucotonalite veins are deformed into isoclinal folds (Plate 3-12). The severely foliated, locally gneissic, tonalitic and granodioritic units do not however contain such folds.

In the northwesterly part of the northeasterly dipping limb of the Mystery Dome, banded amphibolitic rocks containing tightly folded leucotonalite veins are very similar to the Trail Lake series. These units, however, are interbanded with foliated granitoid units and are considered as part of the Transitional sequence.

(x) <u>The Twilight gneiss</u>

The Twilight gneisses are a unit of rocks which are very similar in composition and morphology to those found in the English River metasedimentary migmatite complex. The unit occurs within the central, core regions of the Mystery and Twilight Domes. In general, the unit produces poor outcrop density and quality, a feature consistent with its comparison to the English River metasedimentary migmatites.

The gneiss contains a strong, persistent compositional banding on a scale of approximately 0.5 to 1.0 metre (Plate 3-6). The banding is defined by concentration of mafic minerals as well as texture and fabric. The less mafic units have mafic mineral contents in the range 14% to 20% with dominant biotite accompanied by minor magnetite and rare, variably altered, orthopyroxene. These units have equigranular (1.0mm) interlobate, foliated textures and are internally banded. The more mafic units are internally banded on a fine scale by impersistent mafic rich and leucocratic lenses. The mafic units contain up to 35% mafic minerals represented dominantly by biotite with minor garnet and orthopyroxene. Grain size is normally in the range of 0.5 to 1.0mm and garnet is present as both small equant crystals and as porphyroblasts up to 2 mm in diameter. In the latter case the garnet contains abundant inclusions of quartz and occasional biotite which may be either non-oriented or weakly oriented, generally parallel to the enclosing foliation. Rare garnet poikiloblasts contain inclusions oriented obliquely to the enclosing foliation. Orthopyroxene occurs as anhedral, disseminated grains and is variably altered by a fine grained, brown serpentinous intergrowth. Much of the orthopyroxene is totally pseudomorphed.

Thin, leucocratic lenses and veins containing garnet and having melanosome margins are present in the more mafic units. The more persistent leucocratic veins are generally subparallel to foliation but have been tightly folded in small scale folds with axial planes parallel to the foliation. Within the Mystery dome, local areas contain a high proportion of white, leucocratic granitoid material enclosing contorted enclaves of mafic garnet-biotite gneisses. The leucocratic component has a highly variable grain size ranging from 1mm up to pegmatitic proportions and is usually granitic in composition. It contains pink almandine garnets, both as small equant grains and as coarse, inclusion filled, poikiloblasts up to 3cm in diameter. A not unreasonable interpretation of much of the leucocratic granitoid material is that it represents a mobilisate phase generated during metamorphism from the more mafic garnet-biotite gneisses.

Amphibolitic units are extremely rare in the Twilight gneisses. In fact only one outcrop - containing a single, massive amphibolite band 1 meter thick - was found actually within the Twilight gneisses. A 5-15 metre thick, massive amphibolitic unit is however present at the margin of the Twilight gneiss, in the northeast and southeast limbs of the Mystery Dome.

(xi) The Cliff Lake porphyritic granodiorite

The body of intrusive rock named here the Cliff Lake porphyritic granodiorite is in fact an intrusive complex of porphyritic granodiorite and pink equigranular granite (fig.3-2). In numerous outcrops the grey, porphyritic granodiorite phase may be seen to be intruded by the pink granite phase. In places, xenoliths of the former may be found in the latter. Both phases contain xenoliths of amphibolite, mafic tonalitic gneiss and granitoid gneiss (Cedar Lake gneiss). Dykes, sills and veins associated with the pink granite phase are commonly found injecting all other rock types in the area.

In its most distinctive form, the porphyritic granodiorite contains euhedral megacrysts of pink microcline up to 4cm in length set in a medium grained, grey, tonalitic groundmass. The megacrysts may display a weak preferred orientation within an unfoliated groundmass. The texture is believed to represent a primary, magmatic flow alignment. Some megacrysts are visibly zoned and may contain inclusions aligned within the zoning. Thin rims composed of myrmekitic plagioclase - quartz intergrowths are often present.

The groundmass has a hypidiomorphic, equigranular, medium grained (1-3mm) texture and in places it appears that mafic minerals are interstitial to quartz and plagioclase. Microcline is not a common constituent of the groundmass and where present it occurs as interstitial anhedra frequently associated with myrmekitic intergrowths. Plagioclase is subhedral, strongly twinned, unzoned, has consistent oligoclase compositions (An_{23}) and is commonly antiperthitic. Mafic contents of these rocks range from 6-10% with dominant biotite being rarely accompanied by hornblende. Magnetite, apatite, sphene, zircon, epidote and muscovite occur as accessory minerals.

In the Cliff Lake and Camp Robinson areas the porphyritic granodiorite exhibits a poorly defined textural and compositional zonation. Central areas are occupied by unfoliated, megacryst rich varieties displaying megacryst alignment. More marginal areas tend to be underlain by weakly foliated, tonalitic, megacryst poor phases. The actual marginal units of the intrusive bodies are usually a complex, foliated mixture of equigranular grey tonalite and equigranular pink granite.

The pink granite component of the late intrusive rocks occurs in many forms. The most common occurrence is as irregular bodies consisting of medium to coarse grained (2-5 mm), allotriomorphic intergrowths of quartz, plagioclase and microcline. Biotite, accompanied by minor magnetite, never constitutes more than 5% of the total rock. Some plagioclase (An_{23}) is antiperthitic, and may be corroded with re-entrants and albitic margins adjacent to microcline. Some microcline crystals are weakly poikilitic and enclose partially resorbed plagioclase grains. In this form, the pink granite may be found as dykes and sills intruding all other rock types in the area. It produces large, outstanding outcrops in the Cliff Lake area and is the major component of the Thaddeus Lake pluton to the east.

Discordant pegmatitic veins and dykes are also common throughout the area and are demonstrably later than the equigranular pink granite. Mineralogically, the pegmatites are extremely simple systems of quartz, plagioclase and microcline. Some veins, however, exhibit textural complexities exemplified by granitic margins and coarser grained quartz-plagioclase cores. Graphic textures of quartz in microcline may be present and euhedral microcline crystals up to 20 cm in length have been recorded.

Foliated varieties of the late intrusive rocks are most common in the marginal portions of the larger bodies or where the bodies are relatively thin. Thus the sheet like protrusions south east of the Mystery and Twilight domes contain a pronounced foliation parallel to their margins. Thin sills which intrude the Clay Lake granitoid suite in the Redbluff and Clay Lakes areas have a weakly protoclastic foliation.

The extension of the Cliff Lake porphyritic granodiorite which outcrops on the northwestern flanks of the Cedar Dome is variably foliated. Compositions range from hornblende-biotite tonalite to biotite granite (fig.3-2). Earlier phases of coarse grained, equigranular to weakly porphyritic granodiorite are moderately foliated. The foliation is defined by a weak alignment of mafic minerals and by long axes of sub-augen shaped microclines. The microclines are mildly megacrystic and have irregular, blurred, margins. The foliation is enhanced by parallel alignment of large amphibolitic and gneissic enclaves which have irregular, diffuse contacts with the host rock. The presence of hornblende in the granodiorites may be, in part, a result of assimilative reactions between host and enclaves. Later, cross cutting, equigranular pink granite phases are rarely foliated.

Weakly foliated equigranular biotite tonalite to granodiorite bodies outcropping in the northwest of the area have not been studied in detail. The bodies have outlines concordant with gneissosity in the host rocks and foliation within the bodies is parallel to the margins. Gneissosity in the host rocks, close to the margins of these bodies, is less well defined than elsewhere and often is "swirled" or contorted into highly irregular patterns. A similar phenomenon is locally present adjacent to the margins of the Cliff Lake porphyritic granodiorite.

Rather rare, concordant sills of foliated biotite tonalite to granodiorite of similar appearance are also present in other parts of the area. They intrude Cedar Lake gneisses in the Cedar Dome area, the Transitional Series east of the Mystery Dome and Twilight gneisses in the Twilight Dome. Similar rocks are also present as a partly marginal phase of the porphyritic granodiorite body which outcrops south of Clay Lake. The temporal and genetic associations of these units has not been established. They resemble in some respects the marginal, megacryst poor, phases of the Cliff Lake porphyritic granodiorite and may possibly represent a slightly earlier phase of the same event.

3-4 STRUCTURAL GEOLOGY

(i) General Statement

The current distribution of major lithological units within the Cedar Lake-Clay Lake area is controlled largely by three major structural features. The Cedar, Mystery and Twilight, domes are defined by the orientation of gneissosity, foliation and compositional banding as well as by orientation of gross lithological units, (fig.3-1). The Mystery and Twilight domes are elongate in a NW-SE trend and are separated by a centrally upwarped, doubly plunging synformal structure hereafter referred to as the Redbluff synform. The north-westwards extension of the Redbluff synform is a large basinal structure which has not been mapped in detail due to lack of exposure. The Cedar Dome is mildly elongate in an E-W trend and is flanked to the southwest by a roughly triangular shaped, parasitic upwarp.

The broad area between the Cedar and Mystery domes is occupied by the Cliff Lake porphyritic granodiorite and associated rocks. These late tectonic intrusions thus occupy structurally depressed regions and appear to overlie the gneissic rocks which they intrude. The orientations of inclusions within the late tectonic intrusive rocks define two large, basinal shaped areas which will be referred to as the Cliff Lake and Camp Robinson structures. The major structure in the northwestern Cliff Lake area has an upright axial surface and very steeply plunging axis and is therefore virtually a neutral fold.

The major structures referred to above are believed to have formed at a late stage in the tectonic evolution of the area and may be related to intrusion of the Cliff Lake porphyritic granodiorite and associated units. The gneissic country rocks contain a wide assortment of minor structures varying from intrafolial, isoclinal folds and severe boudinage of more competent units to concentric open folds which deform the gneissosity. It is immediately apparent that these units have undergone a complex tectonic history which probably included several distinct phases of deformation.

(ii) <u>Grouping of minor structures</u>

Minor fold structures are not sufficiently abundant within this area to apply rigorous geometric analysis. Interfering relationships between minor structures are, however, sufficiently abundant to indicate a generalised sequence of deformation. Within this observed sequence, early structures are always more intense than subsequent ones. Isolated structures occur commonly and it has been necessary to assign these to the various structural groups largely on the basis of their severity, their geometry, or the nature of the planar surface which they deform.

The structural groups have been assigned labels in the Fb series indicating that they occur within the English River plutonic complex. In subsequent chapters those structural groups within the English River metasedimentary migmatite complex will be assigned Fa labels and [illegible] the [illegible] subprovince will be assigned Fc labels. In a subsequent section and in following chapters the sequence of deformational events which produced the observed structures will be referred to as D1, D2 etc. The structural groups described below are arranged in order of decreasing severity and in apparent order of decreasing relative age.

Group F_b1 structures are very tight to isoclinal folds with Class 3 geometry (Ramsay 1967). The folds are frequently rootless and intrafolial, isolated structures, with axial planes parallel to enclosing gneissosity. Such folds occur predominantly within thin leucotonalitic veins in the Cedar Lake gneisses.

Group F_b2 structures are tight to almost isoclinal folds with interlimb angles varying from 5° to 20° and geometries which are strictly class 3 but which closely approach class 2. The folds have amplitudes ranging from approx. 10 cm to 1.5 metres and short wavelengths as befits their subisoclinal nature. Hinges are generally angular, limbs planar and axial planes are sub-parallel to enclosing gneissosity or compositional banding. These structures typically deform pre-existing compositional banding and appear to have transformed this banding into parallelism with their axial surfaces. In most cases the banding appears to have acted as a passive element - at least during the later stages of fold development - and an axial planar foliation oblique to the banding is present in the hinge regions of the folds.

Group F_b3 structures are characteristic of an intense, layer normal, compression event. They include both internal boudinage and normal kinking of F_b2 foliation and folds. Severe boudinage of competent members occurred wherever strong ductility contrasts were present. Tight to isoclinal flattened buckle folds (class 1c) in leucotonalite veins in the Clay Lake suite and the Twilight gneisses are also included in this group. Tight, asymmetric folds with class 2 geometry and interlimb angles of 15-30° are present in leucotonalite veins within the Trail Lake series. These folds are tentatively included within group F_b3 but their exact relationship to other structural groups is uncertain due to a lack of critical interfering relationships.

Group F_b4 structures are close folds with interlimb angles in the range 35°-65° and axial planes oblique to regional gneissosity and foliation. The folds have sub-angular to sub-rounded hinges and planar limbs. Fold geometries vary from class 1C to Class 2 depending on the nature of individual folded layers. The range in interlimb angles reflects the somewhat disharmonic nature of the folds which also produces variable wavelengths and amplitudes within a single outcrop.

Group F_b5 structures are close to open folds with interlimb angles in the range 55° to 90°. The folds have rounded hinges, subrounded to planar limbs and geometries of class 1B to Class 1C. Axial surfaces are upright throughout the area and considerably oblique to regional foliation and gneissosity orientations. Folds of this group deform, in addition to gneissic foliations, the dykes and sills associated with the Cliff Lake porphyritic granodiorite.

Group F_b6 folds are essentially kink like in nature and conjugate, intersecting sets are often present. In outcrop, the fold style varies rapidly along the axial trace in a manner typical of internal conjugate folds developed in an anisotropic medium (Plate 3-11). The folds are best developed in the Cedar Lake gneisses but are also present in other lithologies having a strong planar anisotropy. Late granitic pegmatites are frequently injected parallel to axial planes of group F_b6 folds.

Group F_b7 folds are open to gentle warps with interlimb angles in the range 90-150°. The folds are consistently rounded with class 1B geometries and upright axial planes strongly oblique to regional foliation/gneissosity. The axial planes have NE-SW or N-S orientations and are generally perpendicular to axial planes of group F_b5. These folds locally deform pegmatitic granite sills associated with the Cliff Lake porphyritic granodiorite.

Table 3-1 illustrates the proposed sequence of minor structures within individual lithological units defined by mapping.

(iii) Definition of structural sequences

(a) Cedar Lake gneisses

Of all the lithological units present in this area, the Cedar Lake gneisses appear to have undergone the most extensive structural history. Since F_b2 isoclinal folds deform a pre-existing compositional banding in this unit (Plate 3-7) it is possible that Cedar Lake gneisses were involved in a pre F_b2 structural event. The intensity of this event is open to some debate however since it hinges on the choice of a protolith for the gneisses. If the protolith was an originally intrusive granitoid unit then the pre F_b2 event must have been rather intense in order to produce the excellent compositional banding observed. Such an event may be responsible for the F_b1 rootless folds present in thin leucotonalite bands which may originally have been discordant veins (Plate 3-8). If such folds did form during an earlier event their geometry would undoubtedly have been modified during formation of the F_b2 structures. In addition, the presence of thin, pink, leucogranite bands which have been deformed by F_b2 folds suggests an earlier period of granitic vein injection or granitic mobilisate development. The presence of abundant, severely disrupted and boudinaged amphibolitic enclaves in the Cedar Lake gneisses implies that amphibolite units were present prior to the event responsible for the F_b2 structures (Plate 3-9). It is considered most likely that these amphibolites were present originally as dykes intruded into the Cedar Lake protolith during a very early period of extensional fracturing.

The F_b3 structures include internal boudinage and normal kinking, both of which are widespread throughout the Cedar Lake gneiss. Boudinage of F_b2 folds and deflection of these folds by normal kink zones has been frequently observed. At the rare outcrops where three dimensional exposures allow observation of boudin shapes it is immediately obvious that they have oblate rather than prolate geometries. This holds true for both internal boudins affecting F_b2 gneissosity and for small, amphibolitic, boudinaged enclaves. The latter may owe their present shape to the combined effects of both the F_b2 and F_b3 deformations.

Normal kinks often occur as conjugate pairs with angles of 40-60° between kink zone boundary and gneissosity. In several places, however, isolated normal kink zones occur at angles up to 80° from the gneissosity. Elsewhere curviplanar normal kink zones are generated from internal boudin nodes, clearly indicating the genetic relationship between these structures.

The presence of an equigranular, medium to coarse grained, granitic "mobilisate" within the normal kink zones is a feature that is frequently observed in this area but is not fully understood. The granitic material occurs as an anastomosing array of veinlets or as a single band with diffuse margins. Offshoots of the granitic material appear to penetrate the gneissosity on either side of the kink zone for distances up to several centimetres. From a purely intuitive viewpoint it would seem that the normal kink zones are unlikely to be low pressure sites suitable for deposition of "mobilisate" phases derived from the country rocks. On the other hand, the impersistent nature of the granitic material suggests it was not injected from outside of the immediate system after the formation of the normal kinks.

The F_b1 and F_b2 folds have axial planes which are parallel or subparallel to the dominant gneissosity in the Cedar Lake area. In addition it appears - from very limited evidence - that these groups are currently approximately coaxial. On the north and south limbs of the Cedar Dome the folds have moderately inclined axial surfaces and subhorizontal axes (Map C). On the east and west limbs of the Cedar Dome the folds are essentially reclined structures with moderately inclined axial surfaces and moderately plunging axes. This distribution of orientations implies that these early folds had recumbent or gently inclined axial planes and subhorizontal axes trending WNW-ESE, prior to the development of the Cedar Dome. This suggests that the early structures developed during a period of "horizontal tectonics" similar to that envisioned by Bridgewater et al (1974a) to have occurred in the Archean gneissic terrains of Greenland. No large scale structures which can be related to the F_b1 and F_b2 minor structures are apparent in the area. This is most probably due to the paucity of outcrop and the severely discontinuous nature of large scale compositional banding which render mapping of such structures extremely difficult.

F_b4 minor structures in the Cedar Lake gneisses are very sporadically present and record a period of compression subparallel or mildly oblique to the F_b2 transposed gneissosity (Plate 3-10). In the north and northeast limb of the Cedar Dome these folds have axial planes dipping steeply to the north, with fold axes plunging gently eastwards. In minor folds of this type the normal limb dips at 35-50^{o}N and the over-turned limb at 70-85^{o}N. These folds most probably account for part of the variation in regional gneissosity dips in this area and undoubtedly postdate F_b2 folds.

F_b5 minor folds in the Cedar Dome area (Plate 3-11) are upright structures with axes plunging westerly in the western part of the area, subhorizontally in the central region and easterly in the eastern area. These folds have very similar geometric properties to those displayed by a N-S cross section of the Cedar Dome and it seems reasonable to suggest that the major and minor structures were produced during the same deform-ational event. The F_b7 structures with upright, N-S trending axial surfaces are perhaps the complimentary set of minor folds which were generated during the doming event. F_b6 conjugate and kink-like folds are developed about steeply dipping axial planes disposed in a radial fashion around the Cedar Dome. These structures probably developed due to local stresses produced during the doming event.

In summary therefore the Cedar Lake gneisses contain a sequence of minor fold structures - F_b1, F_b2 and F_b3 - developed during an early sequence of events characterised by strong layer normal compression. These are succeeded by less severely compressed structures produced at the same time as the major doming event.

(b) <u>Clay Lake granitoid suite</u>

In contrast to the Cedar Lake gneisses the Clay Lake granitoid suite contains only rare minor folds. Isoclinal F_b1 and F_b2 folds are absent and the characteristic structural feature of this unit is a strong foliation coupled locally with a poorly defined, discontinuous gneissic banding. This deformation fabric is less well developed in the Twilight Dome than in the Mystery Dome. In the latter area the foliation is accentuated by very tightly to isoclinally folded, thin leucotonalite veins. The folds in these veins have geometries similar to flattened buckle folds (Class 1c) and despite their tightness bear little resemblance to F_b1 and F_b2 folds found in the Cedar Lake gneiss.

Within the transitional sequence, the Clay Lake granitoid units are interbanded with amphibolitic units and Cedar Lake gneisses, both of which contain F_b2 isoclinal folds. It is thus postulated that the major foliation in the Clay Lake granitoid suite was produced at a time postdating that of formation of F_b2 folds. It seems reasonable to suggest that the granitoid suite was emplaced at some time towards the end of the deformation which produced F_b2 folds and that the foliation was produced prior to or coevally with the event that produced the F_b3 structures.

Subsequent deformation has produced folds on a very local basis with geometries equivalent to those of groups F_b4-F_b7. In the core of the Redbluff synform two sets of minor folds are present. The more intensively developed set have F_b4 geometries and deform both foliation and thin leucotonalite veins with consequent variations in hinge angularity. These folds are characterised by W shapes with interlimb angles in the range 45-55^{o} and axial planes parallel to the major synform. The second set of folds are more open structures with interlimb angles around 70^{o} and rounded hinges typical of F_b5 structures. These folds have N-S oriented axial planes. Both sets of folds are infrequently developed and time relationships could not be established unequivocally. The F_b4 structures, however, are most probably associated with the NW-SE trending major structures and the F_b5 structures associated with a N-S trending buckle which locally modifies the form of the Redbluff synform.

(c) <u>The Transitional Series</u>

This series is a complexly interbanded unit of varying lithologies. On the north limb of the Mystery Dome, strongly banded amphibolites and mafic tonalitic gneisses within the transitional sequence contain isoclinal minor folds (Plate 3-12) and thin amphibolitic units in this sequence have been severely boudinaged. Adjacent, thick, unbanded amphibolites are agmatitic and interbanded units from the Clay Lake Granitoid suite are very strongly foliated or locally gneissic but do not contain isoclinal folds. In local zones, thin granitic pegmatites are also strongly boudinaged and the gneissosity is severely deformed by internal boudinage and normal kinking (Plate 3-13). The interpreted structural sequence in this area is therefore as follows:

i) Isoclinal folding of a sequence of interlayered massive and banded amphibolitic rocks - possibly including volcanogenic sediments or pyroclastics. Massive amphibolite units are strongly boudinaged during this event which may be equivalent to the event that produced F_b2 structures in Cedar Lake gneisses as recorded from the southeastern limb of the Mystery Dome.

ii) Intrusion of granitoid bodies and associated granitic pegmatites of the Clay Lake suite after formation of the F_b2 isoclinal folds.

iii) Layer normal compression causing foliation of the Clay Lake suite, boudinage of the F_b2 isoclinal folds, boudinage of granitic pegmatites, and secondary pervasive boudinage and normal kinking of the strongly banded units. This event may be the equivalent of the event that produced F_b3 structures in the Cedar Lake gneisses.

As outlined above, the northern limb of the Mystery Dome contains zones of intense deformation produced during two events. On the southeastern limb of the Mystery Dome these events are apparently reduced in their intensity within the Transitional sequence. F_b2 isoclinal folds are still present within banded amphibolites and Cedar Lake gneisses and thin amphibolite units in the latter are strongly boudinaged. The F_b3 structures, however, are less penetrative here. Microcline megacrysts are still recognisable in the Clay Lake suite and the pervasive internal boudinage and normal kinking of the northern limb are absent in the southeast limb of the Mystery Dome. F_b4 folds plunging at moderate angles to the southwest locally deform gneissosity in Cedar Lake gneisses and pre-existing foliation in amphibolite units (Plate 3-10).

(d) Trail Lake series

The quartzofeldspathic gneiss component of the Trail Lake series records a prolonged and complex sequence of deformational events. The most obvious minor folds in this unit have F_b3 geometries and deform a multitude of pre-existing leucotonalite veins which are separated by thin, strongly foliated mafic schlieren (Plate 3-14). The F_b3 folds have predominantly upright axial planes subparallel to the regional gneissosity and variable, generally subhorizontal, fold axes. On subvertical rock faces these folds produce a strong mullion or rodding structure characteristic of the Trail Lake series.

On close inspection one gets the impression that the leucotonalite veins deformed by F_b3 folds are themselves remnants of pre-existing folds. In fact, severely flattened, isoclinal folds with F_b2 geometries are locally present but it cannot be demonstrated conclusively that these folds are refolded by the F_b3 structures. Larger folds, with amplitudes and wavelengths in the order to several metres, are also present and are coaxial with the F_b3 structures. These folds are characterised by F_b4 geometry but, once again, it cannot be proved that they are refolding the F_b3 folds. It is possible that the F_b3 and F_b4 folds are merely reflections of different orders, or scales, of folding produced during a single deformation event.

Coarse grained, granitic dykes and sills associated with the Cliff Lake porphyritic granodiorite have been intruded into the Trail Lake series. These intrusive units have been weakly buckled by upright folds with F_b5 geometry and generally NW-SE trending, gently plunging fold axes. Adjacent to these intrusions, the gneissosity in the Trail Lake series is also deformed by F_b5 folds. A late period of NW-SE compression is recorded by open, F_b7 folds with NE-SW axial planes and steeply plunging fold axes. This late deformation may also be responsible for the warping and variable plunge of F_b3 mullion structures seen on vertical rock faces.

Thick amphibolite units present within the Trail Lake series do not record the complex early deformations exhibited by the quartzo-feldspathic gneisses. The amphibolites are characterised by a strong subhorizontal or gently plunging lineation, a strong, subvertical foliation and weak compositional banding. These features are probably consistent with the originally massive, homogenous and isotropic nature of the amphibolites when compared with the inhomogenous, banded nature of the quartzo-feldspathic gneisses.

(e) <u>Banded-supracrustal amphibolites</u>

Banded amphibolites which the author believes to be of supracrustal origin are present within both the Cedar Lake gneiss and the Cliff Lake porphyritic granodiorite. Those within the porphyritic granodiorite are undoubtedly large screens or xenoliths picked up during intrusion, but those within the Cedar Lake gneiss are of unknown temporal relationship to the gneiss.

The deformation exhibited by the amphibolites is highly variable and depends to a large extent on the perfection of compositional banding; which may be partly an original feature. Thus, strongly banded units at the southern margin of the Cliff Lake porphyritic granodiorite (north of Trail Lake) contain tight to subisoclinal folds affecting both compositional banding and early leucotonalite veins. The compositional banding and foliation in this unit are generally subparallel and local boudinage structures with coarse diopside and hornblende in low pressure zones are also present. Upright folds with $F_b{}^4$ geometry and subhorizontal axes have been developed here in banded iron formation and in thicker leucotonalite veins that appear to have been originally oblique to the compositional banding in the amphibolites.

A similar structural sequence can be determined from various amphibolitic screens within the Cliff Lake structure. Very tight folds in compositional banding are accompanied by boudinage and succeeded by relatively angular upright $F_b{}^4$ structures. Within the major enclave in the core of the Cliff Lake structure, however, the amphibolitic units are dominantly unbanded and weakly foliated and therefore folds are not visible. The pillowed flow unit at Cliff Lake contains deformed pillows with generally oblate forms (Plate 3-4). Axial ratios in the pillows are highly variable but in the order of 7:5:1 with the longest axes pitching steeply in the foliation and shortest axes subperpendicular to foliation. Buckled leucotonalite veins give minimum shortening estimates of 50% on subhorizontal surfaces in the massive, unpillowed, units at this location.

At Pickerel Lake, strongly foliated and weakly banded amphibolites are contained within the Cedar Lake gneisses. A sequence of variably deformed leucotonalite and leucogranite veins are present within the amphibolites. The earliest veins are very thin, leucotonalitic and have been deformed into isoclinal - almost intrafolial - folds with axial planes parallel to the foliation. Coarse grained pods of diopside and hornblende with minor epidote, which are apparently remnants of originally more continuous units, have been strongly boudinaged within the compositional layering and foliation. Later leucotonalite veins were deformed by somewhat disharmonic folds with F_b4 geometry which also fold the pre-existing foliation and composition banding. Axes of these folds pitch at high angles to the southeast in axial planes dipping moderately to the south-southeast. Locally, undeformed granitic pegmatite veins have been emplaced subparallel to the axial planes of the F_b4 folds. Late stage conjugate kink folds deform foliation, composition banding and leucotonalite veins and late, undeformed granitic pegmatites were injected parallel to the axial surfaces of the kinks.

(f) Twilight gneisses

In outcrop, the Twilight gneiss is virtually identical to the northern English River metasedimentary migmatites. The gneiss typically has a well marked, continuous compositional banding on a scale of 0.5 to 1.0 metre which shows very little sign of strong folding. An abundance of thin leucotonalite and leucogranite veins is ubiquitous in outcrops of this unit and these veins always exhibit evidence of considerable flattening perpendicular to the compositional banding (Plate 3-6). The strong foliation present is always parallel or subparallel to the compositional banding and axial planes of dominant subisoclinal minor folds in leucotonalite veins are also parallel to this foliation.

Large scale, tight folds were only recognised in one outcrop but their presence elsewhere is suspected. In the single observed case on the northeast limb of the Mystery Dome the large scale sub-isoclinal fold is outlined by a coarse grained leucotonalite vein. Foliation in the host rock is in part parallel to the vein but becomes axial planar to the fold in the hinge zone. Unfortunately only a single closure is present and the fold morphology is modified on one limb by an irregular, cross cutting dyke of pegmatitic pink granite.

Close folds with F_b4 morphology locally deform the foliation and earlier minor folds in leucotonalite veins (Plate 3-15). Within the Mystery Dome at Highway 105 these folds are upright with axes plunging very gently to the north, whilst northwest of Redbluff Lake the folds are also upright and have axes plunging 40° southeast. On Twilight Lake, very localised F_b4 minor folds deform a very tight or subisoclinal fold in a leucotonalite vein and a weak foliation is present parallel to the axial planes of the later structures.

At the rare localities within the Twilight gneiss where a large proportion of white, inhomogenous "mobilisate" is present the restite fragments are severely contorted and defy geometric analysis.

Intersection of F_b5 and F_b7 minor folds produce very localised, small scale, dome and basin patterns in Twilight gneiss foliation at Clay Lake; on the southwestern limb of the Twilight Dome (fig. 3-3).

(iv) The major structures and late intrusive rocks

The distribution and definition of major structural features has already been considered and therefore the current section will be concerned largely with the probable genesis of these structures.

The most striking feature of the major domal structures in this area is that, despite their gross geometric similarities, they are elongate in different directions. The Cedar Dome is elongated E-W whilst the Mystery and Twilight Domes are elongated NW-SE. In perpendicular cross sections (fig. 3-4) the Cedar and Twilight Domes are both asymmetric with somewhat shallower dipping southern limbs and steeper northern limbs. The Mystery Dome, however, is only slightly asymmetric with consistently more steeply dipping limbs. In longitudinal profiles the Twilight Dome is asymmetric towards the southeast, the Mystery Dome towards the northwest and the Cedar Dome towards the east. The Twilight dome, in fact, contains two culminations centred on late granitic bodies. Major changes in both orientation and style of the major folds can not be ascribed to periodic variations typical of superimposed fold trends. It has not, therefore, been possible to describe the major structures in terms of regularly oriented, through-going, interfering fold trends.

Minor folds of F_b5, F_b6 and F_b7 geometry are believed to be associated with development of the late major structures. These minor folds are certainly the only groups which demonstrably deform dykes and sills associated with the late granitic intrusions. In terms of their orientations and geometries these folds are compatible with development during a major doming event.

As described previously the late-intrusive, granitic bodies tend to occupy structural depressions and have margins which are generally conformable to the major structural trends of country rock gneissosity (fig. 3-5). In the Cliff Lake and Camp Robinson areas the northerly contacts of the late intrusive have generally shallow to moderate inward dips. Trends of inclusions and marginal foliation outline approximately funnel shaped structures with subvertical axes. The marginal foliation is highly variable in intensity and locally produces protoclastic textures in equigranular pink granite.

The northern extension of the Cliff Lake porphyritic granodiorite body appears to be a partly discordant sheet, intruded at a lower structural level in the gneissic country rocks. This extension contains a moderately developed foliation subparallel to its boundaries and the shape of the body suggests that it was involved - in some manner - with the production of the major, neutral fold in the northern Cliff Lake area.

At first sight it would appear therefore that the late granitic intrusive bodies could plausibly be regarded as sub-parallel sided sheets which have been deformed during the event which produced major domal structures in the country rocks. This hypothesis however breaks down when one considers the northern and southern extensions of the Cliff Lake porphyritic granodiorite since these bodies do not occupy the cores of major synforms. A more tenable hypothesis suggests that intrusion of the late granitic bodies was responsible for the major doming deformation in the country rocks. The major structures are therefore a reflection in part of the position of the country rocks <u>between</u> horizontally expanding intrusions and in part their position <u>above</u> vertically rising intrusions.

(v) Correlation of pre-doming tectonic sequences - the inversion problem

The original intention of the tectonic sequence approach was to determine if distinctions could be made between rock units of possibly different relative ages and to determine if "basement" and "cover" relationships were present.

Without doubt, the Cedar Lake gneisses have undergone a more severe and complex tectonic history than any other units in the area. The presence of F_b1 intrafolial folds, F_b2 isoclinal folds in compositional banding and the severely disrupted nature of mafic enclaves are the principal features recording this early deformation. In contrast, the Clay Lake granitoid suite is much less deformed - lacking both isoclinal folds and a well developed compositional layering. Since both the Cedar Lake and Clay Lake units are compositionally similar this contrast must be ascribed to either differences in age or to extreme spatial variations in strain during a single deformational event.

With regard to the later hypothesis, it is certainly true that the Clay Lake granitoid suite becomes more intensely deformed as the boundary with the Cedar Lake gneisses is approached. Even the most intensely deformed members of the Clay Lake suite, however, never contain deformational features of the intensity present in the Cedar Lake gneisses. The two units are clearly distinguishable on the southeast limb of the Mystery Dome within the Transitional Sequence. In this area - as is the case throughout the total area - the contact relationships between these two units have never been directly observed in a single outcrop. However, the rapid change from one unit to the other between closely spaced outcrops tends to argue against the strain variation hypothesis.

The spatial relationships and deformation distinctions between the two units are more plausibly explained by temporal differences. The Clay Lake granitoid suite is therefore considered to be intrusive into the Cedar Lake gneisses. The time of intrusion post-dated formation of F_b2 folds in Cedar Lake gneisses but pre-dated formation of F_b3 structures.

The structural characteristics and sequence observed in the Twilight gneiss are in many ways comparable with those of the Clay Lake suite. The most striking deformational feature of the Twilight gneiss is the strong, layer-normal compression recorded by tight folds in originally discordant leucotonalite veins. The well developed and persistent compositional banding is not markedly deformed and certainly does not exhibit isoclinal F_b2 folds. This banding is believed to be an original feature of the Twilight gneiss which is considered to be of supracrustal, sedimentary origin.

The structural position of the Twilight gneiss in the cores of the Mystery and Twilight Domes presents an intriguing tectonic problem - namely the inversion problem. If the effects of the late doming event are removed, the supracrustal Twilight gneiss is structurally overlain by the intrusive Clay Lake granitoid suite, which is in turn overlain by the Cedar Lake gneisses. The latter show evidence of being the oldest rocks in the area and hence must be considered as potential basement.

Xenoliths of Cedar Lake gneiss also occur in late intrusive pink granites which form the cores to the Mystery and Twilight Domes. This suggests that the Twilight gneiss is structurally underlain by Cedar Lake gneiss. The surface between the two is not, of course, accessible for direct observation and its nature is unknown.

The original spatial and temporal relationships between the Clay Lake suite and the Twilight gneisses may be considered by using negative evidence. The Clay Lake suite does not contain xenoliths of Twilight gneiss and interbanding of the two units has never been observed. The contact between them must therefore be relatively sharp and is unlikely to be an intrusive contact. If the Clay Lake suite formed from an intrusive protolith and the Twilight gneiss from a sedimentary protolith there can be only two interpretations of the aforementioned structural relationships.

(1) If the two are approximate temporal equivalents the surface separating them must be a major structural discordance. This implies a period of low angle thrust faulting which may be a time equivalent of the F_b3 structures. If the lower contact - between Cedar Lake and Twilight gneisses - is a structural discordance there may be two allochthonous thrust slices above an autochthonous "basement" of Cedar Lake gneiss. If the lower contact is an unconformity the upper

package of Clay Lake suite and Cedar Lake gneiss may be allochthonous whilst the lower package of Twilight and Cedar Lake gneisses may be authochthonous. The latter interpretation would imply that sedimentation may have been extensive across the width of the English River subprovince. It may provide a link between the northern metasedimentary migmatites and those of the Wabigoon subprovince to the south.

(2) If the Twilight gneisses and Clay Lake suite are spatial equivalents the contact between them must be a disconformity. The sequence must be structurally inverted because the Twilight gneisses must logically be the younger of the two. The lower contact between Twilight gneisses and Cedar Lake gneisses must therefore be a structural discordance. The upper package of Twilight gneisses, Clay Lake suite and Cedar Lake gneisses may therefore lie on the lower limb of a major recumbent nappe. The lower Cedar Lake gneiss package may be autochthonous and the two packages must be separated by a tectonic slide.

Irrespective of which of the above hypotheses is correct it is most probable that the intense, layer normal flattening structures (F_b3) visible in the Clay Lake suite and Twilight gneiss were caused by the piling up of thrust sheets or recumbent nappes. Any gross structural discordances which may have existed between the F_b2 transposed gneissosity in Cedar Lake gneisses and the compositional banding in

Twilight gneisses were probably reduced considerably or eradicated by the flattening event.

The metamorphic history of this area is the subject of a subsequent section but one factor must be mentioned at this point. Many rocks in the southern part of the Cedar Lake - Clay Lake area have undergone a period of granulitic metamorphism. Strong linear and planar fabrics developed during this event are considered to be coeval with the F_b3 structures. High grade metamorphic conditions therefore appear to have accompanied the recumbent folding or thrusting event. These metamorphic conditions may place restrictions on the structural level at which this event took place.

From the above arguments it appears plausible that the Cedar Lake gneisses represent a granitoid basement. The gneisses contain isoclinal F_b1 folds and an early, folded gneissosity which may be indicative of a very early deformational event (D1). The evidence for considering this as a separate event is very limited but it cannot be entirely rejected. The gneisses were certainly deformed during an event (D2) which produced the F_b2 isoclinal folds and associated gneissosity. This basement was then intruded by the Clay Lake granitoid suite and deposition of a cover sequence of sedimentary rocks (Twilight gneiss) took place. The entire sequence was then involved in a major deformational event (D3) which produced F_b3 structures and involved thrusting or recumbent nappe formation and inter-leaving of basement and cover units.

The subsequent intrusion of late tectonic granitoid bodies into this layered package of rocks has produced a variety of minor fold structures, (Groups F_b4-F_b7). There is no evidence from this area to suggest that these structural groups were produced sequentially. It is suspected that the F_b4 structures are earlier than the others but they may be different expressions of the same deformational event. Evidence from other parts of the English River Subprovince (Chapter 4) suggests that structures similar to the F_b4 group predate those similar to the F_b5, F_b6 and F_b7 groups. For this reason, the F_b4 structures are assigned to deformation event D4 and F_b5, F_b6 and F_b7 structures are asigned to deformation event D5. The absolute time separating these events may not have been very great.

The following question now arises - do the amphibolitic units belong to the "basement" sequence, the "cover" sequence or to both? In this regard it must be pointed out that direct comparison of tectonic sequences or of apparent deformational intensity cannot be made between such markedly dissimilar rock types as amphibolites and granitoid gneisses. Many of the amphibolitic units present in the area were originally thick, massive, competent units which are unlikely to record responses to deformation in the form of mesoscopic folds. Numerous examples are described in the literature from Archean volcanic terrains where massive, weakly flattened volcanic units are juxtaposed with greywacke type sediments of the same age which exhibit complex, multiphase folding.

Strongly banded amphibolites and mafic tonalitic gneisses on the north-east limb of the Mystery Dome within the Transitional sequence exhibit isoclinal, F_b2 folds which are locally boudinaged (Plate 3-12). It is reasonable to suggest that these units were folded during the D2 event and subsequently boudinaged by the D3 event after intrusion of the Clay Lake granitoid suite. These units must therefore belong to the "basement" sequence and their association with unbanded, strongly agmatised amphibolites suggests the banding was a primary feature. If such is the case they are suspected to have been originally supracrustal units that were intruded by the protolith of the Cedar Lake gneiss or were deposited on and subsequently infolded into a Cedar Lake gneiss basement. These units are possibly therefore a supracrustal unit older than the Twilight gneiss.

The tectonic history of the Trail Lake series is still in some doubt. The injection or anatectic development of leucotonalite veins prior to the D3 event (F_b3 folds) is unquestionable but the involvement of these veins in the D2 event is unproven although suspected. Tentatively the Trail Lake series is correlated with the banded and agmatised amphibolites of the Transitional sequence.

The relationship between gneissic units and the amphibolitic rocks occurring as xenolithic screens in the Cliff Lake porphyritic granodiorite is unknown. Banded amphibolites contain very tight folds affecting compositional banding which has also been strongly boudinaged locally. Flattened pillow-form units are preserved in the largest xenolith at Cliff Lake. Whether these features could be due to the D3 event alone or are the result of a combination of D2 and D3 is open to question. Similar amphibolitic units at Pickerel Lake and Peephole Lake pose the same problems. In these cases, however, the amphibolite units are within the Cedar Lake gneisses and their scale of occurrence suggests they were either intruded by the gneissic protolith prior to D2 or were deformed and infolded into it during D2.

Unbanded, agmatised, severely boudinaged amphibolite enclaves within the Cedar Lake gneiss were almost certainly present at the time of the D2 deformation. These amphibolites are so strongly deformed, however, that their original relationship to the protolith of the Cedar Lake gneiss is a matter for pure speculation. They may either have been dikes intruding the Cedar Lake gneiss protolith or alternatively may represent xenoliths incorporated within it.

The ultimate origin of the Cedar Lake gneisses is unknown. They may possibly have been originally plutonic granitic rocks which were involved in a very early deformational event (D1) which produced the compositional banding now deformed and transposed by F_b2 folds. Alternatively the banding may be the result of severe flattening, during the event designated here as D2, of a heterogenous group of granitic plutonic rocks.

3-5 METAMORPHISM

(i) General Statement

At least one, high grade, regional metamorphic event has affected all rock units in the area with the exception of those associated with the Cliff Lake porphyritic granodiorite. Metamorphic mineral assemblages within the Twilight and Mystery domes are indicative of the Regional Hypersthene zone (Granulites). In the surrounding areas, mineral assemblages are indicative of the Upper Amphibolite grade of regional metamorphism (fig.3-6). It is most probable that this latest regional metamorphism was coeval with the D.3 tectonic event and it hence will be referred to as the M.3 event.

High grade regional metamorphism probably also accompanied the postulated D.2 and D.1 tectonic events. The M.3 event has destroyed all but the most tenuous evidence of these earlier metamorphisms.

Minor, but widespread, retrogressive metamorphism accompanied intrusion of the Cliff Lake porphyritic granodiorite.

(ii) The M.3 metamorphism

The typical mineral assemblage preserved in the Cedar Lake gneisses is:

quartz + plagioclase + biotite $\pm$ microcline $\pm$ hornblende

Plagioclase is unzoned with compositions ranging from An_{22} to An_{30} and presumably reflecting bulk rock composition. This assemblage is compatible with amphibolite grade metamorphism. Amphibolites associated with the Cedar Lake gneiss preserve plagioclase + diopside + hornblende assemblages and locally plagioclase + epidote + diopside assemblages indicative of intermediate amphibolite grade metamorphism. Plagioclase compositions in the amphibolites range from An_{30} to An_{50} reflecting bulk rock compositions.

Mineral assemblages from the southern, granulitic, area are more varied and several are diagnostic of regional hypersthene zone metamorphic grade. The typical assemblage in basic rocks is:

plagioclase + hornblende + diopside $\pm$ hypersthene

Hornblende is strongly pleochroic in dark brown and olive green colours and plagioclase compositions range from An_{38} to An_{52} with bulk rock composition. Hypersthene is weakly pleochroic and exhibits no textural criteria of instability. Garnet occurs at only one locality in a coarse grained boudin of garnet + diopside within a strongly banded hypersthene bearing amphibolite.

Tonalitic rocks of the Clay Lake suite contain biotite ± hypersthene assemblages whilst granodioritic rocks of this suite contain biotite ± almandine garnet assemblages. Twilight gneisses contain assemblages of biotite ± almandine garnet ± hypersthene. The hypersthene is very weakly pleochroic and is affected by a pinnitic alteration of variable intensity. There is no textural evidence that the assemblage biotite + almandine + hypersthene was not originally stable. The pinnitic alteration is more reasonably attributed to later retrograde effects.

A detailed analysis of the conditions accompanying the M.3 metamorphic event is not possible due to the absence of aluminous phases, the absence of chemical analyses of individual mineral phases and the lack of textural evidence to indicate mineral reactions. Several generalised comments are, however, pertinent and modified A'F'M diagrams have been constructed to illustrate these.

The A'F'M diagrams are modified after Rheinhardt (1968) using $F^1 = FeO_{TOT} - TiO_2$ because separate analyses for FeO and Fe_2O_3 are not available. The modified calculation scheme produces higher F' and A' values than those of the Reinhardt calculation. Obviously, magnetite has a significant affect on the modified system and prevents the use of this diagram for predicting mineral assemblages. The Rheinhardt A'FM diagram is a projection through K feldspar in the system A'KFM. Since many of the current samples do not contain K feldspar they should not strictly be plotted on this diagram. However, projections in the systems ACFM or $AKCF_m$ do not adequately illustrate the observed ferro-magnesian mineral assemblages.

The distribution of garnet and orthopyroxene in the Clay Lake granitoid suite is controlled by the bulk chemical composition of the rock (fig.3-7). Samples with low A' values tend to contain orthopyroxene whilst those with higher A' values contain garnet. The generalised field observation that tonalites tend to contain orthopyroxene whilst granodiorites contain garnet is only partially confirmed by the chemical analysis. Two of the analysed tonalites contain garnet and two of the granodiorites contain orthopyroxene.

The absence of both sillimanite and cordierite in the Twilight gneiss is significant since both of these minerals are present in the metasedimentary migmatites of the northern part of the English River Subprovince. Both minerals are commonly reported stable phases in other regional hypersthene zone terrains. Their absence from the Twilight gneisses is most probably due to a bulk chemical control, particularly the low A' values of these rocks (fig. 3-7). This geochemical characteristic may have been an original feature of the Twilight gneisses and may suggest that they were derived rather rapidly from an intermediate volcanic terrain without significant chemical weathering.

Local variations in total fluid pressure must have been present during the M.3 metamorphism. This is the logical explanation for the juxtaposition of orthopyroxene bearing assemblages with lenses of pegmatitic granitic "mobilisate". Evidence in favour of an anatectic origin for the pegmatitic mobilisates includes their concordant nature and the presence of well developed melanosome margins. The extreme inhomogeneity in terms of both grain size and composition in the mobilisates and the frequent presence of mafic biotite - garnet enclaves and garnet megacrysts are further evidence of an anatectic origin. The relatively volatile fluid phases and mobilisate were presumably concentrated in a relatively early stage of the metamorphism into specific zones. The fact that the mobilisate portions are only very poorly foliated suggests that the M.3 metamorphism outlasted the D.3 deformational event.

The pressure-temperature conditions of the M.3 metamorphism undoubtedly exceeded those of the minimum melting curve for granitic compositions. Minimum temperatures in the order of 650°C are therefore a reasonable estimate (fig.3-8). The appearance of orthopyroxene in the semi-pelitic and tonalitic assemblages is most reasonably attributed to a reaction of the type:

(a) biotite + quartz = hypersthene + almandine + k feldspar + H_2O

Winkler (1967, 1974) reports this reaction during experimental anatexis of a semi-pelitic greywacke but gives no details of the pressure-temperature conditions. Grant (1973), however, considers that reaction (a) may occur at similar P-T conditions to the reaction:

(b) plagioclase + biotite + garnet + vapour = cordierite + orthopyroxene + liquid

Reaction (b) takes place in the presence of quartz in the temperature range 650°C to 700°C at pressures in the order of 3 Kb to 6Kb. The equivalent reaction in the absence of vapour is very insensitive to pressure and occurs at temperatures close to 750°C (fig. 3-8). Although reaction (b) is not strictly applicable to the present study because cordierite is a product, its possible equivalence to reaction (a) places a reasonable approximation on the temperatures associated with the M.3 metamorphism.

The absence of the aluminous phases muscovite, sillimanite and cordierite in this area once again prevents estimation of metamorphic pressure regimes. Harris (1976) has however, used these phases in the Lac Seul region of the English River Subprovince to estimate metamorphic P-T conditions. Regional studies suggest that the Lac Seul metasedimentary migmatites and their associated metamorphism are temporal equivalents of the Twilight gneisses and the M3 metamorphism of the Cedar-Clay Lakes area. Harris estimates temperatures in the range 650-750°C and pressures in the range 3.5 kb to 6.0 kb. The presence of local hypersthene in basic rocks from the Lac Seul region suggests that the metamorphic conditions were similar to those which existed in the Cedar-Clay Lakes area.

Metamorphic pressures in the range 4.5 kb to 6.5 kb have been estimated from mineral assemblages of the Perrault Falls district (chapter 4). Orthopyroxene is absent and cordierite is present in the Perrault Falls district. Conversely, cordierite is absent and orthopyroxene is present in the Mystery and Twilight domes. These differences are probably due to original rock compositions but may indicate that slightly greater pressures (5-7 kb) accompanied the M3 event in the Mystery and Twilight domes.

The reliability of correlation between metamorphic fabrics and the D.3 tectonic event varies throughout the area. In the Cedar Lake area (amphibolite grade metamorphism), F_b3 internal boudinage and normal kinks frequently contain diffuse granitic material which is probably a mobilisate formed during the M.3 metamorphism. The Cedar Lake gneisses have strong planar fabrics defined by biotite and platy quartz but it is not known whether these fabrics are entirely due to the M.3-D.3 event or if they are inherited from previous events. Amphibolites within the Cedar Lake gneiss only rarely have linear fabrics. Where these are present they are only weakly developed but appear to be generally subparallel to the long axes of boudins which are themselves only weakly prolate.

Strong linear fabrics are present in amphibolites of the Trail Lake series and Transitional sequence on the north-east limb of the Mystery dome. The linear fabrics are parallel to long axes of Fb3 internal boudins and to fold axes of Fb3 folds. They are defined by both physical and crystallographic elongation of plagioclase, hornblende, diopside and hypersthene.

Strong planar fabrics which developed during the D.3-M.3 event in the Twilight gneisses and the Clay Lake granitoid suite are defined by parallel alignment of biotite and lensoid aggregates of quartz and feldspar. Orthopyroxene in these rocks exhibits a weak alignment within the foliation. Garnet occurs dominantly as small, equant grains devoid of inclusions. Rare garnet poikiloblasts in the Twilight gneisses contain oriented inclusions of quartz, plagioclase and very rarely biotite. The inclusions are, in general, oriented parallel to the external foliation which is only mildly distorted around the poikiloblasts. Sigmoidally oriented inclusions indicating syn-tectonic poikiloblast growth were observed in only one sample.

Granitoid mobilisate which is locally abundant within the Twilight gneisses, is generally unfoliated. Diffuse, biotite rich inclusions (probably restite) are individually strongly foliated but trails of such inclusions are severely distorted. The available evidence suggests that the mobilisate remained relatively mobile throughout the D.3 deformation. The M.3 metamorphism most probably, therefore, outlasted the D.3 deformational event.

(iii) Early metamorphic events

The Cedar Lake gneisses had probably been affected by two metamorphic events prior to the M.3 metamorphism. Even allowing for the modification of Fb2 structures by the D.3 tectonic event it is quite probable that the original Fb2 structures were fairly intense and that they were accompanied by a regional metamorphic event (M.2). Leucogranitic lenses and veins with melanosome margins commonly occur parallel to the axial planes of Fb2 folds which suggests that the M.2 event attained a grade high enough to cause partial anatexis. It must be recognised, however, that the leucogranitic veins may represent a mobilisate formed during the M.3 event or that they may be post-M.2 intrusive veins which have been modified by the M.3 event.

It is quite clear that some form of compositional banding existed in the Cedar Lake gneisses prior to the D.2 tectonic event since this banding defines Fb2 folds. The banding includes leucogranitic lenses and discontinuous layers which have been folded by the Fb2 folds. The protolith to the Cedar Lake gneisses may have been a severely inhomogeneous, intrusive granitoid complex with numerous cross cutting phases on a small scale. If so, it is possible that the gneissic banding could have been produced and deformed by Fb2 isoclinal folds during a single tectono-thermal event (D.2-M.2). If, however, the scale and degree of inhomogeneity of the protolith was more like those of more recent intrusive complexes, it is more likely that the gneissic banding was originally produced during an initial tectono-thermal event (D.1-M.1) and was subsequently modified by the D.2-M.2 event.

(iv) Metamorphism due to the Cliff Lake porphyritic granodiorite

Within the northern part of the area the metamorphic effects attributable to intrusion of the Cliff Lake porphyritic granodiorite are not easily distinguished from those of the preceeding major regional metamorphism. Even in areas remote from the contacts the Cedar Lake gneisses contain an abundance of leucogranite veins and lenses. Some of these are associated with melanosome borders and may represent mobilisate produced during the major regional metamorphism. Close to the contacts of the Cliff Lake intrusive the percentage of clearly intrusive, undeformed leucogranite veins increases considerably. In addition, the gneissosity of the host rock in places becomes diffuse, and irregular, 'swirled' patterns are developed. In other areas the contact is marked by migmatite consisting of irregular enclaves of amphibolite and gneiss within a granitic host.

The contact between the Cliff Lake porphyritic granodiorite and the Trail Lake series in the southern area is much more clearly defined. The effects of a potassic metasomatism are readily identifiable within 50 to 100 metres of the contact. Original leucotonalite veins are converted by introduction of microcline to granodioritic compositions, accompanied by a change in colour from pale greenish grey to pale pink. Original orthopyroxene is totally pseudomorphed by a pale brown, serpentinous mineral and partly replaced by biotite; which becomes an important constituent of the mafic selvages.

In local areas S.E. of Cliff Lake, banded amphibolites have undergone potash feldspathisation (Plate 3-16). The coarse microcline megacrysts have a totally random orientation and can be observed to have overgrown the pre-existing foliation and compositional banding. The local presence of poikilitic microcline megacrysts in otherwise tonalitic units of the Clay Lake granitoid suite may also be a result of potassic feldspathisation associated with the Cliff Lake porphyritic granodiorite.

In general, throughout the southern area, local chloritisation of biotite and sericitisation of feldspar is believed to be retrogression associated with the late tectonic intrusives. These effects are particularly noticeable in the Twilight gneiss towards the core intrusion of the Mystery

Dome. Elsewhere, the replacement of orthopyroxene by a pale brown, serpentinous material is wide-spread. The extent of this effect varies from extremely minor to total pseudomorphous replacement. The intensity of this effect cannot be unequivocably correlated with the presence of late intrusives, however, and it is possible that some of the replacement could have occurred during the waning stages of the major regional metamorphism.

Amphibolitic inclusions (xenoliths) within the Cliff Lake porphyritic granodiorite frequently contain randomly oriented diopside porphyroblasts. These are especially well developed in massive flow units of the Cliff Lake volcanogenic amphibolite enclave. Xenoliths of granitoid gneiss have been observed in highly variable stages of assimilation.

3-6. GEOCHEMISTRY, PETROGENESIS AND PROTOLITHS

(i) Sampling and analytical proceedures

Due to the rather sporadic distribution of outcrop and the poor quality of outcrops away from highway and lakeshore locations no attempt was made to sample the rocks of the area on an objective basis. Instead, representative samples were taken wherever suitable outcrop allowed. It is believed, nevertheless, that the samples analysed represent a fair estimate of both the average compositions and range of rock types present within each of the units. Locations of chemically analysed samples are shown on fig. 3-9.

Modal data were acquired by point counts of both thin sections and stained slabs where necessary. Major elements were analysed by the XRF fusion technique and the trace elements Rb, Sr, Ba and Ce were analysed by XRF using pressed rock powder pellets. Full details of analytical procedures and estimates of precision are presented in appendix (1). Chemical and modal analyses of individual samples appear in appendix (2) and appendix (3). Average chemical compositions of defined units appear in tables 3-3 and 3-5.

Functions which serve to discriminate between igneous and sedimentary protoliths have been calculated according to the scheme of Shaw (1972). Shaw (1972) and Jennings (1970) have discussed the various diagramatic methods which purport to make distinctions between such protoliths. Unfortunately, the fields of igneous and sedimentary compositions overlap on all such diagrams and hence their usefulness is limited. Shaw applied discriminant function analysis to screened analyses of 284 igneous rocks and 608 sedimentary rocks. He recommends use of a discriminant function (DF) which results in an assignment error probability of 0.24. The function recommended is calculated as follows (wt%):

$$DF = 10.44 - SiO_2 - 0.32\ Fe_2O_3\ (\text{total Fe}) - 0.98\ MgO + 0.55\ CaO + 1.46\ Na_2O + 0.54\ K_2O$$

Positive values of DF indicate probable igneous parentage; negative values indicate probable sedimentary parentage. All analyses of samples from the Cedar Lake-Clay Lake area, for which DF has been calculated, conform to Shaw's screening procedure. The calculated DF values are presented in appendix (2) with corresponding chemical analyses.

(ii) Cliff Lake porphyritic granodiorite

For the purposes of sampling and analysis the late tectonic granitic rocks were divided into two major groups. The massive group (A) includes equigranular tonalites, porphyritic granodiorites, pink granites, pegmatites and aplites. The foliated group (B) includes coarse grained tonalites and granodiorites (some mildly porphyritic), aplites and foliated pink granites. The massive varieties occur within the Cliff Lake structure. The foliated group is dominantly from the northern lobe - north west of Cedar Lake - with a smaller number of samples from the margins of the Cliff Lake structure. The two groups of rocks are considered on the basis of field evidence to be successive phases of a comagmatic event.

Both groups of samples display normal trends of major oxides when plotted against the Modified Larsen Index (MLI) (fig. 3-10). Similarly both groups exhibit decreasing Ca, Sr and Ca/Sr and increasing K, Rb and K/Rb with increasing MLI, which may be equated with progressive differentiation (fig. 3-11). These correlations are particularly obvious within the foliated group. There is also a strong negative correlation between K/Rb and modal biotite content of the samples (fig. 3-12), suggesting that the controlling factor on K/Rb here is the replacement of biotite by microcline as the dominant K and Rb repository.

A further point of interest is the somewhat higher Sr contents of the massive samples, when compared to the foliated granitoid rocks which were originally believed to be comagmatic. Both the high Sr and low Sr groups contain compositions ranging from tonalite to granite and both include rocks bearing K feldspar megacrysts. The distinction, therefore, is that the high Sr rocks are somewhat later than the others and have not been visibly deformed. There is no obvious evidence to indicate which of these factors exerted the controlling influence on the Sr compositions.

Field evidence indicates that the late granitoid rocks are intrusive into the gneisses at the current level of exposure and hence were not generated in situ. Partial melting of granitoid rocks tends to deplete the Sr content of the melt in relation to that of the residue (McCarthy, 1976). It is unlikely, therefore, that the massive granitoid rocks (Average Sr 529 ppm) were derived at depth from equivalents of the Cedar Lake gneisses (237 ppm Sr) or the Clay Lake granitoid suite (187 ppm Sr).

The similar Sr contents of the massive granitoid rocks and the Twilight gneisses would permit derivation of the former by partial melting of the latter. Other trace element concentrations and major/trace element ratios, however, are incompatible with such a model. In particular, the Rb contents and Rb/Sr ratios of the massive granitoid rocks are considerably lower than those of the proposed parent Twilight gneisses. This is the exact opposite of the relationships predicted for partial melting of greywackes by Arth and Hanson (1975).

(iii) Clay Lake granitoid suite

The Clay Lake suite includes biotite tonalites, hypersthene-biotite tonalites, biotite granodiorites, garnet-biotite granodiorites and garnet-biotite granites. The coarse grain size, relatively low mafic mineral content, lack of well defined compositional banding and presence of deformed microcline megacrysts suggest that the protoliths of this suite were granitoid rocks rather than supracrustal sediments. The presence of xenoliths within the suite suggests that the protolith was originally intrusive rather than extrusive. Calculated discriminant functions (Shaw 1972) are all high positive values indicating igneous rather than sedimentary protoliths.

The suite as a whole displays the same trends of major and trace elements as the foliated group of late tectonic granitoid rocks described previously (figs. 3-10, 3-11). The suite is slightly iron rich in comparison to all other granitoid rocks from this area but displays a normal igneous trend on the F-M-A diagram. Despite its granulitic nature, the suite is not significantly depleted in Rb. K/Rb values range from 230 to 450 and display a marked negative correlation with biotite content (fig. 3-12).

(iv) Cedar Lake gneisses

The spread and variability of both chemical and modal data for this suite reflect the extreme lithologic heterogeneity of the gneisses. The well marked but extremely discontinuous nature of compositional banding and the abundant presence of several generations of "granitic" veins and lenses render sampling extremely difficult. In general terms, samples were taken, where possible, to represent a compositional unit having a width in excess of 20 cm. Obviously late, undeformed, granitic veins were avoided but, inevitably, granitic veins of earlier generations were included in many samples. Interpretation of the analyses is therefore extremely difficult and suspect.

The modal and geochemical trends exhibited by the Cedar Lake gneiss samples are generally similar to those of the Clay Lake suite and the foliated group of late tectonic intrusives (figs. 3-10to 3-13). The Cedar Lake gneisses tend to be more felsic and more potassic than the Clay Lake suite. The geochemical similarity between the Cedar Lake gneisses and the foliated late granitoid rocks (group B) is quite remarkable.

The possible protoliths for the Cedar Lake gneisses include (i) sediments (ii) felsic volcanics (iii) intrusive granitoid rocks. The presence of a strong compositional banding is the only feature which suggests that the Cedar Lake gneisses were derived from a sedimentary protolith. The low mafic mineral contents, coupled with the total lack of pelitic mineral assemblages (garnet, cordierite or Al_2SiO_5 polymorphs) would require that a sedimentary protolith be arkosic in composition. The wide areal extent and great thickness of the Cedar Lake gneisses militate against such a possibility. In addition, calculated discriminant functions are strongly in favour of an igneous origin.

A felsic volcanic protolith is considered unlikely due to the total lack of anything remotely resembling pyroclastic fabrics in the Cedar Lake gneisses. Further, the extent and thickness of the gneisses are far greater than those of any felsic volcanics so far reported from the Archean. The most likely protolith, therefore, for the Cedar Lake gneisses would be an intrusive granitoid complex. The acceptance of this protolith implies that the present banding in the gneisses is the result of extreme deformation of a plutonic body consisting of numerous, compositionally distinctive, injected phases.

(v) Comparison with other Archean granitoid gneisses

Rock suites which are similar in both composition and tectonic setting to the Cedar Lake gneisses and Clay Lake granitoid suite occur in several Archean terrains (Table 3-4). In view of the lack of radiometric ages from the Cedar-Clay Lakes areas, however, it is difficult to pick suitable time equivalent suites for comparison. Current radiometric evidence from other parts of the English River Subprovince suggests that both the Clay Lake suite and the Cedar Lake gneisses were originally emplaced prior to 2.9 b.y. ago.

The most obvious temporal and tectonic equivalents of the Cedar Lake gneisses are the Ancient Tonalitic gneisses of Swaziland, which have Rb/Sr ages in the range 3.14 b.y. to 3.40 b.y. (Hunter 1974). These rocks are chemically similar to the Cedar Lake gneisses except that they are more sodic. Similarly, the Amitsoq gneisses of W. Greenland (3.7 b.y.) and the Uivak I gneisses of Labrador (3.6 b.y.) are more sodic, contain less barium and have lower K/Rb ratios. The Uivak I gneisses, in addition, have distinctly higher Sr contents.

The Northern Light gneiss of Minnesota is distinctly sodic and has a considerably lower Rb/Sr ratio than either the Cedar Lake gneiss or the Clay Lake granitoid suite.

The Morton gneiss of Minnesota is remarkably similar to the Cedar Lake gneiss in terms of both major and trace element geochemistry. The Morton gneiss has recently been assigned an age of 3.8 b.y by Goldich and Hedge (1974).

The Clay Lake suite and the Uivak II gneisses of Labrador (3.6 b.y.) share a similar tectonic setting in that they both intrude a pre-existing suite of gneisses. The similarity is extended to their comparable iron contents (Fe_2O_3 4.0%) but the Clay Lake suite is more potassic and contains less Rb.

(vi) Amphibolites

The amphibolites from the Cedar-Clay Lakes area have been divided into three groups on the basis of their field relationships. Group 1 contains samples from small enclaves within the Cedar Lake gneisses. Group 2 consists of samples from the extrusive volcanogenic enclaves within the Cliff Lake granodiorite. Group 3 are banded and unbanded samples from the Trail Lake Series and the Transitional Sequence. The groups, as defined, are not geochemically distinct.

With the exception of three samples, the amphibolites are classified as tholeiitic basalts (figs 3-14, 3-15) using the criteria of Irvine and Baragar (1971). The three exceptions from group 1 are marginally calc-alkaline and andesitic.

The amphibolites are characterised by low FeO_{TOT}/MgO ratios and plot close to the recent abyssal tholeiite field (fig.3-16a) of Miyashiro (1974) and Miyashiro and Shido (1975). They contain somewhat lower abundances of TiO_2 than recent abyssal tholeiites with comparable FeO_{TOT}/MgO ratios (fig.3-16b). In this respect they are more like recent Island Arc tholeiites. The low TiO_2, Al_2O_3 and high Rb, Ba of the amphibolites when compared to recent oceanic tholeiites is compatible with similar characteristics noted by Glikson

(1972) for Archean greenstones in general.

The Cedar-Cliff Lakes amphibolites do not fall within the field of recent ocean floor basalts on the TiO_2-K_2O-P_2O_5 diagram defined by Pearce et al (1975). The amphibolites have considerably higher K_2O/TiO_2 ratios than average Archean basalts, (fig.3-17a). This feature is most probably related to metamorphism as demonstrated by Pearce et al (1975) for samples of fresh, weathered and greenschist facies basalts from the Mid-Atlantic Ridge and for amphibolites from the Palmer Ridge, Indian Ocean.

Three of the samples from group 3 have marginally komatiitic geochemistry. Field relationships and petrology suggest that sample 357 was originally a lamprophyric dike intruded into the volcanic sequence of the Cliff Lake enclave. The sample contains 76% hornblende, 19% biotite and 5% plagioclase. It is not a true komatiite since the K_2O content (1.29%) is somewhat greater than that permitted by the definition of Brooks and Hart (1974) (Basaltic komatiites should have less than 0.9% K_2O).

Samples 103 and 105 both satisfy all the geochemical criteria of basaltic komatiites. They have CaO/Al_2O_3 ratios greater than 1, MgO greater than 9.0%, TiO_2 less than 0.9%, K_2O less than 0.9% and SiO_2 in the range 46-53%. Sample 103 is from the feature believed to be a concentrically zoned lava tube and sample 105 is from the pillow-form unit. Both are, consequently, considered to be originally extrusive volcanic rocks. The extent of modification to the original geochemistry by metamorphism is difficult to determine. The spatial association of normal tholeiitic basalt samples with the komatiitic samples suggests that the unusual composition of the latter is inherited from the original protolith.

The presence of rocks with komatiitic geochemistry has been used by various authors to indicate a wide variety of paleotectonic environments. These include: sea floor (Glikson 1971); island arcs (Brooks and Hart 1972) and primitive crust (Viljoen and Viljoen 1969). In an excellent summary of the problem, Brooks and Hart (1974) conclude that the presence of komatiites is not, in itself, a reliable indicator of paleotectonic environment. The absence of associated distinctive rock types (e.g. felsic volcanics) in the current situation precludes further definition of the paleotectonic setting of the group 3 amphibolites.

(vii) Twilight gneisses

There is abundant field evidence that the Twilight gneisses were derived from a supracrustal and, most probably, sedimentary protolith. The unit is strongly and continuously banded in a manner reminiscent of the greywacke type sediments commonly found in Archean greenstone belts. The gneisses are relatively mafic rich, rarely containing less than 15% of mafic minerals (fig. 3-2c) and relatively fine grained compared with the Clay Lake suite and the Cedar Lake gneisses. The abundant presence of garnet and an inhomogenous mobilisate combines with the above features to give the Twilight gneiss some similarities to the northern English River metasedimentary migmatites.

Two populations may be distinguished within the Twilight gneisses. Group A are relatively mafic, garnetiferous, biotite gneisses which locally contain hypersthene and are strongly associated with microcline rich mobilisate zones. On the Alk-FeO-MgO plot (fig. 3-18) this group occupies the centre of the field of Archean greywackes defined by Bell and Jolly (1975). The group is also remarkably comparable with a group of 12 English River metasedimentary rocks from the Armstrong area. (Unpublished data supplied by F.W. Breaks, Ontario Division of Mines).

Calculated discriminant functions for group A Twilight gneisses are generally low positive or negative values which are compatible with a sedimentary protolith. The single sample with a higher positive discriminant function contains a wide lens of granitic mobilisate.

The absence of both cordierite and Al_2SiO_5 polymorphs and the local presence of hypersthene indicates that the group A Twilight gneisses contain less aluminum than typical pelitic metasediments. This feature may be due to rather rapid derivation of the group from a volcanic source area of intermediate or basic bulk composition.

Group B Twilight gneisses occur as relatively felsic, coarse grained, structureless units up to one metre thick.

They are interlayered with the type A units and gradational boundaries are commonly present, suggesting a supracrustal protolith. The group B gneisses have dacitic compositions which are more alkalic and siliceous than the group A gneisses. The group B gneisses are also characterised by higher Sr, Ba, K/Rb and lower Rb, K_2O/Na_2O, Ca/Sr values and by particularly low Rb/Sr ratios.

Calculated discriminant functions are consistently high positive values suggesting an igneous protolith. The presence of gradational boundaries to the units suggests, however, that they did not originate as dacitic flows or intrusions. It is likely, therefore, that the group B Twilight gneisses originated either as ash fall tuffs or as relatively fine grained pyroclastic debris which was rapidly reworked by sedimentary processes.

3-7 SUMMARY

The establishment of a tectonic model for the evolution of the Cedar Lake-Clay Lake area depends largely on two factors. These are firstly, the choice of protoliths for the various lithologic units and secondly, the structural history of each unit. The most probable sequence of geological events is summarised in Table 3-6.

The Cedar Lake gneisses are an intimately interbanded, heterolithologic assemblage of rocks varying in composition from amphibolite to granite. The unit as a whole is severely deformed and contains numerous tight to isoclinal Fb2 folds and hence is regarded as being pre-D2 in age. The presence of intrafolial, isoclinal Fb1 folds suggests that parts of the unit underwent an even earlier deformational event (D.1). The D.1 event may also have been responsible for the production of a compositional banding which was subsequently folded during the D.2 event.

The most likely protolith for the felsic portion of the Cedar Lake gneisses would be an intrusive granitoid complex. The acceptance of this protolith implies that the present banding in the gneisses is the result of extreme deformation of a plutonic body consisting of numerous, compositionally distinctive, injected phases.

The presence of both banded and unbanded amphibolite enclaves within the Cedar Lake gneisses poses a problem. It is suggested that the banded varieties represent originally extrusive volcanic material, and hence may have originated as xenoliths within the Cedar Lake protolith. In contrast, it is possible that some of the unbanded amphibolite units were originally injected as mafic dikes into the Cedar Lake gneiss protolith. The Cedar Lake gneiss could thus be regarded as a granitoid complex which was intruded into a mafic volcanic sequence prior to the D.2 deformation. Alternatively, it can be regarded as a coupled granitoid basement and mafic volcanic cover which was extensively reactivated during the D.2 deformation with interfolding of cover and basement.

Amphibolites included within the Transitional Sequence contain Fb2 folds and are most probably equivalent in age to those occurring within the Cedar Lake gneisses. The tectonic history of the Trail Lake series is enigmatic. It was undoubtedly involved in the D.3 tectonic event and involvement in the D.2 event is suspected but not proven. The intimate association of banded and unbanded amphibolites with relatively mafic, quartzo-feldspathic gneisses suggests that the Trail Lake series was originally a supracrustal sequence. It is tentatively correlated with amphibolites of the Transitional Sequence.

Several factors indicate that the Clay Lake granitoid suite was an igneous, plutonic, granitoid suite intruded into the Cedar Lake gneiss complex at some time after the D.2 event. The Clay Lake suite appears to have been a differentiated suite of granitoid intrusive rocks with compositions ranging from biotite tonalite to leucocratic, alaskitic granite. Tonalites are marginally more abundant than granodiorites and the two together are more abundant than granites.

The original configuration of the suite is unknown since the present concordance of units of different compositions may be due to the strong flattening deformation during the D.3 event. It is possible, however, that the various members of the suite were emplaced as concordant sheets, perhaps during the waning stages of the D.2 deformation. The fact that the suite appears to intrude banded amphibolites, mafic tonalitic gneisses and Cedar Lake gneisses - all of which contain isoclinal Fb2 folds - indicates that the intrusion did not take place prior to the D.2 event.

The group A Twilight gneisses are believed to have been derived from a greywacke-type sedimentary protolith. There are strong morphological and geochemical similarities between the group A Twilight gneisses and the metasedimentary gneisses of the northern part of the English River Subprovince. The similarities include the relatively mafic character and the ubiquitous presence of garnet and leucocratic "mobilisate" phases. The relatively low aluminum content of the group A gneisses suggests that they were derived by rapid sedimentation of clastic material from an intermediate to basic volcanic source area.

Group B Twilight gneisses occur as relatively felsic, coarser grained, more massive units subordinate in volume to the group A units. Their interlayering with group A units suggests a supracrustal origin and their dacitic geochemical characteristics, coupled with high positive discriminant functions, suggest they may originally have been felsic to intermediate volcanic rocks. However, the fact that group A and group B horizons have gradational boundaries rules out the possibility of dacitic flows. It is suggested, therefore, that the group B Twilight gneisses represent either ash fall tuffs or fine grained pyroclastic debris rapidly reworked by sedimentary processes.

Establishment of the relative age of the Twilight gneiss is extremely important in terms of the tectonic history of this area. The total lack of Twilight gneiss xenoliths within either the Clay Lake granitoid suite or the Cedar Lake gneisses suggests that the Twilight gneiss post-dates both of these units. Moreover, the Twilight gneiss does not contain isoclinal Fb2 folds deforming the compositional banding and hence is believed to post-date the D.2 deformation. The unit has, however, undergone a strong flattening deformation early in its history which produced tight to isoclinal structures in leucotonalite veins. This deformation is believed to be correlatable with the production of Fb3 structures elsewhere and hence the unit pre-dates D.3. It was also involved in a major metamorphic event which probably accompanied the D.3 event and produced granulitic mineral assemblages.

The relative tectonic age of metavolcanic enclaves within the Cliff Lake porphyritic granodiorite can not be directly determined due to their geologic situation. The metavolcanic rocks include tholeiitic pillow basalts and some samples have komatiitic geochemical characteristics. The metavolcanic rocks have recorded a period of relatively strong deformation in the form of flattened pillows and rare, small scale, tight folds in compositional banding. It seems highly unlikely, however, that these rocks were present during the D.2 deformation event. Had they been present, extensive agmatisation of the massive units would probably have occurred. The folding, flattening, and accompanying development of diopside bearing mineral assemblages is more reasonably attributed to the D.3/M.3 event. This suggests, therefore, that these units may be broadly equivalent in age to the Twilight gneiss.

The structural position of the Twilight gneisses is somewhat enigmatic in that this supracrustal unit lies at a lower structural level than the Clay Lake suite and the Cedar Lake gneisses, both of which predate it. Consequently, it is necessary to postulate a period of subhorizontal thrusting or recumbent nappe formation, probably accompanying the D.3 deformation. If such an event took place it could explain the strong flattening deformation which produced (1) internal boudinage and normal kinking in the Cedar Lake gneiss, (2) the strong foliation in the Clay Lake suite and (3) the isoclinal folding of leucotonalite veins in the Twilight Gneisses without significant distortion of compositional banding.

The piling up of thrust sheets or nappes during D.3 may also have been responsible for the depression of the southern area into a regime suitable for the production of granulitic mineral assemblages. It is significant that the Cedar Lake area, which would have been structurally higher at this time, lacks such assemblages. From a consideration of the mineral assemblages it appears that the M.3 metamorphic event was accompanied by temperatures in the range 650-750°C and pressures in the range 3.5-6.0 kb. In the southern part of the area the conditions were probably in the upper parts of this range whilst in the northern area they were in the lower parts. Significant depletion in Rb of the rocks of the southern area has not taken place, despite the granulitic nature of the metamorphism.

Intrusion of the Cliff Lake porphyritic granodiorite and associated phases clearly post-dates the major D.3/M.3 tectonic event. From limited field data it appears that the early phases of this period of granitic activity were marked by concordant intrusion of equigranular biotite tonalite to granodiorite.

In the north and the south, the porphyritic granodiorite forms tabular, steep sided bodies which are also almost concordant with the gneissic host rocks. These bodies are variably foliated and in places the porphyritic character of the rocks becomes only vaguely definable. The foliation may, in part, be a primary feature produced during intrusion of the bodies; as suggested by the strikingly oriented nature of country rock xenoliths. However, the foliation is locally quite strongly deformed by complex, irregular, poorly defined fold structures and early leucocratic veinlets also exhibit ptygmatic folding. These features may be due to external tectonic factors operative whilst the intrusive bodies were still in a relatively plastic state, perhaps during the late stages of consolidation.

It is suggested therefore that the northern and southern extensions of the Cliff Lake porphyritic granodiorite were of intermediate age in the intrusive episode. Later phases of intrusion were probably responsible for foliation of earlier phases and for the production of major domal structures in the gneissic country rocks. The porphyritic granodiorite intrusions in the central part of the area are funnel shaped bodies with inward dipping contacts. The total shape of these bodies may originally have been somewhat similar to the mushroom shaped, diapiric bodies produced experimentally by Ramberg (1967).

The latest phase of this major granitic event was responsible for the intrusion of numerous dikes, sills, and veins of equigranular pink granite and granitic pegmatite. This phase is ubiquitous throughout the entire area but the areas of most extensive outcrop are intimately associated with the porphyritic granodiorite phase. Undoubtedly there is a genetic linkage between these two phases, the pink granites probably representing a more differentiated intrusion from the same magma source. This linkage is emphasised by the high Sr concentrations present in samples of both porphyritic granodiorite and equigranular granite from the massive (group A) varieties of the late intrusive rocks.

The available geochemical evidence suggests that the late granitoid intrusions were not derived by partial anatexis of either the Cedar Lake gneisses or the Clay Lake suite.

Table 3-1 Proposed Sequence of Minor Structures

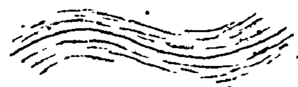
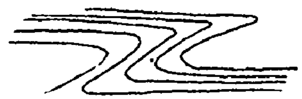
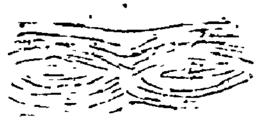
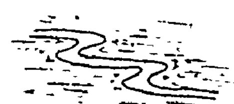
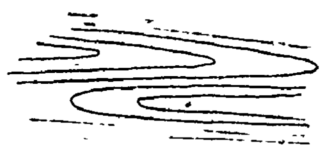
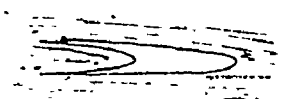
Structural Group				Cedar Lake Gneiss	Amphibolites in Transitional Sequence	Clay Lake Granitoid Suite	Trail Lake Series	Twilight gneiss	Cliff Lake Amphibolites
	Fb7	Open folds		x	x	x	x	x	x
D5	Fb6	Reverse kinks		x	x	x	x	x	x
	Fb5	Close-open folds.		x	x	x	x	x	x
D4	Fb4	Close folds		x	x	x	x	x	x
D3	Fb3	Internal boudinage Normal Kinks	 	x	x	x	x	x	x
		Tight folds in leucotonalite veins		x	x	x	x	x	x
D2	Fb2	Tight-isoclinal folds		x	x				
D1	Fb1	Intrafolial isoclinal folds		x					

Table 3-2

CEDAR LAKE - CLAY LAKE AREA

METAMORPHIC MINERAL ASSEMBLAGES

Northern Area

In Cedar Lake gneiss

Qz + plag + bi $\pm$ Ksp $\pm$ hbl

In mafic tonalitic gneisses

Qz + plag + hbl + bi

In Amphibolites

Plag + hbl $\pm$ diopside $\pm$ epidote ($\pm$ qz $\pm$ bi)

Southern Area

In Clay Lake Tonalites

Qz + plag + bi $\pm$ opx $\pm$ Ksp

In Clay Lake Granodiorites

Qz + plag + Ksp + bi $\pm$ garnet

In Twilight gneiss group A

Qz + plag + bi $\pm$ garnet $\pm$ opx $\pm$ Ksp

In Twilight gneiss group B

Qz + plag + bi $\pm$ Ksp $\pm$ garnet

In mafic tonalitic gneiss

Qz + plag + bi $\pm$ opx $\pm$ hbl $\pm$ Ksp

In amphibolites

Plag + hbl + cpx $\pm$ opx ($\pm$ qz $\pm$ bi)

magnetite, illmenite, sphene, zircon and apatite occur as accessory minerals.

Table 3-3

Average chemical compositions

Granitoid units

	A	B	C	D	E	F
SiO_2	73.00	70.80	71.34	71.10	71.90	69.50
Al_2O_3	15.00	15.86	15.59	14.71	14.69	15.43
TiO_2	.10	.26	.21	.41	.31	.52
Fe_2O_3(TOT)	1.08	2.14	1.88	2.99	2.61	4.04
MnO	.02	.04	.03	.04	.04	.05
MgO	.37	.96	.78	.93	.82	1.05
CaO	1.61	3.27	2.71	2.87	2.80	3.50
Na_2O	3.89	4.55	4.26	3.80	3.97	3.74
K_2O	4.45	2.00	3.04	3.04	2.75	2.45
P_2O_5	.05	.10	.09	.14	.10	.19
Total	99.57	99.98	99.93	100.03	99.99	100.47
Rb	95	58	73	85	76	64
Sr	450	609	529	194	237	187
Ba	1321	831	1023	811	950	751
Ce	39	34	35	92	73	69
K/Rb	390	287	331	295	317	303
K/Ba	32	22	26	31	24	27
Ca/Sr	42	38	42	102	86	140
Rb/Sr	.211	.095	.138	.438	.321	.342
K_2O/Na_2O	1.14	0.44	0.71	0.80	0.69	0.65

A. Cliff Lake pink granite - average of 5 samples
B. Cliff Lake porphyritic granodiorite - average of 8 samples
C. Cliff Lake Intrusion, Group A - average of 14 samples
D. Cliff Lake Intrusion, Group B - average of 15 samples
E. Cedar Lake gneiss - average of 12 samples
F. Clay Lake granitoid suite - average of 20 samples

Table 3-4

Chemical Analyses of Archean Gneisses

	A	B.	C	D	E	F	G
SiO_2	68.60	69.45	71.00	72.21	70.40	69.10	71.16
Al_2O_3	15.90	15.18	14.90	14.39	13.10	17.0	14.84
TiO_2	0.40	0.31	0.26	0.25	0.59	0.20	0.34
Fe_2O_3(TOT)	2.53	2.51	2.69	1.99	4.18	1.81	2.29
MnO	.03	.04	.03	.03	.07	.03	.02
MgO	.94	.81	.72	.60	.83	.69	.95
CaO	2.60	2.80	2.30	1.58	2.48	3.60	3.18
Na_2O	5.28	4.50	4.45	4.37	4.80	5.69	4.67
K_2O	2.47	2.47	3.02	3.57	1.51	1.31	1.64
P_2O_5	0.13	.12	.07	.10	.17	.21	.12
TOTAL	98.88	98.19	99.44	99.09	98.13	99.94	99.21
Rb	111	100	91	80	100	27	73
Sr	725	273	381	278	140	661	250
Ba	263	361	806	ND	947	489	ND
Ce	ND	ND	ND	ND	ND	108	ND
K/Rb	184	198	275	282	125	408	187
K/Ba	78	72	31	-	104	22	-
Ca/Sr	25	73	43	40	126	39	91
Rb/Sr	.153	.366	.238	.287	.714	.040	.29
K_2O/Na_2O	.47	.55	.68	.81	.31	.23	.35

A. Uivak I gneiss, Labrador - average of 10 samples, Bridgwater and Collerson, 1976

B. Amitsoq gneiss, West Greenland - average of 12 samples, Bridgwater and Collerson, 1976

C. Morton gneiss, Minnesota - average of 5 samples, Goldich, Hedge and Stearn, 1970

D. Nelspruit migmatite, South Africa - average of 10 analyses, Viljoen and Viljoen, 1969

E. Uivak II gneiss, Labrador - representative sample #14, Bridgwater and Collerson, 1976

F. Northern Light gneiss, Minnesota - trondhjemite sample #16, Arth and Hansen, 1975

G. Leucotonalitic gneisses, Ancient Gneiss Complex of eastern Transvaal and Swaziland - mean of 6 analyses, Hunter 1974 (Table IV)

Table 3-5

Chemical Analyses of Archean Metasediments and "paragneisses"

	A	B	C	D
SiO_2	60.57	66.50	71.57	64.40
Al_2O_3	17.24	17.40	15.30	15.50
TiO_2	.79	.53	.26	.62
Fe_2O_3(TOT)	7.68	3.21	2.04	6.54
MnO	.10	.04	.03	-
MgO	3.34	1.20	.69	3.12
CaO	3.25	4.31	2.45	2.22
Na_2O	3.69	4.02	5.06	3.74
K_2O	2.95	2.40	2.53	2.44
P_2O_5	.38	.34	.09	-
Total	99.99	99.95	100.02	98.58
Rb	118	65	86	88
Sr	602	1120	351	424
Ba	886	1671	503	ND
Ce	87	65	ND	ND
K/Rb	205	290	243	231
K/Ba	28	13	42	-
Ca/Sr	47	28	50	37
Rb/Sr	.914	.058	.25	.20
K_2O/Na_2O	.80	.60	.50	.65

A. Twilight gneiss, Group A, English River Subprovince - average of 5 samples
B. Twilight gneiss, Group B, English River Subprovince - average of 3 samples
C. Hebron gneiss, Labrador - average of 8 samples, Barton 1975
D. Archean greywackes, Wyoming - average of 23 samples, Arth and Hanson 1975

Table 3-6

Preferred sequence of geological events
Cedar Lake - Clay Lake Area

1. Deformation (D1) of a granitic complex - protolith of Cedar Lake gneiss - produces compositional banding and F_b1 folds.

2. Formation of early supracrustal sequence - protolith of banded amphibolites of Trail Lake Series, Transitional sequence and enclaves in Cedar Lake gneiss. Intrusion of early mafic dykes into Cedar Lake protolith.

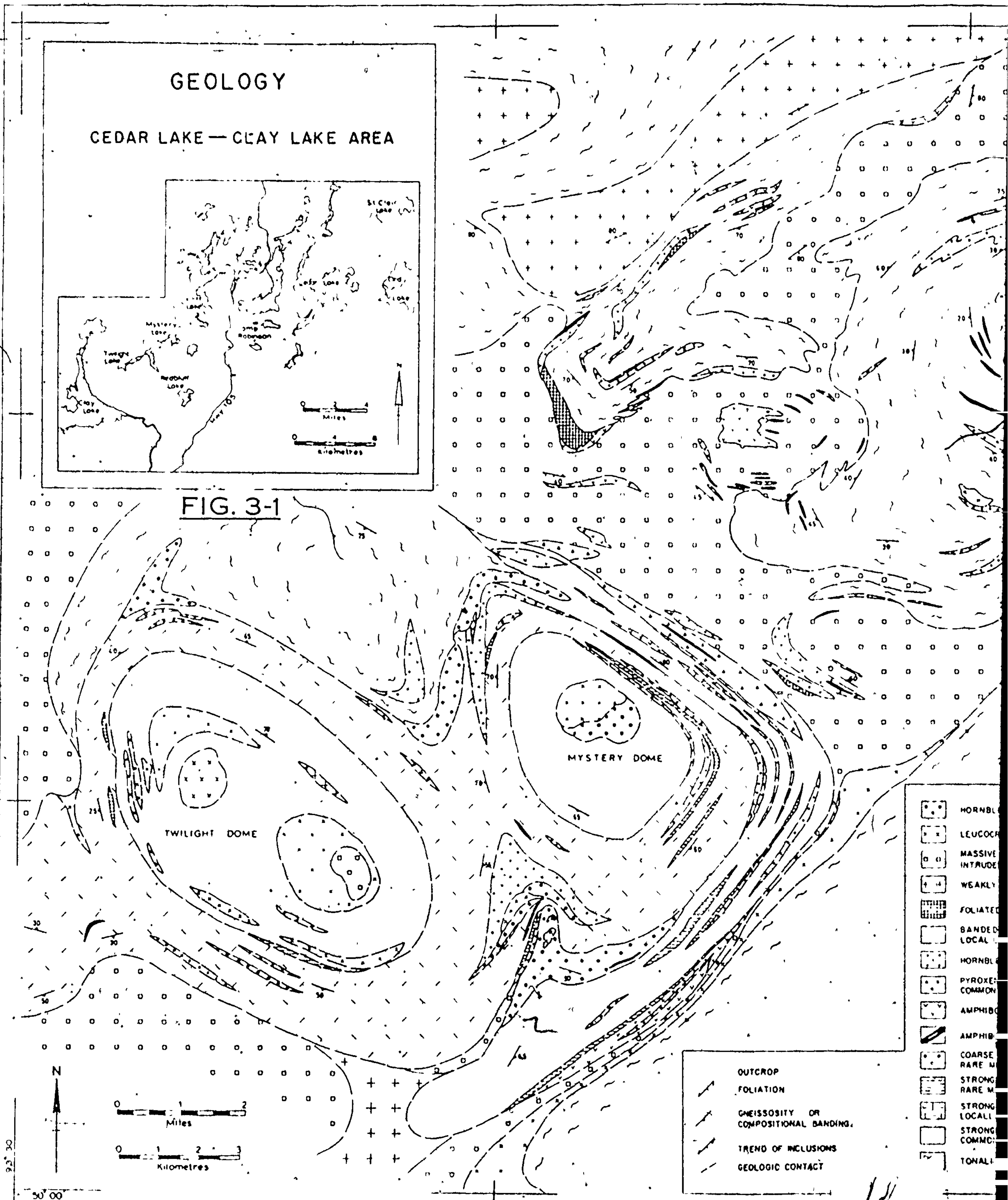
3. Deformation (D2) and metamorphism (M2) produces F_b2 folds, reactivates protolith of Cedar Lake gneiss and causes interfolding of "basement" and early supracrustal sequence.

4. Intrusion of Clay Lake granitoid suite - possibly as concordant sheets.

5. Formation of later supracrustal sequence - protoliths of Twilight gneiss and volcanogenic enclaves in Cliff Lake intrusion.

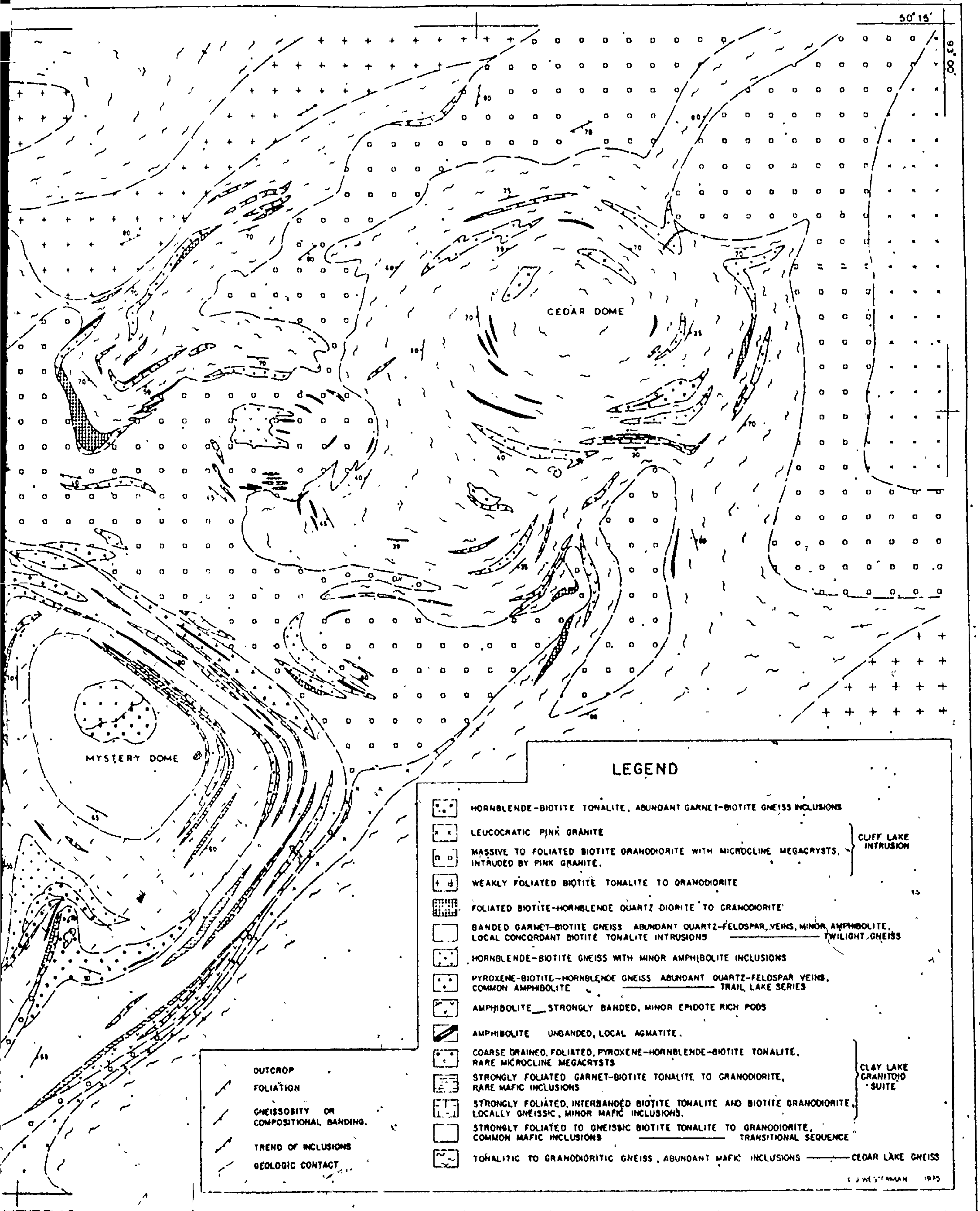
6. Deformation (D3). Subhorizontal tectonics produces interleaving of later supracrustal sequence (Twilight gneiss) and "basement" (Cedar Lake gneiss and Clay Lake granitoid suite). Severe layer-normal compression produces foliation in Twilight gneiss and Clay Lake granitoid suite. Folds leucotonalite veins in Twilight gneiss. Produces F_b3 boudinage and normal kinks. Accompanied by regional metamorphism (M3), upper amphibolite to granulite facies conditions.

7. Emplacement of Cliff Lake Intrusion produces minor folds of groups $F_b4,5,6,7$ and the major domal structures. Local potash metasomatism at intrusive contacts.



GEOLOGY
CEDAR LAKE — CLAY LAKE AREA
MYSTERY DOME
TWILIGHT DOME
Miles
Kilometres
N
OUTCROP
FOLIATION
GNEISSOSITY OR COMPOSITIONAL BANDING.
TREND OF INCLUSIONS
GEOLOGIC CONTACT
MASSIVE
WEAKLY
COARSE

FIG. 3-1



50°15'
93°00'
CEDAR DOME
MYSTERY DOME
LEGEND
HORNBLENDE-BIOTITE TONALITE, ABUNDANT GARNET-BIOTITE GNEISS INCLUSIONS
LEUCOCRATIC PINK GRANITE
MASSIVE TO FOLIATED BIOTITE GRANODIORITE WITH MICROCLINE MEGACRYSTS, INTRUDED BY PINK GRANITE.
CLIFF LAKE INTRUSION
WEAKLY FOLIATED BIOTITE TONALITE TO GRANODIORITE
FOLIATED BIOTITE-HORNBLENDE QUARTZ DIORITE TO GRANODIORITE
BANDED GARNET-BIOTITE GNEISS ABUNDANT QUARTZ-FELDSPAR VEINS, MINOR AMPHIBOLITE, LOCAL CONCORDANT BIOTITE TONALITE INTRUSIONS
TWILIGHT GNEISS
HORNBLENDE-BIOTITE GNEISS WITH MINOR AMPHIBOLITE INCLUSIONS
PYROXENE-BIOTITE-HORNBLENDE GNEISS ABUNDANT QUARTZ-FELDSPAR VEINS, COMMON AMPHIBOLITE
TRAIL LAKE SERIES
AMPHIBOLITE STRONGLY BANDED, MINOR EPIDOTE RICH PODS
AMPHIBOLITE UNBANDED, LOCAL AGMATITE.
COARSE GRAINED, FOLIATED, PYROXENE-HORNBLENDE-BIOTITE TONALITE, RARE MICROCLINE MEGACRYSTS
STRONGLY FOLIATED GARNET-BIOTITE TONALITE TO GRANODIORITE, RARE MAFIC INCLUSIONS
STRONGLY FOLIATED, INTERBANDED BIOTITE TONALITE AND BIOTITE GRANODIORITE, LOCALLY GNEISSIC, MINOR MAFIC INCLUSIONS.
CLAY LAKE GRANITOID SUITE
STRONGLY FOLIATED TO GNEISSIC BIOTITE TONALITE TO GRANODIORITE, COMMON MAFIC INCLUSIONS
TRANSITIONAL SEQUENCE
TONALITIC TO GRANODIORITIC GNEISS, ABUNDANT MAFIC INCLUSIONS
CEDAR LAKE GNEISS
OUTCROP
FOLIATION
GNEISSOSITY OR COMPOSITIONAL BANDING.
TREND OF INCLUSIONS
GEOLOGIC CONTACT

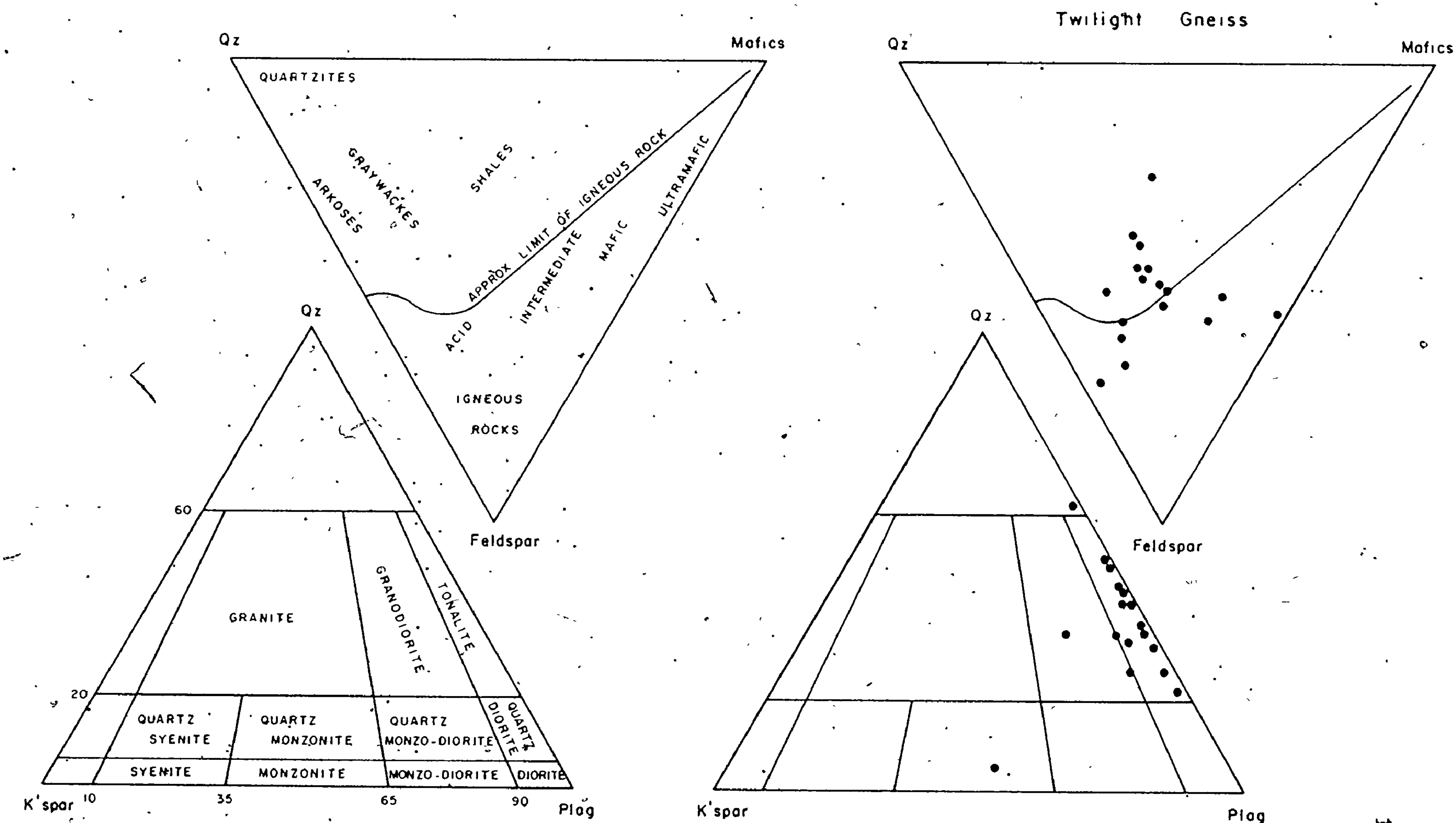


Figure .3-2 Modal Analyses

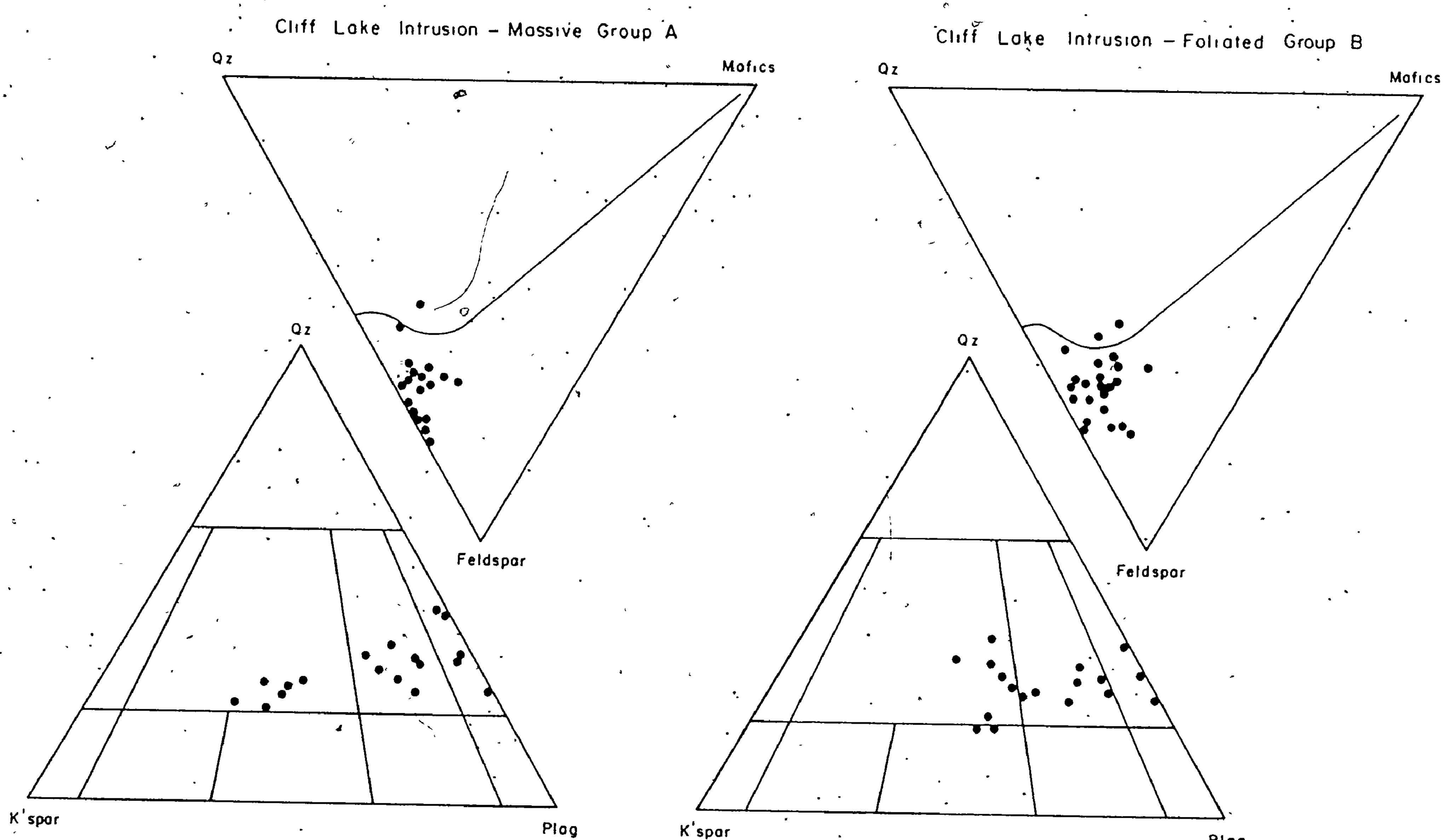


Figure 3-2. (continued) Modal Analyses

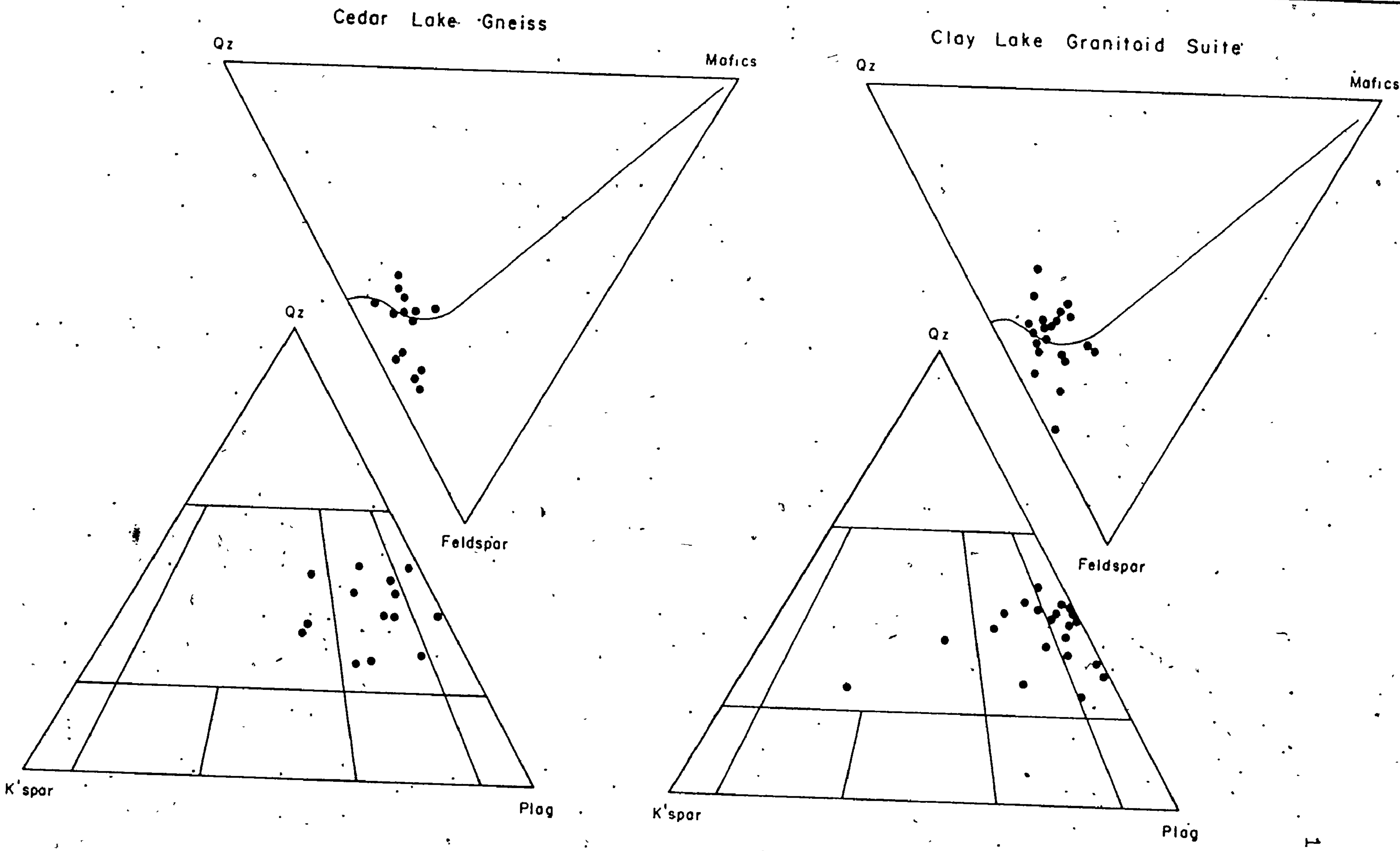


Figure 3-2 (continued) Modal Analyses

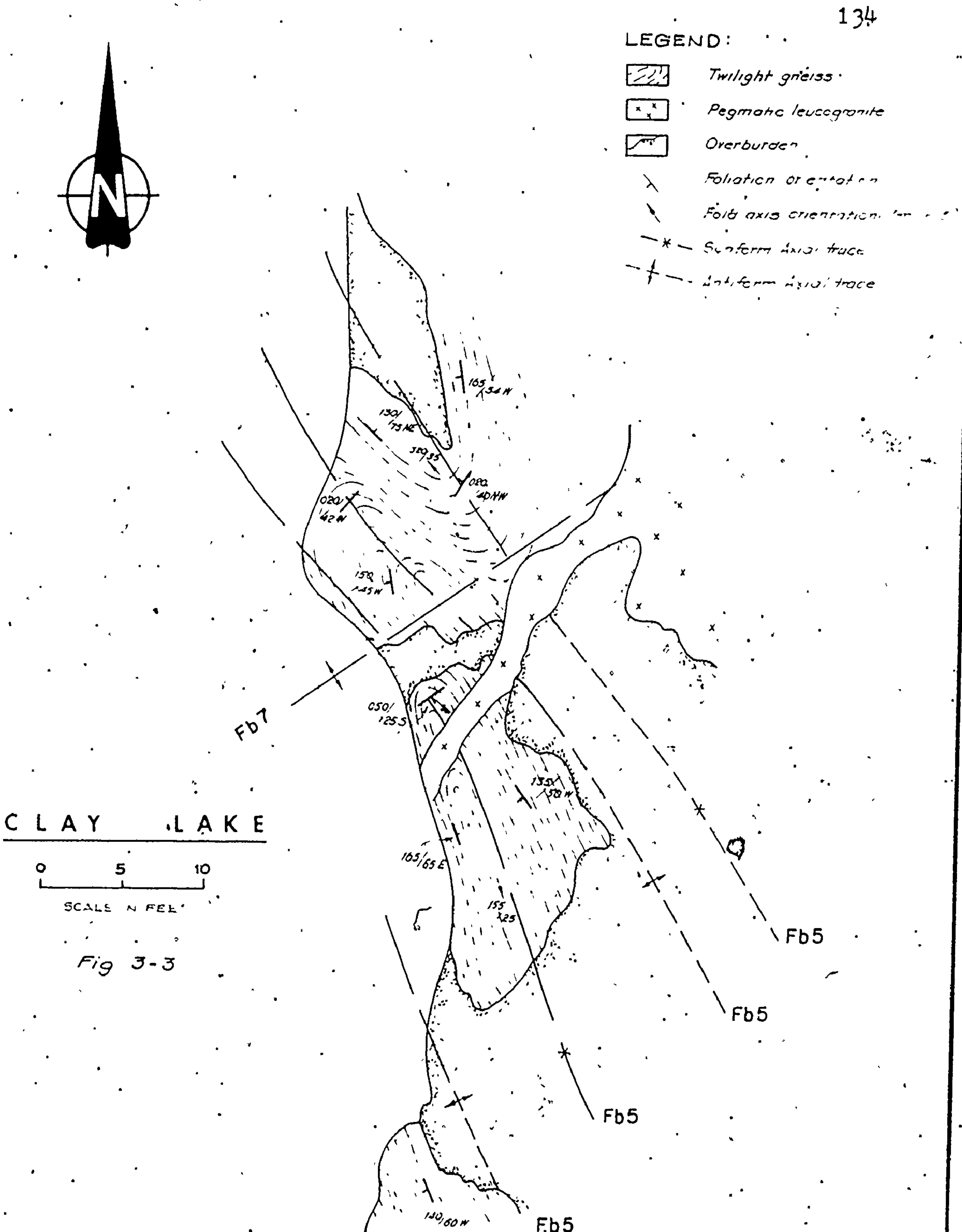


Fig 3-3

Small scale interference pattern in Twilight Gneisses due to intersection of Fb5 folds with Fb7 folds CLAY LAKE

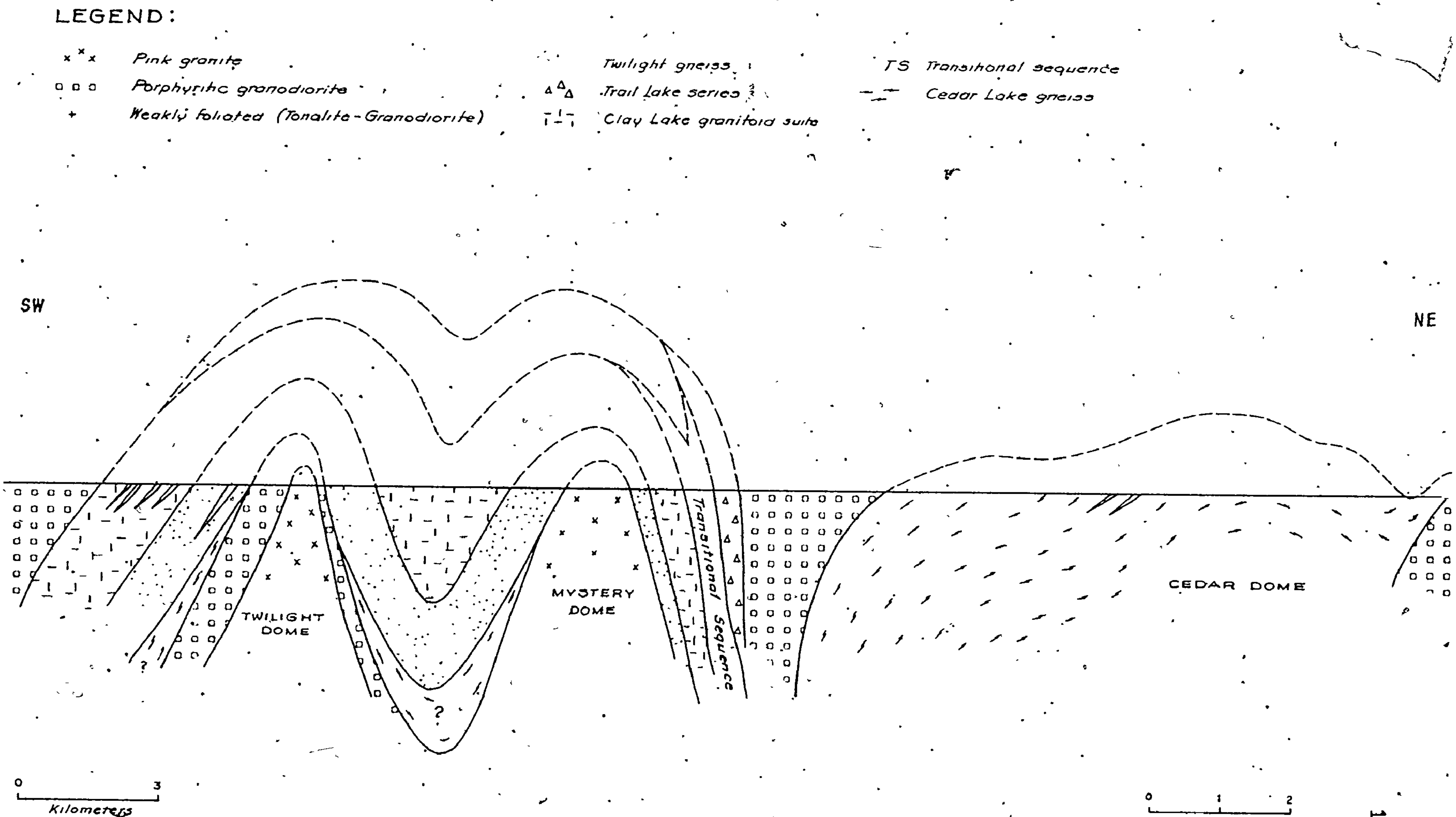


Figure 3-4 Vertical cross-sections of the major structures.

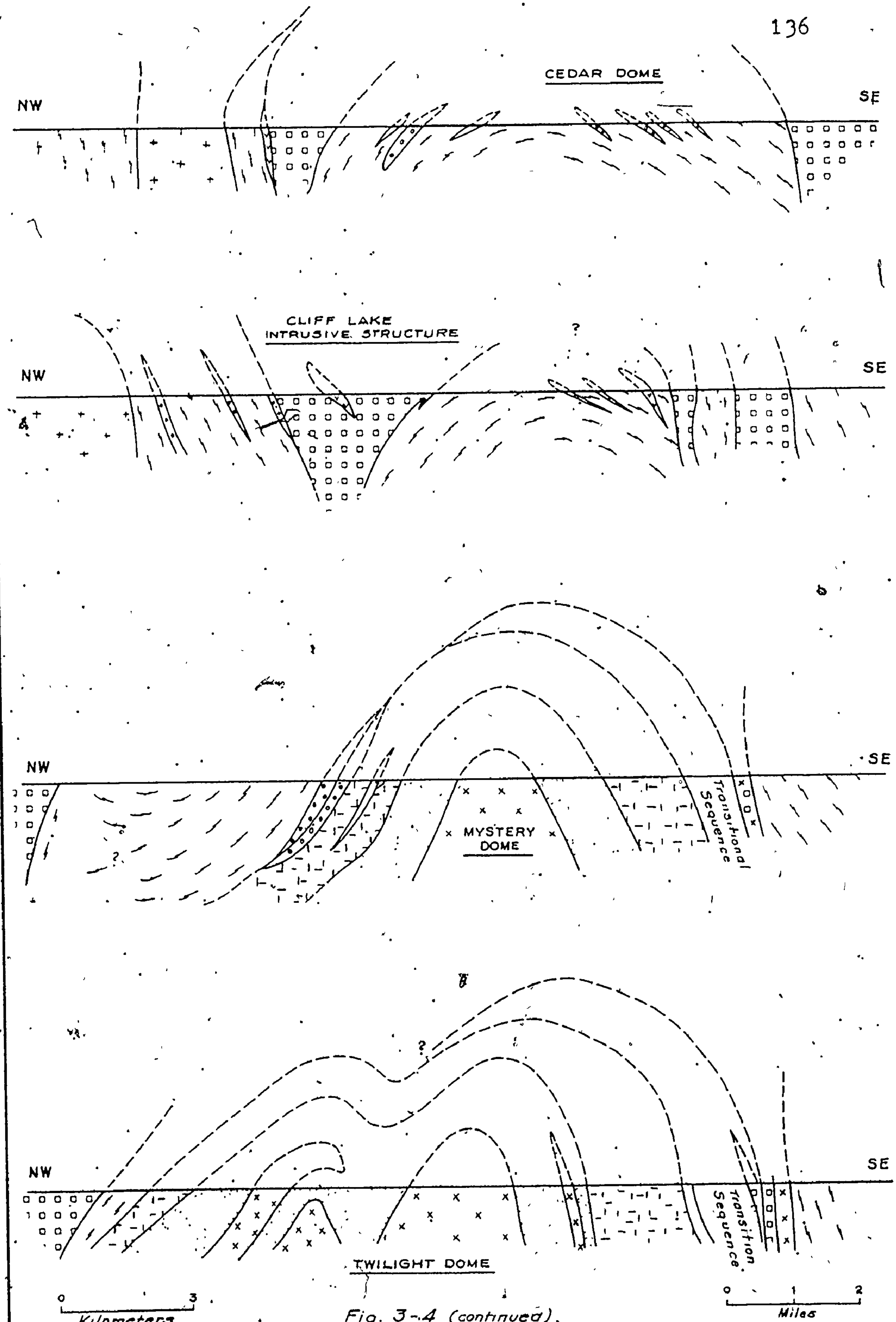


Fig. 3-4 (continued).

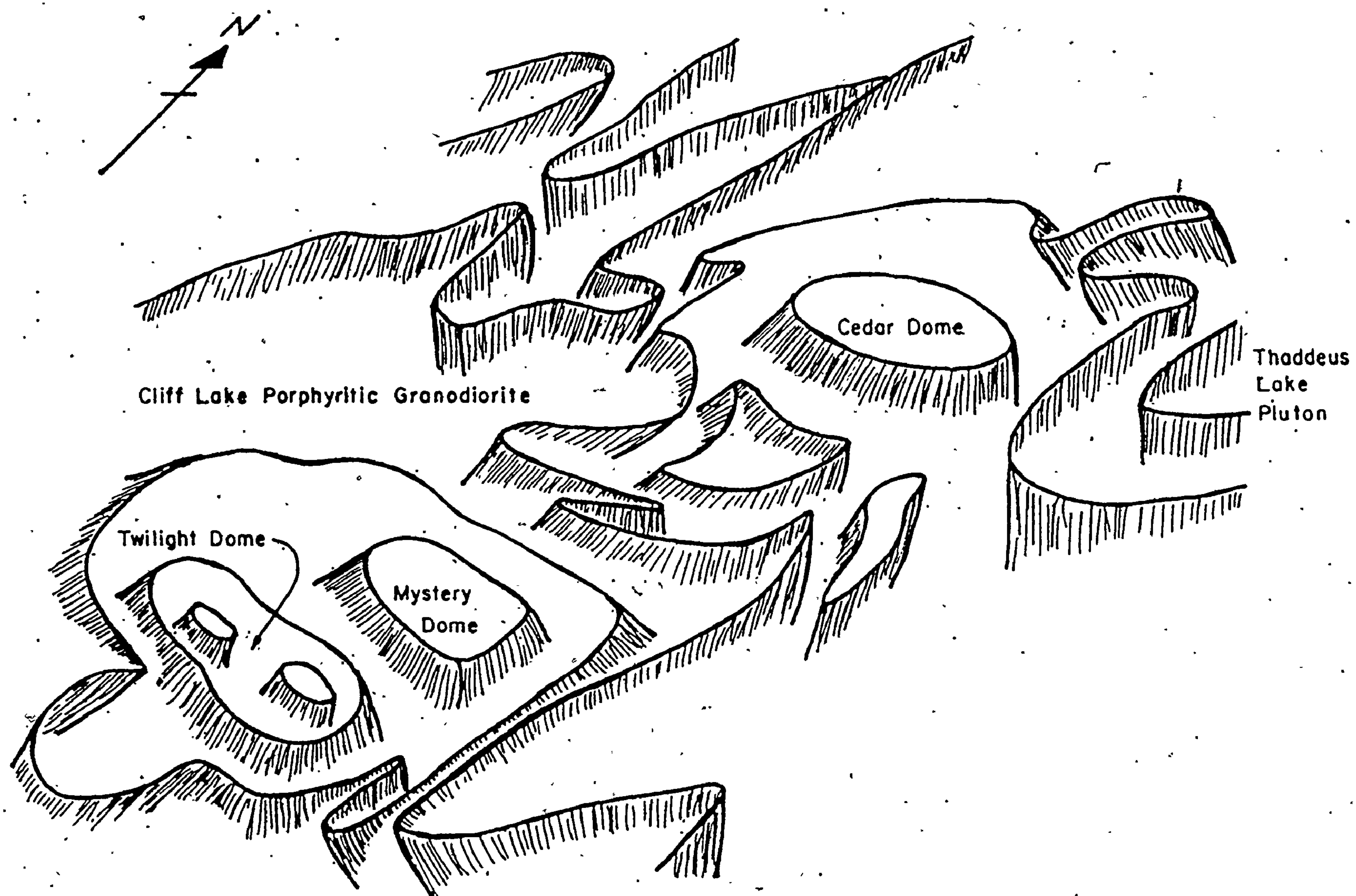


Figure 3-5: Sketch of the Major Structural and Intrusive Features.

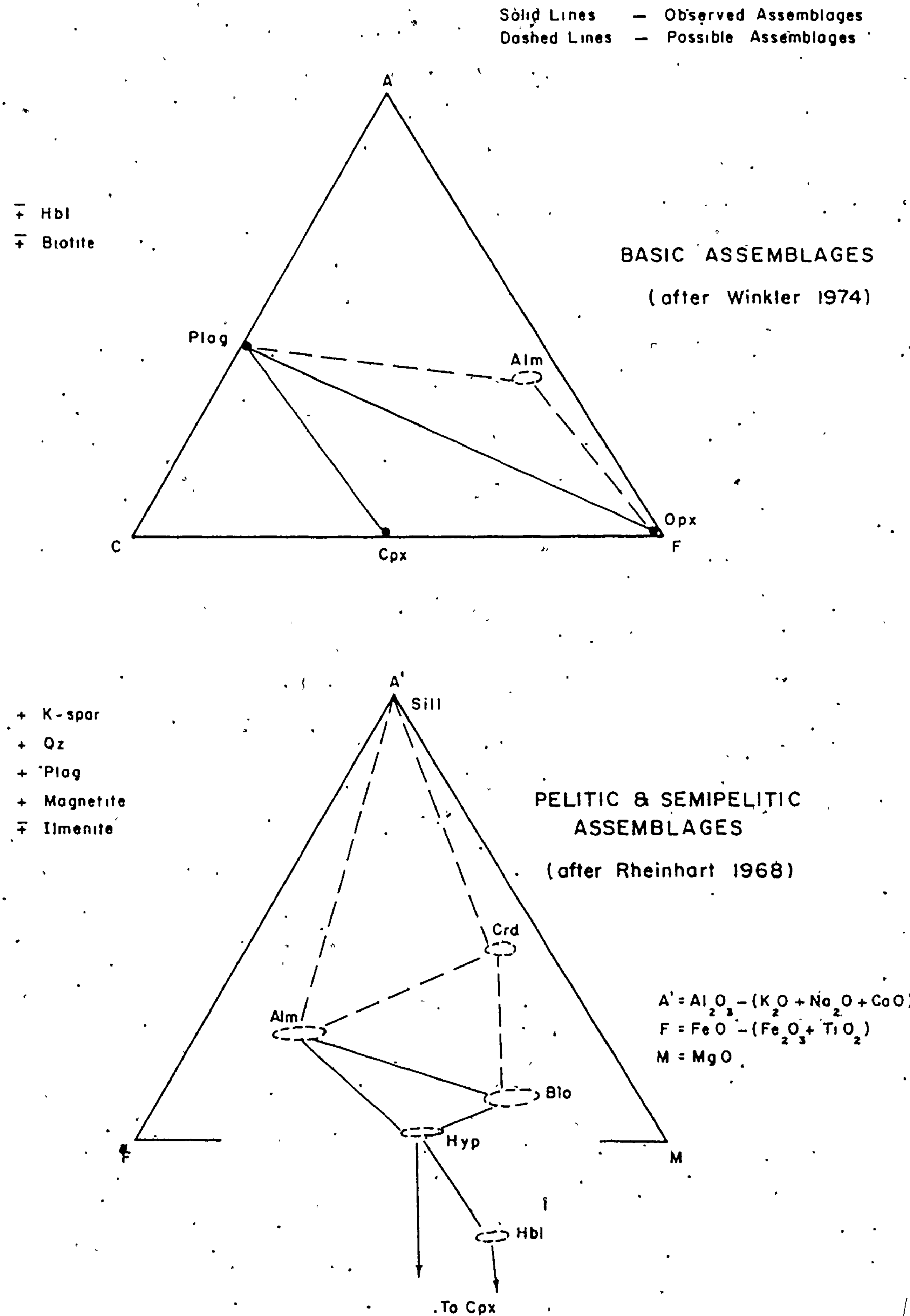
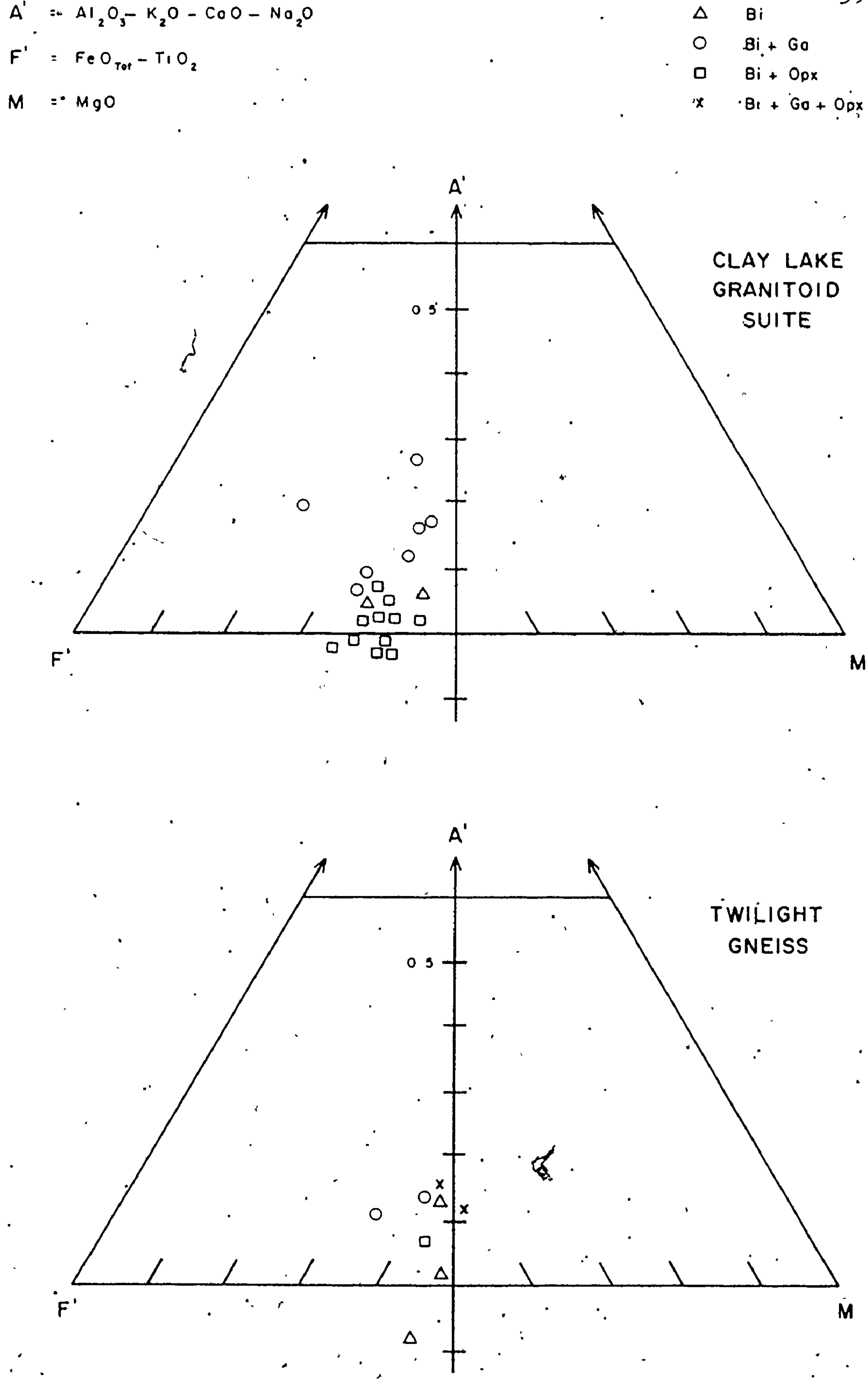


Figure 3-6 Mineral Assemblages – Lower Grade Subzone Of Regional Hypersthene Zone



A' = Al2O3 – K2O – CaO – Na2O
F' = FeOTot – TiO2
M = MgO
Bi
Bi + Ga
Bi + Opx
Bi + Ga + Opx
A'
0.5
CLAY LAKE GRANITOID SUITE
F'
M
A'
0.5
TWILIGHT GNEISS
F'
M

Figure 3-7

Figure 3-8 P,T grid of metamorphic mineral reactions

Quartz is a possible phase in all assemblages

1. Qz + Plag + Ksp + Vap = Liq Tuttle and Bowen 1958
2. Qz + Musc + Plag + Ksp + Vap = Liq Winkler 1974
3. Qz + Musc = Ksp + Sill + Vap Althaus et al 1970
4. Qz + Plag + Musc = Ksp + Sill + Vap Grant 1973
5. Qz + Plag + Musc + Vap = Sill + Liq Storre and Karotke 1972
6. Plag + Sill + Bi + Qz + Vap = Cord + Ga + Liq Grant 1973
7. Qz + Plag + Bi + Ga + Vap = Cord + Opx + Liq Grant 1973

   possible P,T equivalent to

   Qz + Bi = Opx + Ga + Ksp + Vap Winkler 1967, 1974
8. Field of coexisting Ga + Cord + Sill + Qz for bulk rock

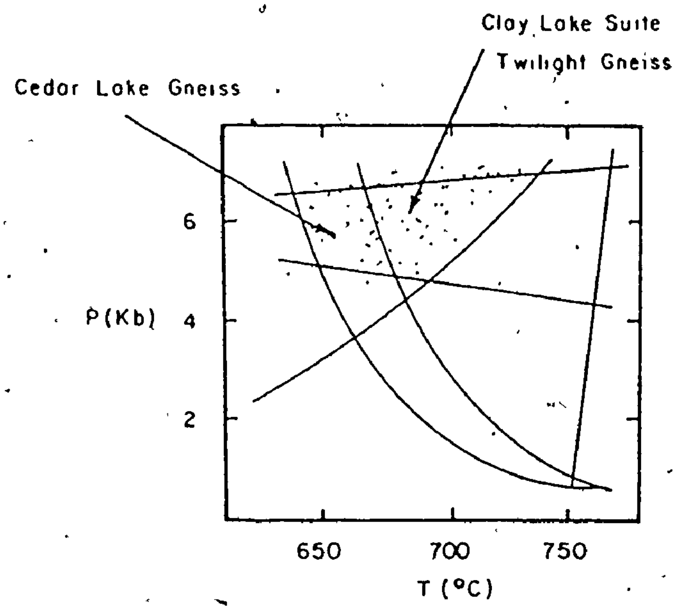
   compositions FeO/FeO + MgO = 0.6 Winkler 1974

   controlled by the reaction

   Cord = Ga + Sill + Qz
9. Plag + Bi + Ga = Ksp + Cord + Opx + Liq Grant 1973

A = Al_2SiO_5
B = Biotite
C = Cordierite
G = Garnet
K = K. feldspar
L = Liquid
M = Muscovite
P = Plagioclase
V = Vapour

facing page 140


Clay Lake Suite
Twilight Gneiss
Cedar Lake Gneiss
P(Kb)
6
4
2
650
700
750
T (°C)

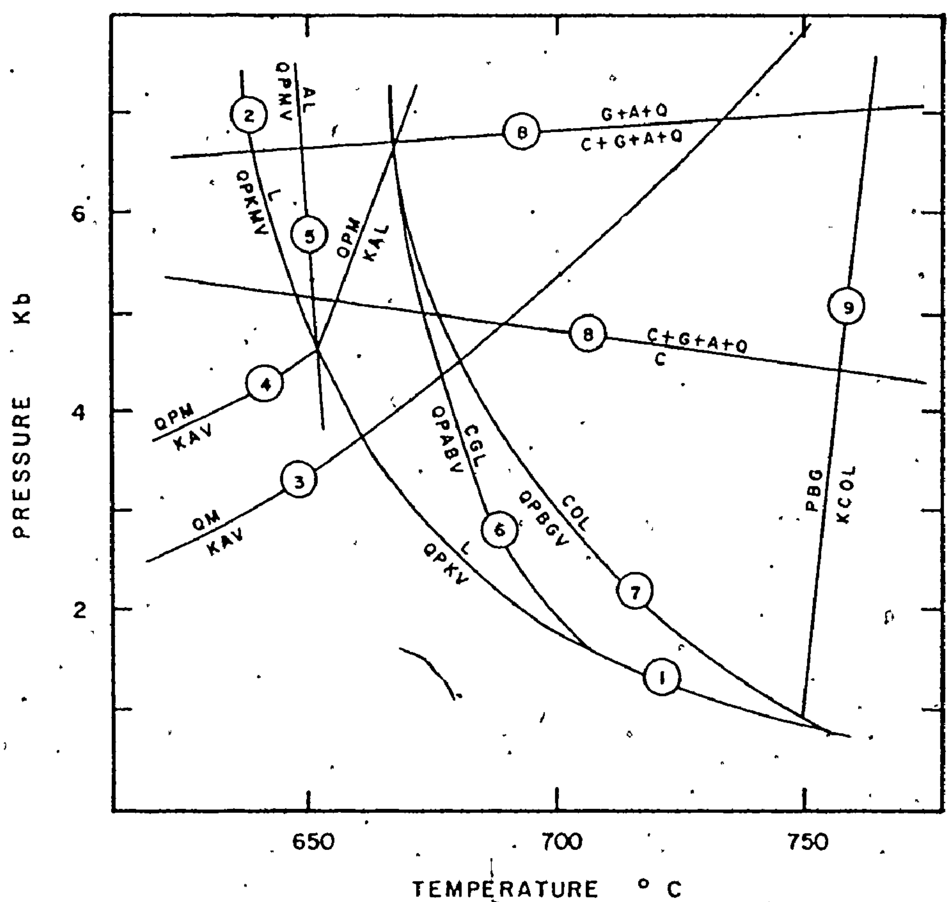

PRESSURE Kb
TEMPERATURE °C
650
700
750
6
4
2
AL
QPMV
L
QPKMV
QPM
KAL
G+A+Q
C+G+A+Q
C+G+A+Q
C
QPM
KAV
QM
KAV
CGL
QPABV
QPBGV
COL
L
QPKV
PBG
KCOL
1
2
3
4
5
6
7
8
8
9

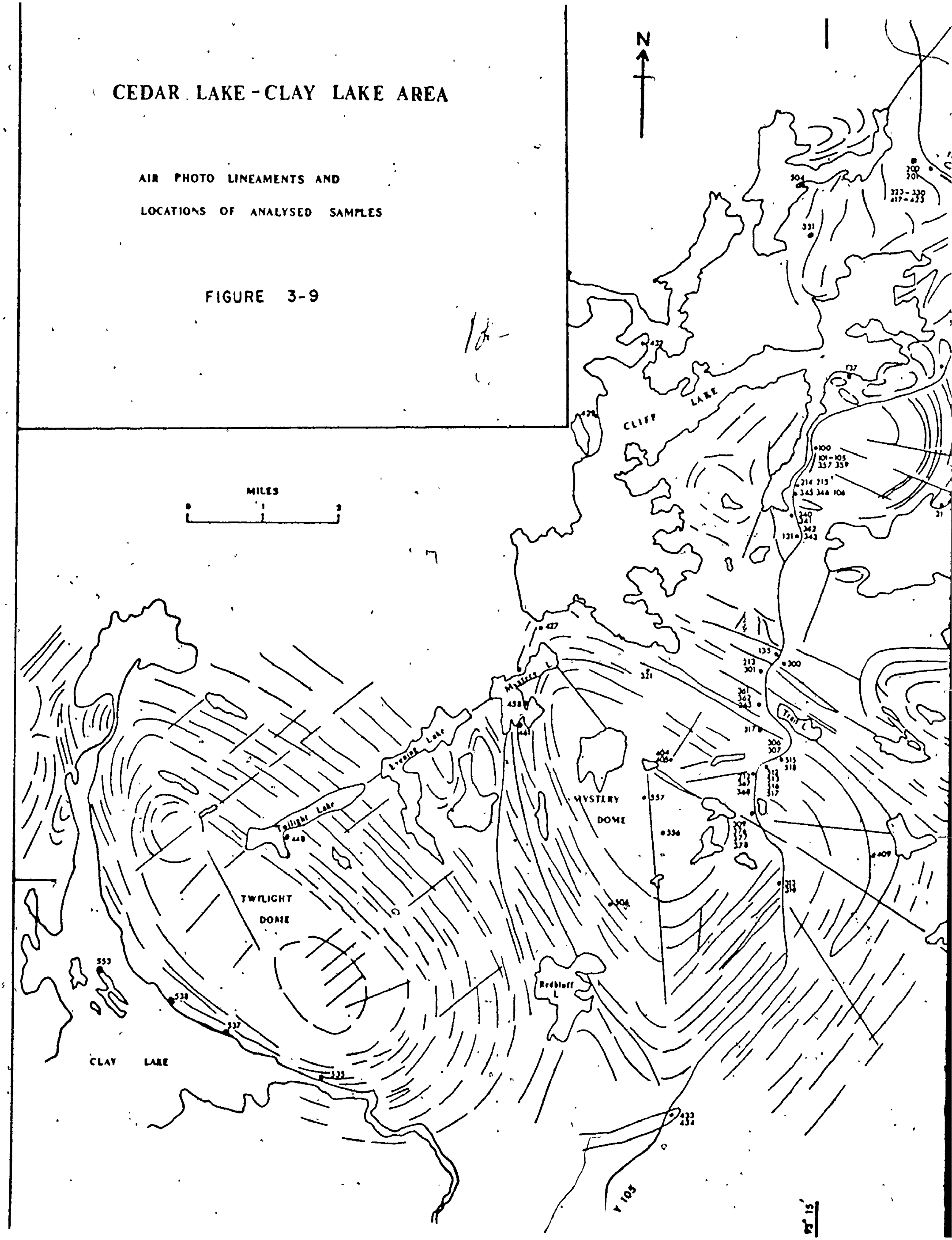
Figure 3-8

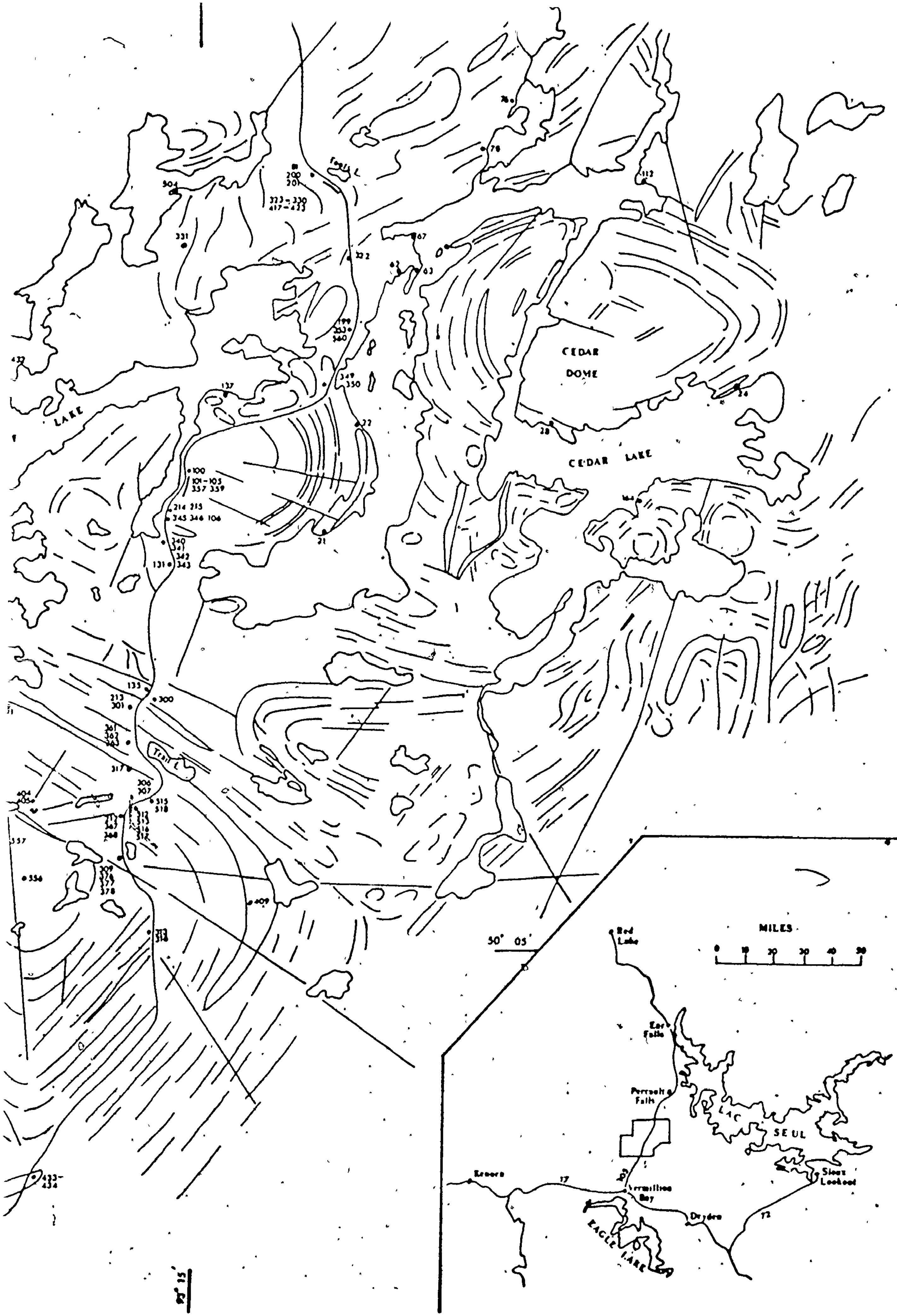
CEDAR LAKE - CLAY LAKE AREA

AIR PHOTO LINEAMENTS AND

LOCATIONS OF ANALYSED SAMPLES

FIGURE 3-9




CEDAR
DOME
CEDAR LAKE
LAKE
Trail L.
50° 05'
93° 15'
MILES
0 10 20 30 40 50
Red Lake
Ear Falls
Perrault Falls
LAC SEUL
Sioux Lookout
Kenora
17
Vermilion Bay
Dryden
72
EAGLE LAKE

242

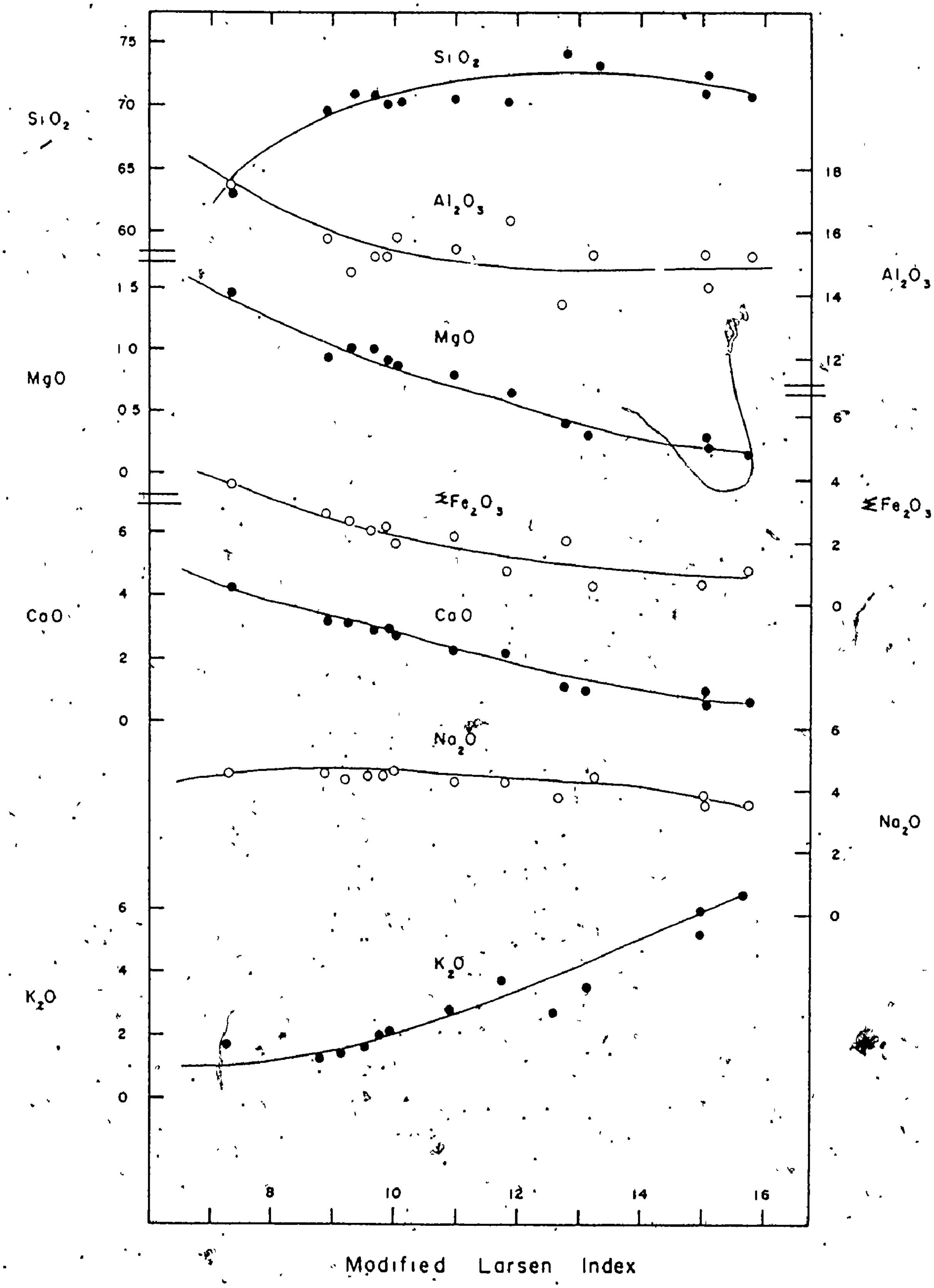


Figure 3-10 Major Oxides – Cliff Lake Intrusion
Massive Group A

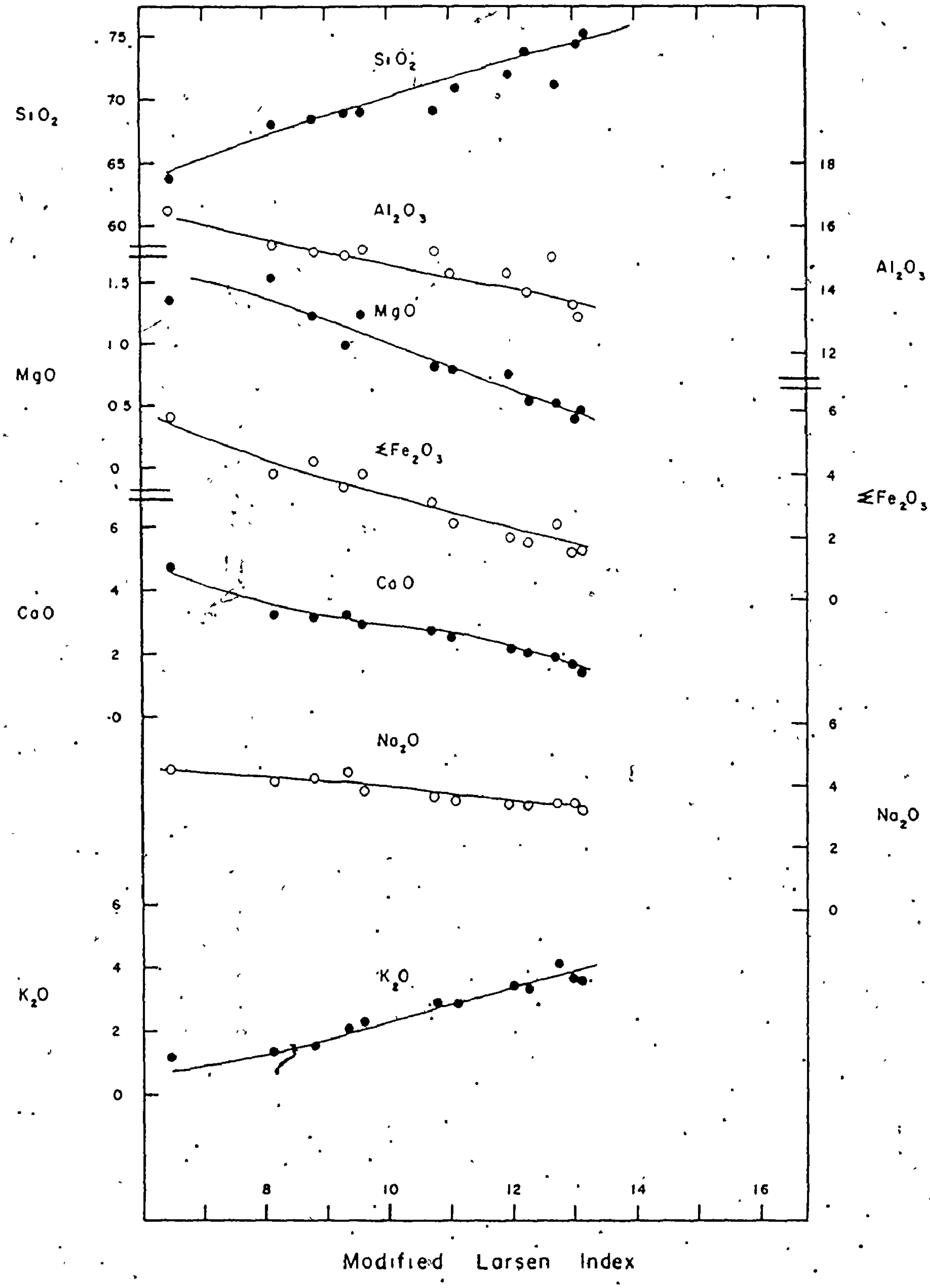


Figure 3-10 (continued) Major Oxides — Cliff Lake Intrusion Foliated Group B

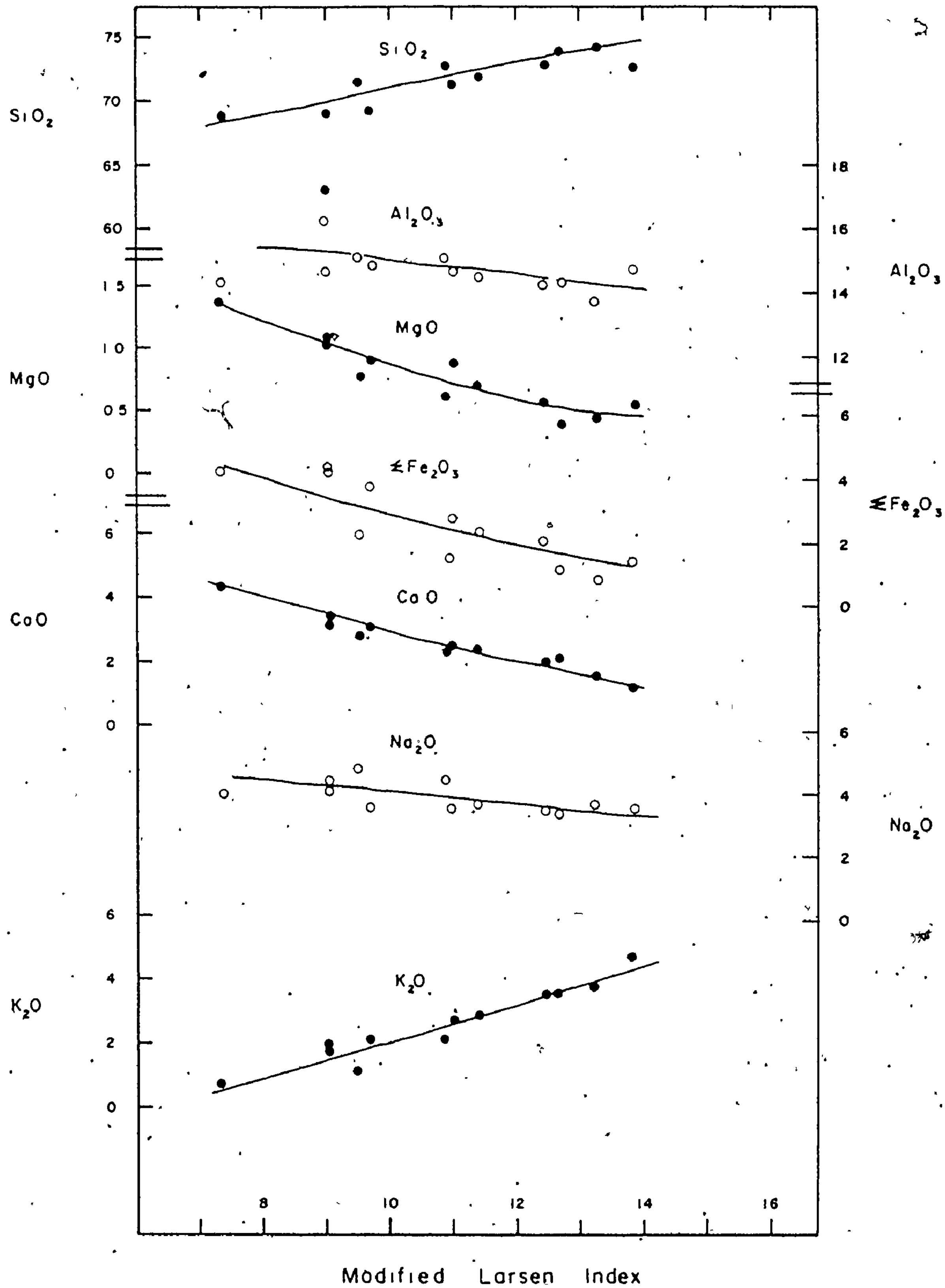


Figure 3-10 (continued) Major Oxides — Cedar Lake Gneisses

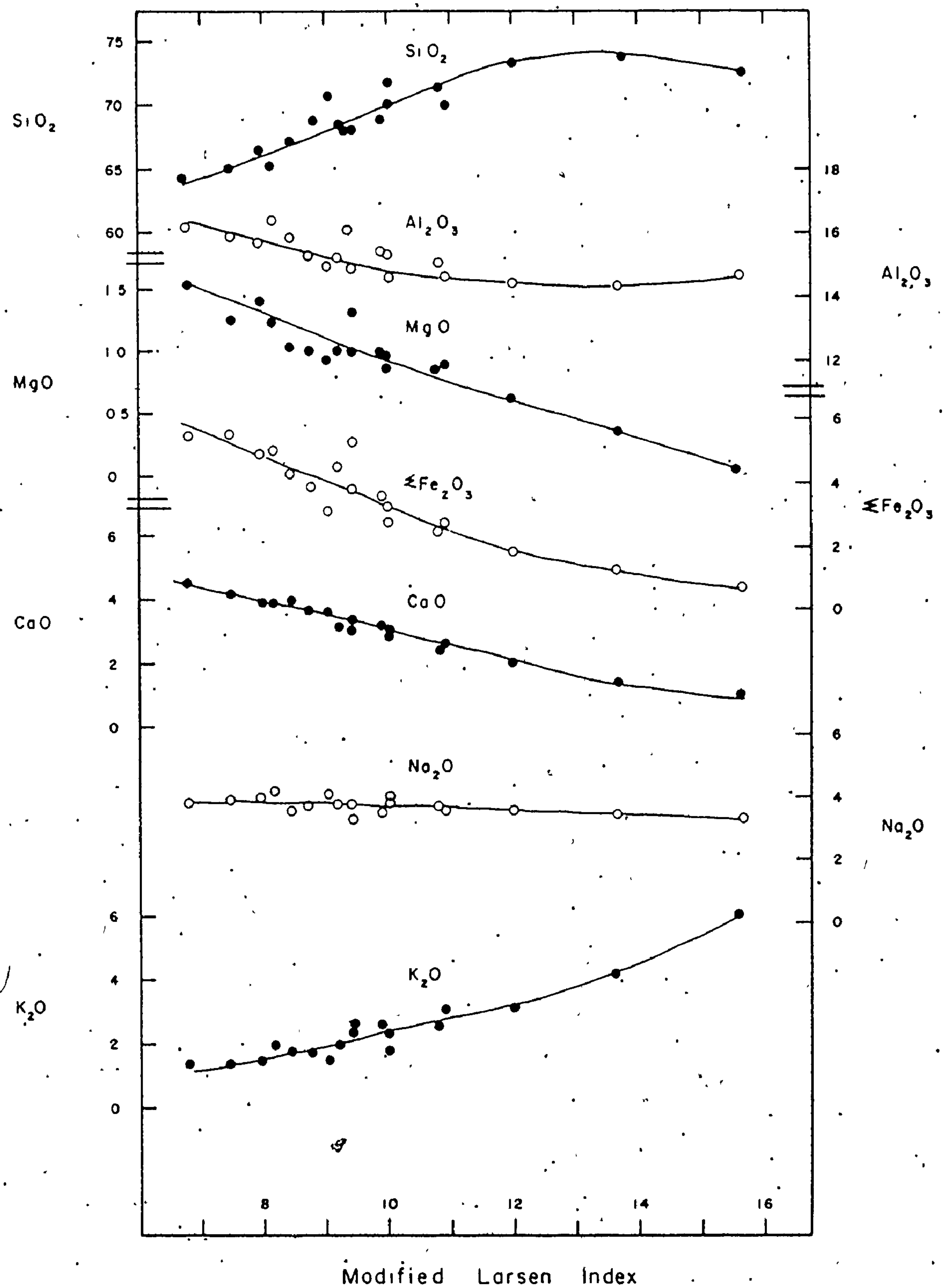


Figure 3-10 (continued) Major Oxides — Clay Lake Granitoid Suite

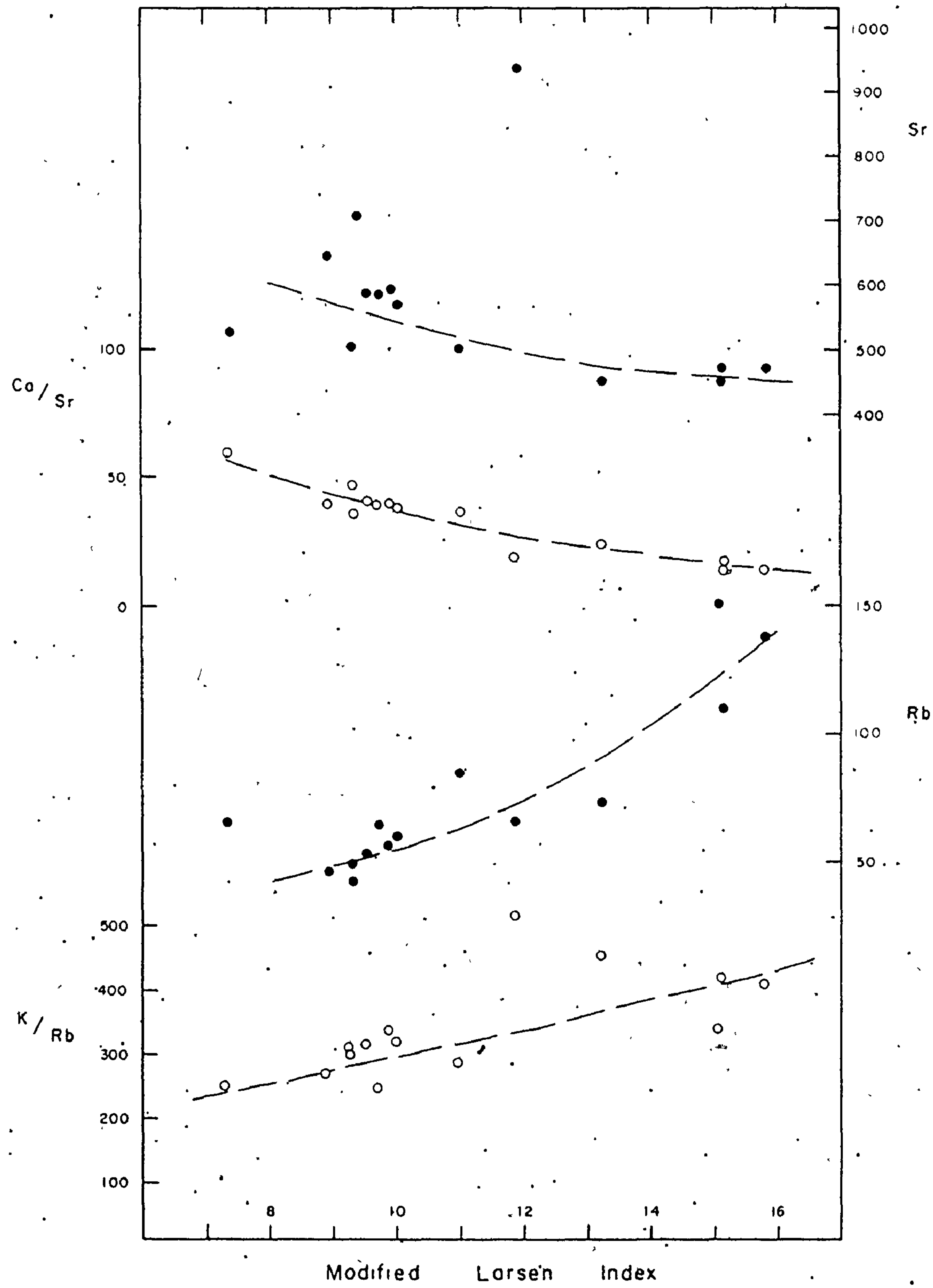


Figure 3-11 Trace Elements — Cliff Lake Intrusion
Massive Group - A

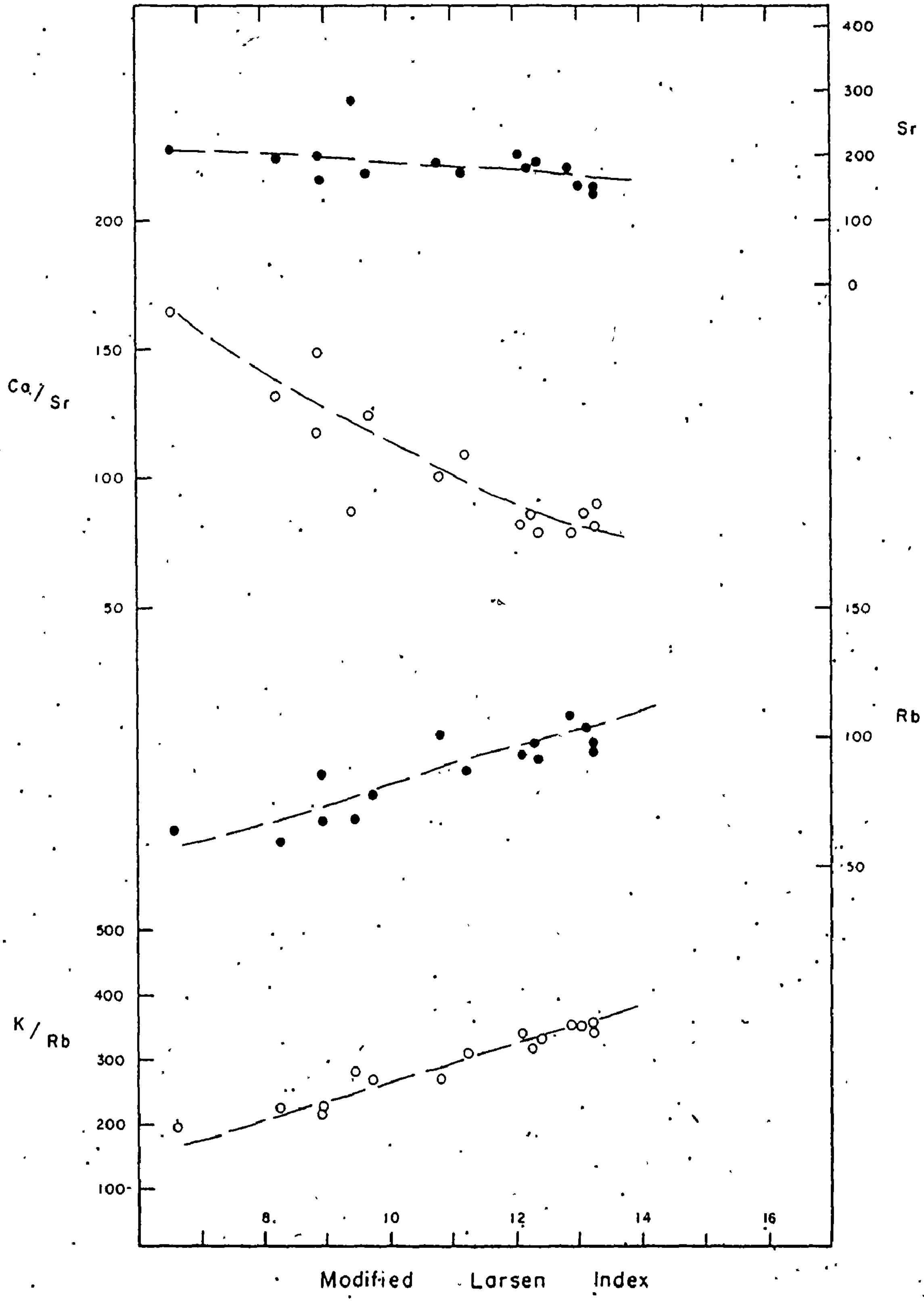


Figure 3-11 (continued) Trace Elements — Cliff Lake Intrusive
Foliated Group B

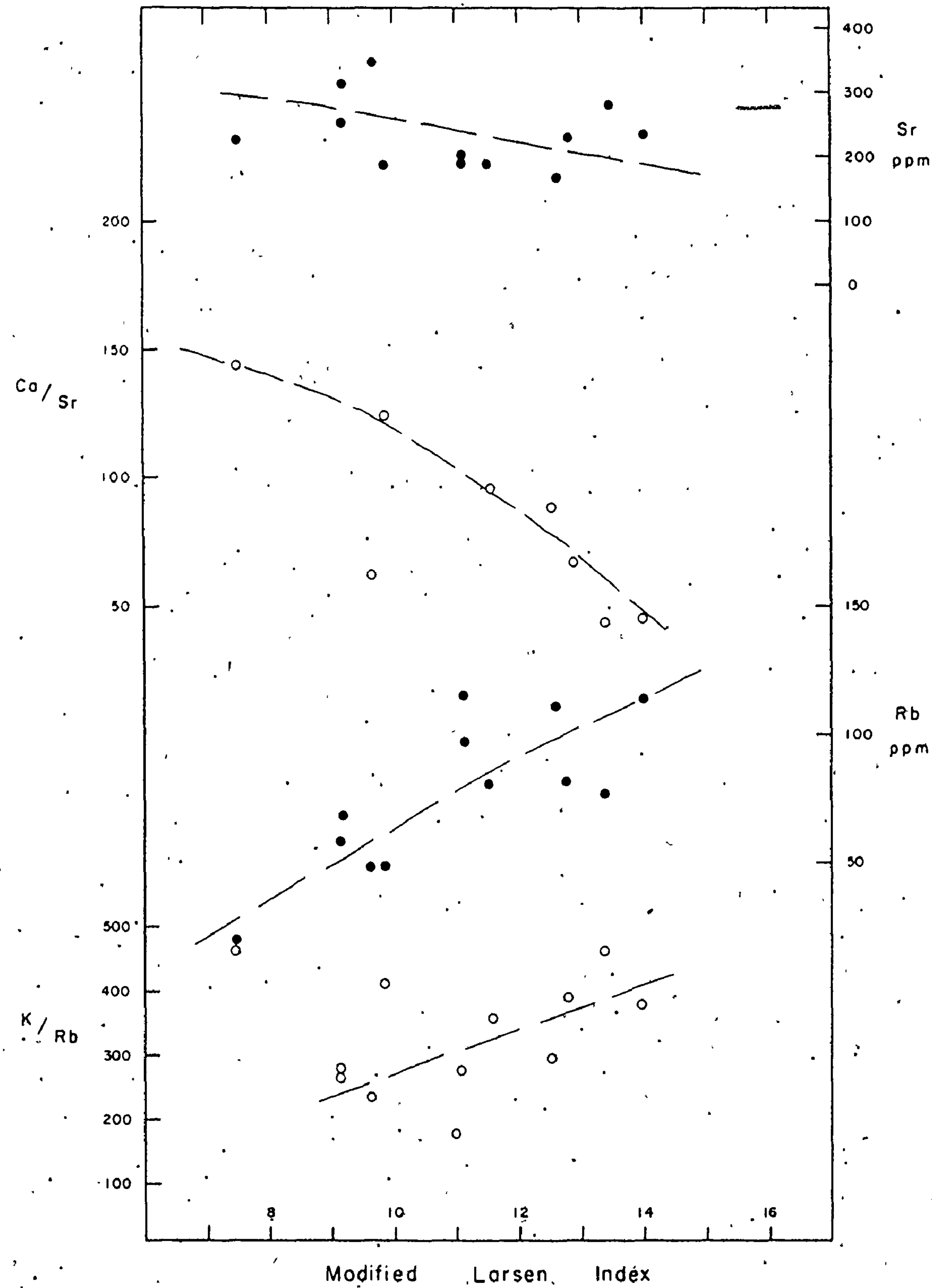


Figure 3-11 (continued) Trace Elements — Cedar Lake Gneisses.

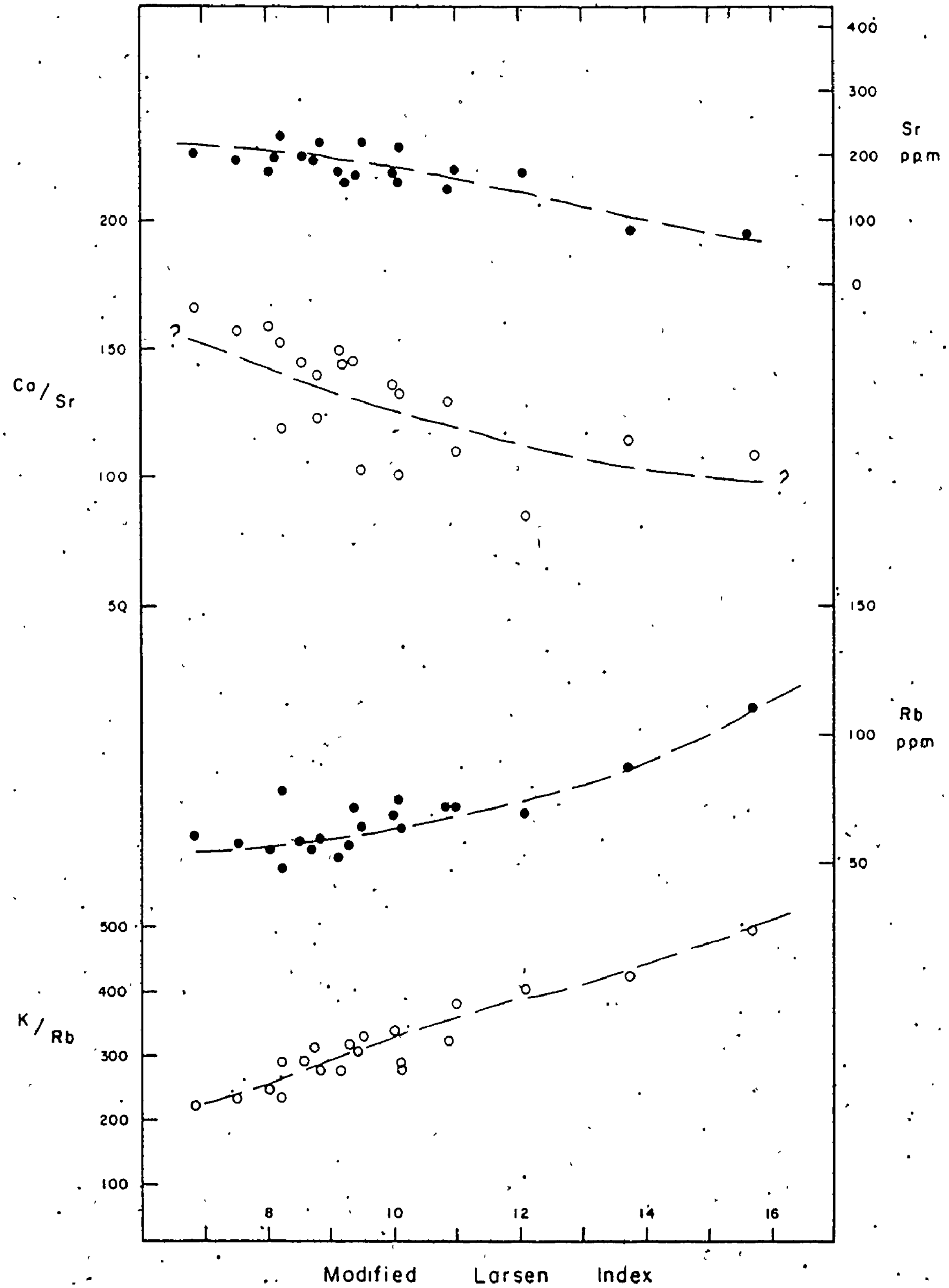


Figure 3-11 (continued) Trace Elements – Clay Lake Granitoid Suite

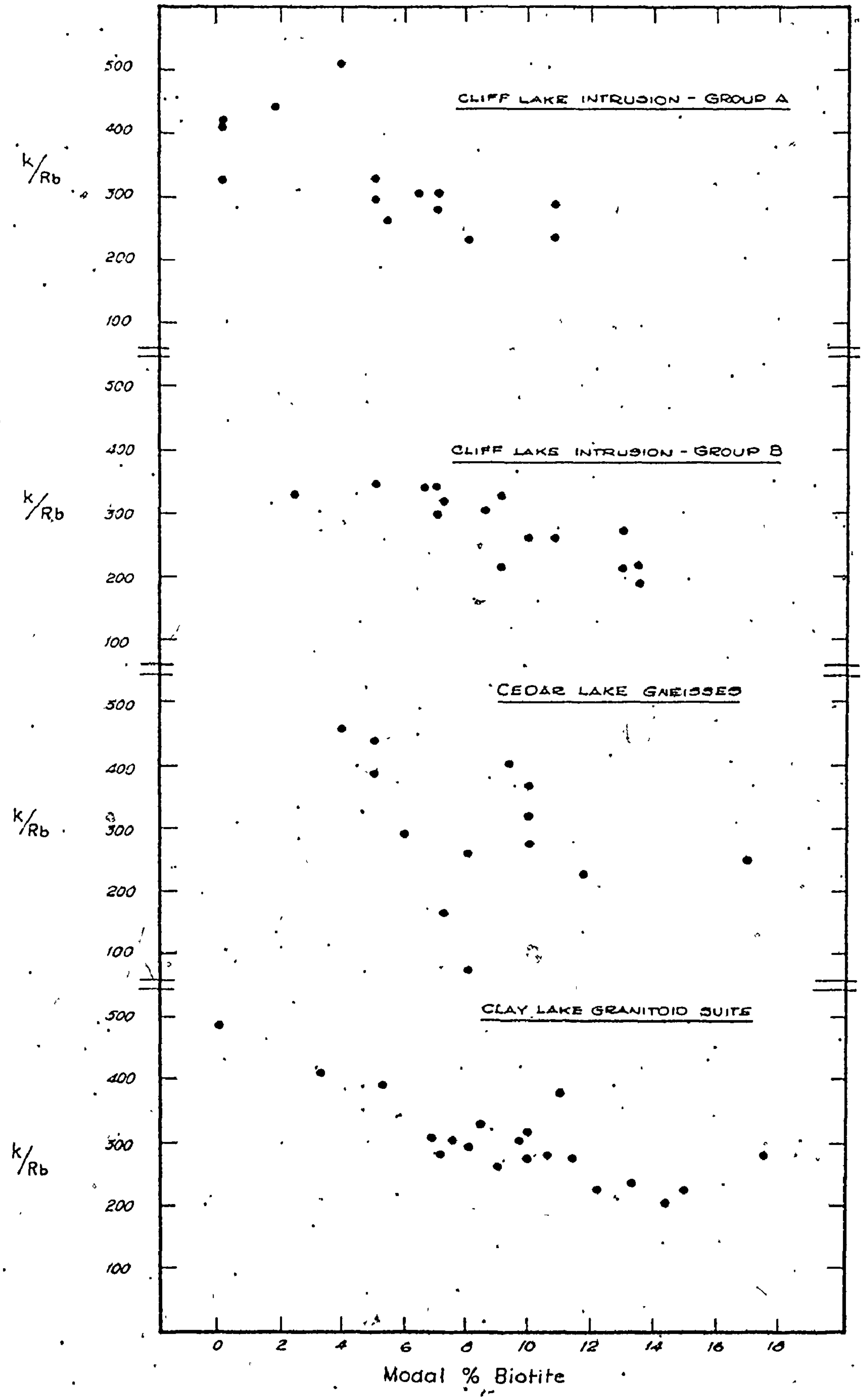
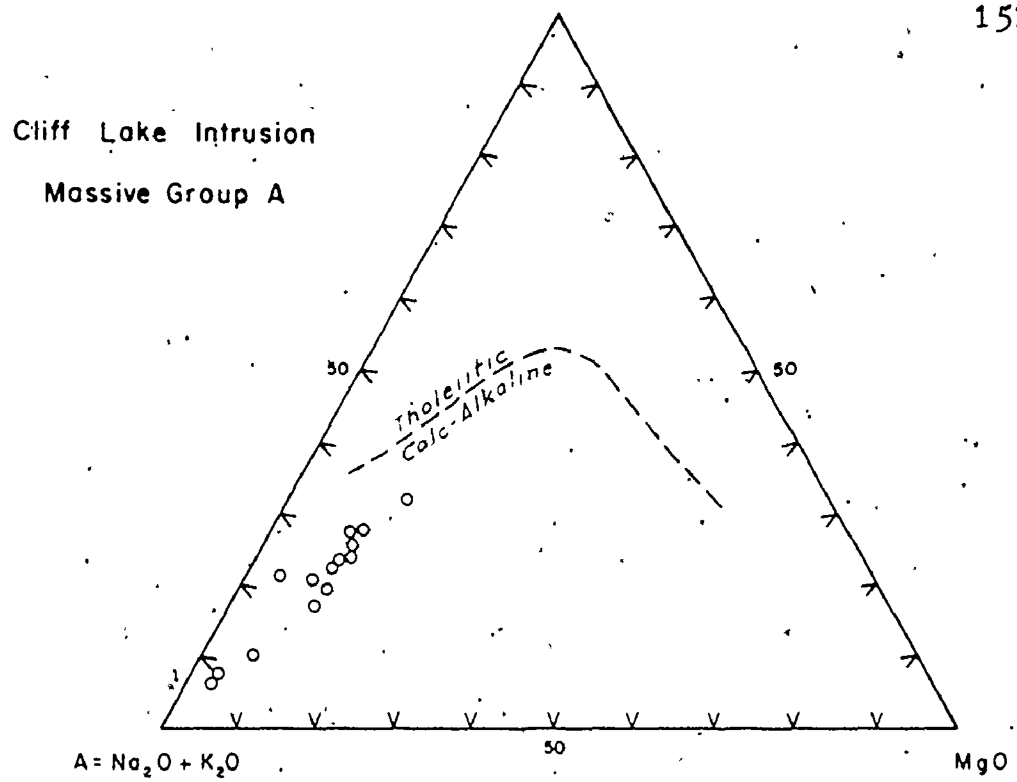


Figure 3-12 Relationship between biotite content and K/Rb - granitoid rocks



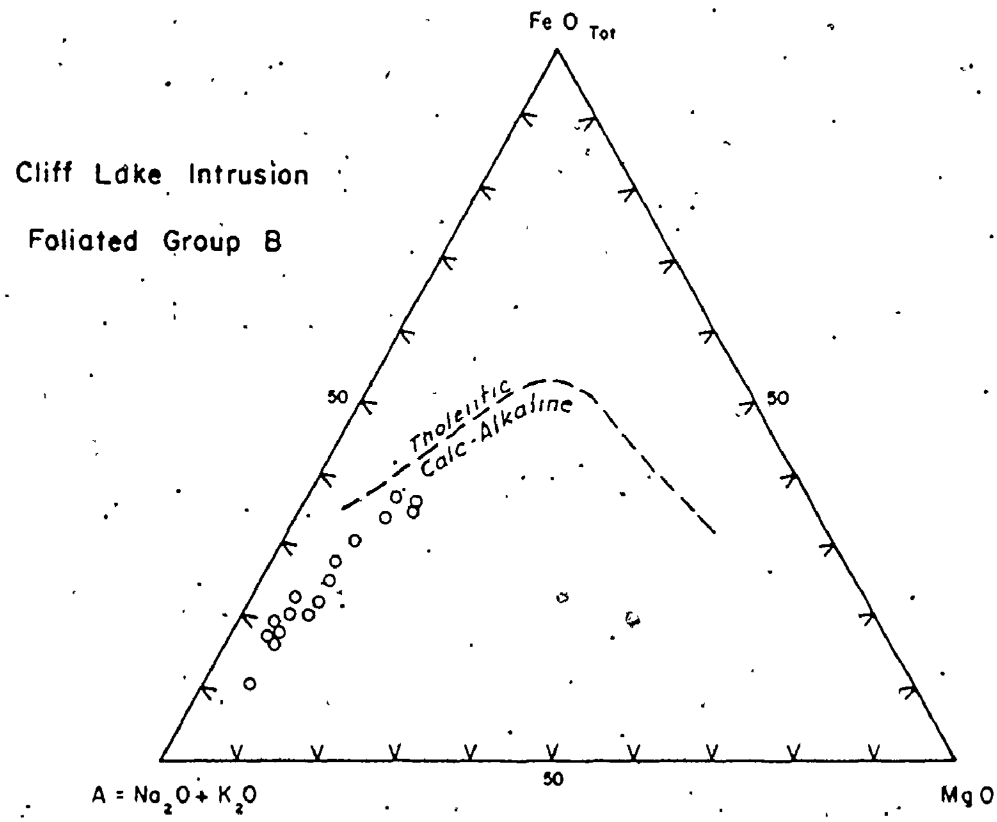
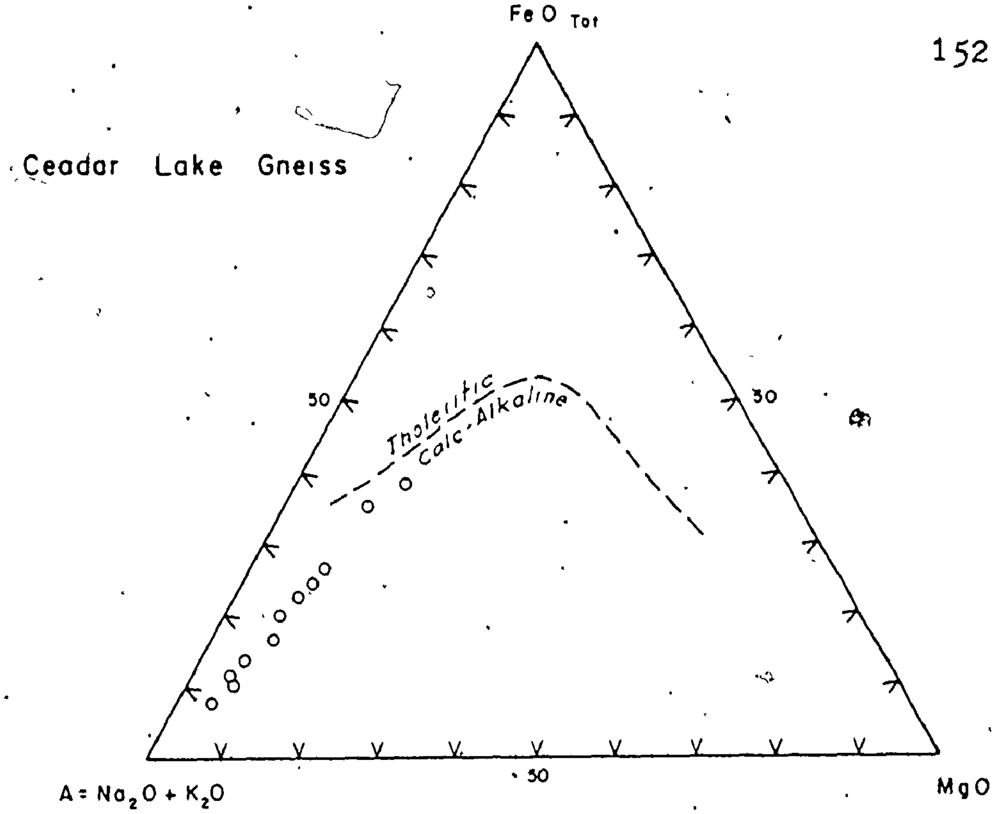


Figure 3-13 FMA Plots For Granitoid Samples



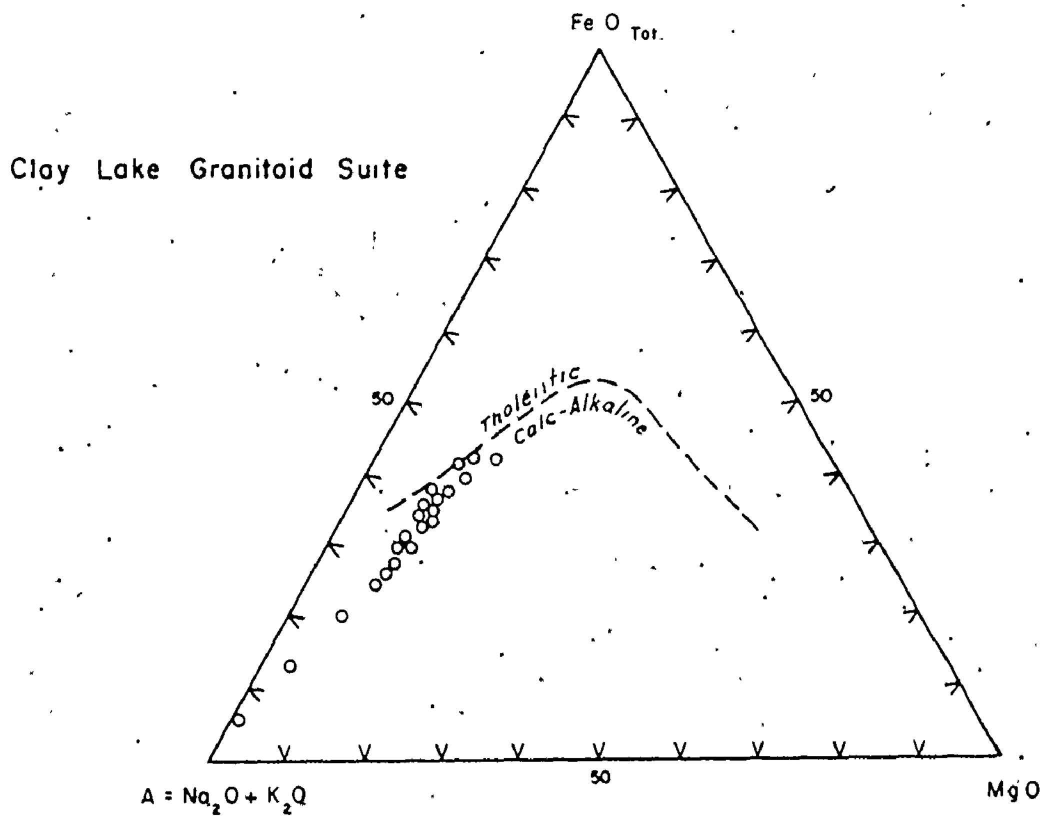


Figure 3-13 (continued) FMA Plots For Granitoid Samples

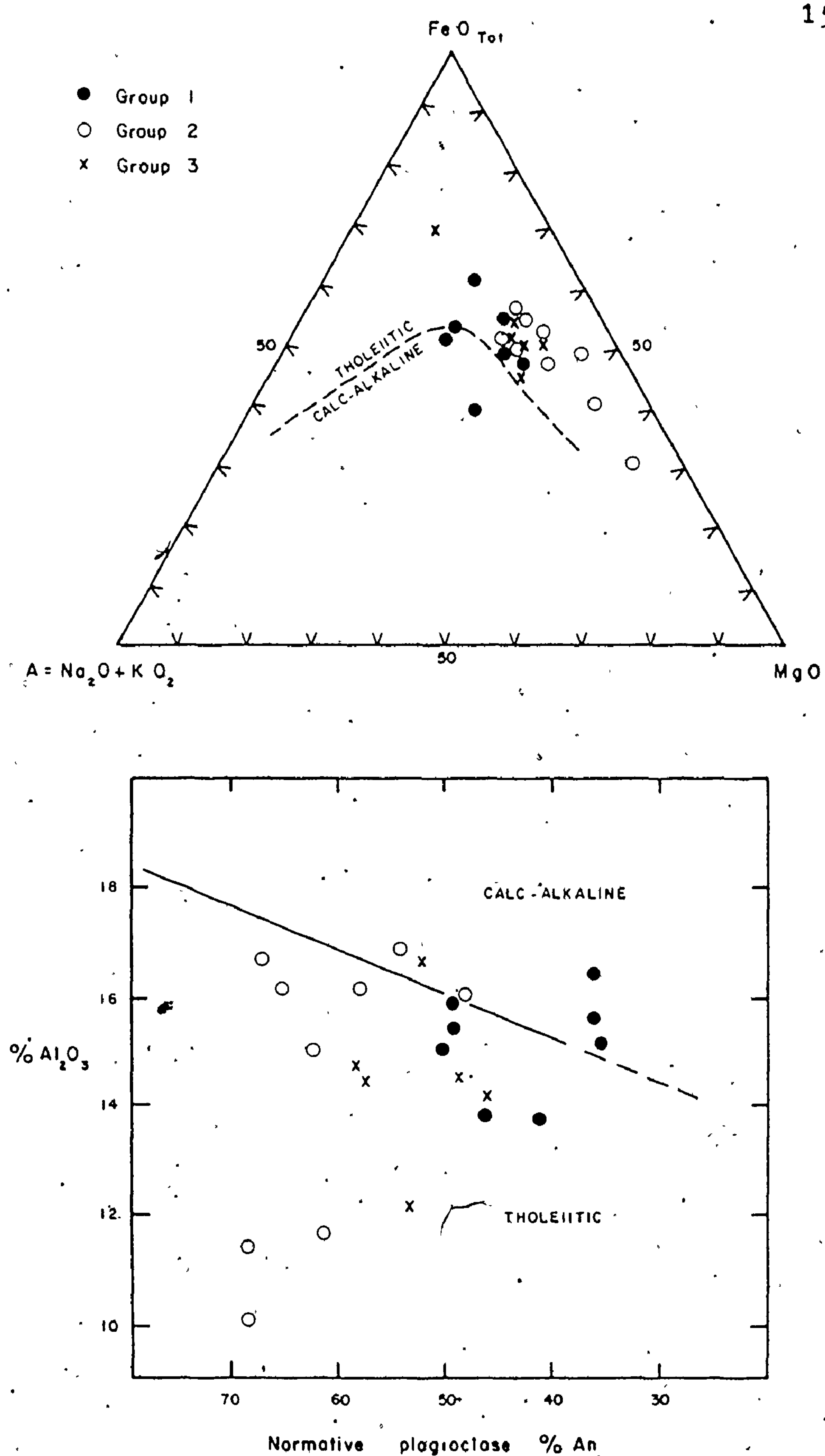


Figure 3-14 Amphibolites – Tholeiitic affinities

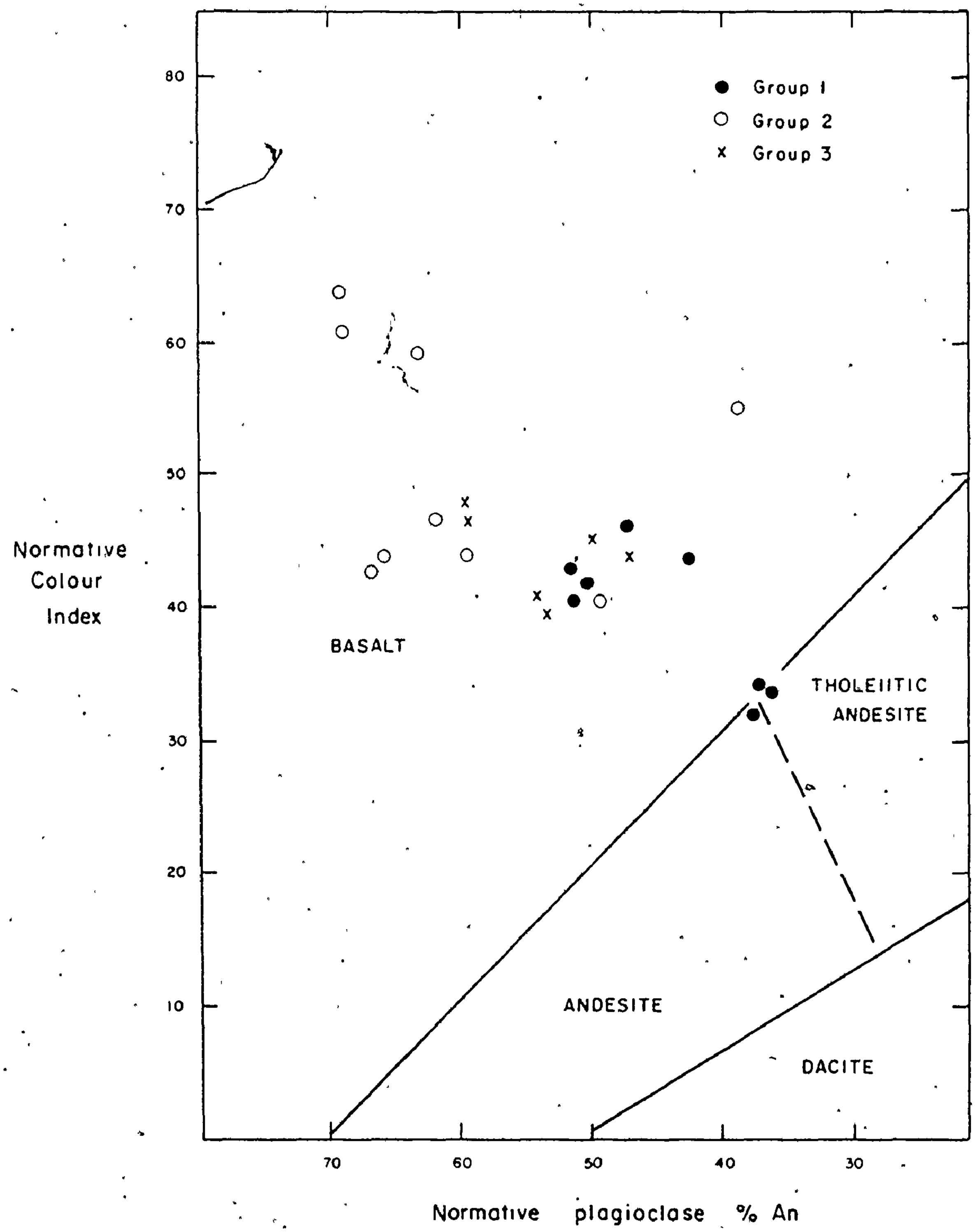
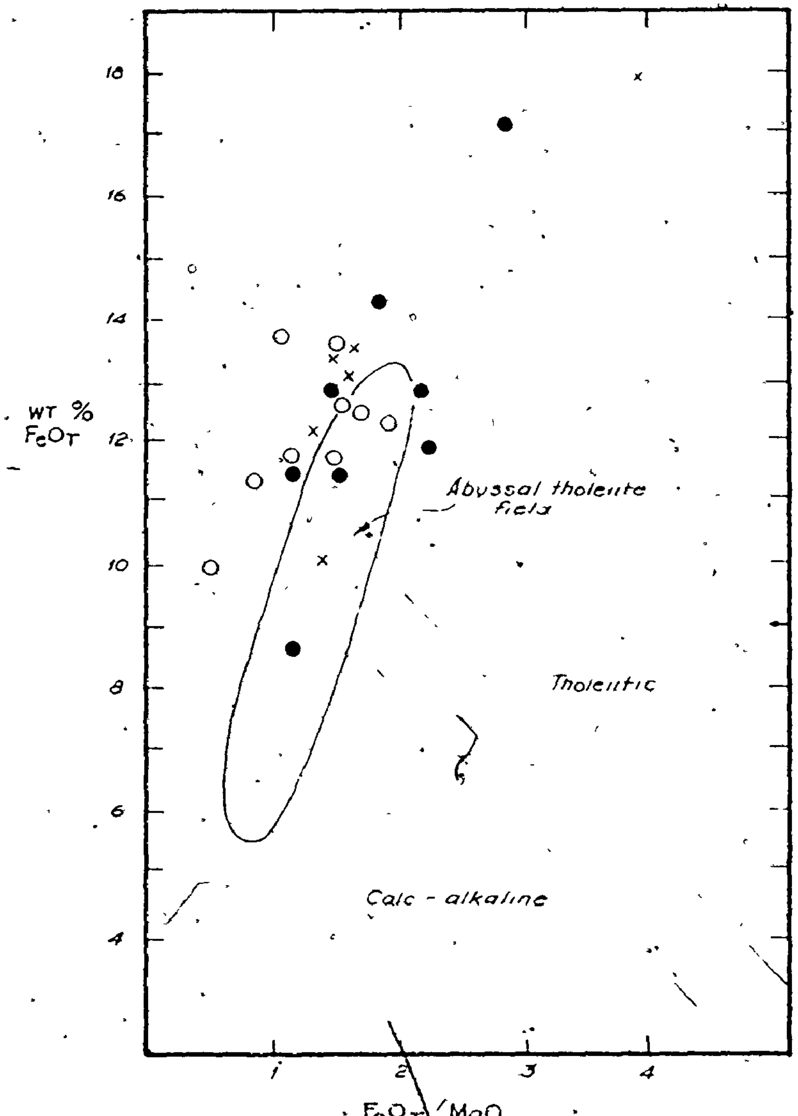


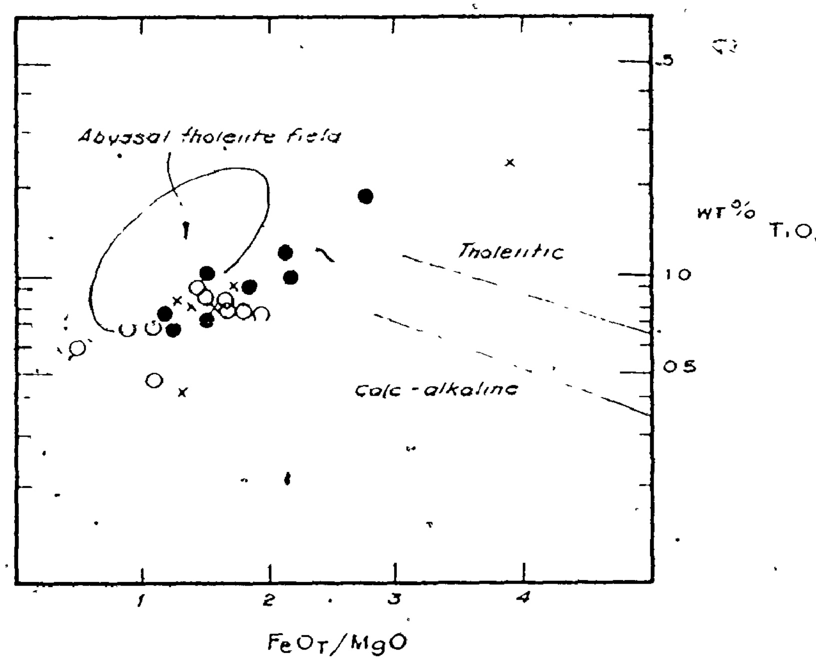
Figure 3-15 Amphibolites — basaltic classification

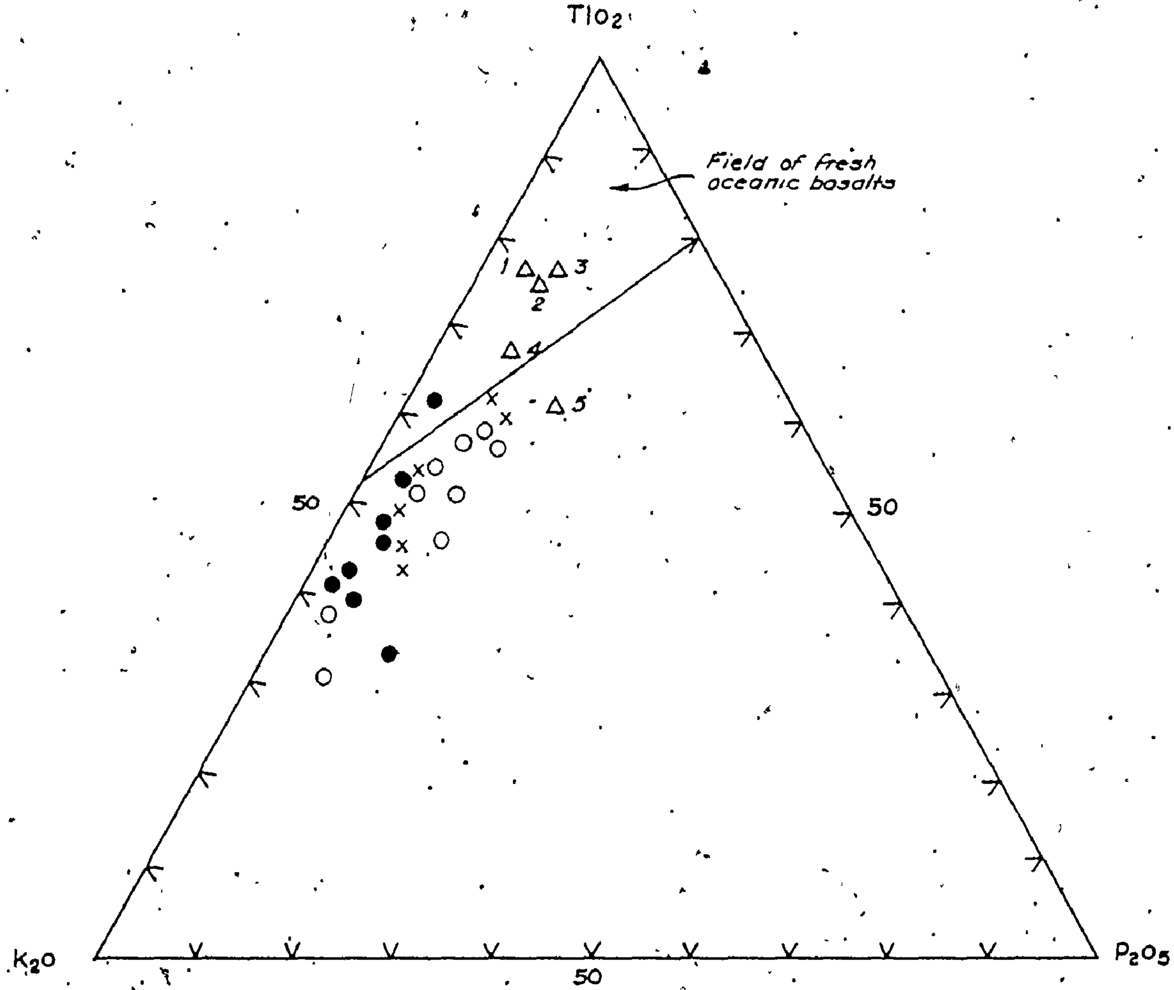
Fig 3-16 Amphibolites

FeO_T and TiO_2 vs FeO_T/MgO

● Group 1
○ Group 2
× Group 3





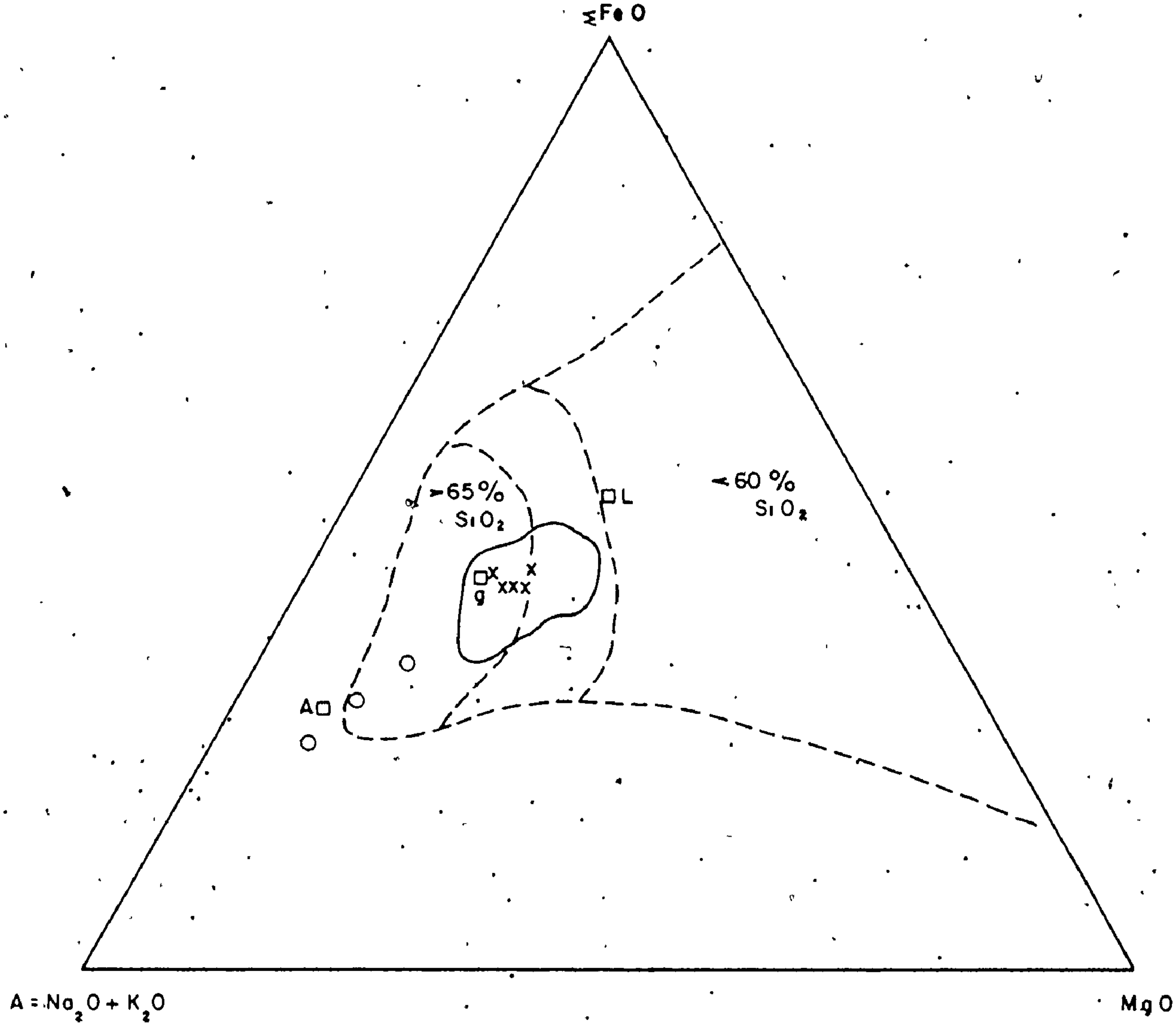


- ● Group 1 Amphibolites
- ○ Group 2 Amphibolites
- × Group 3 Amphibolites

△ "Average" Archean greenstones from Gorman & Birkett (1975)

1. Lower Onverwacht Group, South Africa
2. Mt Shingleton, Yilgarn belt, Australia
3. Timmins - Noranda area, Canada.
4. Norseman area, Kalgoorlie belt, Australia
5. Wabigoon + Abitibi areas, Canada

Fig. 3-17 $K_2O - TiO_2 - P_2O_5$ plot of amphibolites



x Type A Twilight gneiss
○ Type B Twilight gneiss

□ L Average Lithic Arenite
□ g Average Greywacke
□ A Average Arkose
Pettijohn, 1963

Field of greywackes Bell & Jolly, 1975

Field of greywackes from the Armstrong Area (English River Subprovince)

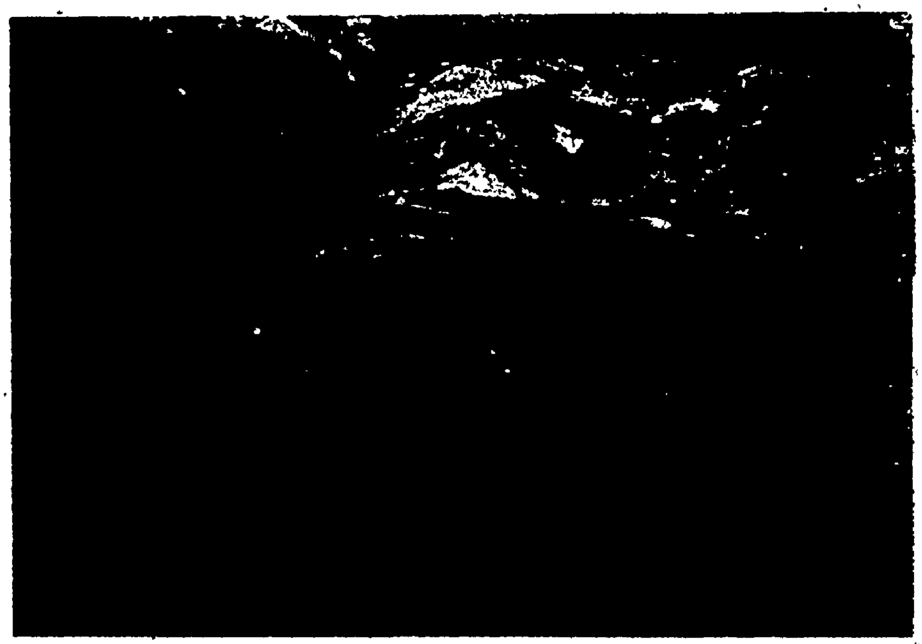
Figure 3-18 Twilight gneiss – AFM comparison with greywackes

Plate 3-1 Cedar Lake gneiss. Type locality at Highway 105 and Cedar Lake

Plate 3-2 Deformed, sigmoidal microcline megacrysts in a granodiorite of the Clay Lake granitoid suite. Outcrop on Highway 105 at the Lands and Forests game check station, 18.9 miles north of Vermilion Bay

Plate 3-3 Possible lava tube from volcanic enclave at Cliff Lake on Highway 105

Plate 3-4 Deformed pillow structures in amphibolite. Location as Plate 3-3



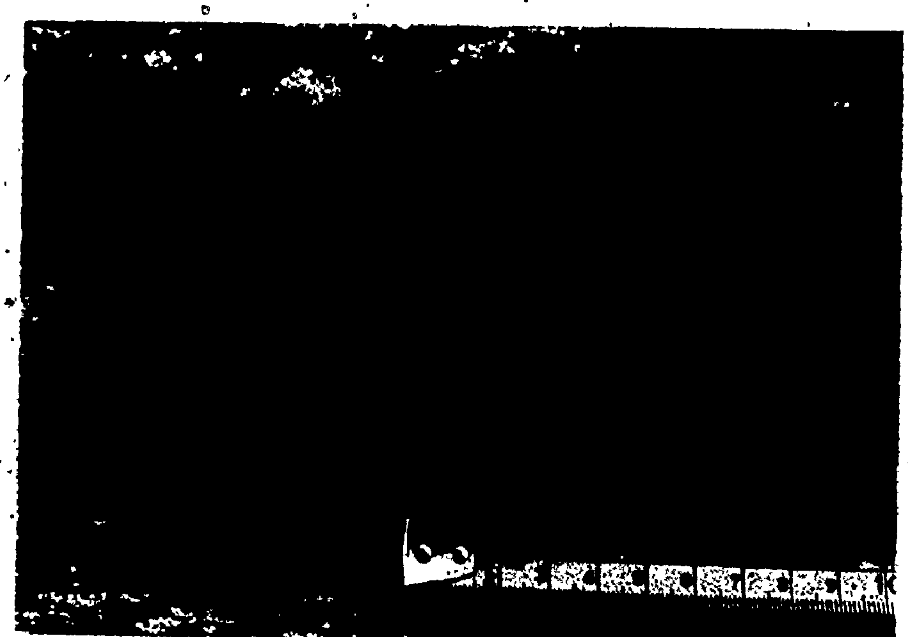
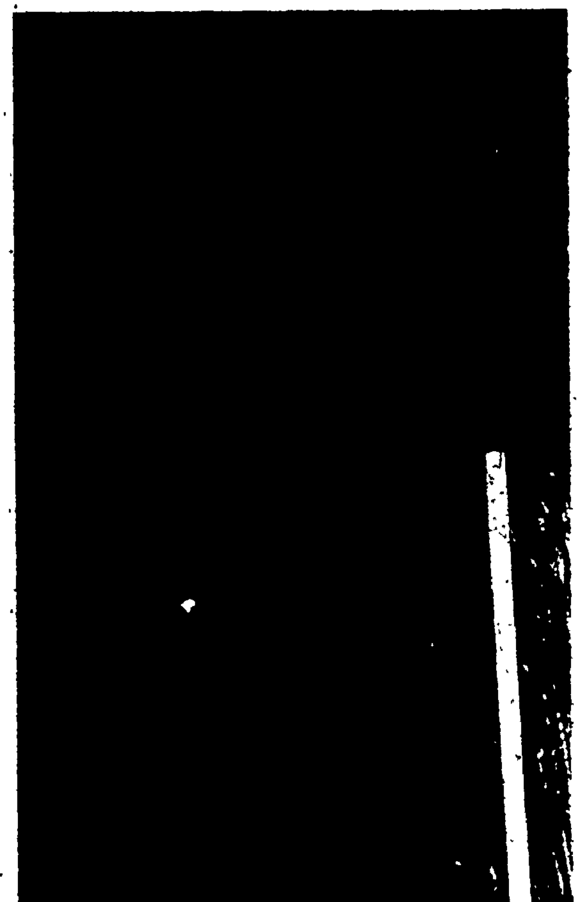


Plate 3-5 Banded, quartz-magnetite iron formation. Volcanic enclaves at the southern margin of the Cliff Lake granodiorite on Highway 105, northwest of Trail Lake

Plate 3-6 Twilight gneiss. Type locality on Highway 105 south of Trail Lake and 20.4 miles north of Vermilion Bay



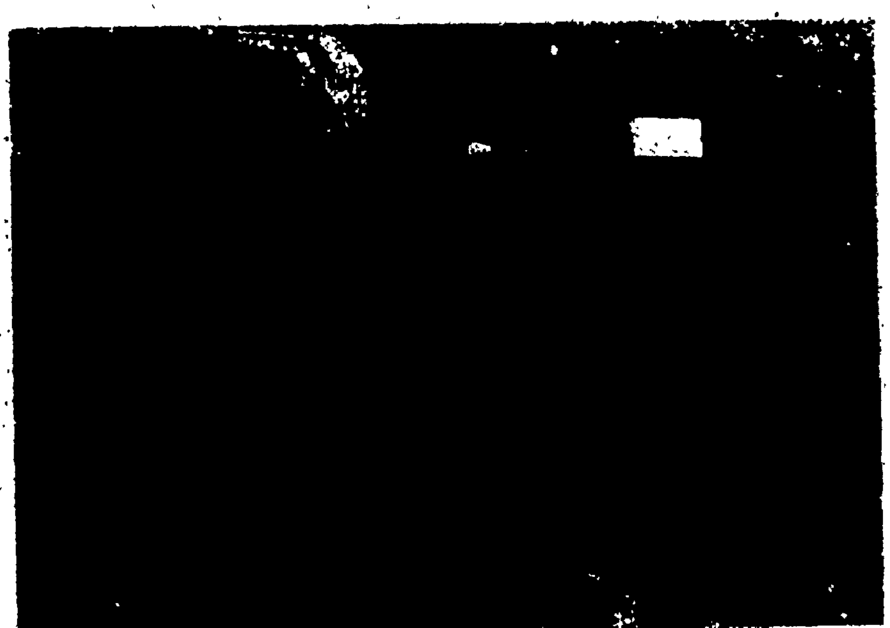


Plate 3-7 F_b2 folds deforming compositional banding in Cedar Lake gneiss. West arm of Cedar Lake

Plate 3-8 Isoclinal F_b1 fold in Cedar Lake gneiss. West arm of Cedar Lake

Plate 3-9 Boudinaged amphibolite enclaves in Cedar Lake gneiss. North arm of Cedar Lake

Plate 3-10 Oblique section of F_b4 folds in Cedar Lake gneiss within the Transitional Sequence, southeast limb of the Mystery Dome

Plate 3-11 F_b5 folds in Cedar Lake gneiss.
North arm of Cedar Lake

Plate 3-12 Isoclinal Fb2 fold in compositionally banded amphibolites from the Transitional sequence. Note F_b3 boudinage and normal kinks. Outcrop on Highway 105, 0.2 miles south of Trail Lake

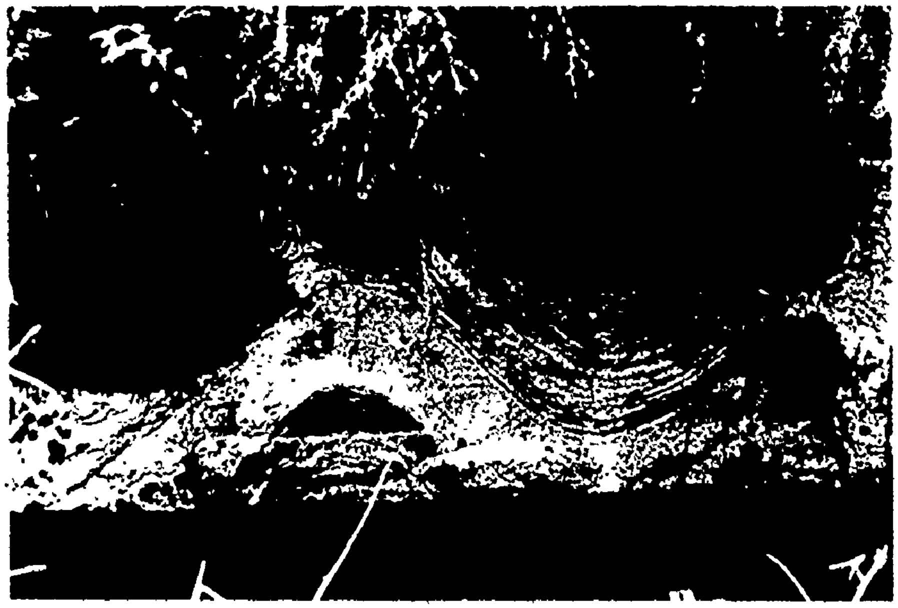
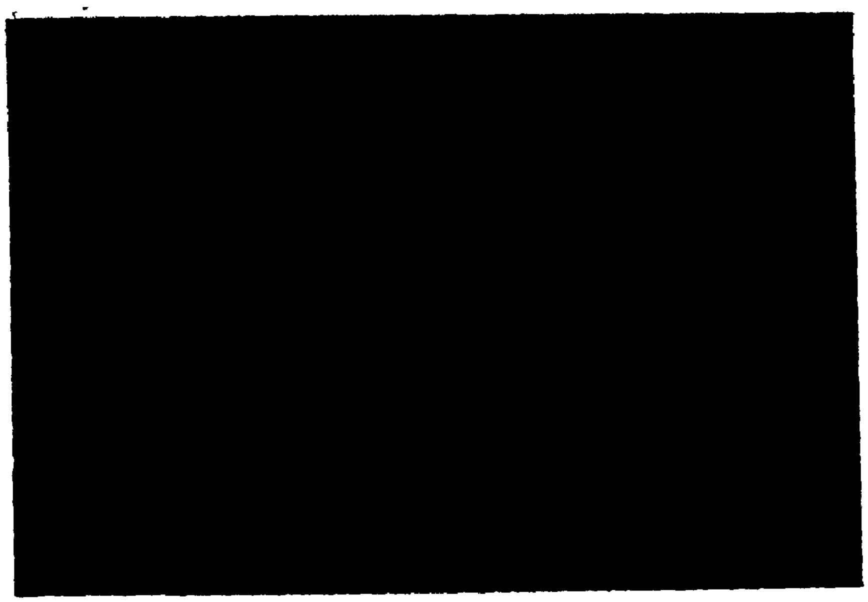


Plate 3-13 F_b3 internal boudins and normal kinks in the Transitional Sequence. Outcrop southeast of Trail Lake

Plate 3-14 Tight folds in compositional banding of Trail Lake Series. Relative age uncertain - possibly equivalent to F_b3. Outcrop on Highway 105, west of Trail Lake

Plate 3-15 Fb4 folds in Twilight gneiss.
Location as Plate 3-6.

Plate 3-16 Post tectonic microcline megacrysts in banded amphibolite. Close to the southern margin of the Cliff Lake granodiorite. Outcrop on Cliff Lake logging road



CHAPTER 4

GEOLOGY OF THE PERRAULT FALLS - VERMILION BAY DISTRICT

4-1 INTRODUCTION

During the summer of 1975 the author was employed by the Ontario Division of Mines, Geological Branch and was attached to Operation Kenora - Ear Falls. The operation - a continuation of Operation Kenora-Sydney Lake (1974) - was a helicopter supported reconnaissance mapping program in the area bounded by latitudes 49°45'N and 51°00'N and by longitudes 93°30'W and 92°00'W. The author was responsible for geological mapping of a 1300 square mile area adjacent to highways 17 and 105 in the Perrault Falls - Vermillion Bay - Dryden district (fig. 4-1). The district includes the northern margin of the Wabigoon Subprovince, the English River Plutonic Complex and the southern margin of the English River Metasedimentary Migmatite Complex, the latter two units being within the English River Subprovince.

Data from helicopter traverses done within the southern part of the district during the operation has been supplied by W.D. Bond of the Ontario Division of Mines. The data forming the basis of this chapter and fig. 4-1 are courtesy of the Ontario Division of Mines.

Previous work within the district includes the mapping of Moorhouse (1941) in the Eagle River area; a petrologic study of the Perrault Falls Clotty Granite by Morin (1970) and Morin and Turnock (1975); and a petrologic study of metamorphism along the Red Lake highway by Jones (1973). Dwibedi (1966) also sampled rocks along the Red Lake highway as part of his reconnaissance petrological and geochemical study of the English River Subprovince.

4-2 DISTRIBUTION OF LITHOLOGIES

The extreme northern portion of the district is underlain by rocks belonging to the English River metasedimentary migmatite complex. The metasedimentary migmatites are best exposed in the area north of Perrault Falls and east of Anishinabi Lake. The dominant rock type is a medium grained, banded, foliated garnet and cordierite bearing biotite-quartz-plagioclase paragneiss of greywacke bulk composition. Local mafic to intermediate, volcanogenic interlayers are present and rare mafic dikes also occur. Varying proportions of leucocratic, white weathering granitoid material are present as dikes, sills, veins and segregations. Locally concentration of this granitoid fraction has formed granitoid bodies mapped as inhomogeneous, white leucotonalite to granite. Metasedimentary migmatites (Twilight gneiss) are also present in the cores of two domal structures in the Clay Lake Area (Chapter 3).

The southern margin of the metasedimentary migmatite complex is marked locally by a thin, highly discontinuous, mafic volcanic unit at Wabaskang Lake. At Perrault Lake the mafic unit is succeeded northwards by a thin conglomerate unit containing mafic amphibolite clasts and clasts of weakly foliated, biotite tonalite to granodiorite. At Perrault Lake and Wine Lake, the southern margin of the metasedimentary migmatite complex has been intruded by concordant bodies of weakly foliated, biotite tonalite - granodiorite. Due to the prevailing vertical attitude of foliation and the lack of "way up" criteria the facing direction of this sequence is unknown. Elsewhere the margin is marked by a complex zone of injection of massive, pink, equigranular granite.

These injection zones are marginal to several much larger plutonic bodies of massive pink granite, the largest of which occurs in the Thaddeus Lake area. A thin sheet of pink granite extends across central Perrault Lake to join with a second large pluton centred on Ryan Lake in the area between Perrault Falls and Fleet Lake. A protrusion from the western margin of the Ryan Lake pluton extends northwards through Aerobus Lake and then eastwards into the central Wabaskang Lake area. At Wabaskang Lake the intrusive component is a mixed assemblage of weakly foliated biotite granodiorite and massive pink granite. The trend of enclaves within the Anishinabi Lake pluton suggests that it is a discrete body. Outcrops of massive pink granite are, however, continuous from the Anishinabi Area through southern Wine Lake into the Wabaskang and Aerobus Lake areas.

A large body of coarse grained porphyritic (alkali feldspar) granite occurs south of the Anishinábi Lake area and is centred on Bornite Lake. The body has a mildly foliated border phase.

Two large, tabular bodies of weakly foliated, equigranular biotite tonalite to granodiorite intrude gneissic rocks south of the Fleet Lake area. The easterly body extends north eastwards into the Perrault Lake area where it is intruded by massive pink granite. A similar body occurs south of the Clay Lake area.

In the central portion of the English River Plutonic Complex a widespread, sheet like body of porphyritic (alkali feldspar) granodiorite intrudes gneissic rocks in the Cedar Lake and Clay Lake areas. The porphyritic granodiorite is generally unfoliated but locally - for example north of Cedar Lake - it becomes weakly to moderately foliated. The body is extensively intruded by small dikes and sills of massive pink granite and is intruded by the Thaddeus Lake pluton.

Gneissic rocks are present throughout the Fleet Lake, Cedar Lake, Ross Lake, Clay Lake and Quibel Lake areas. These severely foliated and variably banded rocks exhibit considerable compositional and morphological variation. They are extensively intruded by small, granitic pegmatoid bodies and predate the intrusion of the major granitoid bodies previously described. Large domal structures are present in these gneissic rocks in the Cedar and Clay Lakes areas. At Clay

Lake the rocks are granulitic, containing orthopyroxene and garnet.

The Mafeking area is underlain by a variety of variably foliated granitoid intrusive rocks with minor screens of gneissic enclaves. The oldest intrusive unit in this area is composed of moderately to strongly foliated, equigranular, biotite tonalite and granodiorite. Compositionally and morphologically similar rocks intrude gneisses in the Fleet Lake area and in the area between Ross and Thaddeus Lakes. This unit is intruded by massive to moderately foliated, porphyritic granodiorite in the Mafeking area. An extensive, mappable unit of intermixed massive, medium grained to pegmatoid, pink granite and equigranular, weakly foliated, grey tonalite to granodiorite is present south and east of the Ross Lake area. Similar rocks occur south of the Quibel Lake area and in the Rugby Lake area east of Mafeking.

In the Rugby Lake area contact relationships between this unit and rocks of the Wabigoon Subprovince are obscure. Further west however, in the vicinity of Soma Lake, two small stocks of weakly foliated, biotite granodiorite mixed with massive, pink pegmatoid granite contain numerous enclaves of metavolcanic rocks from the Wabigoon Subprovince. At the Red Lake Highway, strongly flattened, volcanic rocks of the Wabigoon Subprovince are separated from a thin sliver of hornblende-biotite gneisses by massive, equigranular, pink granite. Further west at Langton Lake the same pink granite contains enclaves and screens of metavolcanic rock. Within this district therefore the boundary between the English River and Wabigoon Subprovinces is obscured by intrusive rocks.

A belt of metavolcanic rocks 1-2 km wide occurs north of Vermilion Bay at the northern margin of the Wabigoon subprovince. This belt represents the easterly continuation of the Tustin-Bridges metavolcanic belt mapped by Pryslak (1971). Rock types include mafic, massive, pillowed and porphyritic flows; intermediate tuffs and agglomerates and minor intercalations of greywacke like metasediments. At the extreme eastern end of the metavolcanic belt a narrow zone of intermediate to acid tuffs is exposed approx. 1 km S.E. of Wildrice Lake.

A large area to the east of Vermilion Bay (Eagle River - Oxdrift) is underlain by metasedimentary rocks. The rocks appear to have been originally greywacke type sediments with locally abundant oxide facies iron formation in the Eagle River area. Garnet and cordierite are locally abundant in the metasediments. Veins, stringers and segregations of leucocratic granitoid material are ubiquitous. Thicker sills of coarser grained to pegmatoid, white leucotonalite and medium grained, foliated, white granodiorite to granite are very common. Over a large portion of the Oxdrift area such granitoid material constitutes greater than 90% of individual outcrops and the area has been mapped as inhomogeneous, white leucotonalite to granite. The margins of these bodies are somewhat difficult to define but field relationships indicate that the inhomogeneous leucotonalite-granite is intrusive into the metasediments at the present level of exposure.

South of the Oxdrift Area the northern margin of a mafic to intermediate volcanic belt which has been mapped by Moorhouse (1939) extends far beyond the boundaries of the district currently under discussion.

South and west of Vermilion Bay metasedimentary rocks are preserved as strongly mobilised paragneissic remnants within an intrusive plutonic complex. Massive to weakly foliated hornblende and biotite bearing tonalites and granodiorites intrude the metasediments and the metavolcanic rocks of the Tustin-Bridges metavolcanic belt. These early intrusions are themselves intruded by massive, equigranular, pink granite.

4-3 LITHOLOGIES - ENGLISH RIVER SUBPROVINCE

(i) Metasedimentary Migmatites

English River type metasedimentary migmatites are well exposed north of Perrault Falls on Wabaskang and Wine Lakes. Similar rocks, the Twilight gneisses, which outcrop in the Cedar Lake and Clay Lake areas have been fully described in the previous chapter. The current description will therefore be restricted to rocks present in the northern sector of the district.

The dominant component of these rocks is a brown weathering, strongly banded, medium to fine grained, foliated, biotite-quartz-plagioclase paragneiss. Compositional banding which probably reflects original bedding in the paragneisses is frequently present, individual bands varying from a few centimetres to one or two metres in thickness (Plate 4-1).

Medium grained, greyish-brown, massive to weakly foliated, units are interlayered with generally thinner units having a pronounced foliation. The thicker units are generally in the order of one or two metres thick and rarely contain distinct leucosomes. They are therefore referred to as "unreacted units". The rocks are, however, strongly recrystallised and have a foliated equigranular, interlobate texture of quartz, plagioclase and biotite with grain size in the range of 0.2 - 0.6mm. Minor cordierite porphyroblasts may be present and a few small almandine garnets have been recorded. The layers generally lack internal structure and contacts with other units may be either sharp or gradational.

Thinner layers which will be called "reacted units" are coarser grained (0.5 to 2.0mm); strongly foliated and exhibit patchy or veinitic granitoid leucosomes. Garnet occurs both as small equant grains and as coarser (2.5mm) porphyroblasts which frequently contain an abundance of non-oriented quartz and biotite inclusions. Some garnets with inclusion-free rims have been noted. Cordierite occurs as coarse, tabular to elongate porphyroblasts which are occasionally poikiloblastic with respect to the groundmass. It has commonly undergone strong pinnitic alteration and a pale yellowish-brown biotite replacing marginal areas has also been observed. The groundmass consists of an equigranular, foliated, interlobate intergrowth of quartz, plagioclase (An_{27-31}) and biotite with grainsize varying from 0.5 mm to 1.5 mm.

Reacted units consistently display the development of a granitoid leucosome which is believed to be a mobilisate produced during high grade regional metamorphism and partial anatexis (Mehnert 1968, p.118). The mobilisate development is characterised on the smallest scale by the presence of lensoid segregations of quartz and feldspar which are slightly coarser grained than the host (1-2 mm). In outcrop the coalesence of lensoid leucosomes may produce discontinuous leucosome banding with thicknesses in the order of 2 - 5 mm. Thin, biotite rich, melanosomes are frequently developed as borders to thicker, in situ, leucosomes. The in situ leucosomes are leucotonalitic or rarely granodioritic.

The thinner veins are usually complexly folded ptygmas with axial planes subparallel to the foliation in the host (Plate 4-2). Evidence of severe flattening of these veins is abundant, suggesting that they were injected early in the deformational history. Such early veins have a foliated, equigranular, interlobate texture with grain size in the range of 0.5mm to 2.0mm and compositions ranging from leucotonalite to leucogranite. A single vein is generally relatively homogenous in terms of composition.

Thicker, intrusive mobilisate units are less deformed and often demonstrably discordant. They are consistently white coloured regardless of their composition, which may range from leucotonalite to leucogranite over very short distances within a single body. Similarly, grain size within a single hand sample may be markedly inhomogeneous varying from 0.5 mm in groundmass crystals upwards to 3 cm megacrysts of feldspar. The mobilisate frequently contains pink almandine garnets, both in the form of small, equant, inclusion-free grains and as coarse (3 cm), spongy or sieve textured porphyroblasts. Bluish-grey and mauve cordierite megacrysts are associated with coarser grained mobilisate units. Biotite, muscovite, apatite, magnetite and sphene occur widely as minor and accessory minerals.

Throughout most of the area between Perrault Falls and Anishinabi Lake the metasedimentary migmatites contain between 20% and 75% leucocratic granitoid mobilisate. They are thus compositionally and texturally equivalent to <u>metatexites</u> (Scheumann, 1936, 1937; Mehnert, 1968; Brown, 1973). Locally, however, as on Perrault Lake and to the north of Wine Lake, the granitoid mobilisate phase becomes dominant and large bodies of inhomogenous leucotonalite to leucogranite are mappable. The bodies are generally concordant with foliation in the surrounding metasedimentary migmatites and contain between 5% and 20% enclaves of these rocks. Enclave density is apparently greatest at the margins of the bodies, the internal parts being locally schlieritic or nebulitic (Plate 4-3). The coarser grained, more homogenous parts of these bodies contain diffuse mafic clots of cordierite, garnet, biotite and quartz. Compositionally and texturally these units are equivalent to the diatexites of Mehnert (1968) and Brown (1973).

There seems to be little dispute amongst current workers that the biotite - plagioclase - quartz gneisses of the northern part of the English River Subprovince are sedimentary in origin. The high mafic content of these rocks (15-30% biotite ± garnet ± cordierite) and the scale and relatively continuous nature of compositional banding are factors which favour a sedimentary origin. Unreacted units may originally have been psammitic or semipelitic greywackes and reacted units probably represent originally pelitic shales or shaley greywackes. The nature of the interlayering of these rock types is similar to that of the turbidite bearing Resedimented Association of Turner and Walker (1973).

Van der Kamp (pers. comm.) has studied similar rocks in the Pakwash Lake and Lac Seul areas north and east of the Perrault Falls area. He has noted the relatively low quartz (25-35%) and high plagioclase (40-60%) contents of these rocks and their compositional similarity to dacitic volcanic rocks. Both Van der Kamp and Beakhouse (1974) have suggested compositional similarities between the Ohanapecosh Formation of the Mt. Rainier area, Washington State (Fiske 1963) and the English River metasedimentary migmatites. The Ohanapecosh Formation is a sub-aqueous deposit derived rather directly from andesitic to dacitic pyroclastic material and a similar origin has been suggested for the English River metasedimentary migmatites. There is, unfortunately, no direct textural or fabric evidence to support such a comparison.

(ii) Metaconglomerate

In the north-central part of Perrault Lake a thin metaconglomerate unit separates mafic amphibolite in the south from metasedimentary migmatites to the north. The unit is a polymictic orthoconglomerate, 50-75 ft wide, and traceable for approximately one mile along strike. The unit is dominated by coarse clasts of coarse grained tonalitic granitoid rocks with lesser proportions of mafic amphibolite clasts (Plate 4-4). Identification of matrix and estimation of relative clast/matrix abundance are difficult due to the deformation fabric imposed on the rock.

The most abundant clasts (35% by area) are a foliated, coarse grained (1 - 3 mm), hornblende-biotite tonalite containing approximately 12% mafic minerals, 25% quartz and 63% feldspar. Stained outcrops suggest that potassic feldspars are virtually absent from this clast type. Larger clasts of this type are ellipsoidal, having dimensions of approx. 45 cm x 15 cm with a relatively constant axial ratio of 3:1. Smaller clasts are much more elongate and frequently have splayed extremities.

Coarse grained, weakly foliated <u>leucotonalite</u> clasts occupy approximately 30% of the total outcrop area. Such clasts contain approximately 5% biotite, 30% quartz and 65% feldspar. Plagioclase is dominant but up to 5% potassic feldspar may be present - often in thin, diffuse veinlets within the clast. Leucotonalite clasts are generally smaller and more equidimensional than hornblende-biotite tonalite clasts. Coarser clasts range up to 27 cm x 18 cm with roughly constant axial ratios in the order of .5:1. Several much more elongate clasts of similar composition are however also present.

Fine grained, strongly foliated, <u>black amphibolite</u> clasts occupy approximately 25% of the total area. The clasts are strongly elongate, often display severe tectonic thinning at extremities and have been deformed around and between the more competent tonalitic clasts.

Approximately 10% (or less) of the total area is occupied by fine grained (1mm), <u>siliceous tonalitic material</u> containing approximately 5-10% mafic minerals, 35-40% quartz and 55-60% plagioclase. In places this material appears to form highly elongate and deformed clasts with irregular boundaries. Elsewhere the material is found between coarser grained tonalitic clasts where it appears originally to have been matrix. Compositionally and texturally, this possible matrix is very similar to relatively siliceous, unreacted units, which locally form a high proportion of the metasedimentary migmatite assemblage, immediately to the north on Perrault Lake.

The facing direction of the conglomerate bearing succession at Perrault Lake is unknown due to the prevailing vertical foliations and strongly deformed nature of rocks in the vicinity. Derivation of the black amphibolite clasts from a thin mafic amphibolite unit outcropping immediately south of the conglomerate seems however to be a reasonable suggestion. If this is correct the succession must be north-facing and the conglomerate therefore forms a basal unit to the overlying greywacke succession that now forms the bulk of the metasedimentary migmatite complex.

Provenance of the tonalitic clasts is at present an unresolved problem. They most closely resemble thin, sheet like, foliated tonalitic units which intrude the amphibolites at Perrault Lake and both amphibolites and metasedimentary migmatites at Wine Lake. Their provenance from this unit seems unlikely however in view of the time relationships just suggested. There is a significant absence of anything resembling a gneissic fabric in the tonalitic clasts. This suggests that the gneissic plutonic rocks currently exposed immediately to the south were not locally exposed during the formation of the conglomerate.

The conglomerate is intruded by concordant and discordant dykes of pink pegmatitic granite associated with the Perrault Lake - Thaddeus Lake granite pluton.

(iii) Metavolcanic rocks

Metavolcanic units associated with the English River metasedimentary migmatite complex occur in two settings: (a) internal to the complex, and (b) as a discontinuous southern margin to the complex.

At North Wine Lake, possible metavolcanic rocks within the complex form a unit approximately 30-50 metres wide across strike and extending approximately 1.5 km along strike. Thinly banded, schistose, chloritic rocks are associated with minor psammitic to semi-pelitic metasediments and sporadic massive to foliated, mafic amphibolites which rarely exceed 1 metre in thickness. In thin section the banded, schistose rock contains approximately 15% quartz, 55% plagioclase (An_{30}), 20% chlorite and 15% epidote; with an average grain size of 0.6mm. Rare, lenticular, soft, dark green, fine grained aggregates noted in outcrop but absent from the thin section are believed to represent chloritised and pinnitised pseudomorphs after cordierite. The most likely protolith for this rock would be a fine grained, intermediate tuff.

A unit of very similar looking rocks, 25-30 metres thick, outcrops north of Perrault Falls and just west of highway 105. Compositional banding in these rocks varies from 2 cm to 1.5 metres thick Thicker units are massive to weakly foliated but thinly banded units contain tight, small scale folds with axial planes subparallel to gross composition banding. The finer grained, thinly banded units display a weak protoclastic texture in thin section and contain approximately 55% chlorite, 20% quartz, 10% plagioclase and 15% muscovite. Thin, cross cutting fractures are filled with iron stained chlorite and epidote.

Two small outcrops of probable volcanic rocks are exposed in cuttings on the C.N. Railroad (Griffith Mine branch line) 6 kilometres northeast of Perrault Falls. The outcrops are both roughly 30 metres across strike and separated by approximately 0.5 km in an extensively drift covered area. Foliated, weakly banded mafic amphibolites contain hornblende, pale green pyroxene, biotite, and plagioclase with rare epidote rich pods. These are interlayered with 5-10 metre thick, fine grained, strongly foliated and banded biotite-quartz-plagioclase gneisses which are folded by tight, upright disharmonic folds. The gneisses may be weakly reacted metasediments or fine grained intermediate tuffs. The succession is intruded by sills and veins of white foliated, leucocratic quartz monzonite which have also been folded. Late dykes of massive pink granite are also present.

Mafic amphibolite rocks, inferred to be of volcanic origin, occur as a highly discontinuous unit at the southern margin of the English River metasedimentary migmatite complex. In the north east of Anishinabi Lake compositionally banded amphibolites containing coarse grained pods and stringers of epidote and plagioclase are associated with coarse grained massive amphibolites and metasedimentary migmatites. On the east arm of Wine Lake, strongly banded mafic amphibolites containing 5% of epidote-plagioclase pods are associated with thinly banded, siliceous biotite-quartz-plagioclase gneisses containing up to 40% coarse, equant pink garnet.

Similar lithologies were found on a small lake south and east of Aerobus Lake. At this locality mafic amphibolite is interbanded on a scale of 1-25 cm with siliceous biotite-plagioclase-quartz gneisses. The banding is severely deformed, local concentrations of clinopyroxene occur and several thin bands containing up to 80% pink garnet are present. Small outcrops in the central arm of Aerobus Lake display compositionally banded, clinopyroxene-hornblende-plagioclase amphibolites with minor flattened and boudinaged lenses of coarse grained epidote and plagioclase. The amphibolite contains a band, 0.5 to 1.0 metre wide, of thinly banded magnetite-quartz iron formation.

A pillowed mafic amphibolite unit occurs in the central part of McLeod Bay (Wabaskang Lake) at the southern margin of the English River metasedimentary migmatite complex (Plate 4-5). Although the pillows are strongly flattened, with a fairly constant 10:1 axial ratio, continuous pillow selvages are excellently preserved and inter-pillow material has recrystallised to coarse grained aggregates of pyroxene, hornblende and plagioclase. The pillowed unit is approximately 10 metres thick which is heavily injected by leucotonalite veins.

As described in the previous section, the conglomerate at Perrault Lake is bordered to the south by a thin, unbanded, foliated, mafic amphibolite unit containing numerous white leucotonalite veins. A possible continuation of this unit occurs as a very large enclave within coarse grained, massive pink granite at Spadina Lake to the east of Perrault Lake. At Spadina Lake the strongly banded and foliated, biotite bearing amphibolite is interlayered with 1 to 10 metre thick units of weakly blow banded or nebulitic, white weathering leucocratic granite. The enclave is at least 100 metres wide across strike but its strike length is unknown.

Rare occurrences of mafic volcanic rocks are known to be present within the English River plutonic complex. Occurrences including pillow form amphibolites and associated banded iron formation from the Cedar Lake area have been described in Chapter 3.

(iv) Gneissic rocks

Large areas within the English River plutonic complex are underlain by gneissic rocks of extremely variable composition and fabric. Within a single outcrop several different rock types may be complexely interbanded and interwoven and isoclinal folds and severe internal boudinage indicate that the gneissic rocks have suffered severe compression perpendicular to the present gneissosity. It is most probable, therefore, that originally discordant relationships between various rock types have been destroyed and that the present day compositional banding is largely the result of transposition. The gneissic rocks contain the following lithologies, although not all lithologies are present at a single outcrop.

(a) Amphibolites are common both as small, severely boudinaged layers and as larger more continuous layers in the gneisses. The thicker, more continuous units (up to 400 metres thick) are usually compositionally banded on a scale of 1-20 cm. The compositional banding is defined by variations in the plagioclase content. Biotite rich layers are also found in the banded amphibolites and pods or stringers of coarse grained epidote and/or diopside plus hornblende and plagioclase are commonly present. The vast majority of the banded amphibolite occurrences are within the Cedar and Clay Lake areas and have been previously described (Chapter 3).

Massive, lineated or foliated medium grained (0.5-2.0mm) amphibolite units with thicknesses ranging from 15 cm to 20 metres generally lack compositional banding. They frequently occur as isolated enclaves or as strongly boudinaged units within the tonalitic and granodioritic gneisses. Thin, leucotonalite veins are ubiquitous and often tightly folded within the amphibolite enclave. Agmatitic amphibolite units containing an intersecting vein network of leucotonalite are also common. The vast majority of unbanded amphibolite units are concordant to gneissosity in their host rocks. Locally, however, mildly discordant relationships have been noted suggesting that some of these units may originally have been dikes intruded into the protolith of the gneissic rocks.

(b) Mafic hornblende-biotite gneisses occur as compositional bands on all scales. They are medium grained (1-2mm) strongly foliated, contain a weak compositional banding and generally have a colour index in the range 20-40. Larger units frequently are associated with and contain inclusions of unbanded amphibolite.

(c) Variably foliated biotite-hornblende quartz-diorite to tonalite units are a rare constituent of the gneissic rocks. These units are medium grained (1-4 mm), moderately foliated but unbanded, generally contain roughly equal proportions of biotite and hornblende and have colour indices ranging from 20 to 30. Fairly continuous units in the Cedar Lake area occur at the margins of late intrusive granodiorite granite bodies and are invariably associated with amphibolite units. Elsewhere this rock type occurs as a consistent but very minor constituent of the gneisses in the form of irregular enclaves.

(d) Tonalitic and granodioritic gneisses are volumetrically the most important component of the gneissic rocks. These units are compositionally banded on all scales, the most common being in the range 10-50 cm with internal banding in the range 1-2 cm. The quality of compositional banding varies from thin highly discontinuous, units to thicker units traceable for several tens of metres. Banding is defined largely by abundance of mafic minerals - biotite and minor hornblende - and by grain size. Colour index is generally in the range 5 to 20 but very thin mafic schlieren may contain up to 75% biotite. More mafic bands tend to be finer grained (0.5-1.0 mm) and strongly foliated, less mafic bands coarser grained (1-4 mm) and less foliated. Contacts between bands of different composition may be sharp or gradational.

(e) Strongly foliated to gneissic tonalite and granodiorite forms the major component of the gneissic rocks in the Clay Lake area. This lithology is distinguished from unit (d) by the absence of a well defined, small scale compositional banding. The unit is nevertheless strongly or severely foliated and locally a very poor, discontinuous, thin banding may be present. The rocks are medium to coarse grained and have a foliated, granoblastic interlobate texture. Biotite is the dominant mafic mineral accompanied locally by hornblende; the colour index varies from 8 to 20. In the Clay Lake region rocks of this type contain orthopyroxene (see Chapter 3).

(f) Leucotonalite occurs as thin concordant bands and as strongly deformed, mildly discordant veins in all other rock types. Within the tonalitic and granodioritic gneisses thin veins of leucotonalite up to 1 or 2 cm thick often outline isoclinal, intrafolial folds. The medium grained (1-2 mm), homogenous leucotonalite veins generally have weakly foliated, allotriomorphic textures and colour indices less than 5. Biotite is the dominant mafic mineral; but hornblende also occurs, principally in leucotonalite associated with amphibolites. Some leucotonalite units have thin, biotite rich borders (melanosome) suggesting an anatectic origin; others are clearly discordant and intrusive.

(g) Pink leuco-granite is a widespread and locally volumetrically important component of the gneissic rocks. Its mode of occurrence ranges from irregular patches through severely deformed lenses and veins to clearly cross cutting dikes. Grain size ranges from aphanitic to pegmatitic and the fabric may be foliated or massive. Clearly, several phases of pink granite development and injection have taken place. The earliest event produced medium grained, 1-3 cm thick, pink granite layers concordant to, and isoclinally folded with, the gneissic compositionally banding. Locally, biotitic melanosomes are marginal to such layers suggesting an anatectic origin. Obviously cross cutting, medium grained to pegmatitic, undeformed dikes are probably the latest event. Between these two extremes a host of variably deformed modes of occurrence are present.

Due to the presence in individual outcrops of several lithologically distinct phases it became necessary, for the purpose of reconnaissance mapping, to divide the gneissic rocks into units defined on the basis of associations of components. These components and associations are listed in Table 4-1. The procedure facilitated the outlining, in reconnaissance fashion, of areas underlain dominantly by specific associations. Local aberrations are present and detailed mapping will modify these associations.

The northern half of the Fleet Lake area is underlain dominantly by rocks of the strongly foliated to gneissic, tonalite-granodiorite category (association A). The rocks are weakly banded and contain only a moderate volume (up to 10%) of mafic enclaves which are generally unbanded amphibolite. In the southern part of the Fleet Lake area the rocks are strongly banded tonalitic and granocioritic gneisses with abundant mafic enclaves (association B). Locally, the banded tonalitic gneiss association (H) or the gneissic amphibolite - gneissic tonalite association (F) becomes dominant.

The Cedar Lake area is underlain by association B. Locally, hornblende-biotite gneisses (association C) and amphibolite form relatively continuous units too small to show at the reconnaissance scale. Gneissic lithologies within the Clay Lake area are distinctly different from those of the rest of the district due to their granulitic nature. Detailed descriptions of gneissic rocks of the Cedar and Clay Lake areas have been presented in Chapter 3.

The Ross Lake area is characterised by alternating bands of associations B and H approximately 2.5 km wide. The repetition of associations in this area suggests the presence of large scale folds with steep plunges but this could not be confirmed during the reconnaissance mapping. Within the areas dominated by association B, a secondary interlayering on a scale of approximately 300-400 metres is also suggested by the reconnaissance mapping. Units of strongly foliated, but weakly banded, gneissic tonalite with few mafic enclaves are apparently interlayered with strongly banded tonalitic and granodioritic gneissis with many mafic enclaves. The relationships between these units could not be established due to a lack of time, but outcrop density is good in this area and detailed mapping could be rewarding.

The Quibel Lake area is underlain dominantly by the banded tonalitic gneiss association (H). At Quibel Lake, in the centre of this area, banded granodioritic and tonalitic gneisses with abundant mafic enclaves (association B) are present. The boundary between the two associations at Quibel Lake is gradational over 50 metres or so.

(v) Granitoid Intrusive rocks

A wide variety of compositionally and morphologically distinctive granitoid intrusive rocks occurs within the district. In the course of reconnaissance mapping an attempt was made to differentiate these rocks using the following criteria: presence or absence of foliation, quality of foliation when present, presence or absence of phenocrysts, grain size, presence or absence of recrystallisation textures, percentage of potassium feldspar, percentage and type of mafic minerals present. It has become clear that these criteria can be used to describe a complete spectrum of granitoid types. The spectrum ranges from moderately foliated, recrystallised, equigranular, medium grained, relatively mafic tonalites to massive, porphyritic, coarse grained, leucocratic granites. In general terms the time relationships indicate a progression from early tonalitic intrusives to late granitic intrusives.

(a) Moderately foliated tonalite-granodiorite

Large bodies of moderately foliated tonalitic rocks occur in the western part of the Fleet Lake area, northeast of the Ross Lake area, in the Mafeking area and northwest of the

Quibel area. The body west of the Fleet Lake area is in fact a complex. The southern part of the body is dominantly a grey, moderately foliated, medium to coarse grained (2-6 mm), somewhat inequigranular tonalite. The rock contains approximately 6% biotite and has been recrystallised with slightly coarser grained plagioclases (4-6 mm) having hazy, irregular margins elongate in the foliation. Small enclaves of foliated but unbanded amphibolite are common and rare enclaves of coarse grained, foliated, hornblende quartz diorite are also present. The latter enclaves presumably come from a thin marginal phase exposed at the eastern extremity of the body.

The northern part of the body is composed of moderately to strongly foliated, equigranular, grey biotite tonalite having a slightly finer grain size (1-3 mm) and containing somewhat more biotite (8-10%). The entire body is laced by a network of thin, generally undeformed, white, leucogranite veins. The northern, biotite tonalite is also cut by a few thin veins (10-20 cm thick) of fine grained, mafic, biotite tonalite which post date coarse grained, zoned granitic pegmatites but predate aplitic granite veins.

A thin, concordant body of moderately foliated tonalite-granodiorite intrudes the southern margin of the English River metasedimentary migmatite complex at Perrault Lake. The body is complex, containing both a moderately foliated, equigranular (1-4 mm) granodiorite with 5% biotite and 12% potassium feldspar and a more strongly foliated, biotite tonalite with up to 12% biotite.

A semi-ellipsoidal body of moderately foliated tonalite-granodiorite occurs at Bowden Lake, between the Clay Lake and Quibel areas. The dominant rock type is a medium grained (1-3 mm) allotriomorphic, moderately foliated, biotite tonalite containing between 7% and 10% biotite. Locally, however, the rock is a granodiorite containing up to 20% potassium feldspar in diffuse layers or somewhat patchy areas. Potassium feldspar varies in grain size from less than 1 mm to approximately 10 mm, the coarser grains having hazy, irregular outlines. The overall texture suggests a metasomatic origin for the potassium feldspar. The tonalitic rocks contain up to 5% enclaves of amphibolite and individual outcrops may contain up to 20% of discordant, pegmatitic granite veins.

The granitoid intrusive body occurring in the north-western portion of the Ross Lake area is poorly defined - both outcrops and data stations are few. At Puzzle Bay on Ord Lake the body is in fact a complex of moderately foliated, medium to coarse grained tonalitic and granodioritic rocks. The dominant rock type is an equigranular, medium grained, biotite tonalite containing up to 10% biotite. Locally the rocks become coarser grained, contain less biotite and occasional microcline megacrysts (up to 1.5 cm) with hazy, irregular outlines are present. Foliated, medium to fine grained, leucocratic, white weathering granite is also present locally. Minor amphibolite enclaves (up to 15%) are always present, as are late, discordant, pink pegmatitic granite veins.

Intrusive granitoid relationships in the Mafeking area are extremely complex. A large, northeasterly trending area is underlain dominantly by moderately foliated, medium grained, (1-3 mm) allotriomorphic, equigranular biotite tonalite, containing up to 10% biotite. Locally the tonalite is strongly foliated with a diffuse, irregular banding defined by alternations of leucotonalite and finer grained, biotite rich (15%) tonalite. In places protoclastic textures were observed. The tonalite may contain between 5% and 10% enclaves of foliated, unbanded mafic amphibolite with irregular leucotonalite veins. Locally, reaction with mafic enclaves has produced a foliated hornblende-biotite quartz diorite. At Rosamund and Rugby Lakes the "background" of moderately to strongly foliated tonalites has been extensively intruded by weakly foliated (locally massive), pinkish weathering, medium to coarse grained, granodiorite. Both of the previous rock types are in turn extensively intruded by massive, coarse grained to pegmatitic pink granite.

(b) Weakly foliated tonalite-granodiorite

Two large elongate bodies of moderately to weakly foliated biotite tonalite-granodiorite occupy the area south of Fleet Lake and extend eastwards into the Perrault Lake area.

The dominant rock type is a grey, medium grained (2-4 mm) equigranular biotite tonalite with a hypidiomorphic to allotriomorphic texture. A weak foliation and/or lineation defined by orientation of biotite and occasionally by elongate quartz is usually present. Biotite contents are in the range 8-10% and potassium feldspar contents range from zero to 10%. Minor amphibolitic enclaves are present and thin, discontinuous biotitic schlieren are common. Gneissic enclaves are abundant at the northern margin of the Fleet Lake body. The grey tonalite-granodiorite has been extensively injected by discordant dikes and veins of massive, medium grained to pegmatitic pink granite.

A large body of tonalite-granodiorite essentially identical to those just described outcrops in the area south of Clay Lake. The contact zone between this body and the moderately to strongly foliated, tonalitic body centred on Bowden Lake is a thin unit of foliated granodiorite to granite. The body is apparently intruded by massive to weakly foliated porphyritic granodiorite. Similar relationships hold true for the foliated, equigranular, biotite tonalite-granodiorite unit situated midway between the Mafeking and Quibel Lake areas.

(c) <u>Pink granite and grey tonalite-granodiorite</u>

Two large bodies of this association are situated northwest and southeast of the Mafeking area. Massive to weakly foliated or lineated, medium to coarse grained (2-10 mm), hypidiomorphic, biotite (9%) granodiorite is usually the most abundant phase. It is always accompanied, and often dominated, by an extensive network of injected, massive, medium grained to pegmatitic pink leucogranite. The medium grained varieties of the pink leucogranite have an allotriomorphic granular fabric and appear to have been mildly recrystallised. Amphibolitic enclaves within the granodiorite constitute 1% to 5% of individual outcrops. The enclaves are frequently elongate parallel to the weak foliation in the host, have maximum dimensions ranging up to 2 metres and contain epidote.

Lithologically and morphologically similar units intrude the more strongly foliated tonalitic rocks of the Mafeking area and also occur adjacent to the English River Subprovince - Wabigoon Subprovince boundary. In the latter situation the intrusive rocks contain enclaves clearly derived from metavolcanic and metasedimentary rocks of the Wabigoon Subprovince.

(d). Porphyritic Granodiorite

Extensive sheet like bodies of porphyritic granodiorite occur throughout the English River plutonic complex. A detailed description of the porphyritic granodiorite from the Cedar - Clay Lakes area has been presented in Chapter 3.

(e) Massive equigranular pink granite

Large, homogenous bodies of equigranular, massive, pink granite are restricted to the northern part of the English River plutonic complex. Three plutons centred on Thaddeus, Ryan and Anishinabi Lakes are interconnected by apophyses extending through Perrault, Aerobus and Wabaskking Lakes. The dominant rock type is a hypidiomorphic-granular, medium grained (1-4mm), unfoliated, pink coloured, leucocratic granite which rarely contains more than 5% mafic minerals (biotite $\pm$ magnetite). Potassium feldspar content very rarely exceeds two thirds of the total feldspar content. Pegmatitic phases are common and weakly foliated varieties are locally but sparsely present. Enclaves of country rock in the interior portions of the plutons are rare but the margins of the plutons are often difficult to define due to an abundance of enclaves.

The pink granites are clearly intrusive into both the gneissic rocks of the English River plutonic complex and the metasediments of the English River metasedimentary migmatite complex. Compositionally and texturally similar rocks are also extensively injected as veins, dikes and sills of the latest phase into all other rock units in both the English River and Wabigoon Subprovince.

(f) Massive porphyritic granite

A large pluton of coarse grained porphyritic granite is centred on Bornite Lake, south of the Anishinabi Lake area. In the centre of the pluton, euhedral microcline megacrysts averaging 2 cm x 4 cm are present in a coarse grained hypidiomorphic groundmass. The megacrysts generally exhibit a marked alignment interpreted as a primary flow texture, and in places constitute as much as 50% of the total rock. The groundmass is generally impoverished in potassic feldspar and has a tonalitic composition. Mineralogical abundances are as follows: quartz 25-40%, plagioclase 15-25%, microcline 35-50%, biotite 5%. Trace amounts of hornblende and magnetite are also present. The margins of the pluton exhibit a weak foliation and the rock tends to lose its porphyritic texture. Coarse grained, subhedral microclines with hazy, irregular margins are set in a coarse grained granodioritic groundmass. Recrystallised, lenticular, discontinuous quartz aggregates are also common in the marginal fabric.

Within the area mapped, the porphyritic granite pluton is entirely surrounded by massive, pink, equigranular granite and the mapped distribution suggests that the former is intrusive into the latter. However, on Aerobus Lake the marginal phase of the porphyritic granite is cut by thin, mildly discordant dikes of equigranular, medium grained, pink granite which suggests reversed age relationships. Discordant, pegmatitic, granite dikes were also noted to be intruding both the marginal and central portions of the porphyritic granite.

On the eastern arm of Wine Lake a narrow dike 10 to 15 metres wide of porphyritic syenite intrudes weakly foliated granodiorite. The syenite contains approximately 65% microcline, as coarse, euhedral, strongly aligned megacrysts up to 9 cm x 1.5 cm in dimension. The megacrysts have medium to fine grained plagioclase rims which comprise approximately 20% of the total rock volume. The matrix (15% by volume) consists of a medium to coarse grained intergrowth of hornblende and biotite with traces of magnetite and quartz. The porphyritic syenite is cut by discordant, fine grained, grey aplitic granite veins 6-15 cm wide which have bleached, white reaction margins 2-3cm wide. The occurrence is unique within the district and presumably is connected in some way with the Bornite Lake porphyritic granite.

4-4. LITHOLOGIES - WABIGOON SUBPROVINCE

(i) Metavolcanic rocks

A broad belt of metavolcanic rocks which are the easterly continuation of the Tustin-Bridges metavolcanic belt (Pryslak 1971) occurs north of Vermilion Bay. The belt is dominated by mafic to intermediate pyroclastic rocks and foliated, mafic volcanic flows, now amphibolitic.

(ii) Metasedimentary rocks

A large area east of Vermilion Bay is underlain by metasedimentary gneisses and migmatites. Metasedimentary lithologies are interdigitated with metavolcanic lithologies along highway 105 immediately north of Vermilion Bay. In many respects the Wabigoon Subprovince metasediments are very similar to the northern, English River metasedimentary migmatites.

The rocks are strongly and continuously banded on scales from 2 cm to several metres. Biotite rich, relatively pelitic, units alternate with semipelitic to psammitic units and produce a morphology similar to that found in greywacke - turbidite units elsewhere in the subprovince. Fabrics suggestive of metamorphically reversed graded bedding are occasionally present but are never sufficiently well preserved to use as facing indicators. Rather lean, magnetite-quartz banded iron formations occur interbanded with garnetiferous metasediments in the Eagle Lake and Eagle River areas. Mafic volcanic rocks are extremely rare and restricted to thin (20-50 cm thick) concordant, medium grained, massive to weakly foliated, mafic amphibolite units that could be originally intrusive sills.

The degree of metamorphism and anatexis of the metasedimentary rocks is very similar to that found in the northern English River metasedimentary migmatites. Typically the metasediments consist of a granoblastic, equigranular (0.1-0.5 mm), foliated intergrowth of biotite, plagioclase (An_{30}) and quartz. Fine to medium grained (1-3 mm), equant, almandine garnets are frequently present and poikiloblastic cordierite crystals (up to 6 mm) are commonly aligned in the foliation. More pelitic units frequently contain thin lensoid aggregates of quartz and plagioclase interpreted to be in situ mobilisate. Microcline is a rare constituent of the metasediments and where present is usually in the form of irregular fine grained patches.

In the Eagle Lake area, southwest of Vermilion Bay and locally in the eastern Oxdrift area metasedimentary migmatites contain a high percentage of granitoid mobilisate. The rocks retain a primary compositional banding which is rendered discontinuous by irregular, anastomosing, sheets of leucotonalite to leucogranite mobilisate. The mobilisate comprises up to 75% of the total volume, is compositionally inhomogeneous, severely inequigranular and has a schlieritic to nebulitic fabric.

(iii) <u>Inhomogeneous leucotonalite and leucogranite</u>

White intrusive rocks varying in composition from leucotonalite to granite are ubiquitous constituents of the metasedimentary migmatites and occur in a variety of forms from thin veins to thicker dikes and sills. Thin, mildly discordant and often strongly deformed veins are most commonly of leucotonalitic composition. The veins rarely constitute more than 10% of an individual outcrop. Thin melanosome margins to the veins are extremely rare. The most common occurrence of leucotonalite - granite is as 1-15 metre wide sills concordant to compositional banding and foliation in the host. The sills are often lithologically and texturally complex and some produce a thin, biotite rich, melanosome zone in the metasedimentary host.

In the Oxdrift area the coalescence of such units with the consequent subjugation of the metasedimentary component produces outcrops with a plutonic igneous appearance. Mapping of these outcrops has outlined a large, irregular complex composed of inhomogeneous white, leucotonalite to leuco-granite. There are two dominant phases within the complex. The most common rock type is a coarse grained to pegmatitic, white, unfoliated leucotonalite to leucogranodiorite. The rock has a markedly inequigranular, seriate texture. It contains coarse grained, subhedral to euhedral, bluish coloured plagioclase accompanied by lesser volumes of quartz and minor microcline, muscovite and biotite. Fine grained, pink garnet and pale blue apatite are consistent accessory minerals. The second most common rock type is a medium grained, massive to weakly foliated, equigranular leucogranite containing approximately equal proportions of quartz, plagioclase and potassic feldspar. Muscovite, apatite, garnet and biotite are common accessory minerals.

Both rock types may contain small enclaves of meta-sedimentary rock which generally exhibit melanosome reaction rims. Locally, thin units of white, equigranular granite contain mafic 'clots' in which cordierite is accompanied by garnet, biotite and quartz. It would seem that these two dominant phases must have been intruded coevally since mutually intrusive relationships may be found throughout the area. The latest granitic phase in the complex consists of pinkish-white coloured, granitic pegmatite veins which locally contain coarse euhedral tourmaline crystals.

It is the opinion of the present author that the Oxdrift leucotonalite-leucogranite complex represents allochthonous, intrusive mobilisate derived from partial anatexis of metasedimentary rocks currently at a deeper level. This opinion is based on the following observations:

(a) white leucotonalite and leucogranite are restricted to an association with metasedimentary rocks and frequently contain schlieritic enclaves of metasediment.

(b) the white leucotonalite and leucogranite display intrusive relationships to adjacent metasediments.

(c) a zone of severely mobilised metasedimentary migmatites is absent from the margins of the complex which suggests that it was not generated in situ.

(iv) <u>Intrusive rocks of the Vermilion Bay Area</u>

Granitoid rocks intruding metavolcanics and metasediments in the Vermilion Bay area range in composition from tonalites to granites. In the southeast of the area metasediments are intruded by a medium to coarse grained, massive to very weakly foliated, grey, hypidiomorphic biotite tonalite. A small pluton of similar rock occurs 4 km WSW of Vermilion Bay. Intrusive rocks due east and due west of Vermilion Bay are weakly foliated, medium grained, biotite tonalites and granodiorites which locally contain abundant metavolcanic and metasedimentary enclaves. South of Vermilion Bay, weakly foliated, medium grained hornblende-biotite tonalites contain small mafic amphibolitic enclaves. All of these units have been intruded by rocks associated with the large, equigranular, massive, pink granite pluton that occupies the southeastern corner of the district. This pluton is texturally and compositionally similar to the Thaddeus Lake and Anishinabi Lake plutons of the English River Subprovince.

4-5 STRUCTURAL GEOLOGY

(i) English River metasedimentary migmatite complex

Only a small part of the total metasedimentary migmatite complex is present within the district examined. Throughout the major part of the area, compositional banding and foliation are coplanar with dominant E-W strikes. The regional orientation of dominant foliation has been deflected in some areas by late granodiorite and granite intrusions.

The earliest structures (F_a1) recognised in the area were probably produced by a strong layer-normal compression. This event postdated the intrusion of originally discordant, leucotonalite veins which are now deformed into "ptygmatic" folds (Plate 4-2). The folds probably originated as simple buckle folds and were subsequently flattened to produce the present class 1C to class 2 geometry (Ramsay 1967, p.366). The development of a foliation, which is generally parallel to compositional banding, in the metasedimentary rocks can be inferred to have occurred during this event. Thin, concordant amphibolite units and concordant leucotonalite veins were also boudinaged at this time. Tight to isoclinal folds in primary compositional layering, which one might expect to be associated with this early event are extremely rare (Plate 4-7).

Subsequent folding events have produced tight to close folds in compositional layering and foliation. These folds have been separated into two groups based on fold style and presence or absence of associated axial planar foliation. It must be emphasised that the temporal relationship of these fold groups has not been established.

F_a2 folds are generally assymetric, tight to close folds with interlimb angles varying between 25^o and 70^o (Plate 4-8). The folds are commonly disharmonic, have upright axial planes and fold axes plunging at shallow angles to the west. Fold geometry is generally class 1C and there is usually an axial planar foliation developed. The F_a2 foliation can only be distinguished from the F_a1 foliation in hinge regions of F_a2 folds - elsewhere the two foliations are subparallel to compositional banding.

Thin, leucocratic, granitoid mobilisate veins are frequently emplaced parallel to axial planes of the F_a2 folds. F_a2 folds clearly postdate F_a1 folds (Plate 4-9). Rare, discordant, mafic amphibolite dykes which appear to postdate the F_a1 event are disharmonically folded by the F_a2 event. It is possible that the F_a2 folds predate or are synchronous with the development of major inhomogeneous leucotonalite - leucogranite bodies. Enclaves of metasedimentary gneiss in these bodies are frequently deformed by tight F_a2 folds. Compositional layering and foliation at the margins of the bodies are severely and disharmonically contorted; reflecting the highly mobile state of the migmatites.

F_a3 folds are relatively concentric (Class 1B-1C), close to open folds with interlimb angles between 60^o and 110^o. The folds have upright, NW-SE axial planes with steeply plunging fold axes and are apparently restricted to those areas where the dominant foliation and banding has a NE-SE orientation. Locally, kink like folds with patchy veins of granitoid pegmatite parallel to their axial planes are associated with F_a3 folds (Plate 4-10). It seems likely that F_a3 folds predate or are associated with the intrusion of pink granite and grey granodiorite bodies.

(ii) English River Plutonic Complex

Within the English River plutonic complex the dominant E-W structural trend of the English River Subprovince is strongly distorted by intrusive granitoid plutons. In general terms the overall arrangement of lithologic units has a broadly WSW-ENE trend. In the Cedar and Clay Lakes areas this trend is disrupted by large, elliptical, domal structures in the gneissic rocks.

The earliest visible structures (F_b1) within the gneissic rocks are intrafolial, rootless, class 3 folds generally outlined by thin leucotonalite veins. These folds are contained within a heterolithologic compositional banding. The compositional banding is itself deformed by tight to isoclinal, similar (class 2) folds with axial planes parallel to gneissosity (F_b2). The event which produced the F_b2 folds has therefore most probably transposed a pre-existing compositional banding. Amphibolitic enclaves which may represent original dikes have been tightly folded and severely boudinaged during this event. The formation of these F_b2 folds was succeeded by intense layer-normal compression causing internal boudinage and normal kinking in the gneissic layering (F_b3 structures).

The formation of the major domal structures in the Cedar – Clay Lakes areas appears to have been at least partially coeval with intrusion of large, sheet-like bodies of porphyritic granodiorite. Minor structures probably associated with the doming event include relatively close folds with class 1C morphology (F_b4) and two groups of upright, open to close, class 1B minor folds having mutually perpendicular axial planes (F_b5, F_b7). The latter folds locally deform porphyritic granodiorite and pink granite dykes and sills associated with the major late tectonic intrusions. The relative intensity of these two fold groups varies throughout the Cedar and Clay Lakes areas and they may well have been produced during a single deformational episode.

(iii) Wabigoon Subprovince

With the exception of the area south and west of Vermilion Bay, lithological units in the Wabigoon Subprovince have dominantly east-west trends and vertical or near vertical dips. The metavolcanic and metasedimentary rocks have been moderately flattened with the development of a strong foliation in most lithologies. In several cases it can be demonstrated that the only foliation present in the rocks is discordant to compositional banding.

In places, internal folding of originally mildly discordant leucotonalite veins has produced tight folds in the veins with axial planes subparallel to compositional layering, without significantly disrupting the layering itself. Elsewhere, early deformation of thicker leucotonalite units has produced tight folds in the adjacent compositional banding

(F_c1). Such early folds invariably have steeply plunging fold axes contained in the steeply dipping foliation.

A later set of asymmetric, class 1C, tight to close, upright folds with variably plunging fold axes (F_c2) deform the early foliation, compositional banding and early granitoid mobilisate in the metasediments. The latest folding event (F_c3) produced upright, open, class 1B folds with subhorizontal axes and relatively large wavelengths in the order of 15 metres.

(iv) The Wabigoon-English River Subprovince boundary

The boundary between the metavolcanic and metasedimentary rocks of the Wabigoon Subprovince and gneissic rocks of the English River Subprovince is almost totally obscured by later phases of granitic intrusion. In the section along highway 105, 3-4 km north of Vermilion Bay, the metavolcanic rocks are separated from gneissic rocks by a zone of granitic intrusion 300-400 metres wide.

As the border is approached the metavolcanic rocks become more severely foliated and rapidly increasing strain is recorded by agglomeratic units and pillowed flows. Volcanic pillows, 1500 ft south of the boundary, have major axis ratios in horizontal section on the order of 12:1 and similar ratios in vertical section. Coarse fragment agglomerates, 1300 ft from the boundary, contain early leucotonalite veins which were originally perpendicular to present foliation. The veins have been buckled quite severely and indicate shortening perpendicular to foliation in the order of 75%. Coarse felsic fragments in the agglomerates have been flattened and currently have principal axis ratios of approximately 10:10:1 (Plate 4-6). These rocks have therefore undergone an oblate, flattening type of strain. Mafic amphibolites, 400 ft from the boundary, contain what appear to be extremely flattened pillow forms. The presumed pillows have axial ratios in horizontal section on the order of 200:1. Coarse garnets in the presumed pillow selvages have also been flattened to strongly oblate ellipsoids (Plate 4-11).

Outcrops immediately north of the intrusive pink granite zone consist of severely foliated and banded hornblende-biotite tonalitic and granodioritic gneisses. Gneissosity and contained isoclinal folds are locally distorted by concordantly bounded, steeply dipping, zones of simple shear which record a left lateral displacement.

The evidence suggests, therefore, that the boundary between metavolcanic rocks and gneissic rocks in this area was originally a fault zone which currently has a subvertical orientation. The fault zone has served as a locus for preferred intrusion of the later granite bodies.

(v) Correlation of deformational events

Numerous, small scale, early isoclinal folds (F_b1, F_b2) deform compositional banding of granitoid gneisses in the English River plutonic complex. The formation of these folds was succeeded by an intense flattening event which produced internal boudinage and normal kinking (F_b3) of the transposed gneissosity. The earliest recognisable folds (F_a1) in the metasedimentary migmatites are invariably present in originally discordant veins. The formation of these folds was apparently accompanied by intense flattening - without appreciable minor folding - of the compositional banding.

It seems reasonable to postulate, therefore, that the F_b3 structures in the granitoid gneisses and the F_a1 structures in the metasedimentary migmatites were formed during the same deformation event (D3). If such is the case, the granitoid gneisses record a structural history (F_b1 - D1; F_b2 - D2) which predates that of the metasedimentary migmatites. It is possible therefore that the granitoid gneisses represent a sialic basement on which the protolith of the metasedimentary migmatites was deposited.

In the Mystery and Twilight domes of the Cedar - Clay Lakes area, however, metasedimentary migmatites are structurally overlain by granitoid gneisses. In order to explain this structural anomaly, it has been suggested (Chapter 3) that the early flattening event (D3) recorded by the metasedimentary migmatites, was accompanied either by major recumbent folding or by large scale sub-horizontal thrusting.

Subsequent folding events which produced the F_a2 and F_a3 structures in the metasedimentary migmatites and the late domal structures in the granitoid gneisses may also be correlatable (D4, D5). These structures were most probably associated with intrusion of the late tectonic granitoid plutons.

4-6 METAMORPHISM

(i) English River Metasedimentary Migmatite complex

Metamorphic conditions within the complex have exceeded those required to produce widespread partial anatexis of the metasediments. The evidence in favour of an anatectic origin for the widespread granitoid "mobilisate" portion of the migmatites has been presented in section 4-3(i). The compositional variability of the mobilisate most probably reflects local variations in protolith composition. Microcline is notably concentrated in the mobilisate and is rarely present in quantities exceeding 2% in the non-mobilisate portion (restite?). Coarse primary muscovite is also locally present in the mobilisate but is absent from the non-mobilisate portion (except as a retrograde phase). Irregular mafic clots containing biotite, quartz, garnet and/or cordierite are frequently present in the mobilisate. These clots are most probably a refractory residue from the anatexis of the paragneisses as was suggested by Morin and Turnock (1975) for the Perrault Falls clotty granite.

Within the metasedimentary component of the complex, pink almandine garnet occurs both as small, equant grains and as coarse porphyroblasts containing abundant quartz inclusions. Cordierite is frequently associated with garnet and occurs as ragged, poikiloblastic crystals aligned parallel to the dominant foliation. Fibrous sillimanite was recorded in a couple of outcrops but was only present in one thin section studied.

Texturally stable mineral assemblages developed during the main metamorphic event in the metasediments include: (fig. 4-2)

Biotite + garnet

Biotite + cordierite

Biotite + cordierite + garnet ∓ microcline

Quartz and plagioclase (An_{27-31}) are always present

The single example of sillimanite noted in thin section occurs as a coarsely crystalline inclusion within a large cordierite poikiloblast. The hand sample also contains minor almandine garnet which unfortunately is absent from the thin section. The two phase system sillimanite - cordierite can probably be considered to be stable but it cannot be texturally proven that the assemblage biotite + garnet + cordierite + sillimanite was stable.

The distribution of muscovite, microcline and sillimanite is considered to be significant. Bulk chemical composition of the rocks may be a controlling factor on the prominence of these mineral phases but the absence of chemical analyses prevents an assessment of this effect. Pelitic compositions are certainly not abundant, however, because Al_2SiO_5 mineral phases are very rare.

Harris (1976) reports muscovite bearing assemblages in paragneisses from the Eastern Lac Seul region which can be traced into prograde muscovite-free assemblages containing sillimanite. Harris ascribes the disappearance of muscovite to the reaction:

Muscovite + Quartz = Sillimanite + Microcline + H_2O .....(a)

Within the present district the absence of muscovite and paucity of sillimanite in non-mobilisate portions and the preferential occurrence of microcline in granitoid mobilisate may be better explained if muscovite breakdown occurred by the following reaction:

Muscovite + Quartz + Plagioclase + Microcline + H_2O
= liquid ....(b)

The equilibrium conditions for reaction (b) are, within the limits of experimental accuracy, the same as those for the beginning of melting in the system albite + microcline + quartz + H_2O (Tuttle and Bowen 1958, Merrill et al 1970). Reaction (b) implies water pressures greater than 3.5 kb and temperatures greater than 625°C (fig. 4-3).

The relative abundances of almandine and cordierite are almost certainly controlled by bulk rock composition. However, the coexistence of almandine and cordierite with quartz and locally with sillimanite may be significant. Hensen and

Green (1971, 1972, 1973) and Currie (1971) have experimentally investigated the reactions

Cordierite = Almandine + Sillimanite + Quartz

Cordierite + Biotite = Almandine + Microcline + H_2O

Winkler (1974) has used this data to outline the P-T fields of the coexistence of cordierite + almandine + sillimanite + quartz for various FeO/FeO + MgO ratios of bulk rock composition. Chemical analyses of rocks from the present district are not available. However, similar rocks from the Armstrong district of the English River Subprovince have FeO/FeO + MgO ratios in the range 0.55 to 0.65 (Data supplied by F.W. Breaks, Ontario Division of Mines). Assuming, therefore, an FeO/FeO + MgO ratio of 0.6 for rocks in the present district; temperatures in the range 650°-750° and assuming the validity of Winkler's diagram, the mineral assemblages suggest pressures in the range 4.5 kb to 6.5 kb.

The major metamorphic event appears to have coincided with the initial structural event (Fa1 structures) to produce a foliation defined by strongly oriented biotite and lenticular quartz grains.

The temporal relationships between structural events and the leucogranitoid portion of the complex is not fully understood. Some leucotonalite veins which were originally discordant have been severely deformed by the F_a1 structures. In contrast, concordant pegmatitic mobilisate is generally unfoliated. Examples have been observed however, of concordant pegmatitic mobilisate which is deformed by F_a2 folds which, in turn, have leucotonalite veins parallel to the axial plane. Enclaves of metasedimentary gneiss within the major diatexite bodies (inhomogeneous leucotonalite-leucogranite) frequently have been deformed by F_a2 folds.

The conflicting field evidence suggest that more than one period of mobilisate generation occurred. There may have been a diachronous relationship between anatexis and certain structural events - particularly the F_a2 structures.

Minor retrograde chlorite and muscovite are present in most samples and cordierite is frequently strongly pinnitised. Limited evidence suggests that the retrogression was synchronous with development of F_a2 structures. In one section studied, the early foliation - defined by parallel alignment of biotite, quartz and cordierite - has been deformed by small scale folds probably associated with F_a2 structures. On the limbs of these folds strongly pinnitised cordierite poikiloblasts form irregular augen shaped masses with blurred edges. In the cores of the folds cordierite is less deformed and less severely pinnitised.

Large lensoid areas exceeding 1 km long and several tens of metres wide within the metasedimentary migmatite complex have been mapped as probable intermediate tuffs and mafic volcanic rocks. Samples of fine grained material from these units have equigranular amoeboid textures consisting of quartz, plagioclase and chlorite with muscovite or epidote. The exact field relationships between these units and the surrounding metasedimentary migmatites have not been established. It is possible however that these units may represent selective metamorphic regression.

(ii) English River Plutonic Complex

Gneissic rocks of the complex do not, in general, have compositions suitable for the formation of critical metamorphic grade indicator minerals. The granitoid gneisses generally contain assemblages consisting of quartz + plagioclase + biotite ± microcline ± hornblende. Muscovite is absent (except as a retrograde mineral) and microcline is abundant. There is also an abundance of leucogranitoid phases which in many cases may have anatectic origins. Associated amphibolitic enclaves generally contain hornblende and plagioclase (An_{33-40}) with minor diopside and occasionally contain biotite, quartz and epidote. These factors suggest that the gneissic rocks have undergone at least one period of medium to high grade metamorphism.

Orthopyroxene and garnet are present in a wide variety of rock types throughout the Clay Lake area. Cordierite is not present in this area. The assemblages recorded are diagnostic of the regional hypersthene zone (granulite grade) of high grade metamorphism (Chapter 3 section 5). This metamorphic event is believed to have occurred simultaneously with the deformational event which produced F_b3 structures.

A widespread, but relatively mild, retrogressive metamorphic event is also recorded in the gneissic rocks. In the Clay Lake area this event produced an extensive serpentinous alteration of orthopyroxene and minor chloritic alteration of biotite and garnet. Elsewhere, sericitisation of plagioclase and growth of secondary muscovite, locally accompanied by epidote, is widespread. This event is believed to be related to intrusion of late granitic plutons. Amphibolitic enclaves within the plutons may contain randomly oriented diopside crystals.

(iii) Wabigoon Subprovince

The main metamorphic event within the Wabigoon Subprovince coincided with and probably outlasted the early deformational event. The major foliation in metasedimentary gneisses is defined by parallel orientation of biotite and by elongation of quartz. In the Highway 105 area and throughout a large area west of Oxdrift the metasedimentary gneisses contain cordierite and minor garnet. Cordierite poikiloblasts are generally aligned parallel to the foliation and may contain irregular inclusions of quartz and lesser biotite. Minor traces of fibrolitic sillimanite intergrown with biotite were observed replacing the inner portions of cordierite porphyroblasts in only one thin section studied. Garnet generally occurs as small equant grains distributed throughout the rock. It often occurs as small inclusions within plagioclase and was found as an inclusion in cordierite in one sample.

The following texturally stable assemblages were observed in the metasedimentary gneisses:

quartz + plagioclase + biotite + cordierite

quartz + plagioclase + biotite + garnet

quartz + plagioclase + biotite + garnet + cordierite

Plagioclase compositions range from An_{27} to An_{38} with a distinct modal maximum at An_{32}. Leucotonalitic mobilisate phases may contain coarse cordierite. Granitic mobilisate phases containing mafic clots of garnet, biotite and quartz are also present. Retrogressive effects are generally mild in the metasedimentary gneisses, involving pinnitisation of cordierite and chloritisation of biotite.

Within the Tustin-Bridges metavolcanic belt, intermediate tuffs contain quartz, plagioclase (An_{24}), biotite and hornblende. Minor quantities of chlorite, muscovite, epidote and carbonate also occur. The latter minerals cannot always be assigned with any certainty to retrogressive events. Mafic amphibolites close to the northern margin of the belt, near Wildrice Lake, contain coarse porphyroblasts of pink garnet in a foliated plagioclase and hornblende bearing groundmass with minor quartz and magnetite. The plagioclase composition could not be determined with any accuracy due to lack of well developed twinning. Refractive indices greater than quartz and positive biaxial optic figures with very high 2V suggest the plagioclase is within the andesine range. Jones (1973) reports plagioclase compositions of An_{38} from metavolcanic rocks of the Tustin-Bridges belt exposed along highway 105.

The above assemblages and the presence of mobilisate phases in the metasedimentary gneisses indicate that the major metamorphic event attained conditions equivalent to those of cordierite-almandine high grade metamorphism (Winkler 1974). These conditions are similar to those determined to exist during metamorphism of the English River metasedimentary migmatite complex.

Table 4-1

Gneissic rocks - components

(a) Amphibolite

(b) Mafic hornblende-biotite gneiss

(c) Biotite - hornblende quartz diorite

(d) Tonalitic and granodioritic gneiss

(e) Foliated to gneissic tonalite and granodiorite

(f) Leucotonalite

(g) Leucogranite

Gneissic rocks - associations

Association A........components (d) ± (a)

Association B........components (d) + (a) ± (c) ± (b)

Association C........components (b) ± (a)

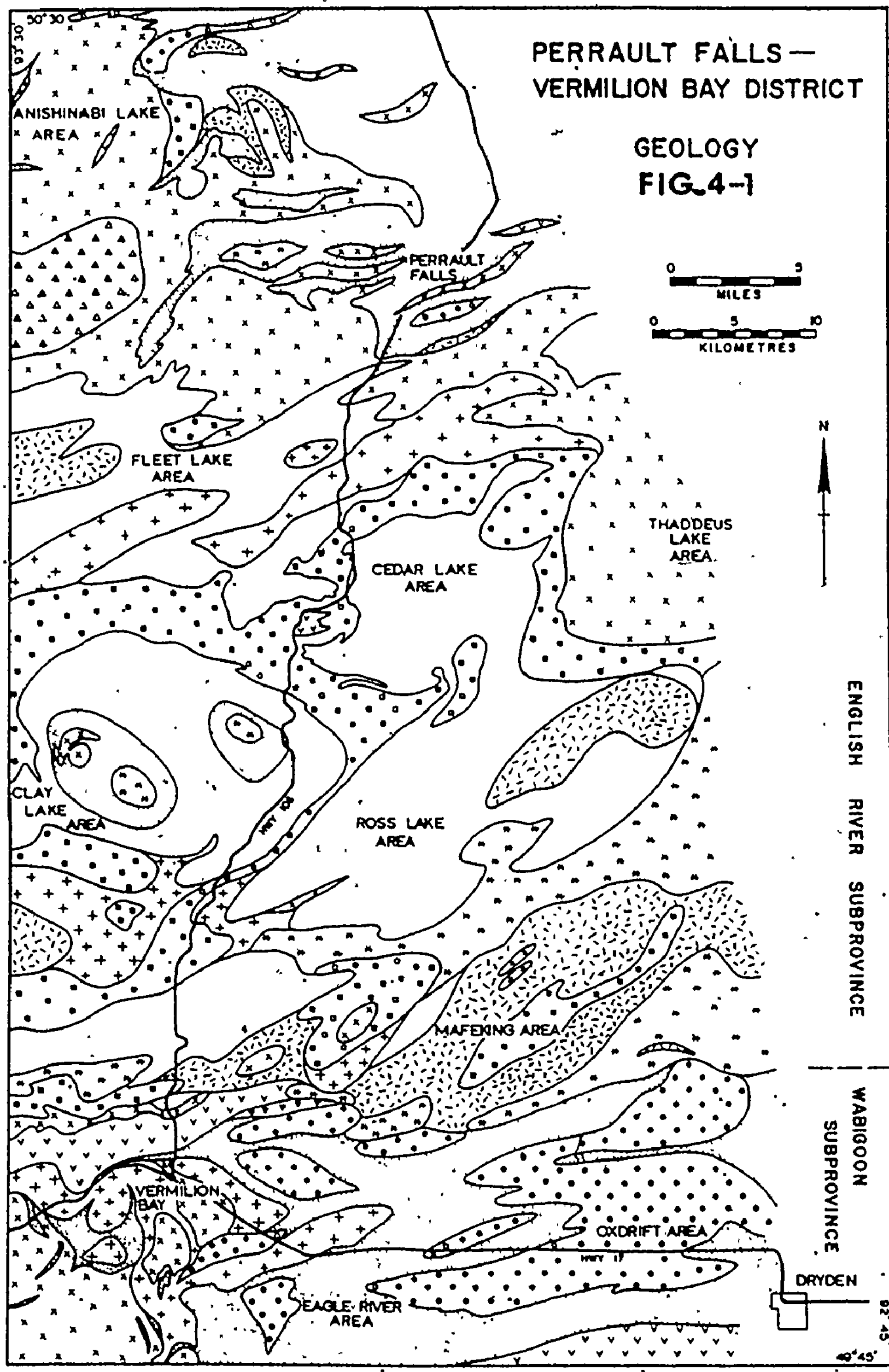
Association F........components (a) ± (b) + (e)

Association G........components (e) ± (a)

Association H........components Tonalitic equivalent of (d) + essential (f), minor (g)

Association K........components (a) + (b) ± (e)

all associations contain variable proportions of components (f) and (g)



PERRAULT FALLS — VERMILION BAY DISTRICT

GEOLOGY

FIG. 4-1

MASSIVE TO WEAKLY FOLIATED INTRUSIVE ROCKS

- PORPHYRITIC GRANITE
- EQUIGRANULAR PINK GRANITE
- GRANODIORITE WITH MICROCLINE MEGACRYSTS
- EQUIGRANULAR TONALITE–GRANODIORITE
- PINK GRANITE AND GREY TONALITE–GRANODIORITE

MODERATELY FOLIATED INTRUSIVE ROCKS

- GRANODIORITE WITH MICROCLINE MEGACRYSTS
- EQUIGRANULAR TONALITE–GRANODIORITE

- INHOMOGENOUS WHITE LEUCOTONALITE–GRANITE
- METAGRAYWACKE AND METASEDIMENTARY GNEISS
- MAFIC–INTERMEDIATE METAVOLCANIC ROCKS
- INTERMEDIATE–FELSIC METAVOLCANIC ROCKS

- TONALITIC–GRANODIORITIC GNEISSIC ROCKS

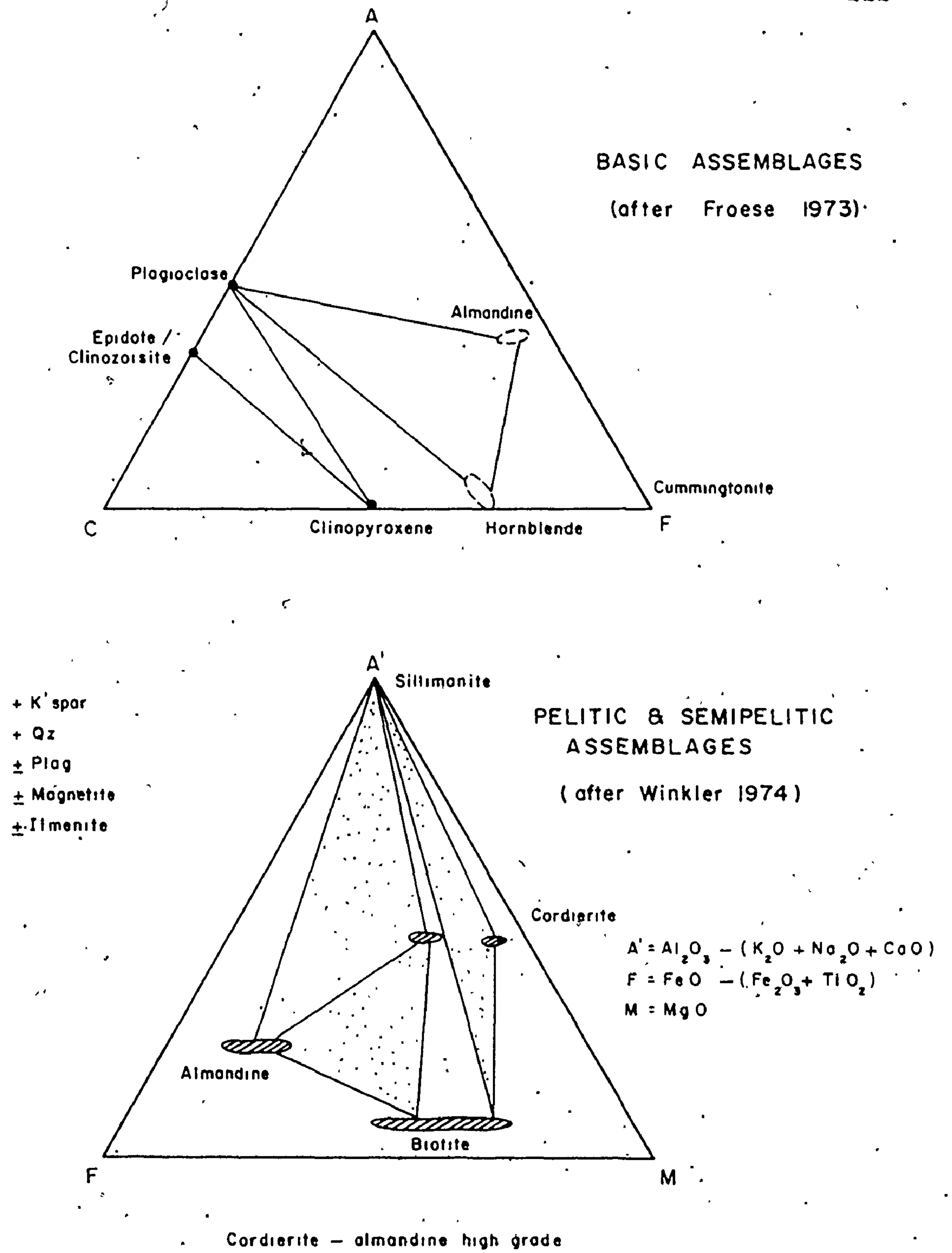


Figure 4-2 Mineral Assemblages Of High Grade Metamorphism (Amphibolite Facies)

Figure 4-3 P,T grid of metamorphic mineral reactions

Quartz is a possible phase in all assemblages

1. Qz + Plag + Ksp + Vap = Liq Tuttle and Bowen 1958
2. Qz + Musc + Plag + Ksp + Vap = Liq Winkler 1974
3. Qz + Musc = Ksp + Sill + Vap Althaus et al 1970
4. Qz + Plag + Musc = Ksp + Sill + Vap Grant 1973
5. Qz + Plag + Musc + Vap = Sill + Liq Storre and Karotke 1972
6. Plag + Sill + Bi + Qz + Vap = Cord + Ga + Liq Grant 1973
7. Qz + Plag + Bi + Ga + Vap = Cord + Opx + Liq Grant 1973

   possible P,T equivalent to

   Qz + Bi = Opx + Ga + Ksp + Vap Winkler 1967, 1974
8. Field of coexisting Ga + Cord + Sill + Qz for bulk rock

   compositions FeO/FeO + MgO = 0.6 Winkler 1974

   controlled by the reaction

   Cord = Ga + Sill + Qz
9. Plag + Bi + Ga = Ksp + Cord + Opx + Liq Grant 1973

A = Al_2SiO_5
B = Biotite
C = Cordierite
G = Garnet
K = K. feldspar
L = Liquid
M = Muscovite
P = Plagioclase
V = Vapour

facing page 223

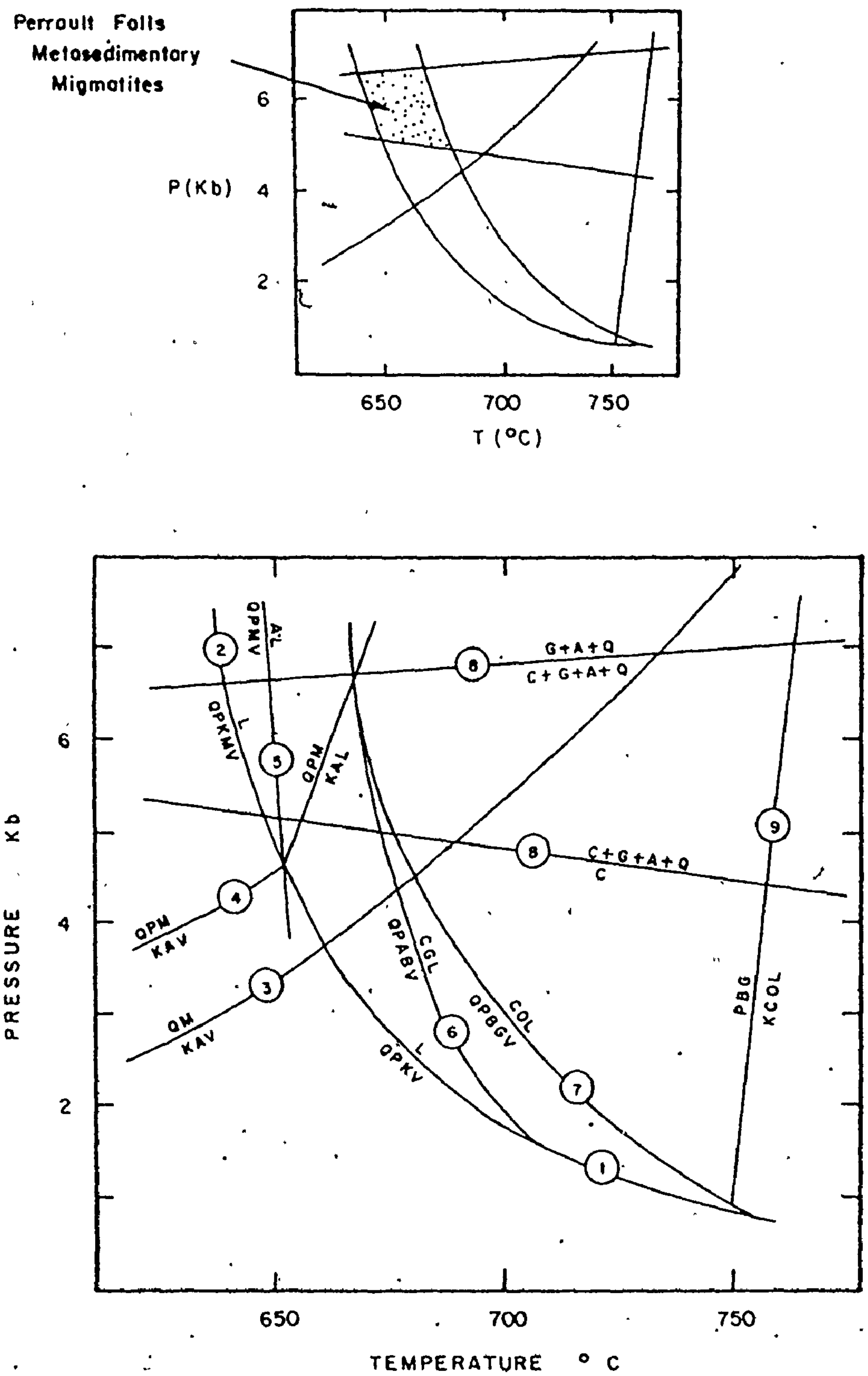

Perroult Falls
Metasedimentary
Migmatites
P(Kb)
T (°C)
PRESSURE Kb
TEMPERATURE °C
G+A+Q
C+G+A+Q
C+G+A+Q
C
QPM
KAV
QM
KAV
QPM
KAL
QPKMV
L
QPMV
AL
QPABV
CGL
QPBGV
COL
QPKV
L
PBG
KCOL

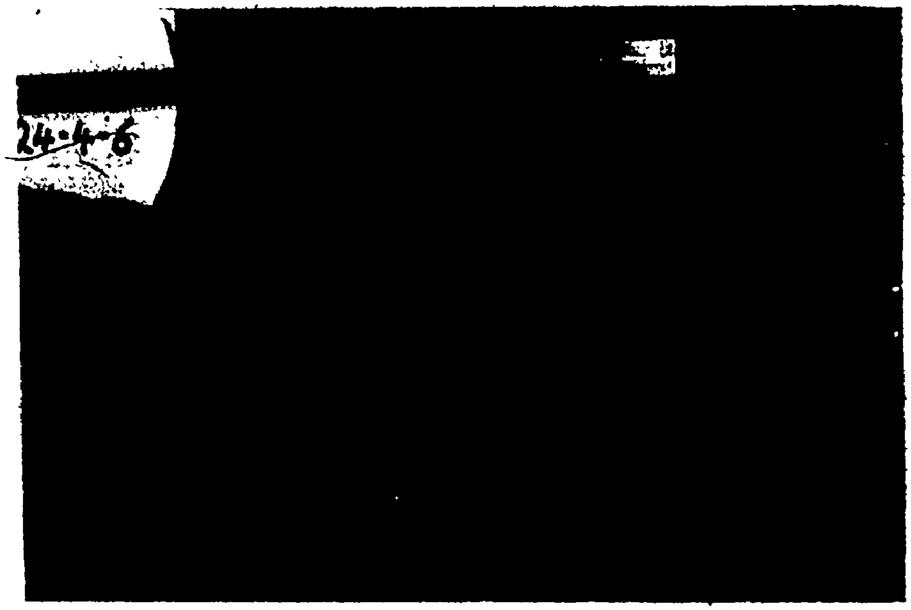
Figure 4-3

Plate 4-1 Reacted and unreacted compositional banding in a metasedimentary migmatite. Note the injected granitic leucosome which contains garnet and cordierite megacrysts. Reacted bands contain garnet and cordierite. Wabaskang Lake

Plate 4-2 Ptygmatic leucotonalite veins in a weakly reacted metasedimentary migmatite. North of Perrault Falls

Plate 4-3 Schlieritic, inhomogeneous leuco-tonalite-leucogranite (Diatexite) Wabaskang Lake

Plate 4-4 Deformed metaconglomerate, Perrault Lake. Dark clasts are amphibolite, lighter clasts are foliated biotite tonalite and foliated leucotonalite. Note the absence of gneissic clasts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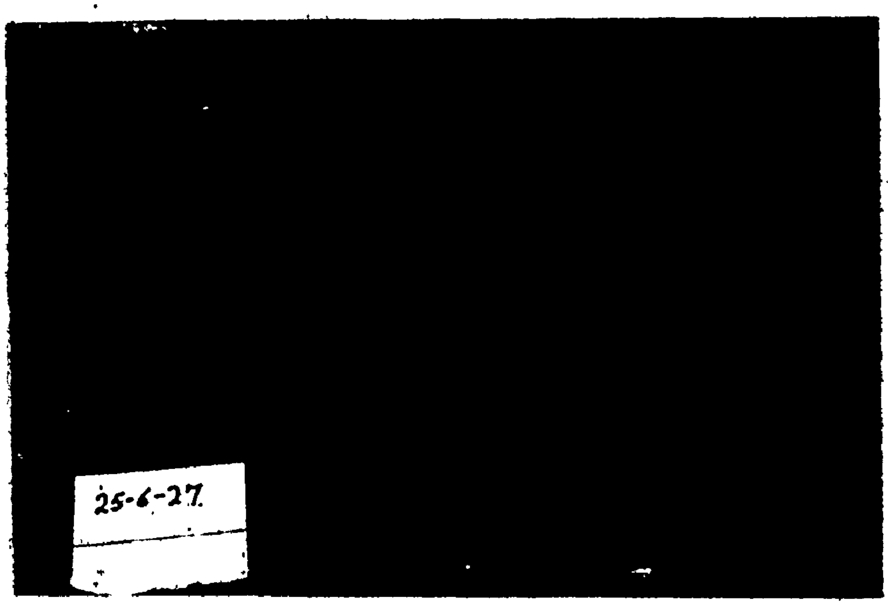
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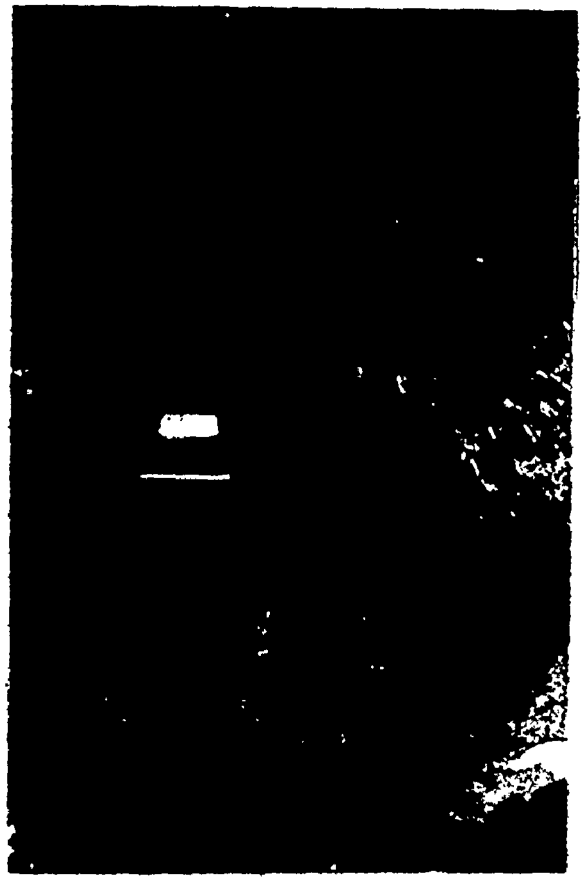
Plate 4-5 Pillow-form amphibolite from the southern margin of the English River Metasedimentary Migmatite Complex - McLeod Bay, Wabaskang Lake

Plate 4-6 Flattened, intermediate agglomerate from the northern margin of the Tustin-Bridges metavolcanic belt, Wabigoon Subprovince. Outcrop on Highway 105, 3.5 km north of Vermilion Bay



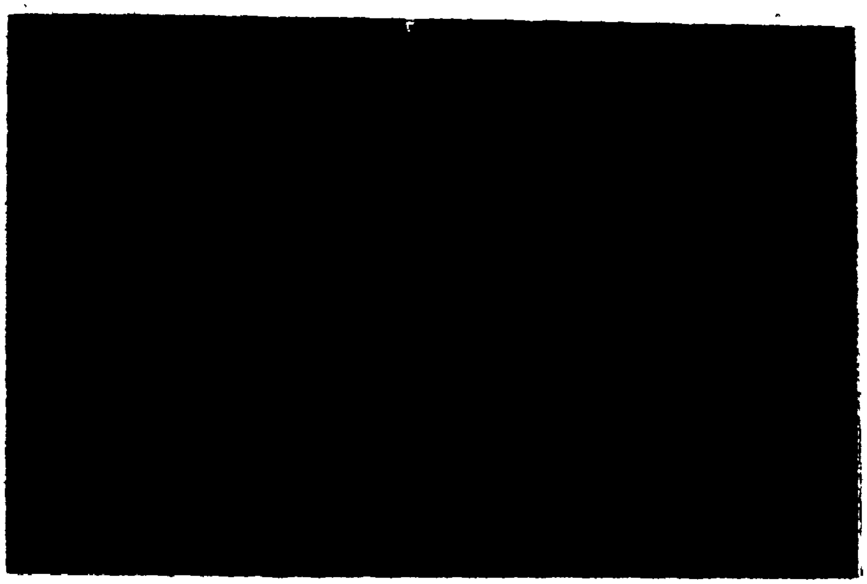


Plate 4-7 Isoclinal F_a1 fold in compositional banding of a garnetiferous metasedimentary migmatite, Wabaskang Lake

Plate 4-8 F_a2 folds deforming compositional banding in a metasedimentary migmatite, 16 Km north of Perrault Falls

Plate 4-9 Tight F_a1 fold in compositional banding of a metasedimentary migmatite refolded by a more open F_a2 fold. Wabaskang Lake

Plate 4-10 Kink like F_a3 folds in metasedimentary migmatite with pink granitic pegmatite segregations parallel to the axial planes. Wabaskang Lake

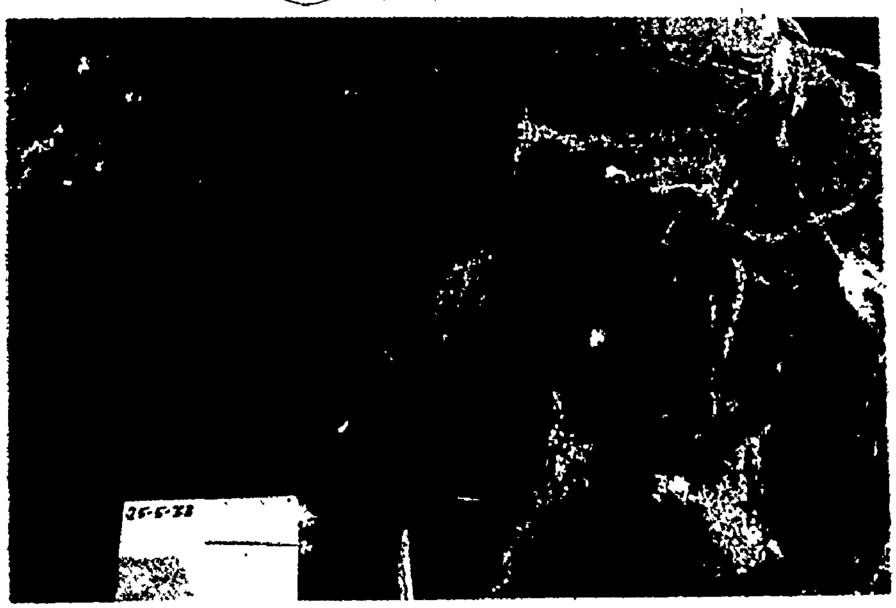
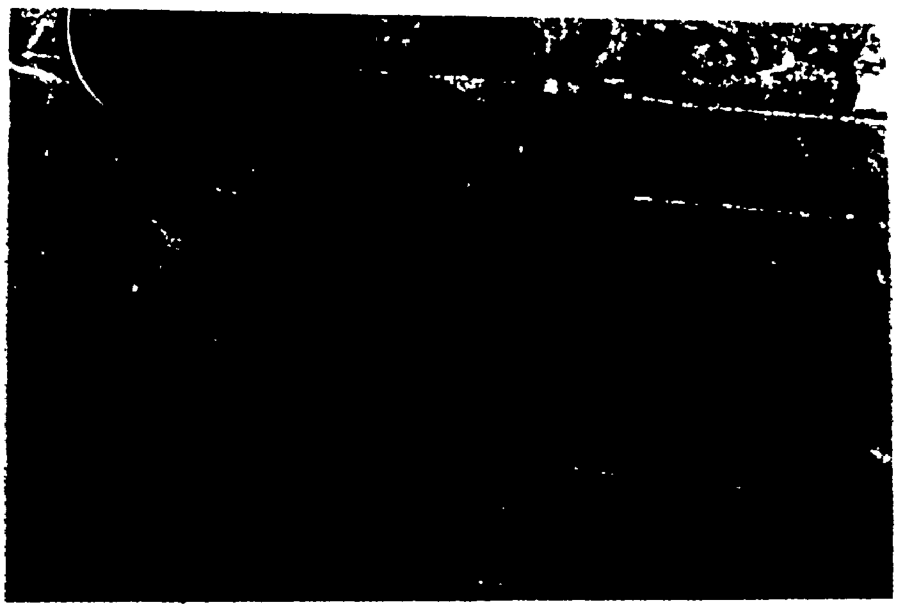


Plate 4-11 Flattened garnets in pillow selvages of a mafic volcanic sequence. Tustin-Bridges metavolcanic belt, Wabigoon Subprovince. Less than 0.5 km from the Wabigoon Subprovince - English River Subprovince boundary. 4 km north of Vermilion Bay, on Highway 105.



CHAPTER 5

TECTONIC EVOLUTION OF THE ENGLISH RIVER SUBPROVINCE

Compilation of data from the current research program and from Operation Kenora - Ear Falls (Fig. 5-1) permits the construction of a proposed tectonic evolution for the English River subprovince. It is quite clear that at least three, tectonically distinctive, assemblages of rocks outcrop within the boundaries of the English River Subprovince.

Severely deformed granitoid gneisses (tectonic assemblage I) are exposed in the southern parts of the subprovince and in the east this assemblage extends well into the central parts of the subprovince. These gneisses are considered to be the oldest tectonic assemblage present. Tectonic assemblage II, composed of supracrustal metasedimentary migmatites and minor metavolcanic rocks, occupies a 20-30 km wide zone in the north of the subprovince. Evidence suggests that this assemblage was deposited on, or adjacent to, a sialic basement composed of assemblage I. Tectonic assemblage III consists of granitoid plutonic rocks varying in composition from quartz diorite to granite which clearly intrude and hence postdate both of the previous assemblages. The granitoid plutons are concentrated towards the central axis of the English River subprovince, but are by no means restricted to this area.

Granitoid gneisses of tectonic assemblage I are considered to be the oldest rocks present in the subprovince. This conclusion is based dominantly on detailed work in the Cedar-Clay Lakes area where the assemblage has suffered a complex deformational history predating deposition of the protolith of the Twilight gneisses. The granitoid gneisses were most probably derived from early intrusive granitoid plutons. The presence of amphibolite enclaves within the gneisses suggests the presence also of an early supracrustal volcanic assemblage which was deformed along with the gneisses during the D2 event in the Cedar-Clay Lake area. Similar suggestions concerning the relationship between granitoid and amphibolitic gneisses of the Kenora district have also been made by Gower (pers. com, 1975).

Severely foliated to gneissic tonalites and granodiorites also belonging to tectonic assemblage I may represent an early period of intrusion into the granitoid gneisses at some time postdating D2. In the Cedar-Clay Lake area, the gneissic tonalites and granodiorites (Clay Lake suite) are clearly younger than the granitoid gneisses (Cedar Lake gneisses). Elsewhere, however, the relationship is less clear and is the subject of some controversy amongst current workers.

Krogh et al (1975) have obtained a probable U/Pb zircon age of 3043 $\pm$ 35 m.y. from rocks of tectonic assemblage I outcropping in the Eastern Lac Seul area. It is still not clear, however, whether this sample is representative of the granitoid gneiss subgroup or the gneissic tonalite-granodiorite subgroup.

Mafic to intermediate metavolcanic rocks of tectonic assemblage II form a thin, highly discontinuous unit at the southern margin of the English River metasedimentary migmatite complex. The metavolcanic unit may be traced in discontinuous selvages from Perrault Lake, through Wabaskang, Anishinabi, Oak and Separation Lakes into the Bird River greenstone belt in Manitoba. Metasedimentary migmatites of tectonic assemblage II outcrop north of the metavolcanic belt and the two rock groups are separated locally by an orthoconglomerate (Perrault Lake, Oak Lake, Booster Lake and Ryerson Lake). The conglomerate contains both foliated metavolcanic fragments and foliated tonalite fragments and is hence most probably a basal facies of the metasediments (Definitive evidence for the facing direction of these sequences has not been reported).

Van de Kamp (pers. comm. 1974) and Beakhouse (1974b) have suggested that the metasedimentary migmatites of the Ear Falls area were derived and rapidly deposited from a predominantly volcanic terrain. Similar conclusions have been reached in regard to the Twilight gneisses of the Cedar-Clay Lakes area. The most logical provenance areas for the material which formed the English River metasedimentary migmatites are the volcanic terrains of the Rice Lake greenstone belt and the Uchi subprovince. The volcanic rocks of these terrains may thus be coeval with or slightly older than the English River metasedimentary migmatites. A more sialic, and perhaps local, provenance area is indicated by basal orthoconglomerate and siliceous metasedimentary units in the Perrault Falls area. The lack of granitoid gneiss clasts in the Perrault Falls conglomerate is puzzling. It indicates, perhaps, that the local provenance area was dominated by intrusive granitoid bodies similar to the protolith envisaged for the Clay Lake granitoid suite.

The regular and consistent compositional layering and local presence of poorly preserved graded bedding suggest that the English River metasedimentary migmatites of greywacke bulk composition were deposited as turbidites. Further evidence of the depositional environment of this assemblage is lacking due to the obliterating effects of the later, high grade, metamorphism. The exact age of tectonic assemblage II is unknown at present. It must, however, be greater than 2.7 b.y. which is the approximate age of the major metamorphic event in the Manigotagan gneiss belt (Krough et al 1975).

If the proposed correlations between the Twilight gneiss and the northern, English river metasedimentary migmatites are correct, the earliest deformation recorded in the northern area must be coeval with the D3 event recorded from the Cedar-Clay Lakes area. This event was apparently dominated everywhere by an intense flattening normal to compositional layering and the production of a strong foliation. Examples of folds affecting compositional layering which may be correlated with this event are, however, extremely rare. In the Cedar-Clay Lakes area the D3 deformation was apparently responsible for subhorizontal interleaving of cover (Twilight gneiss) and basement (Cedar Lake gneiss) assemblages.

The third tectonic assemblage present in the English River subprovince consists entirely of intrusive granitoid plutons which clearly postdate assemblage I and II. This assemblage may in fact be divided into as many as three sub-assemblages based on the degree of foliation and metamorphic recrystallisation. In very general terms it would appear that there was a progressive sequence of intrusions starting with more basic compositions and ending with acidic, potash rich plutons.

Relatively mafic, foliated, hornblende quartz diorite plutons in the Kenora district probably predate intrusion of the Dalles foliated-biotite-tonalite/granodiorite pluton (Gower pers. comm. 1975). In the Mafeking area, moderately foliated biotite tonalites and granodiorites are intruded by massive to weakly-foliated biotite granodiorite. The large pluton of massive, porphyritic granodiorite which forms the central axis of the English River plutonic complex post-dates foliated biotite tonalites but is intruded by equigranular pink granite. Similar age relationships hold for the large pluton of weakly foliated to massive porphyritic granite which occupies the area between Oak and Bornite Lakes. Massive, equigranular pink granite forms bodies of all sizes ranging from major plutons to small dikes and is obviously the latest phase of granitic activity recorded in the subprovince.

The sequence of granitoid intrusion described above is extremely generalised and may well be a gross oversimplification. It is clear, for instance, that massive, unrecrystallised granodiorite bodies are locally present, as are foliated, recrystallised pink granite bodies. There may therefore be included within tectonic assemblage III several cycles of granitoid intrusion whose composition varied both in space and time.

The exact age relationships between granitoid intrusion, deformation and metamorphism are also unclear. In the Cedar-Clay Lakes area, granitoid intrusions of tectonic assemblage III obviously post-date the D3/M3 dynamothermal event. They appear, however, to be intimately associated with the later structural events, including development of domal structures in the country rocks. A tentative correlation may be made between development of these structures and that of the two later groups of structures recognised in the Perrault Falls - Wabaskang Lake area of the English River metasedimentary migmatite complex.

It is suggested, therefore, that there was an early phase of tectonic activity controlled by subhorizontal movements (D3) and a later phase (or phases) controlled by vertical, diapiric emplacement of granitoid plutons. The time interval separating these phases - in terms of absolute years - may not have been very great. A major metamorphic event in the Manigotagan gneiss belt and the metasedimentary migmatites of the eastern Lac Seul area has been dated by U/Pb zircon at 2680-2690 m.y (Krogh et al 1974, 1975). Reported Rb/Sr ages of granitoid intrusions of tectonic assemblage III from Manitoba range from 2610 m.y. to 2735 m.y. (fig.2-6). The rather high errors quoted for these ages make them virtually inseparable, but it is probable that intrusive activity occurred over a time interval of at least 175 m.y. and may have been episodic.

It appears, therefore, that a sialic nucleus did exist within the English River subprovince prior to 3.0 b.y. ago. This nucleus consisted dominantly of granitoid gneiss and lesser intrusive granitoid plutons with remnants of an early, volcanogenic supracrustal assemblage.

A major supracrustal depositary developed along the northern flanks of the English River sialic nucleus 3.0 b.y. - 2.75 b.y ago. This depositary received detritus from two flanking volcanic belts which imparted a rough bilateral symmetry to the system. Relatively little detritus was derived from the sialic nucleus but it must have been at least locally emergent. The northern volcanic chain (Rich Lake-Uchi

Lake greenstones) was volumetrically dominant. The southern volcanic chain (Bird River-Separation Lake greenstones) may originally have been discontinuous and particularly so towards the east.

Temporal relationships between supracrustal rocks of the Uchi and English River subprovinces and those of the Wabigoon subprovince are uncertain. Both, however, predate intrusive granitoid plutons of tectonic assemblage III and postdate granitoid gneisses of tectonic assemblage I. They could thus be regarded as broadly coeval. However, the time span separating tectonic assemblages I and III must be at least 250-300 m.y.; which is more than adequate for the development of sequential, rather than coeval, volcano-sedimentary sequences.

The major deformational event postdating deposition of the supracrustal assemblages in the English River subprovince was accompanied by (and outlasted by) a major thermal event. This deformation produced subhorizontal interleaving of gneissic basement and supracrustal rocks in the Cedar-Clay Lakes area. The event was responsible for severe flattening in the English River metasedimentary migmatite complex and the production of local isoclinal folds. The original orientation of these folds was probably approximately E-W but the attitude of their axial planes is unknown. The major thermal event caused metamorphism with grades increasing towards the axis of the English River plutonic complex. Granulitic assemblages were developed in the Cedar-Clay Lakes area during this event.

Subsequent deformational events were probably coeval with, and controlled by, emplacement of granitoid plutons. Major faulting at the southern boundary of the English River subprovince partly predated this emplacement and partly was coeval with it. Major faulting at the northern boundary of the subprovince postdated the intrusive event. It is possible therefore that faulting and/or intrusion were diachronous across the subprovince. It is probable that granitoid intrusion occurred over a time interval of some 130 m.y. If the major faulting events in the north and south were coeval it would imply that granitic intrusive activity became progressively younger towards the south. Published Rb/Sr ages - taken uncritically - tend to support such a hypothesis

5-2 Suggestions for future research

Since the basic geological and tectonic framework of the English River subprovince is now well documented several important, unsolved problems can be approached logically and systematically. Many of these problems are concerned with the age and origin of the granitoid rocks of tectonic assemblages I and III. The problems should be tackled with a combination of limited, detailed mapping followed by detailed study of trace element and isotopic geochemistry.

A large part of the Ross Lake area may prove to be suitable for a detailed study of tectonic assemblage I. Within this area, excellent exposures and access produced by recent logging operations contain rocks believed to be equivalents of both the Cedar Lake gneisses and the Clay Lake granitoid suite. The excellent exposures here would permit far more detailed mapping than was possible inthe Cedar-Clay Lakes area immediately to the west. Furthermore, the gneissic rocks of the Ross Lake area experienced only amphibolite facies metamorphism whilst those of the Clay Lake area were undergoing the granulite facies event. U/Pb zircon and Rb/Sr geochronology may be useful here in determining the time of initial emplacement and that of the subsequent metamorphism of the Clay Lake suite equivalents. If the Clay Lake suite equivalents yield ages c.a. 3.0 b.y. - as suspected - it is possible that even older ages may be preserved in the gneisses considered to be equivalents of the Cedar Lake gneisses.

Granitoid intrusions of tectonic assemblage III present two intriguing research possibilities. The first is strictly geochronologic - does the assemblage represent several "pulses" of intrusion - or was intrusion continuous over a long time interval? The second problem concerns the ultimate origin of the granitoid intrusions. Field evidence suggests that some of these were derived from supracrustal units of tectonic assemblage II - the "diatexites" of Breaks et al (1974,1975) and the "inhomogeneous leucotonalite - leucogranite" of this thesis. The origin of the remainder of the tectonic assemblage III intrusions - dominantly those within the English River plutonic complex - is thus far unknown. Detailed geochemical studies - particularly of trace element and rare earth contents - may indicate a specific source. If that source involves pre-existing supracrustal rocks it could have profound implications in the choice between "plate tectonic" and fixist" models for Archean tectonic evolution.

Figure 5-1

GEOLOGY

OPERATION KENORA - EAR FALLS

LEGEND

1. Mafic volcanics
2. Intermediate to felsic volcanics
3. a. Metasediment
   b. Metatexite: metasedimentary migmatite
   c. Diatexite: inhomogenous leucotonalite - leucogranite
4. Tonalitic - granodioritic gneiss
5. a. Metagabbro
   b. Foliated diorite, quartz diorite
6. a.* Strongly foliated to gneissic tonalite - granodiorite
   b. Moderately foliated tonalite - granodiorite
   c. Weakly foliated tonalite - granodiorite
   d. Weakly foliated porphyritic granodiorite
   e. Weakly foliated porphyritic granite
   f. Foliated granite
7. Massive diorite - quartz diorite
8. a. Massive tonalite - granodiorite
   b. Massive porphyritic granodiorite
   c. Massive porphyritic granite
   d. Massive equigranular leucogranite
   e. Clotty granite

Tectonic Assemblage I - units 4, 6a

Tectonic Assemblage II - units 1,2,3a,3b

Tectonic Assemblage III - units 3c,5,6b-6f,7,8

* May be in part equivalent to 4

Compiled from Ontario Division of Mines, Geological Series Preliminary Maps P1026-P1031 (1975) and P1199-P1204 (1976)

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Appendix 1 - Analytical Methods

(a) Modal analysis

Modal analyses for samples with grain size less than 3.0 mm were determined by point counting a single thin section using a mechanical stage with 1.0 mm spacing interval. 500 points were counted on each section. The procedure for rocks with grain size greater than 3.0 mm was slightly more complex. The samples were slabbed, etched with hydroflouric acid and stained with sodium cobaltinitrite. This stain is specific for potassium but the combined etching and staining procedure permits rapid differentiation of quartz, plagioclase and K feldspar. It is also possible - with practice - to distinguish biotite from amphibole since the biotite stains a dark yellowish green colour. Colour transparency photographs of the stained slabs were projected onto a screen with a square grid and point counting proceeded as normal. Using this method it is possible to count 500 points per sample with a count interval of approximately 3-5 mm. Accessory minerals were estimated from thin sections and combined with the slab modes.

(b) Major element analysis

Analyses for the major element oxides SiO_2, Al_2O_3, TiO_2, Total Fe as Fe_2O_3, MnO, MgO, CaO, Na_2O, K_2O and P_2O_5 were obtained by X.R.F. techniques. Unweathered rock samples amounting to approximately 2 Kg were crushed to coarse fragment size in a mechanical jaw crusher. The sample was passed through a sample splitter until approximately 100 gms remained (coarse split) and this material ground to less than 200 mesh in a carbon-tungstide shatterbox (fine split). Rock powder pellets were prepared by mixing 3 drops of 2% Mowiol binding solution (Mowiol N30-98 Hoechst Chemicals) with 5.5 gms of dried rock powder. The powder mix was placed in a die and pressed lightly into pellet shape. Approximately 6 gms of boric acid powder were added to the die and the pellet was formed by applying 10 tons per sq. in. for 60 secs. Fusion powder pellets were prepared using a mixture of 4 gms lithium tetraborate and 2 gms of rock powder. The mixture was placed in a carbon crucible and fused at 1100°C for 30 minutes. The resulting glass bead was cooled, ground to less than 200 mesh and powder pellets prepared as before. Estimates of the analytical precision are presented in table A1-1. For the fusion method, the estimates are based on analyses of 6 replicate pellets made from a single fine split of a single sample. Estimates of precision for the powder method have been presented by Marchand (1976) (Appendix C, p.111-114).

Initially, all analyses were performed on the rock powder pellets using the multi-standard procedure of Brown, Hughes and Esson (1973). This method produces acceptable results for granitoid rocks containing less than 1.75% MgO.

(see table A1-2). The method fails, however, to deal with the problem of secondary fluourescence of Mg caused by $Al_{K\alpha}$, which may produce gross errors in the MgO analysis of a sample containing more than 1.75% MgO (see Gunn, 1974, for a discussion of this problem). Consequently, all samples with indicated MgO contents greater than 1.75% were reanalysed by the fusion precedure.

At the time that fusion analysis was initiated at McMaster University, reliable standards with compositions in the range 60% to 65% SiO_2 and 1.5% to 4.0% MgO were not available. It was necessary, therefore, to prepare synthetic standards with a suitable composition range. To this end, three synthetic standards (Table A1-3) were prepared by accurately weighing mixtures of four reliable standards whose compositions are quoted by Abbey (1975). This procedure is far from ideal, but various lines of evidence suggest that the prepared synthetic standard are reliable. By taking one of the prepared mixtures (Mix-B) as a standard and analysing the other two as unknowns, it can be demonstrated that the three prepared mixtures are internally consistent (Table A1-4). Moreover, analyses of GSP-1 and SY-2 (run as unknowns) using MIX-B as a standard, yield results (Table A1-5) which are in excellent agreement with values quoted by Abbey (1975). The analysed values for SiO_2 in GSP-1 are consistently low by approximately 1%. The discrepancy may indicate that this particular GSP-1 pellet is not truly representative. The results are, however, well within the precision estimates of the fusion pellet method.

Operating conditions and parameters used for XRF major element analyses are quoted in table A1-6. Computation of final results from raw data, for the powder method, was performed using the computer program XRFMAJ modified from Brown, Hughes and Esson (1973) by M. Marchand (McMaster University). Computations for the fusion method were carried out by programs WESLIM and MASABS modified by the present author from programs PRELIM and MASABS which were originally supplied to McMaster University by B.M. Gunn (The University of Montreal).

The analyses of samples from the Cedar Lake - Clay Lake area quoted in Appendix 2, are accompanied by a symbol indicating whether the powder or fusion method was used. In general, granitoid samples containing greater than 67% SiO_2 and less than 1.75% MgO have been analysed by the powder method. The standards used for these analyses were: T-1, A, GSP-1, G-2, GA, JG-1, NIMG and GH (values quoted in Abbey 1975). Granitoid samples with MgO contents in excess of 1.75% (as indicated by the powder method) were analysed by the fusion method using MIX-B as a standard. Amphibolite samples were analysed by the fusion method using W-1 as a standard. Reliability of the amphibolite analyses can be judged from table A1-7, which presents replicate analyses of JB-1 run as unknown.

(c) Trace element analysis - Rb and Sr

Elemental concentrations of Rb (ppm), Sr (ppm) and ratios of Rb/Sr were determined on pressed powder pellets by XRF techniques. The procedures used and estimates of precision and accuracy are quoted by M. Marchand (Geol. Dept. McMaster University, Tech. Memo 73-2). The techniques are essentially modifications of those of Powell et al (1969) and Doering (1968).

In view of the crushing and sample preparation procedures used by the present author, estimates of precision quoted by Marchand cannot be applied directly to the present analyses. Consequently, two samples were selected for replicate analyses. Sample A containing approximately 400 ppm Sr and 70 ppm Rb; and sample B containing approximately 100 ppm Sr and 10 ppm Rb. Ten replicate pellets from 10 individual coarse splits and ten replicate pellets from a single fine split were prepared for each sample. Results of these replicate analyses are presented in table A1-8.

Replicate samples from a fine split yield better precision and fine grinding of the whole sample prior to splitting is recommended if high precision is desired. The precision estimates obtained through the use of a coarse split are well within the limits required in the present work.

(d) Trace element analysis - Ba and Ce

Elemental concentrations of Barium and Cerium were determined by an XRF technique developed at McMaster University by the present author. The prime objective of the technique was a semi-quantitative analysis for Barium; Cerium concentrations were obtained as a by-product of the technique.

Analysis for Barium was performed using the BaL_{β_1} line which is overlapped by the CeL_{α_1} line. As a consequence the measured BaL_{β_1} net intensity data must be corrected by an amount proportional to the contribution, at this wavelength, of CeL_{α_1}. This contribution was estimated by measuring the net intensity of the CeL_{β_1} radiation and multiplying this intensity by a factor proportional to the theoretical intensity ratio of $CeL_{\alpha_1}/CeL_{\beta_1}$. The CeL_{α_1} contribution was then subtracted from the BaL_{β_1} intensity. This initially corrected intensity was then subjected to a mass absorption correction which was calculated from the known major element composition of each sample

The six standard rocks - NIMN, W-1, NIML, BCR-1, AGV, G-2 - were then used to calculate a least squares linear regression function of intensity (mass absorption corrected) vs concentration for both Ba and Ce. Calculated linear correlation coefficients for Ce analysis average .9978 (σ = .0006) and for Ba analysis average .9996 (σ = .0002).

The method also provides a further estimate of the linear correlation in that, following calculation of the linear function, the standard intensities are used to calculate indicated standard concentrations. These values for 7 independent analysis batches are presented in table A1-9. An estimate of the accuracy of the method may be obtained from table A1-10, where analyses of standard rocks which were not used to calculate the linear correlation (i.e. run as unknowns) are reported. At the very worst, the Ba analyses are considered to be accurate to $\pm$ 10% whilst precision at the 1200 ppm level is in the order of 1.5% (1 standard deviation), (Table A1-11). Accuracy of the Ce analyses cannot be adequately assessed and the method is considered, by the present author, to be semi-quantitative at best.

Calculations of concentration from raw intensity data were carried out by the computer program BACEPPM written by the present author.

Table A1-1

Precision - X.R.F. Fusion Method

6 replicate pellets

Oxide	$\bar{x}$	σ	ε%
SiO_2	59.83	0.32	0.53
Al_2O_3	14.55	0.10	0.68
TiO_2	0.53	0.006	1.13
Fe_2O_3(TOT)	6.15	0.12	1.95
MnO	0.12	0.004	3.30
MgO	4.78	0.07	1.46
CaO	6.39	0.08	1.25
Na_2O	3.75	0.08	2.13
K_2O	2.05	0.06	2.90
P_2O_5	0.16	0.008	4.90

Table A1-2

X.R.F. - Powder Method

G-2 run as unknown

Sample	1	2	3	Abbey 1975
SiO_2	69.31	69.36	69.67	69.19
Al_2O_3	15.59	15.61	15.24	15.35
TiO_2	.45	.45	.45	0.50
Fe_2O_3(TOT)	2.46	2.43	2.42	2.67
MnO	.03	.03	.03	.04
MgO	.81	.79	.81	0.77
CaO	1.94	1.95	1.96	1.98
Na_2O	4.10	4.06	4.13	4.06
K_2O	4.57	4.57	4.57	4.52
P_2O_5	.13	.13	.12	.14
TOTAL	99.38	99.38	99.39	99.22

TABLE A1-3

X.R.F. FUSION METHOD

CALCULATED COMPOSITIONS
MIX STANDARDS*

	MIX-A	MIX-B	MIX-C
	50% NIMN 50% NIMG	50% NIMN 50% JG-1	50% JB-1 50% JG-1
SiO_2	64.19	62.48	62.46
Al_2O_3	14.30	15.35	14.45
TiO_2	.15	.23	.81
Fe_2O_3(T)	5.46	5.58	5.67
MnO	.10	.12	.11
MgO	3.81	4.15	4.26
CaO	6.12	6.83	5.74
Na_2O	2.92	2.93	3.11
K_2O	2.65	2.11	2.70
P_2O_5	.03	.14	.18
TOTAL	99.71	99.90	99.47

*Data from Abbey (1975)

TABLE A1-4

X.R.F. FUSION METHOD

	MIX A UNKNOWN (MIX B STANDARD)				MIX C UNKNOWN (MIX B STANDARD)	
	1	2	3	4	1	2
SiO_2	64.15	63.72	63.92	64.08	62.53	62.35
Al_2O_3	14.38	14.40	14.41	14.38	14.44	14.50
TiO_2	.15	.15	.15	.15	.77	.78
Fe_2O_3(T)	5.51	5.46	5.54	5.55	5.52	5.56
MnO	.10	.10	.10	.10	.11	.11
MgO	3.69	3.71	3.73	3.72	4.16	4.18
CaO	6.16	6.20	6.17	6.17	5.76	5.75
Na_2O	3.05	2.95	2.96	2.88	3.15	3.10
K_2O	2.59	2.58	2.60	2.59	2.69	2.70
P_2O_5	.08	.11	.07	.10	.29	.29
TOTAL	99.85	99.38	99.65	99.72	99.40	99.30

Table A1-5

X.R.F. Fusion Method

Sample	SY-2 unknown - Mix B standard 1	2	3	4	Abbey 1975	GSP-1 unknown - Mix B standard 1	2	3	Abbey 1975
SiO_2	59.68	59.64	59.81	59.97	60.07	66.11	66.16	65.98	67.31
Al_2O_3	12.13	12.18	12.18	12.10	12.15	15.00	15.17	15.07	15.19
TiO_2	.15	.15	.16	.16	.15	.66	.65	.66	.66
Fe_2O_3(TOT)	6.18	6.16	6.28	6.25	6.32	4.31	4.31	4.41	4.33
MnO	.26	.26	.26	.26	.32	.06	.06	.06	.04
MgO	2.72	2.66	2.65	2.71	2.66	.97	.98	.99	.96
CaO	7.86	7.85	7.80	7.79	8.03	2.15	2.12	2.10	2.02
Na_2O	4.40	4.47	4.35	4.31	4.37	2.89	2.85	2.76	2.80
K_2O	4.36	4.33	4.37	4.35	4.52	5.27	5.30	5.36	5.53
P_2O_5	.71	.71	.67	.68	.44	.38	.38	.36	.28
TOTAL	98.45	98.40	98.52	98.57	99.03	97.80	97.99	97.76	99.12

Table A1-6

X.R.F. Operating Conditions

(i) Major elements - 50 kv, 50 Ma, Cr radiation

Elements Si, Al, Mg, Na, K, P - K_α line, TLAP Crystal

Elements Ti, Fe, Mn - K_α line, LIF200 Crystal

Elements Ca - K_{β_1} line, LIF200 Crystal

(2) Rb, Sr - 60 kv, 30 Ma, Mo radiation, LIF200 crystal

(3) Ba, Ce - 50 kv, 30 Ma, Mo radiation, LIF200 crystal

All analyses performed in vacuum using pulse height discrimination. Flow counter used for Ba, Ce and major element analyses. Scintillation counter used for Rb, Sr analyses.

Table A1-7

X.R.F. Fusion Method

JB-1 unknown - W.1 standard

Sample	1	2	3	Abbey 1975
SiO_2	52.58	52.91	52.59	52.49
Al_2O_3	14.63	14.63	14.63	14.66
TiO_2	1.30	1.29	1.29	1.37
Fe_2O_3(TOT)	9.13	9.17	9.17	9.08
MnO	.16	.16	.16	.16
MgO	8.05	7.93	7.82	7.80
CaO	9.48	9.42	9.41	9.31
Na_2O	2.65	2.70	2.62	2.80
K_2O	1.40	1.40	1.40	1.42
P_2O_5	.20	.21	.21	.26
TOTAL	99.58	99.81	99.29	99.35

Table A1-8

Precision: Rb ppm, Sr ppm, Rb/Sr

Sample	Element	$\bar{X}$	σ	ε%
10 Pellets made from a single fine split				
A	Sr ppm	305.8	0.5	0.15
B	Sr ppm	102.5	0.5	0.49
A	Rb ppm	69.5	0.6	0.88
B	Rb ppm	9.9	0.4	3.82
A	Rb/Sr	.2243	.0029	1.32
B	Rb/Sr	.0814	.0038	4.60
10 Pellets made from 10 coarse splits				
A	Sr ppm	305.9	1.9	0.63
B	Sr ppm	103.0	1.7	1.60
A	Rb ppm	69.2	1.5	2.13
B	Rb ppm	9.5	1.1	11.30
A	Rb/Sr	.2231	.0052	2.33
B	Rb/Sr	.0771	.0102	13.20

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TABLE A1-9

Standard	Indicated concentrations Ba ppm							$\bar{x}$	σ	ε%	Abbey 1975
NIMN	112	93	100	91	98	91	91	97	7.7	8.0	110
W-1	164	165	153	163	162	158	155	160	4.7	1.8	160
NIML	485	466	467	478	464	493	475	475	10.8	2.3	450
BCR-1	637	684	686	679	686	659	690	674	19.4	2.9	680
AGV	1185	1189	1193	1183	1188	1201	1195	1190	6.2	0.5	1200
G-2	1867	1851	1849	1856	1853	1848	1845	1852	7.2	0.4	1850

Standard	Indicated concentrations Ce ppm							$\bar{x}$	σ	ε%	Abbey 1975
NIMN	13	6	6	4	2	5	7	6	3.4	55.	15
W-1	26	23	24	24	26	24	24	24	1.1	4.5	23
BCR-1	51	57	57	56	61	62	56	57	3.6	6.3	54
AGV	71	71	69	73	71	71	73	71	1.4	2.0	63
G-2	154	164	167	167	162	156	156	161	5.5	3.4	150
NIML	285	279	278	277	279	282	283	280	2.9	1.0	280

TABLE A1-10

Standards run as unknowns

Barium analyses (ppm)

Standard	Analysed			Abbey 1975
NIMS	2466	2472		2400
BR	1065	1119	1096	1050
GA	821	805		850
DRN	378	379		380
NIMG	190	173		210

Cerium analyses (ppm)

Standard	Analysed			Abbey 1975
NIMS	13	13		12
BR	140	154	154	?
GA	68	71		?
DRN	46	45		?
NIMG	210	193		200

TABLE A1-11

Standard GSP run as unknown - 8 analyses

	$\bar{x}$	σ	$\varepsilon\%$	Abbey 1975
Barium (ppm)	1297	16	1.2	1300
Cerium (ppm)	313	10	3.4	390

Appendix 2

Chemical Analyses. Cedar - Clay Lakes Area

Cliff Lake Intrusion - Group A

Sample	100	106	131	135	214	215	300	340	341	342
SiO_2	62.86	70.67	71.45	70.05	70.99	71.03	69.98	69.43	70.42	74.10
Al_2O_3	17.48	15.18	14.74	16.34	15.21	15.22	15.82	17.27	15.97	14.05
TiO_2	.45	.22	.33	.18	.29	.22	.33	.22	.23	.05
Fe_2O_3 (TOT)	3.93	2.26	2.61	1.05	2.31	2.14	2.42	1.59	1.84	.85
MnO	.05	.04	.03	.02	.04	.04	.03	.03	.04	.02
MgO	1.51	.95	1.02	.68	1.05	.87	.99	.91	.97	.29
CaO	4.44	3.31	3.45	2.69	3.15	2.72	3.68	3.34	3.04	1.17
Na_2O	4.43	4.45	4.13	4.26	4.41	4.16	4.51	4.79	4.68	3.48
K_2O	1.84	2.09	1.40	3.95	1.75	2.83	1.40	1.71	2.11	5.46
P_2O_5	.37	.09	.08	.12	.09	.08	.09	.12	.10	.02
Total	97.36	99.25	99.25	99.34	99.27	99.29	99.24	99.41	99.41	99.50
Rb	65	54	40	65	64	86	45	48	58	111
Sr	536	607	513	954	593	515	660	721	582	460
Ba	926	1039	373	1849	424	1383	680	433	893	1934
Ce	38	31	20	46	41	19	36	34	44	30
K/Rb	238	329	297	510	232	278	264	298	304	413
K/Ba	17	17	32	18	35	17	18	33	20	24
Ca/Sr	61	40	49	20	39	38	41	34	38	18
Rb/Sr	.122	.089	.078	.068	.108	.166	.069	.066	.099	.240
K_2O/Na_2O	.42	.47	.39	.93	.40	.68	.31	.36	.45	1.57
MLI	7.3	9.9	9.3	11.9	9.7	11.0	8.9	9.3	10.0	15.2
DF	+4.04	+3.37	+2.27	+4.54	+2.84	+3.05	+3.33	+4.21	+3.75	+2.97
Method	F	P	P	P	P	P	P	P	P	P

Major Element Analyses P= Powder Method, F= Fusion Method

Appendix 2

Chemical Analyses. Cedar - Clay Lakes Area

	Cliff Lake - Group A				Cliff Lake - Group B				
Sample	343	345	346	429	76	81	200	201	323
SiO_2	71.56	71.63	69.96	73.40	67.91	68.50	75.15	68.25	74.32
Al_2O_3	15.12	15.34	15.76	15.24	15.63	15.25	13.04	15.17	13.58
TiO_2	.07	.06	.27	.06	.58	.59	.23	.58	.21
Fe_2O_3(TOT)	1.06	.85	2.31	.52	4.00	4.09	1.63	4.51	1.60
MnO	.01	.01	.05	.01	.06	.06	.02	.06	.02
MgO	.20	.28	1.02	.36	1.52	1.26	.45	1.25	.46
CaO	1.13	1.35	3.30	1.68	3.77	3.12	1.88	3.48	1.92
Na_2O	3.42	3.71	4.65	4.36	4.19	3.99	3.24	4.13	3.46
K_2O	6.74	6.15	1.95	3.87	1.46	2.37	3.79	1.72	3.82
P_2O_5	.06	.03	.13	.03	.20	.18	.04	.19	.06
Total	99.39	99.42	99.38	99.54	99.32	99.41	99.48	99.36	99.45
Rb	140	154	53	72	58	77	96	66	93
Sr	488	479	591	461	204	181	167	212	151
Ba	1904	1675	976	1012	315	715	1001	401	833
Ce	21	30	33	14	101	138	135	105	51
K/Rb	402	333	306	447	210	256	332	218	343
K/Ba	30	31	17	32	39	28	32	36	38
Ca/Sr	17	20	41	26	134	125	81	119	92
Rb/Sr	.286	.320	.090	.156	.283	.426	.569	.311	.610
K_2O/Na_2O	1.97	1.66	.42	0.89	.35	.59	1.17	.42	1.10
MLI	15.9	15.2	9.6	13.3	8.2	9.7	13.3	8.9	13.2
DF	+4.10	+4.31	+3.67	+3.86	+2.37	+2.31	+1.48	+2.30	+2.00
Method	P	P	P	P	P	P	P	P	P

Appendix 2

Chemical Analyses. Cedar - Clay Lakes Area

Cliff Lake Intrusion - Group B

Sample	324	325	328	329	330	417	418	420	421	423
SiO_2	63.19	69.37	73.38	72.91	67.54	71.58	71.87	68.65	70.78	73.37
Al_2O_3	16.46	15.28	13.91	13.91	15.27	14.55	14.49	15.07	14.95	13.88
TiO_2	.72	.42	.26	.29	.59	.35	.32	.47	.34	.24
Fe_2O_3(TOT)	5.89	3.16	1.90	2.15	4.49	2.53	2.09	3.60	2.58	1.65
MnO	.08	.04	.02	.03	.06	.03	.03	.05	.03	.02
MgO	1.36	.85	.57	.69	1.59	.86	.83	1.05	.63	.57
CaO	5.08	2.98	2.27	2.32	3.52	2.79	2.44	3.54	2.13	1.98
Na_2O	4.57	3.90	3.54	3.45	3.84	3.57	3.57	4.54	3.45	3.56
K_2O	1.42	3.05	3.45	3.49	2.16	3.02	3.69	2.14	4.42	4.15
P_2O_5	.40	.12	.07	.09	.19	.12	.11	.21	.10	.07
Total	99.18	99.17	99.38	99.34	99.24	99.41	99.43	99.32	99.41	99.50
Rb	64	100	90	97	85	85	93	66	108	101
Sr	219	199	207	193	169	182	216	297	194	163
Ba	569	831	941	989	631	1132	959	497	1185	929
Ce	100	124	51	69	118	60	63	104	136	66
K/Rb	185	257	322	301	213	299	332	274	340	344
K/Ba	21	31	31	30	29	22	32	36	31	37
Ca/Sr	167	109	80	89	150	111	82	87	79	88
Rb/Sr	.291	.498	.433	.499	.497	.461	.429	.219	.556	.618
K_2O/Na_2O	.31	.78	.97	1.01	.56	.85	1.03	.47	1.28	1.17
MLI	6.5	10.8	12.4	12.3	8.9	11.2	12.1	9.4	12.9	13.2
DF	+3.84	+3.00	+2.12	+1.94	+1.90	+2.11	+2.38	+3.58	+2.68	+2.46
Method	F	P	P	P	P	P	P	P	P	P

Appendix 2

Chemical Analyses. Cedar - Clay Lakes Area

Cedar Lake Gneiss

Sample	21	22	24	62	78	322	331	349	350
SiO_2	69.46	69.13	72.23	74.17	71.62	71.89	72.76	62.28	69.26
Al_2O_3	14.80	14.20	14.70	14.15	15.18	14.33	14.11	16.04	14.52
TiO_2	.54	.26	.18	.13	.31	.28	.26	.54	.43
Fe_2O_3(TOT)	3.84	4.31	1.51	1.04	2.34	2.40	2.09	4.15	4.20
MnO	.05	.09	.03	.02	.03	.03	.04	.05	.07
MgO	.95	1.38	.62	.44	.80	.75	.62	1.07	1.12
CaO	3.38	4.65	1.46	2.25	3.00	2.61	2.16	3.45	3.61
Na_2O	3.69	4.06	3.67	3.52	4.80	3.82	3.52	4.35	4.10
K_2O	2.23	.83	4.98	3.68	1.24	3.06	3.72	2.05	1.80
P_2O_5	.15	.06	.05	.05	.09	.09	.07	.20	.18
Total	99.11	98.97	99.44	99.46	99.40	99.29	99.35	99.28	99.29
Rb	47	16	113	80	48	79	110	68	57
Sr	197	235	245	239	357	196	175	324	253
Ba	1135	347	1497	1313	427	983	1178	687	641
Ce	112	44	27	34	66	62	96	184	96
K/Rb	399	453	367	383	221	324	283	251	266
K/Ba	17	21	28	24	25	26	26	25	23
Ca/Sr	125	145	43	68	61	96	89	77	104
Rb/Sr	.240	.069	.458	.334	.134	.402	.624	.209	.221
K_2O/Na_2O	.60	.20	1.36	1.05	.26	.80	1.06	.47	.44
MLI	9.8	7.4	14.0	12.8	9.6	11.5	12.6	9.1	9.1
DF	+2.13	+2.09	+3.01	+2.45	+3.18	+2.46	+2.17	+3.28	+2.38
Method	P	P	P	P	P	P	P	P	P

Appendix 2

Chemical Analyses. Cedar - Clay Lakes Area

	Cedar Lake Gneiss			Clay Lake Granitoid Suite				
Sample	432	504	560	212	306	307	316	317
SiO_2	71.34	72.95	74.77	71.75	70.31	64.29	67.92	65.12
Al_2O_3	14.57	15.01	13.70	14.52	14.96	16.12	14.85	16.35
TiO_2	.35	.20	.12	.33	.40	.62	.69	.64
Fe_2O_3(TOT)	2.86	1.49	.92	2.69	3.04	5.51	5.36	4.98
MnO	.04	.03	.01	.03	.03	.08	.08	.06
MgO	.93	.63	.51	.94	.95	1.58	1.36	1.28
CaO	2.68	2.48	1.82	3.10	3.78	4.83	3.27	4.05
Na_2O	3.59	4.51	3.69	3.85	3.98	3.70	3.17	4.11
K_2O	2.91	2.16	3.96	1.98	1.57	1.45	2.40	2.13
P_2O_5	.13	.08	.04	.06	.14	.38	.18	.31
Total	99.39	99.53	99.55	99.26	99.13	98.55	99.30	99.02
Rb	96	115	74	61	50	59	63	79
Sr	205	197	292	221	184	208	231	244
Ba	1084	658	1246	576	465	488	2025	1273
Ce	62	27	63	47	53	64	160	114
K/Rb	253	158	448	273	267	205	317	225
K/Ba	22	28	27	29	29	25	10	14
Ca/Sr	95	91	45	102	150	168	103	120
Rb/Sr	.466	.575	.251	.277	.271	.284	.274	.321
K_2O/Na_2O	.81	.48	1.07	.51	.39	.39	.76	.52
MLI	11.1	11.0	13.4	10.1	9.1	6.8	9.5	8.2
DF	+1.88	+3.12	+2.44	+1.95	+2.50	+2.07	+0.75	+3.02
Method	P	P	P	P	P	F	P	F

Appendix 2

Chemical Analyses. Cedar - Clay Lakes Area

Clay Lake Granitoid Suite

Sample	321	367	368	409	427	433	434	455	458	461
SiO_2	66.87	73.99	73.33	67.48	67.58	65.00	70.75	68.56	69.94	68.39
Al_2O_3	15.62	14.29	14.24	15.93	16.06	15.87	14.63	15.36	15.30	15.17
TiO_2	.62	.13	.22	.64	.58	.62	.44	.54	.43	.73
Fe_2O_3(TOT)	4.87	1.23	1.92	4.15	3.90	5.58	2.78	3.92	3.21	4.50
MnO	.06	.03	.04	.04	.04	.07	.02	.04	.04	.08
MgO	1.47	.40	.67	1.10	1.06	1.28	.96	1.10	.98	1.05
CaO	4.02	1.60	2.22	4.19	3.61	4.40	2.95	3.97	3.12	3.40
Na_2O	3.94	3.55	3.66	3.56	3.79	3.91	3.52	3.69	3.78	3.75
K_2O	1.48	4.25	3.16	1.91	2.45	1.53	3.17	1.84	2.38	2.01
P_2O_5	.19	.04	.06	.25	.19	.36	.14	.23	.16	.19
Total	99.14	99.52	99.50	99.23	99.26	98.62	99.36	99.26	99.35	99.29
Rb	53	86	67	56	70	56	70	58	73	55
Sr	180	99	188	207	176	201	193	235	169	170
Ba	549	548	638	829	688	616	1264	923	604	840
Ce	87	25	24	91	74	91	60	67	49	101
K/Rb	235	412	395	283	294	231	378	264	272	305
K/Ba	23	65	41	19	30	21	21	17	33	20
Ca/Sr	161	117	85	147	149	158	111	123	135	146
Rb/Sr	.292	.875	.353	.275	.393	.275	.361	.250	.431	.328
K_2O/Na_2O	.38	1.20	.86	.54	.65	.39	.90	.50	.63	.54
MLI	8.0	13.8	12.1	8.5	9.4	7.5	11.0	8.8	10.1	9.3
DF	+2.10	+2.47	+2.01	+2.38	+2.78	+2.40	+2.20	+2.27	+2.26	+2.01
Method	P	P	P	P	P	F	P	P	P	P

Appendix 2

Chemical Analyses. Cedar - Clay Lakes Area

Clay Lake Granitoid Suite

Sample	512	513	516	517	553
SiO_2	68.85	68.40	72.51	71.65	67.79
Al_2O_3	15.47	15.60	14.76	14.99	15.82
TiO_2	.52	.61	.04	.33	.59
Fe_2O_3(TOT)	3.48	3.70	.63	2.38	3.94
MnO	.04	.04	.01	.03	.04
MgO	1.04	1.06	.10	.88	1.10
CaO	3.46	4.32	1.28	2.76	3.99
Na_2O	3.52	3.83	3.23	3.72	3.86
K_2O	2.71	1.48	6.35	2.58	1.91
P_2O_5	.20	.23	.03	.10	.21
Total	99.29	99.28	98.84	99.42	99.25
Rb	68	44	110	70	53
Sr	182	206	85	153	204
Ba	949	548	975	552	658
Ce	72	83	8	43	61
K/Rb	333	280	486	309	301
K/Ba	24	23	55	39	24
Ca/Sr	138	153	110	131	142
Rb/Sr	.373	.213	1.299	.454	.263
K_2O/Na_2O	.77	.39	1.97	.69	.49
MLI	10.0	8.2	15.8	10.9	8.7
DF	+2.34	+2.63	+3.72	+2.11	+2.72
Method	P	P	P	P	P

Appendix 2

Chemical Analyses. Cedar - Clay Lakes Area

Sample	Twilight Gneiss Group A 309	376	377	535	537	Twilight Group B 378	448	538
SiO_2	60.55	56.68	62.58	63.67	54.38	67.77	67.28	62.09
Al_2O_3	16.44	18.10	15.83	15.67	18.76	16.59	16.47	18.59
TiO_2	.73	.85	.67	.61	1.05	.37	.72	.47
Fe_2O_3(TOT)	7.60	8.97	6.77	6.91	7.60	3.15	3.04	3.32
MnO	.11	.11	.08	.11	.07	.03	.02	.07
MgO	3.04	3.86	3.15	1.99	3.19	1.13	1.08	1.13
CaO	3.07	2.24	2.81	2.83	5.07	3.92	2.51	6.26
Na_2O	3.63	3.20	3.73	3.91	3.71	4.09	4.04	3.80
K_2O	2.32	4.75	2.28	2.15	3.01	1.99	3.81	1.31
P_2O_5	.17	.11	.19	.17	1.25	.19	.29	.52
Total	97.65	98.87	98.09	98.02	98.08	99.24	99.25	97.54
Rb	110	177	87	83	136	61	89	46
Sr	505	413	404	269	1445	844	1186	1330
Ba	680	1068	620	667	1398	945	1923	2146
Ce	49	61	49	43	237	37	99	62
K/Rb	178	225	221	218	186	273	358	240
K/Ba	29	37	31	27	18	18	17	5
Ca/Sr	44	39	51	76	25	34	15	34
Rb/Sr	.217	.426	.214	.308	.093	.072	.074	.035
K_2O/Na_2O	.64	1.48	.61	.55	.81	.49	.94	.34
MLI	7.3	9.0	7.8	8.4	5.4	8.8	11.3	5.6
DF	+0.01	+0.25	-0.06	+0.70	+2.94	+3.30	+3.59	+4.54
Method	F	F	F	F	F	P	P	F

Appendix 2

Chemical Analyses. Cedar - Clay Lakes Area

Amphibolites - Group 1

Sample	28	63	67	112	137	164	199	353
SiO_2	48.17	49.42	47.03	49.27	49.00	53.09	51.38	54.23
Al_2O_3	14.92	13.64	13.44	15.31	15.65	16.22	15.45	14.94
TiO_2	.96	.94	1.77	.69	.70	.68	1.05	.98
Fe_2O_3(TOT)	12.78	14.28	17.17	11.43	11.35	8.46	12.76	11.68
MnO	.20	.20	.26	.18	.20	.13	.22	.17
MgO	7.63	7.12	5.55	8.09	6.71	6.35	5.20	4.65
CaO	10.83	10.23	9.49	10.98	11.37	8.30	7.65	7.08
Na_2O	2.72	2.79	3.08	2.84	2.95	4.18	3.92	3.92
K_2O	.93	.74	1.03	.98	.76	1.13	1.37	1.30
P_2O_5	.10	.10	.11	.11	.11	.24	.11	.10
Total	99.24	99.46	98.92	99.87	98.78	98.78	99.11	99.07
Rb	8	6	22	6	4	18	34	35
Sr	66	128	159	94	160	1125	286	288
Ba	34	44	207	70	83	618	187	210
Ce	18	9	25	-	11	123	33	27
K/Rb	985	1100	391	1309	1528	532	340	309
K/Ba	232	138	42	116	76	15	61	52
Ca/Sr	1173	575	431	839	512	53	193	177
Rb/Sr	.126	.049	.141	.073	.030	.016	.118	.119
MLI	-4.30	-3.40	-2.10	-4.30	-4.10	-0.70	+0.50	+1.60
Method	F	F	F	F	F	F	F	F

Appendix 2

Chemical Analyses. Cedar - Clay Lakes Area

Amphibolites - Group 2

Sample	101	102	103	104	105	213	301	357	359
SiO_2	48.42	47.66	49.38	48.90	49.53	49.37	48.15	47.66	47.55
Al_2O_3	16.36	15.82	11.35	16.68	11.29	15.79	15.89	9.87	14.84
TiO_2	.75	.75	.68	.95	.48	.84	.71	.61	.89
Fe_2O_3(TOT)	10.86	12.24	11.22	11.67	13.73	12.26	11.62	9.99	13.46
MnO	.21	.20	.17	.18	.25	.20	.16	.16	.20
MgO	5.65	5.89	12.55	6.97	11.07	6.51	8.68	16.93	8.25
CaO	13.85	13.36	11.32	10.23	11.94	10.75	10.90	10.42	11.05
Na_2O	1.87	1.89	1.51	2.83	1.20	3.10	2.43	.95	1.99
K_2O	.40	.65	.63	.69	.37	.69	.38	1.29	.55
P_2O_5	.14	.13	.17	.10	.10	.13	.11	.15	.11
Total	98.51	98.57	99.04	99.20	99.96	99.63	99.03	98.04	98.88
Rb	5	16	20	25	8	6	4	77	14
Sr	143	121	162	140	65	123	94	33	119
Ba	40	65	136	67	44	88	37	58	37
Ce	6	3	41	5	8	4	2	30	6
K/Rb	638	335	265	225	376	933	834	141	329
K/Ba	84	84	38	85	71	65	101	187	123
Ca/Sr	701	798	499	527	1311	627	921	2309	670
Rb/Sr	.042	.138	.124	.183	.132	.055	.054	2.411	.110
MLI	-5.7	-5.4	-7.6	-3.5	-7.3	-3.5	-5.5	-9.6	-5.3
Method	F	F	F	F	F	F	F	F	F

Appendix 2

Chemical Analyses. Cedar - Clay Lakes Area

Amphibolites - Group 3

Sample	313	361	362	363	515	518
SiO_2	49.54	50.73	52.41	52.06	51.25	49.81
Al_2O_3	14.23	14.27	14.06	16.57	11.85	14.73
TiO_2	.87	.86	.88	.43	2.19	.79
Fe_2O_3(TOT)	13.57	13.42	13.03	10.13	18.26	12.20
MnO	.21	.20	.18	.17	.27	.18
MgO	7.23	8.27	7.27	7.24	4.18	8.38
CaO	10.35	7.87	8.29	9.47	6.82	11.59
Na_2O	2.13	2.76	2.95	2.99	1.93	2.25
K_2O	.92	.79	.69	.50	1.12	.38
P_2O_5	.11	.09	.10	.09	.35	.11
Total	99.16	99.25	99.83	99.64	98.20	100.42
Rb	14	20	10	5	59	3
Sr	123	126	103	148	103	88
Ba	224	482	155	116	830	24
Ce	26	11	25	7	415	7
K/Rb	551	325	570	778	157	1127
K/Ba	34	14	36	36	11	134
Ca/Sr	604	447	575	458	482	934
Rb/Sr	.116	.154	.081	.030	.576	.020
MLI	-3.5	-2.3	-1.7	-2.9	+1.5	-5.4
Method	F	F	F	F	F	F

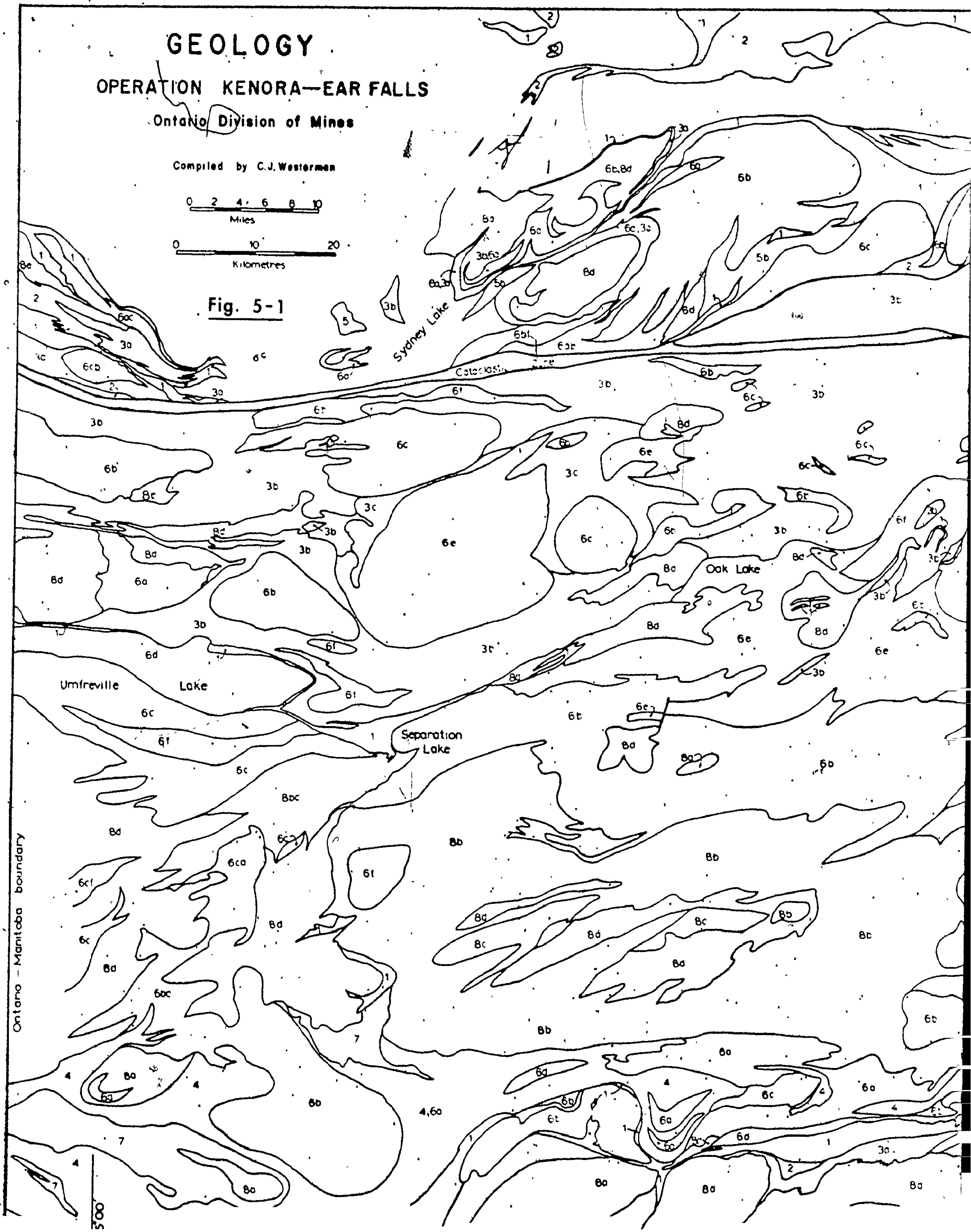
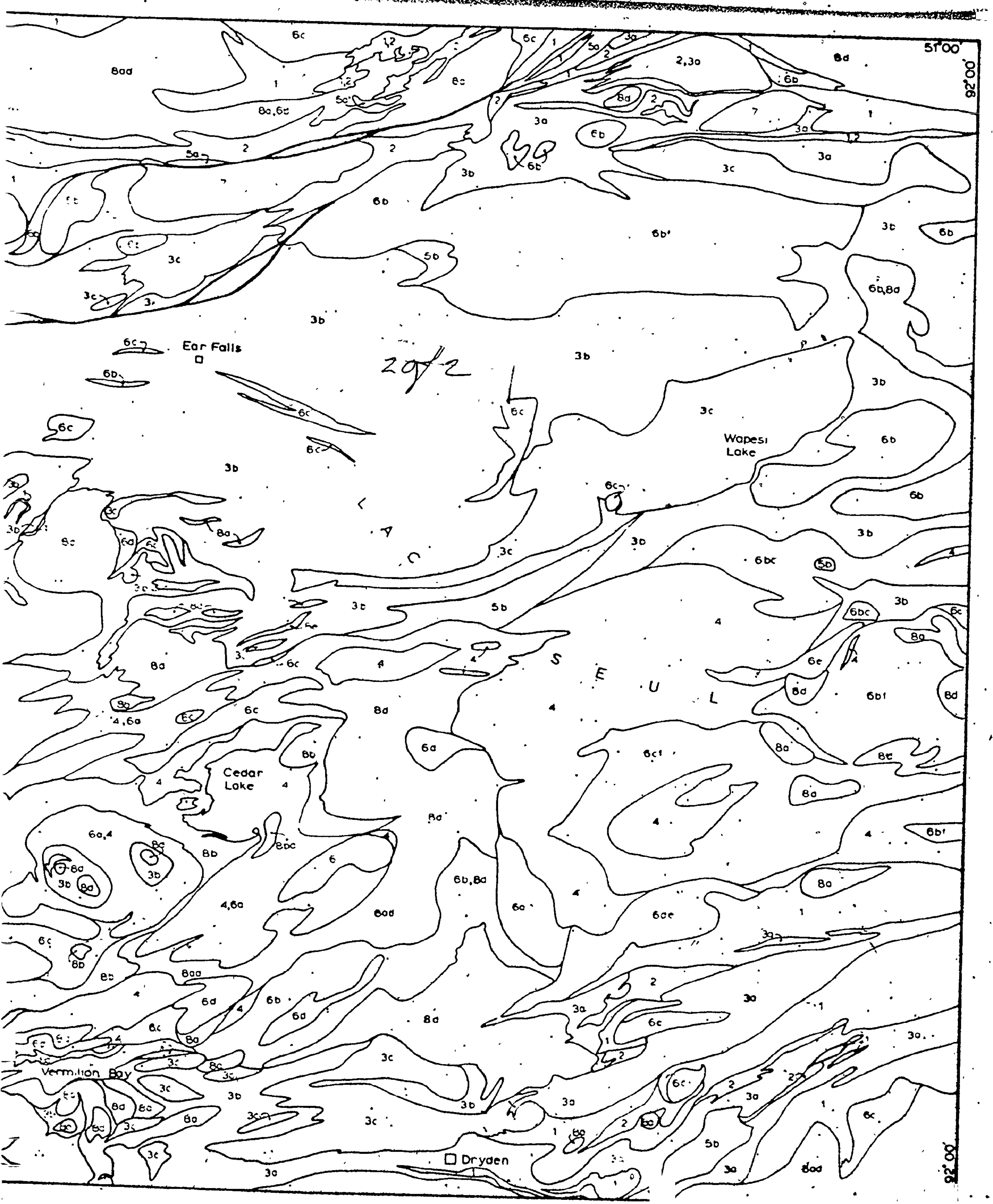

GEOLOGY
OPERATION KENORA—EAR FALLS
Ontario Division of Mines
Compiled by C.J. Westerman
0 2 4 6 8 10
Miles
0 10 20
Kilometres
Sydney Lake
Oak Lake
Umfreville Lake
Separation Lake
Ontario - Manitoba boundary

Fig. 5-1


51°00'
92°00'
Ear Falls
Wapesi Lake
L A C
S E U L
Cedar Lake
Vermilion Bay
Dryden
92°00'

Appendix 3 Modal Analyses

CLIFF LAKE INTRUSION - GROUP A

SAMPLE	100	106	131	135	214	215	300	340	341	342
Quartz	23.0	29.0	38.0	28.6	39.0	26.6	31.8	31.0	34.0	28.1
Plagioclase	64.4	54.0	48.8	48.6	52.4	51.0	58.5	61.0	46.8	36.8
Microcline	1.0	10.0	2.4	18.9	0.6	15.3	3.0	3.0	12.2	34.5
Biotite	10.8	5.0	10.8	3.9	8.0	7.0	5.2	5.0	7.0	-
Hornblende	-	2.0	-	-	Tr	-	-	-	-	-
Clinopyroxene	-	-	-	-	-	-	1.5	-	-	-
Orthopyroxene	-	-	-	-	-	-	-	-	-	-
Garnet	-	-	-	-	-	-	-	-	-	-
Magnetite	0.2	Tr	Tr	Tr	Tr	Tr	Tr	-	Tr	0.2
Apatite	0.6	Tr	Tr	-	Tr	Tr	Tr	Tr	Tr	-
Epidote	Tr	-	-	-	-	-	-	-	-	-
Sphene	Tr	Tr	-	-	Tr	-	-	-	Tr	-
Zircon	-	-	-	-	-	-	-	-	Tr	-
Muscovite	Tr	-	-	Tr	-	-	-	-	Tr	-
Chlorite	-	-	-	-	-	-	-	-	-	-
An% Plag.	30	23	27	22	23	23	26	23	20	23
I.U.G.S.	TON	GD	TON	GD	TON	GD	TON	TON	GD	GR

Appendix 3 Modal Analyses

	CLIFF LAKE INTRUSION-GROUP A				CLIFF LAKE INTRUSION-GROUP B				
SAMPLE	343	345	346	429	76	81	200	201	323
Quartz	20.2	26.0	29.2	32.0	28.6	28.2	30.4	28.3	32.5
Plagioclase	35.3	36.6	52.0	45.4	59.4	54.0	40.6	55.6	37.3
Microcline	44.5	36.8	10.0	19.6	1.0	7.8	26.6	1.0	23.2
Biotite	-	-	6.2	1.8	9.0	10.0	2.4	13.5	6.6
Hornblende	-	-	1.2	-	1.5	-	-	-	-
Clinopyroxene	-	-	0.6	-	-	-	-	-	-
Orthopyrene	-	-	-	-	-	-	-	-	-
Garnet	-	-	-	-	-	-	-	-	-
Magnetite	-	0.6	0.4	0.4	0.5	Tr	Tr	1.0	0.4
Apatite	Tr	Tr	0.4	-	-	Tr	Tr	Tr	Tr
Epidote	-	-	-	-	-	-	-	-	-
Sphene	-	-	Tr	-	-	Tr	-	Tr	Tr
Zircon	-	-	Tr	-	-	-	-	-	Tr
Muscovite	-	-	Tr	0.8	-	Tr	Tr	-	-
Chlorite	-	-	-	-	-	-	-	-	-
An% Plag.	23	24	23	20		23	25	26	24
I.U.G.S.	GR	GR	GD	GD	TON	GD	GR	TON	GR

Appendix 3 Modal Analyses

CLIFF LAKE INTRUSION - GROUP B

SAMPLE	324	325	328	329	330	417	418	420	421	423
Quartz	21.0	29.6	29.3	30.2	25.0	25.2	25.1	26.0	22.8	27.8
Plagioclase	56.0	49.2	38.9	36.5	54.4	46.0	43.9	49.6	53.0	43.2
Microcline	0.6	10.2	24.4	24.5	7.6	20.0	22.0	10.4	17.2	24.0
Biotite	13.6	10.4	7.2	8.6	13.0	6.8	9.0	13.0	7.0	5.0
Hornblende	7.8	-	-	-	-	2.0	-	Tr	-	-
Clinopyroxene	-	-	-	-	-	-	-	-	-	-
Orthopyroxene	-	-	-	-	-	-	-	-	-	-
Garnet	-	-	-	-	-	-	-	-	-	-
Magnetite	0.4	0.6	0.2	0.2	Tr	Tr	Tr	1.0	Tr	Tr
Apatite	0.4	Tr	Tr	Tr	Tr	Tr	Tr	-	Tr	Tr
Epidote	-	-	-	-	-	-	-	-	-	-
Sphene	0.2	-	Tr	Tr	Tr	-	-	Tr	Tr	-
Zircon	Tr	Tr	Tr	Tr	Tr	-	Tr	-	Tr	Tr
Muscovite	-	-	-	-	Tr	-	-	-	Tr	-
Chlorite	-	-	-	-	-	-	-	-	-	-
An% Plag	28	26	25	24	27	24	22	27	25	24
I.U.G.S.	TON	GD	GR	GR	GD	GD	GD	GD	GD	GR

Appendix 3 Modal Analyses

CEDAR LAKE GNEISS

SAMPLE	21	22	24	62	78	322	331	349	350	432
Quartz	38.0	40.2	35.7	26.6	42.2	34.4	42.7	30.6	33.4	37.6
Plagioclase	44.0	41.6	29.8	49.8	43.2	44.8	30.2	49.0	46.2	37.8
Microcline	5.8	7.2	24.1	18.6	1.8	10.0	21.0	1.2	9.4	16.4
Biotite	9.4	4.2	10.2	5.0	11.8	10.0	6.0	17.2	10.0	8.2
Hornblende	1.6	5.8	-	-	0.2	-	-	Tr	-	-
Clinopyroxene	-	-	-	-	-	-	-	-	-	-
Orthopyroxene	-	-	-	-	-	-	-	-	-	-
Garnet	-	-	-	-	-	-	-	-	-	-
Magnetite	0.8	1.0	0.2	Tr	0.8	0.8	Tr	0.6	0.4	Tr
Apatite	0.4	Tr	Tr	Tr	Tr	Tr	-	0.8	Tr	Tr
Epidote	-	-	-	-	-	-	-	-	-	Tr
Sphene	Tr	-	-	-	-	Tr	Tr	0.4	-	Tr
Zircon	-	Tr	-	-	-	Tr	-	0.2	0.4	-
Muscovite	-	-	-	Tr	Tr	-	-	-	0.2	-
Chlorite	-	-	-	-	-	-	-	-	-	-
An% Plag.	30	28	27	26	25	24	22	23	22	26
I.U.G.S.	GD	GD	GD	GD	TON	GD	GR	TON	GD	GD

Appendix 3 Modal Analyses

	CEDAR LAKE GNEISS		CLAY LAKE GRANITOID SUITE						
SAMPLE	504	560	212	306	307	316	317	321	367
Quartz	27.2	26.3	43.0	41.4	27.2	37.2	47.6	36.6	34.6
Plagioclase	57.6	48.3	40.2	41.2	54.6	46.6	38.0	47.4	33.8
Microcline	8.0	20.4	5.2	8.6	-	2.6	-	-	27.0
Biotite	7.2	5.0	10.6	7.2	14.4	10.0	12.2	13.4	3.2
Hornblende	-	-	-	-	-	-	-	Tr	-
Clinopyroxene	-	-	-	-	-	-	-	-	-
Orthopyroxene	-	-	-	1.4	2.4	-	1.4	1.6	-
Garnet	-	-	-	-	-	1.0	-	-	1.4
Magnetite	-	Tr	0.8	0.4	0.8	2.2	0.2	0.4	Tr
Apatite	Tr	Tr	0.2	Tr	0.4	0.4	0.6	0.6	-
Epidote	-	-	-	-	0.2	Tr	-	-	-
Sphene	-	-	-	-	-	-	Tr	-	-
Zircon	Tr	Tr	-	-	-	Tr	-	-	-
Muscovite	Tr	-	-	-	-	-	-	-	-
Chlorite	-	-	-	-	-	-	-	-	-
An% Plag.	24	23	28	30	36	33	34	28	26
I.U.G.S.	GD	GD	GD	GD	TON	TON	TON	TON	GR

Appendix 3 Modal Analyses

CLAY LAKE GRANITOID SUITE

SAMPLE	368	409	427	433	434	455	458	461	512	513
Quartz	36.2	36.0	37.2	24.6	37.2	30.2	30.4	39.4	35.6	35.6
Plagioclase	40.2	44.4	48.6	56.4	38.0	52.6	50.2	49.6	51.2	47.6
Microcline	16.2	-	4.2	-	12.8	6.2	8.0	2.6	1.6	-
Biotite	5.4	17.6	8.0	15.2	11.0	9.0	10.0	7.6	8.4	11.4
Hornblende	-	-	-	-	-	-	-	-	-	-
Clinopyroxene	-	-	-	-	-	-	-	-	-	-
Orthopyroxene	-	-	2.0	2.0	1.0	2.0	-	-	2.0	4.8
Garnet	2.0	-	-	-	-	-	1.4	0.2	-	-
Magnetite	Tr	Tr	-	1.2	Tr	Tr	-	0.6	0.8	-
Apatite	-	Tr	Tr	0.6	Tr	Tr	Tr	Tr	0.4	0.6
Epidote	Tr	Tr	-	-	-	-	-	-	-	-
Sphene	-	Tr	-	-	-	-	-	-	-	-
Zircon	-	Tr	-	Tr	Tr	Tr	-	Tr	Tr	Tr
Muscovite	Tr	-	Tr	-	-	-	-	-	-	-
Chlorite	-	Tr	-	-	-	-	-	-	-	-
An% Plag.	26	30	24	34	26	35	26	27	29	30
I.U.G.S.	GD	TON	TON	TON	GD	TON	GD	TON	TON	TON

Appendix 3 Modal Analyses

	CLAY LAKE SUITE			TWILIGHT GNEISS - GROUP A				
SAMPLE	516	517	553	309	376	327	404	405
Quartz	23.6	38.6	36.0	41.8	3.6	37.8	32.6	14.6
Plagioclase	23.2	43.6	52.6	24.4	30.0	36.2	45.8	45.0
Microcline	52.0	6.8	4.2	Tr	25.2	Tr	-	4.0
Biotite	-	9.8	7.2	22.0	32.8	18.0	19.6	30.4
Hornblende	-	-	-	-	-	-	-	-
Clinopyroxene	-	-	-	-	-	-	-	-
Orthopyroxene	-	-	Tr	-	0.6	3.2	-	-
Garnet	1.2	0.6	-	10.4	7.6	4.0	Tr	3.4
Magnetite	-	0.6	Tr	0.8	0.2	0.6	2.0	2.6
Apatite	-	Tr	Tr	-	Tr	0.2	-	-
Epidote	-	Tr	-	0.6	-	-	-	-
Sphene	-	-	-	-	-	-	-	-
Zircon	-	Tr	Tr	Tr	-	Tr	-	Tr
Muscovite	Tr	Tr	-	-	-	-	Tr	Tr
Chlorite	-	-	-	-	-	-	-	-
An% Plag.	24	27	31	28	28	27	27	27
I.U.G.S.	GR	GD	TON					

Appendix 3 Modal Analyses

	TWILIGHT GNEISS-GROUP A				TWILIGHT GNEISS - GROUP B				
SAMPLE	506	535	537a	537b	378	448	538	556	557
Quartz	37.4	31.8	24.2	15.8	30.2	29.2	25.2	37.8	34.0
Plagioclase	37.4	42.6	51.2	55.8	50.0	43.2	64.8	48.2	43.0
Microcline	-	0.8	-	Tr	6.0	15.2	-	-	-
Biotite	24.2	21.4	20.0	25.6	12.8	12.4	10.0	12.2	16.0
Hornblende	-	-	-	-	-	-	-	-	-
Clinopyroxene	-	-	-	-	-	-	-	-	-
Orthopyroxene	-	-	3.6	-	1.0	-	-	Tr	1.6
Garnet	1.0	1.2	-	-	-	-	-	1.8	7.0
Magnetite	Tr	2.0	1.0	1.6	-	-	-	Tr	0.4
Apatite	Tr	0.2	Tr	0.8	Tr	Tr	Tr	Tr	Tr
Epidote	-	-	Tr	0.2	-	-	-	-	-
Sphene	-	-	-	-	-	-	-	-	-
Zircon	-	-	Tr	Tr	-	Tr	-	-	-
Muscovite	Tr	Tr	-	Tr	-	-	-	-	-
Chlorite	Tr	-	-	-	-	-	-	-	-
An% Plag.	27	28	25	28	31	24	42	36	36

Appendix 3 Modal Analyses

AMPHIBOLITES - GROUP 1

SAMPLE	28	63	67	112	137	164	199	353
Quartz	2.8	1.4	1.2	0.4	-	1.4	4.2	3.0
Plagioclase	37.6	29.0	38.0	37.5	32.2	49.2	34.0	40.0
Microcline	-	-	-	-	-	-	-	-
Biotite	2.0	0.8	3.6	0.8	-	5.6	8.0	11.0
Hornblende	50.2	66.2	41.6	57.8	57.8	38.6	49.4	41.0
Clinopyroxene	6.6	0.8	10.2	3.5	10.0	4.0	-	-
Orthopyroxene	-	-	-	-	-	-	-	-
Garnet	-	-	-	-	-	-	-	-
Magnetite	0.8	1.6	5.4	-	Tr	1.0	3.0	3.6
Apatite	-	-	-	-	-	0.2	0.4	0.4
Epidote	-	-	-	-	-	-	-	-
Sphene	-	0.2	-	-	Tr	-	1.0	1.0
Zircon	-	-	-	-	-	-	-	-
Muscovite	-	-	-	-	-	-	-	-
Chlorite	-	-	-	-	-	-	-	-
An% Plag.	37	35	30	38	33	27	26	26

Appendix 3 Modal Analyses

AMPHIBOLITES - GROUP 2

SAMPLE	101	102	103	104	105	213	301	357	359
Quartz	-	-	-	-	-	-	-	-	-
Plagioclase	40.2	33.6	17.2	37.2	20.4	47.6	32.6	4.6	32.2
Microcline	-	-	-	-	-	-	-	-	-
Biotite	-	-	-	-	-	-	-	19.4	1.6
Hornblende	20.4	30.2	82.4	62.4	69.2	23.8	62.4	76.0	65.2
Clinopyroxene	37.2	34.8	-	-	10.0	23.4	4.0	-	Tr
Orthopyroxene	-	-	-	-	-	-	-	-	-
Garnet	-	-	-	-	-	-	-	-	-
Magnetite	-	1.4	Tr	0.4	0.4	5.2	1.0	Tr	1.0
Apatite	-	-	-	-	-	-	-	-	-
Epidote	2.2	Tr	Tr	-	Tr	-	-	-	Tr
Sphene	-	-	-	Tr	-	Tr	-	-	-
Zircon	-	-	-	-	-	-	-	-	-
Muscovite	-	-	-	-	-	-	-	-	-
Chlorite	-	-	-	-	-	-	-	-	-
An% Plag.	48	52	48	49	?	50	55	?	60?

Appendix 3 Modal Analyses

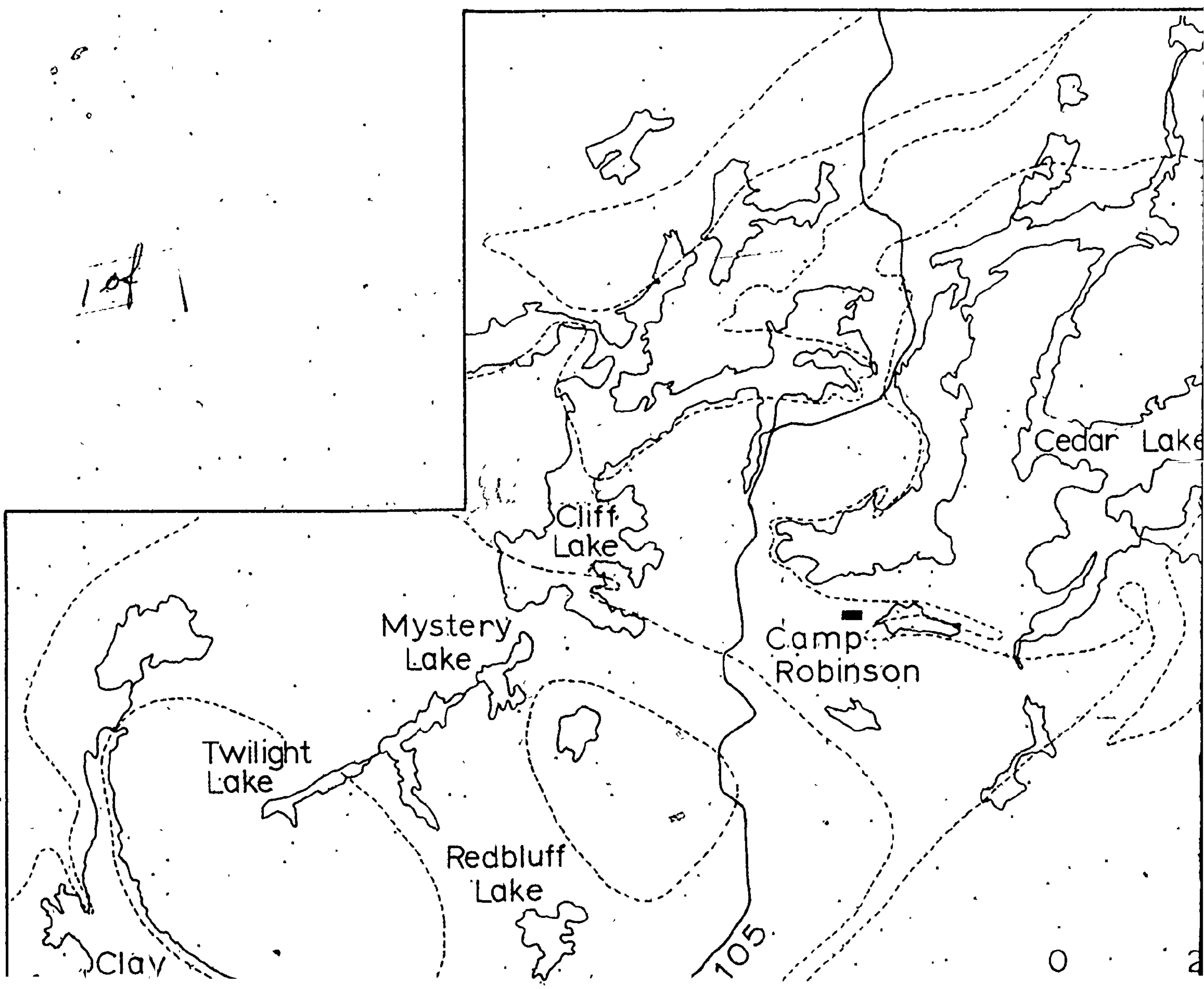
AMPHIBOLITES - GROUP 3

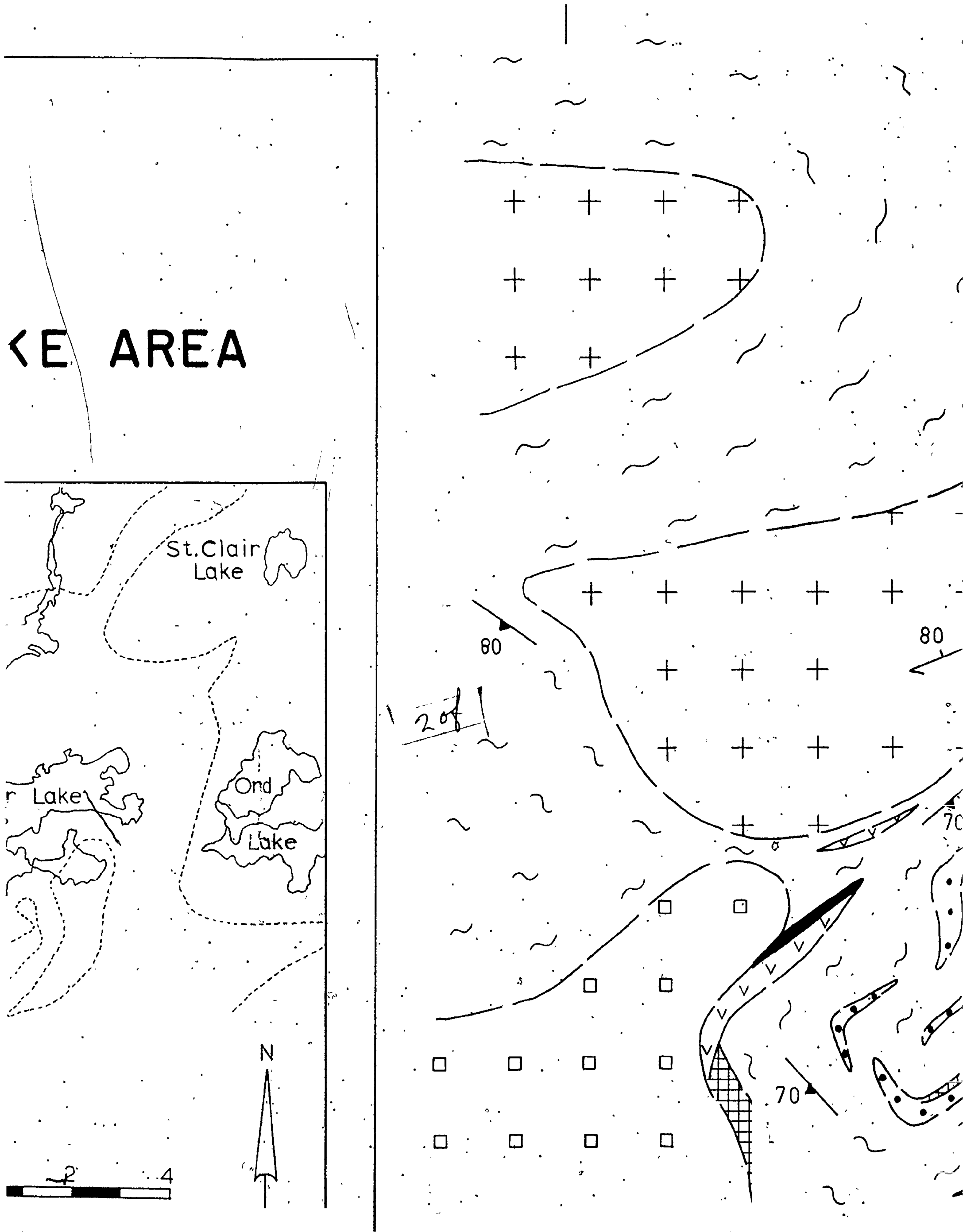
SAMPLE	313	361	362	363	515	518
Quartz	-	-	-	2.0		-
Plagioclase	37.0	42.5	49.4	53.0		42.4
Microcline	-	-	-	-		-
Biotite	-	-	19.2	1.2		-
Hornblende	59.0	39.5	-	23.4		33.2
Clinopyroxene	3.6	1.0	15.6	2.4		15.4
Orthopyroxene	-	17.0	15.8	18.0		8.2
Garnet	-	-	-	-		-
Magnetite	Tr	Tr	Tr	Tr		0.8
Apatite	-	-	-	-		-
Epidote	-	-	-	-		-
Sphene	Tr	-	-	-		-
Zircon	-	-	-	-		-
Muscovite	-	-	-	-		-
Chlorite	-	-	-	-		-
An% Plag.	52	38	?	?		42

GEOLOGY

CEDAR LAKE — CLAY LAKE

1 of 1

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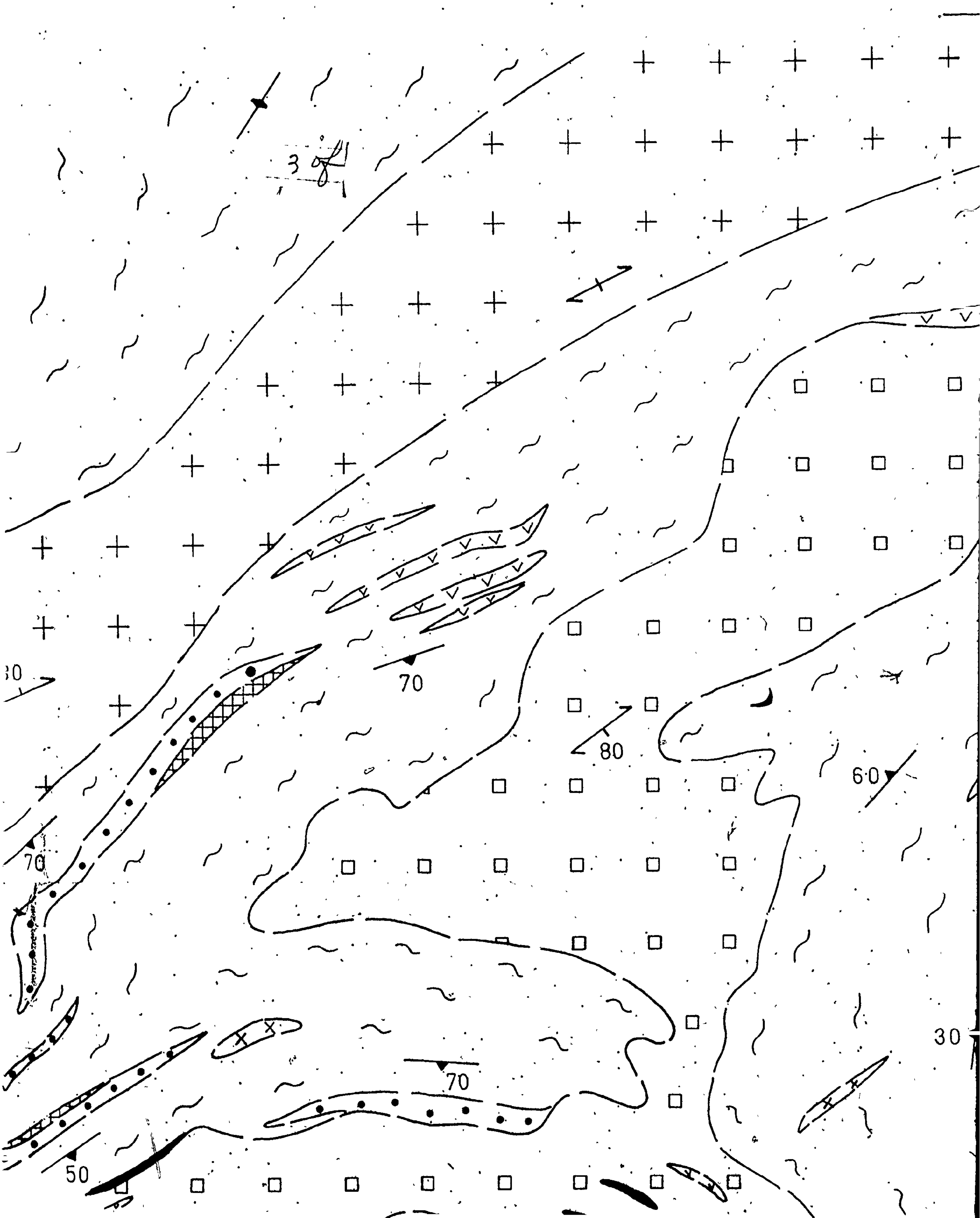

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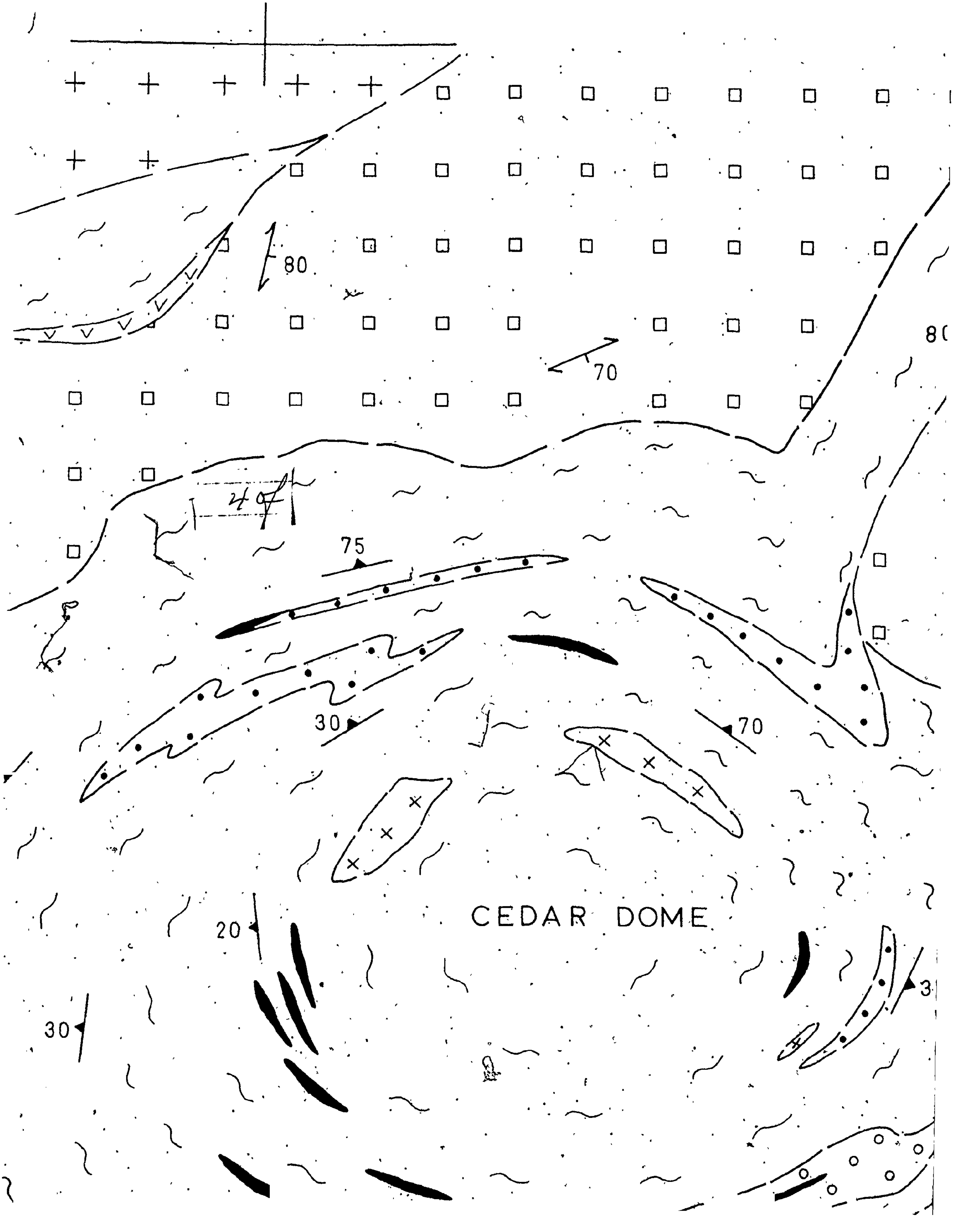
80
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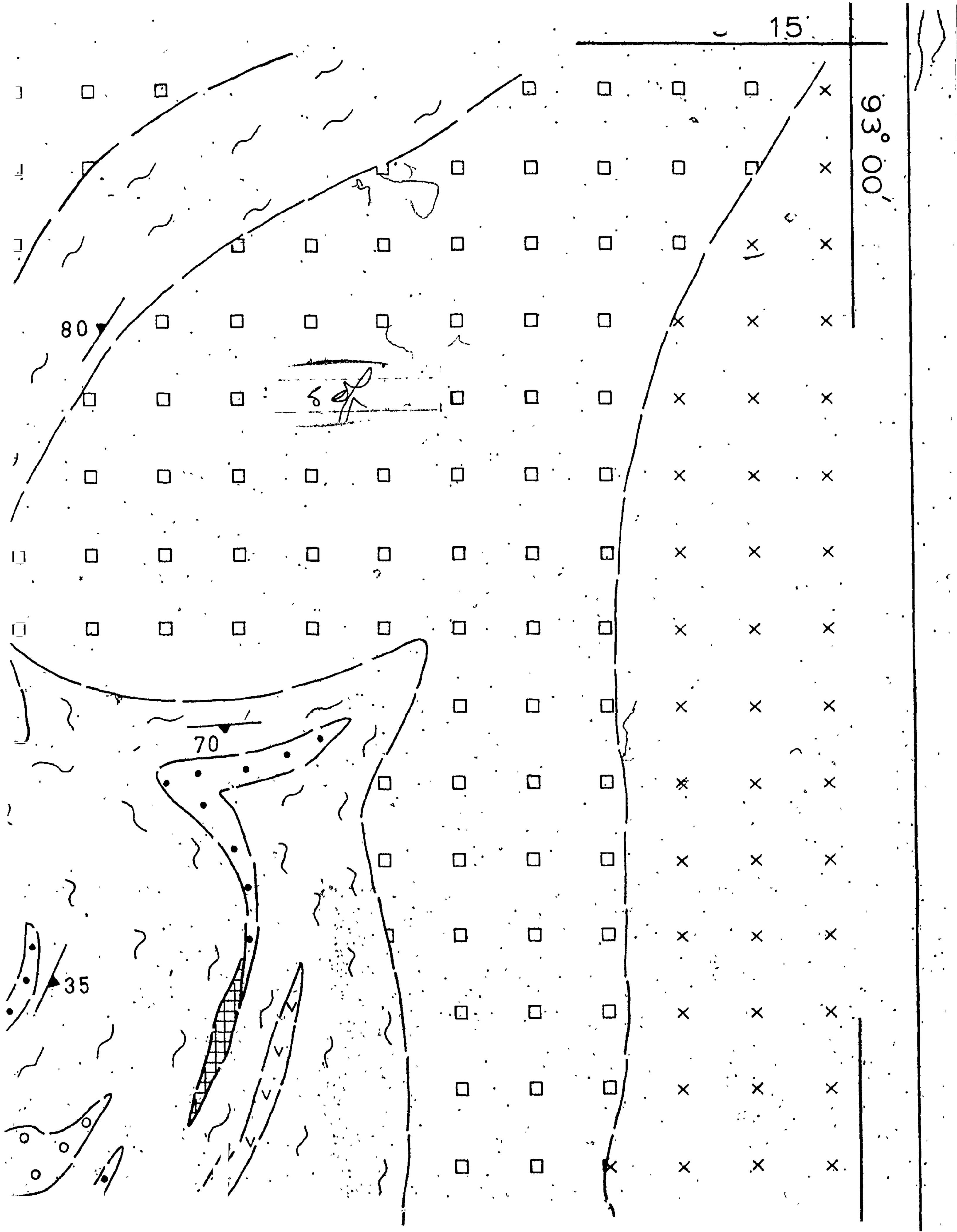
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93° 00′
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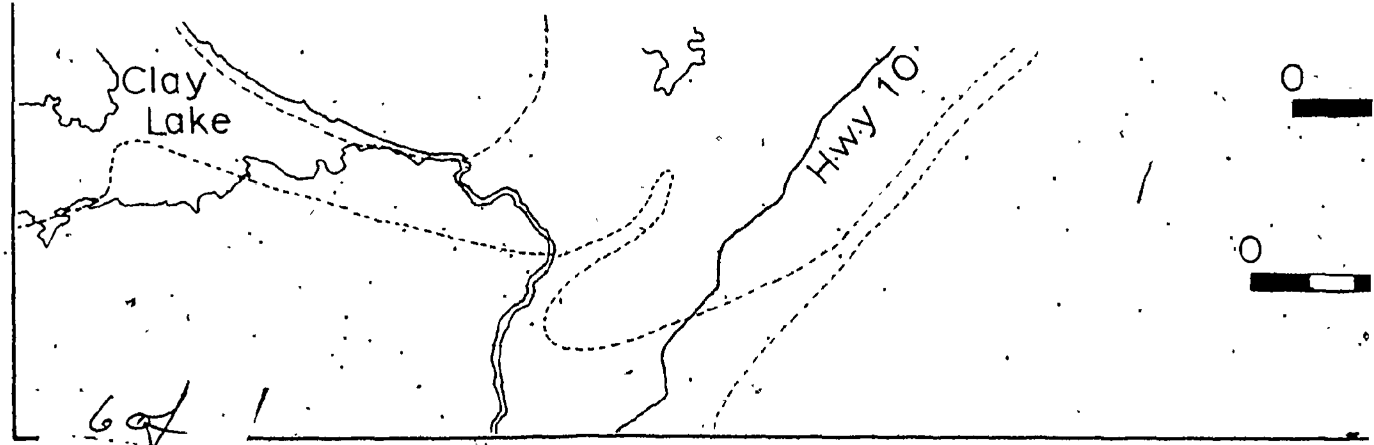
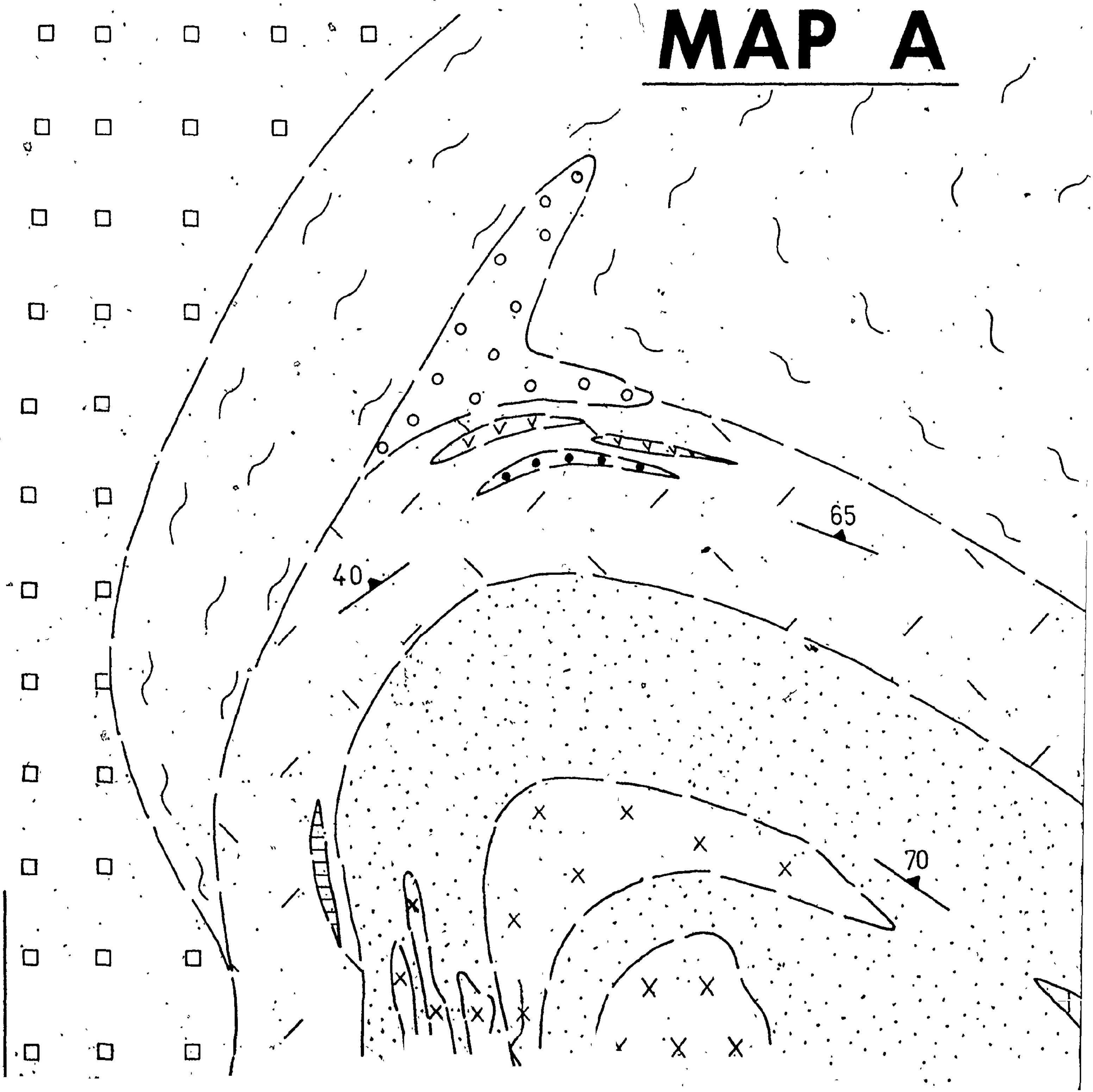
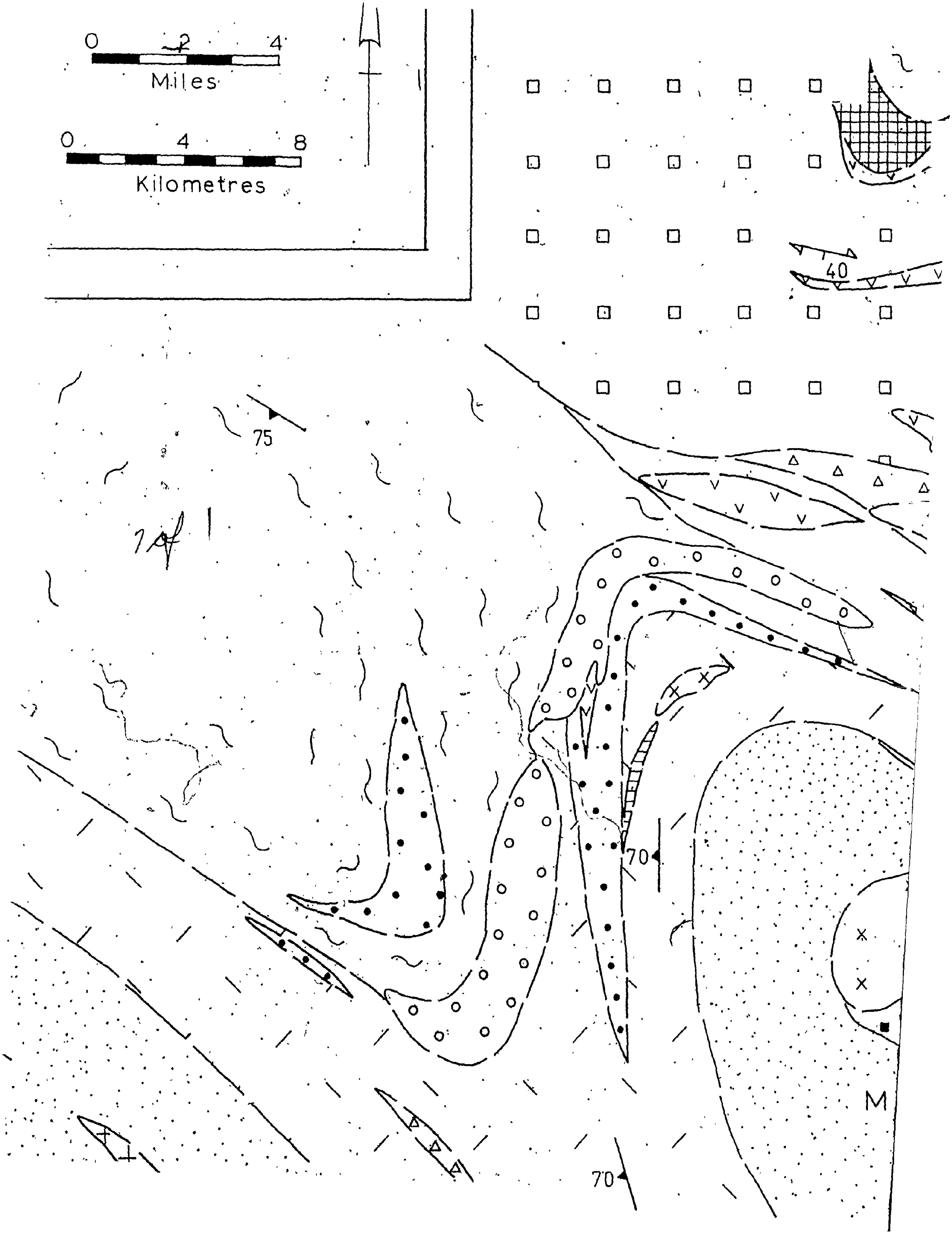


MAP A





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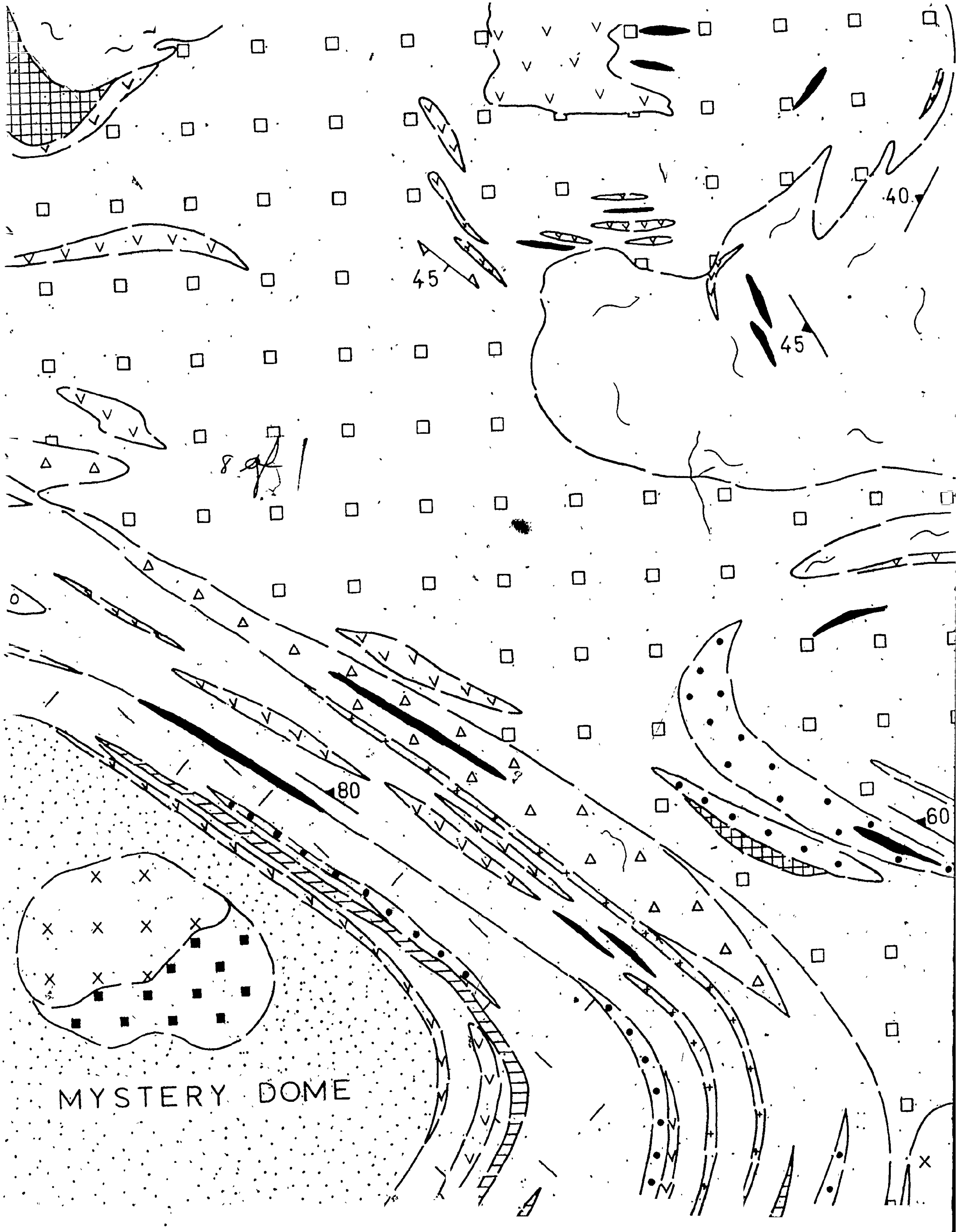
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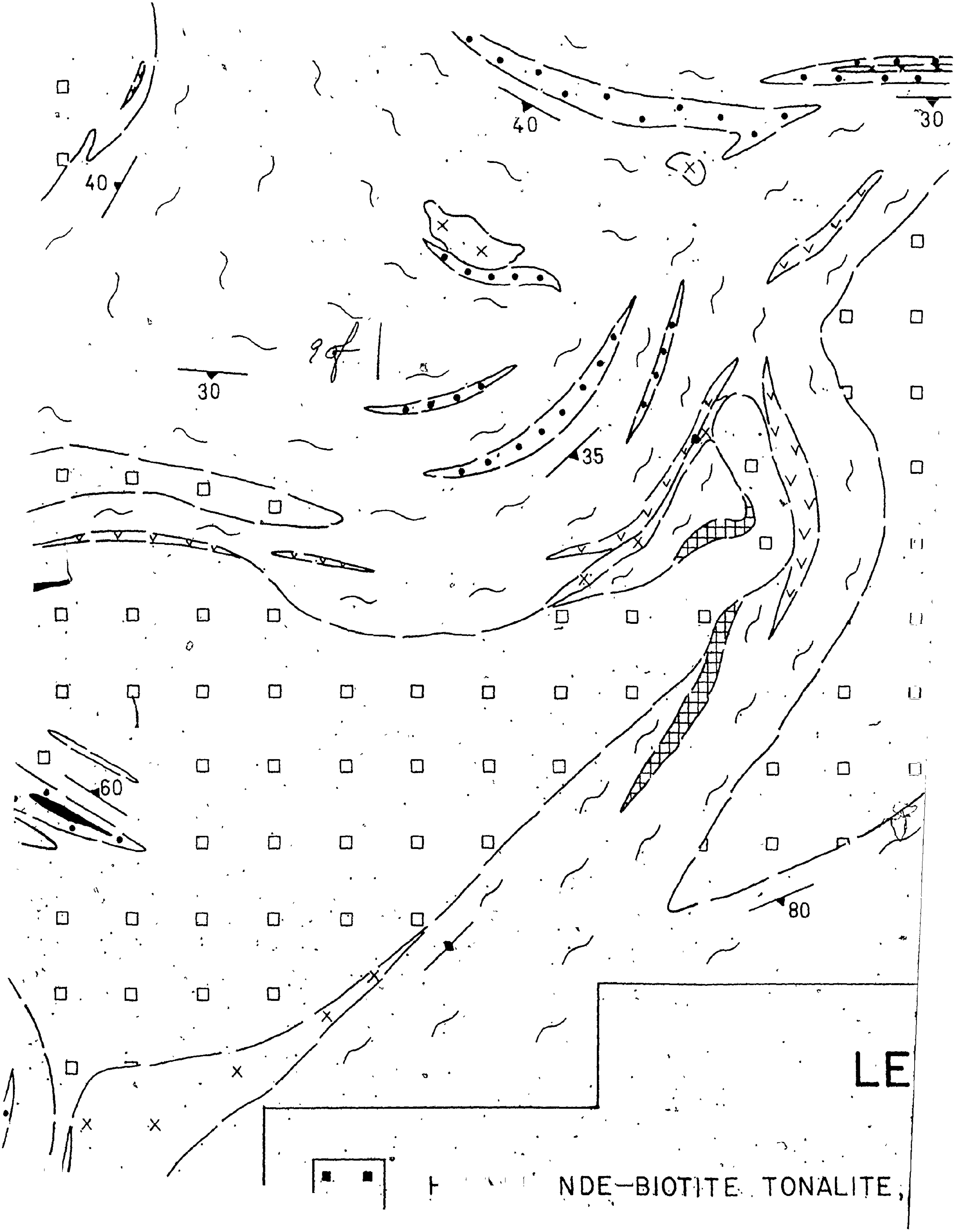
MYSTERY DOME



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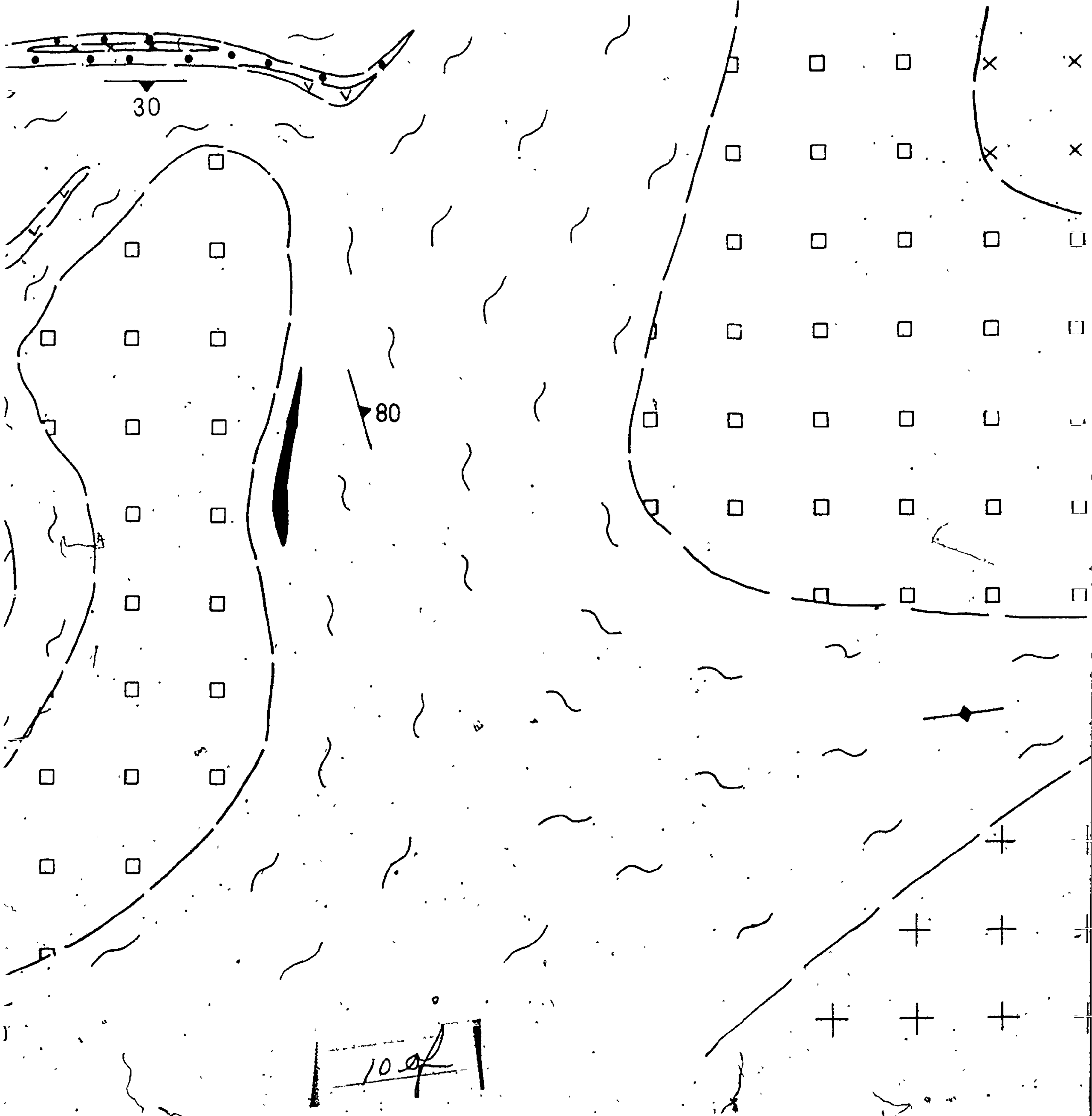
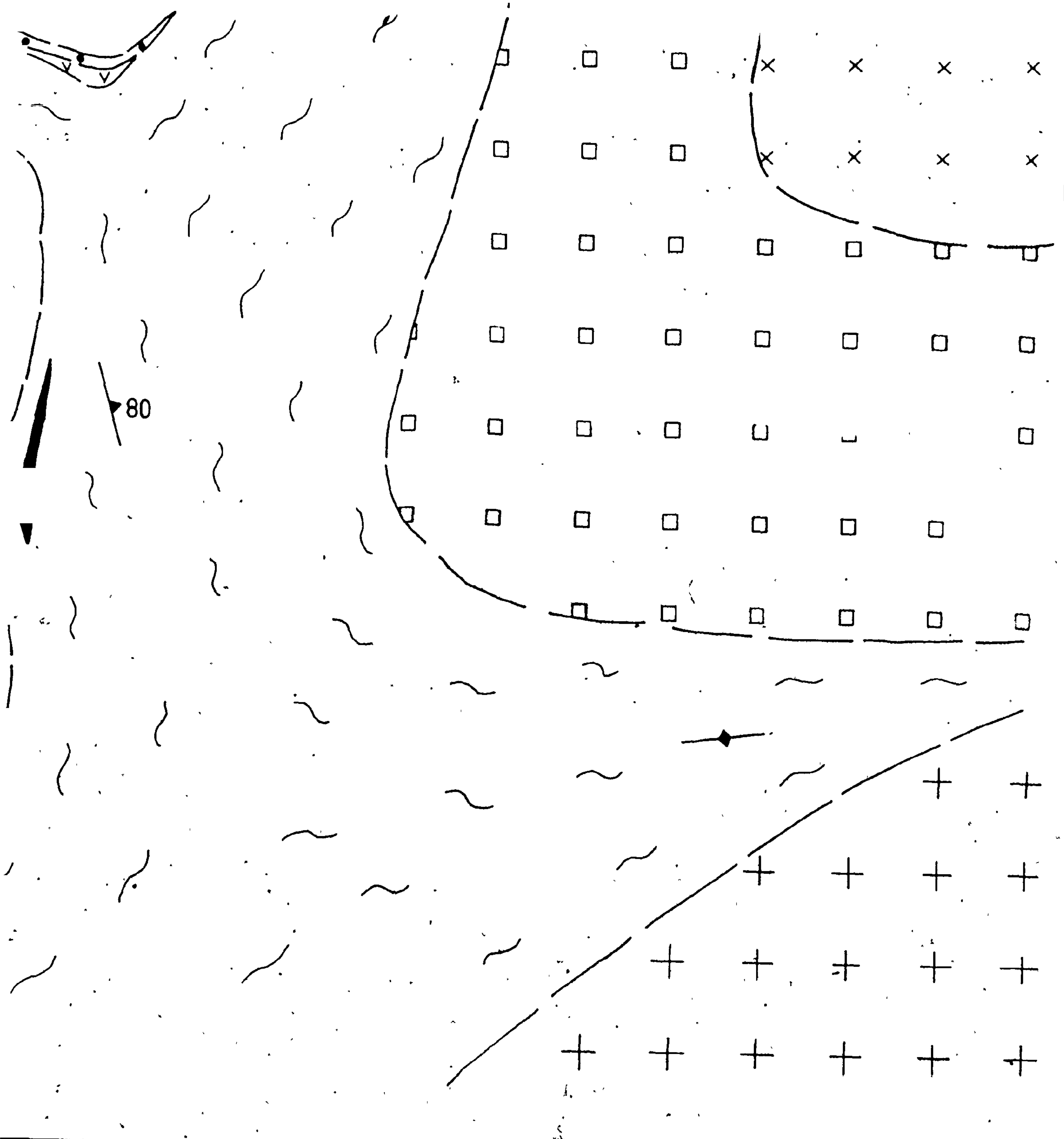
LE
NDE-BIOTITE TONALITE,



LEGEND

NALITE, ABUNDANT GARNET–BIOTITE GNEISS INCLUSIONS.



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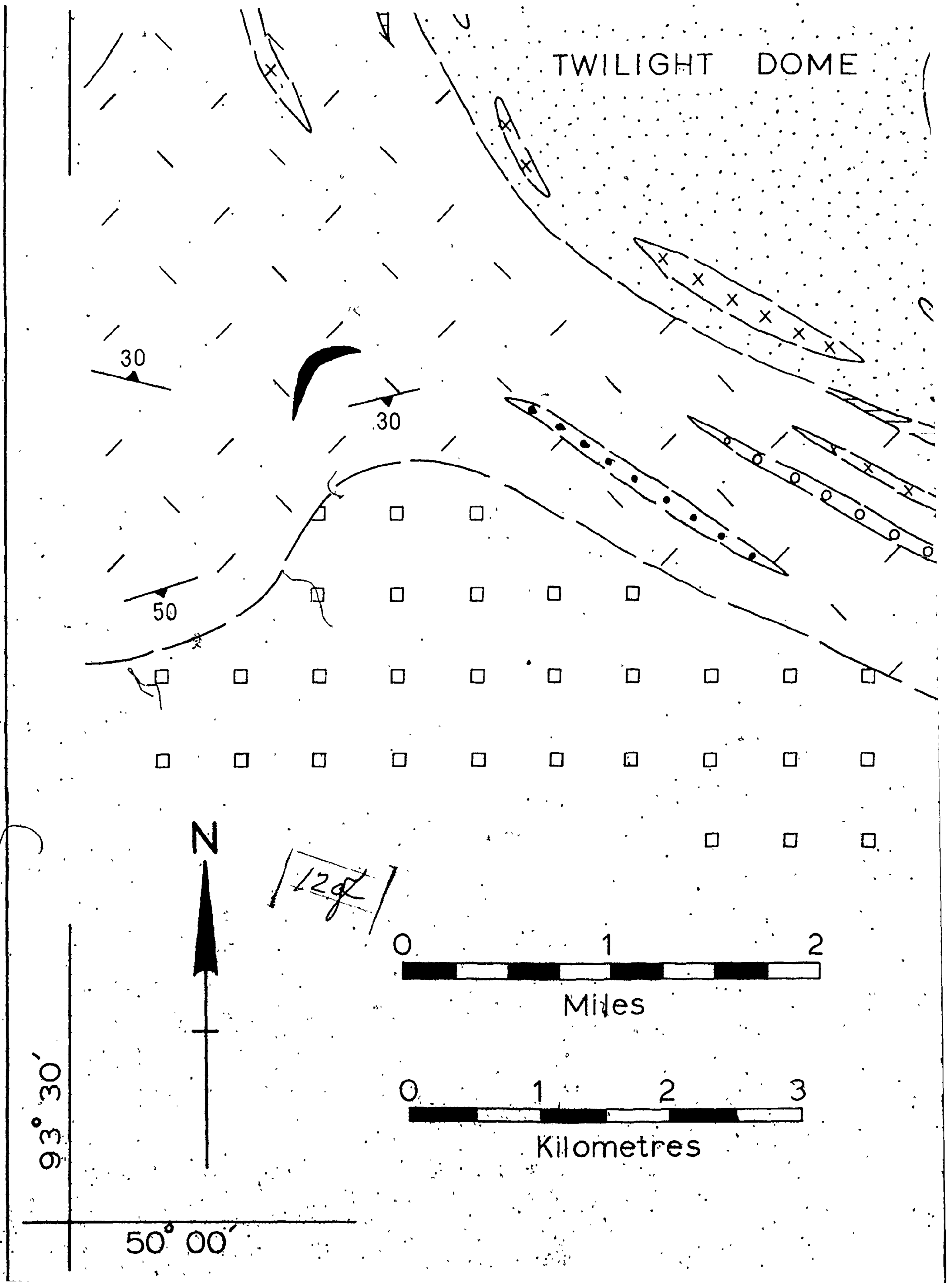
ᑎT GARNET–BIOTITE GNEISS INCLUSIONS.



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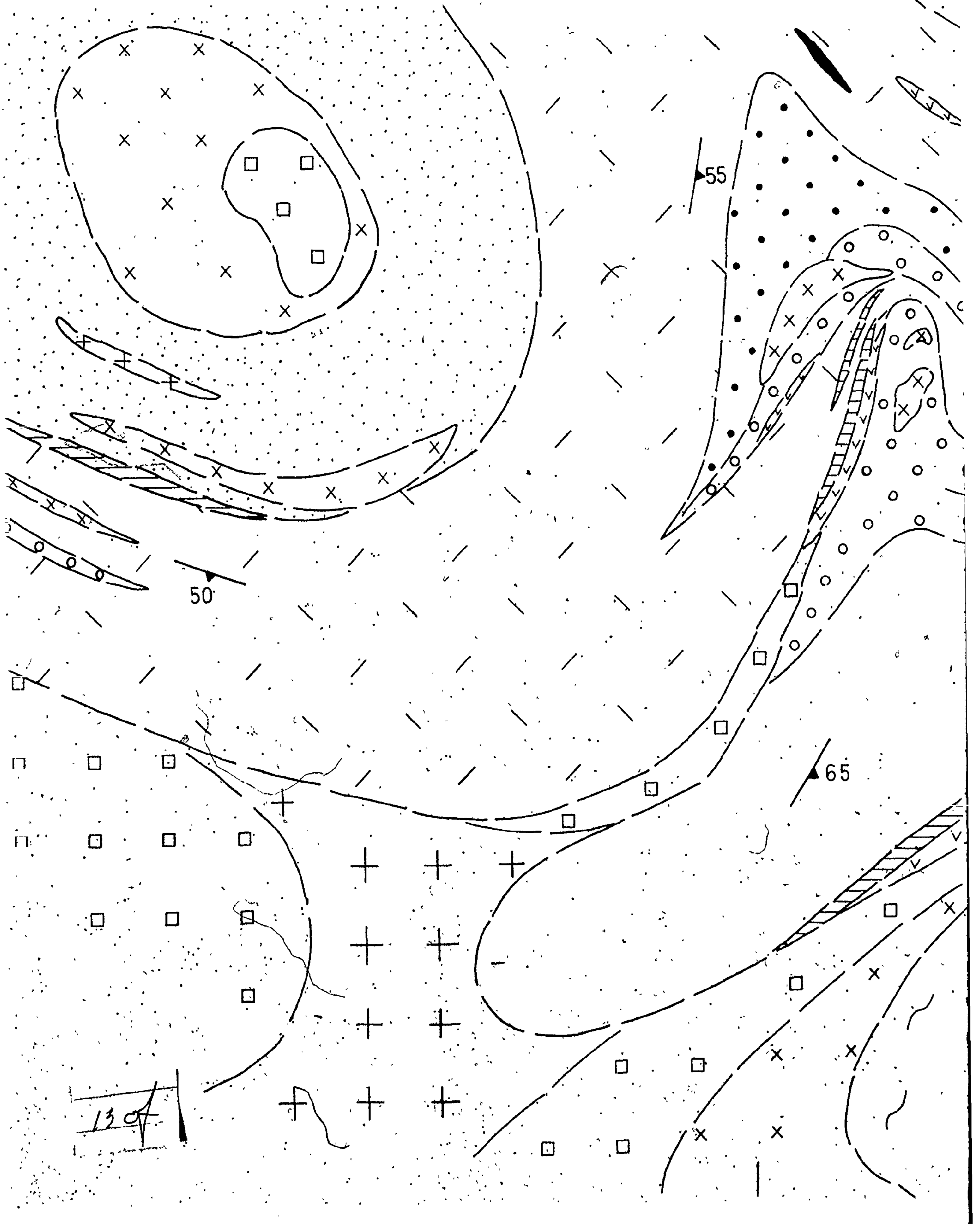
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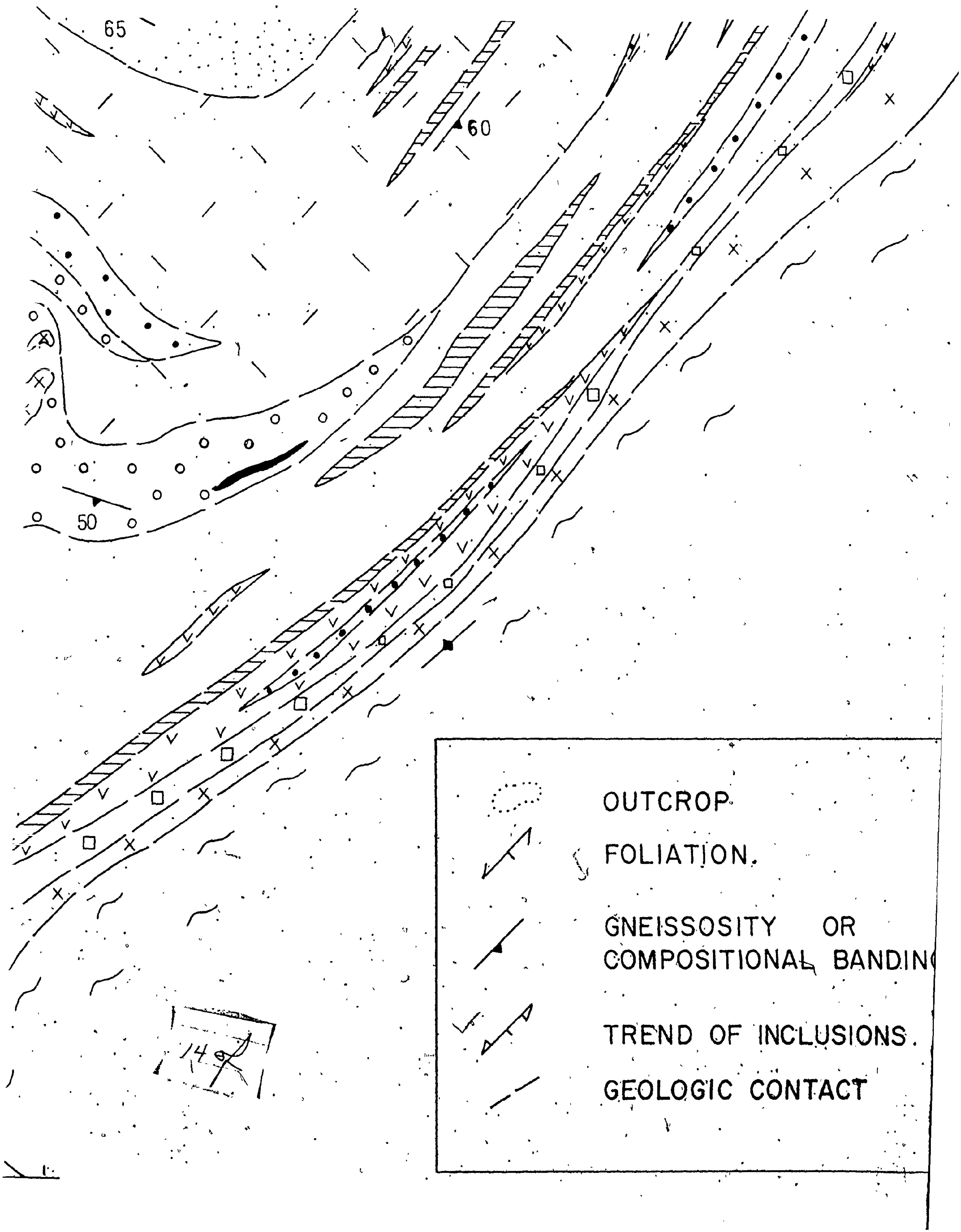
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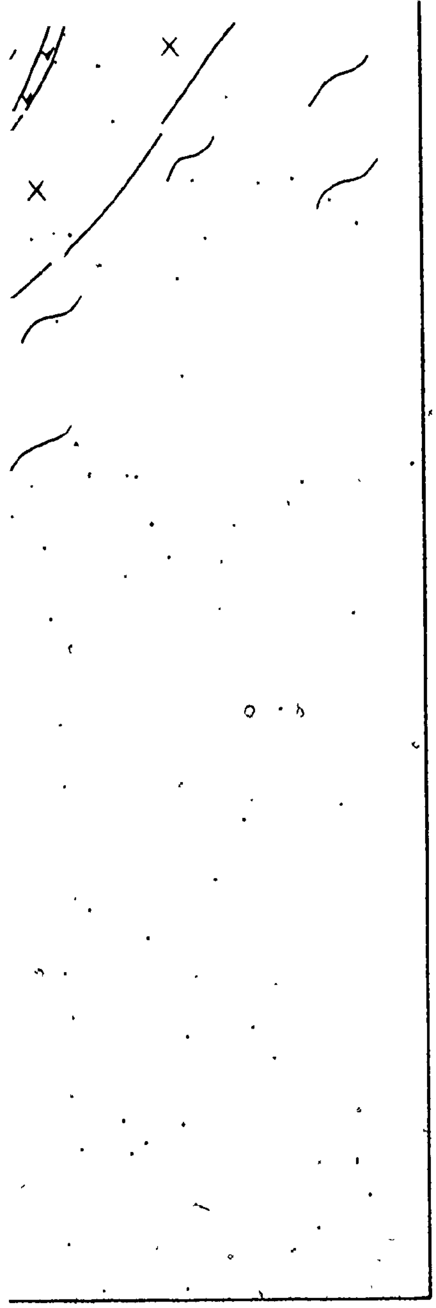
OUTCROP
FOLIATION.
GNEISSOSITY OR
COMPOSITIONAL BANDING
TREND OF INCLUSIONS.
GEOLOGIC CONTACT



LEUCOCRATIC PINK GRANITE.

MASSIVE TO FOLIATED BIOTITE GRAN
INTRUDED BY PINK GRANITE.

WEAKLY FOLIATED BIOTITE TONALIT

FOLIATED BIOTITE–HORNBLENDE QUA

BANDED GARNET–BIOTITE GNEISS. AB
LOCAL CONCORDANT BIOTITE TONALIT

HORNBLENDE–BIOTITE GNEISS WITH M

PYROXENE–BIOTITE–HORNBLENDE GNEI
COMMON AMPHIBOLITE.

AMPHIBOLITE : STRONGLY BANDED,

AMPHIBOLITE : UNBANDED, LOCAL A

COARSE GRAINED, FOLIATED, PYROXENE
RARE MICROCLINE MEGACRYSTS.

STRONGLY FOLIATED GARNET–BIOTIT
RARE MAFIC INCLUSIONS.

STRONGLY FOLIATED, INTERBANDED B
LOCALLY GNEISSIC, MINOR MAFIC IN

STRONGLY FOLIATED TO GNEISSIC B
COMMON MAFIC INCLUSIONS.

TONALITIC TO GRANODIORITIC GNEI

NDING.

NS.

15 of

GRANODIORITE WITH MICROCLINE MEGACRYSTS, } CLIFF LAKE INTRUSION

NALITE TO GRANODIORITE.

QUARTZ DIORITE TO GRANODIORITE.

S. ABUNDANT QUARTZ–FELDSPAR VEINS, MINOR AMPHIBOLITE,
NALITE INTRUSIONS ——— TWILIGHT GNEISS

VITH MINOR AMPHIBOLITE INCLUSIONS.

GNEISS. ABUNDANT QUARTZ–FELDSPAR VEINS,
——— TRAIL LAKE SERIES

NDED, MINOR EPIDOTE RICH PODS.

AL AGMATITE.

OXENE–HORNBLENDE–BIOTITE TONALITE,

BIOTITE TONALITE TO GRANODIORITE,

DED BIOTITE TONALITE AND BIOTITE GRANODIORITE,
IC INCLUSIONS.

} CLAY LAKE GRANITOID SUITE

SSIC BIOTITE TONALITE TO GRANODIORITE,
——— TRANSITIONAL SEQUENCE

GNEISS, ABUNDANT MAFIC INCLUSIONS. ——— CEDAR LAKE G

16 of

C.J. WESTERMAN.

ITE WITH MICROCLINE MEGACRYSTS, } CLIFF LAKE INTRUSION

GRANODIORITE.

RITE TO GRANODIORITE.

T QUARTZ-FELDSPAR VEINS, MINOR AMPHIBOLITE,
USIONS ——————— TWILIGHT GNEISS

MPHIBOLITE INCLUSIONS.

JNDANT QUARTZ-FELDSPAR VEINS,
——— TRAIL LAKE SERIES

EPIDOTE RICH PODS.

12 of 17

LENDE-BIOTITE TONALITE,

LITE TO GRANODIORITE, } CLAY LAKE GRANITOID SUITE

TONALITE AND BIOTITE GRANODIORITE,
S.

TONALITE TO GRANODIORITE,
——— TRANSITIONAL SEQUENCE

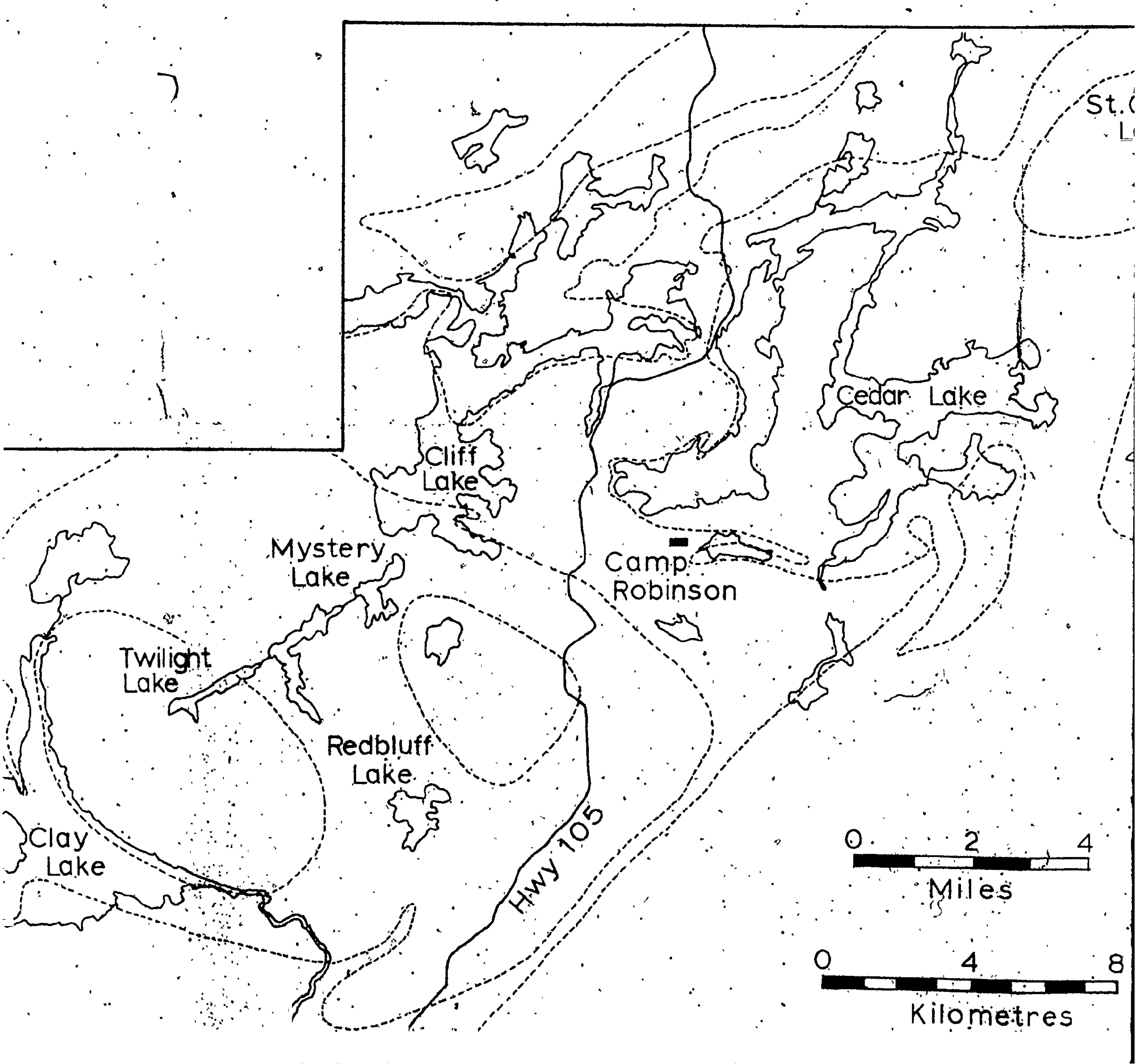
JNDANT MAFIC INCLUSIONS. ——— CEDAR LAKE GNEISS

C.J. WESTERMAN. 1975.

LITHOLOGY AND OUTCROP

CEDAR LAKE — CLAY LAKE AR

1 of



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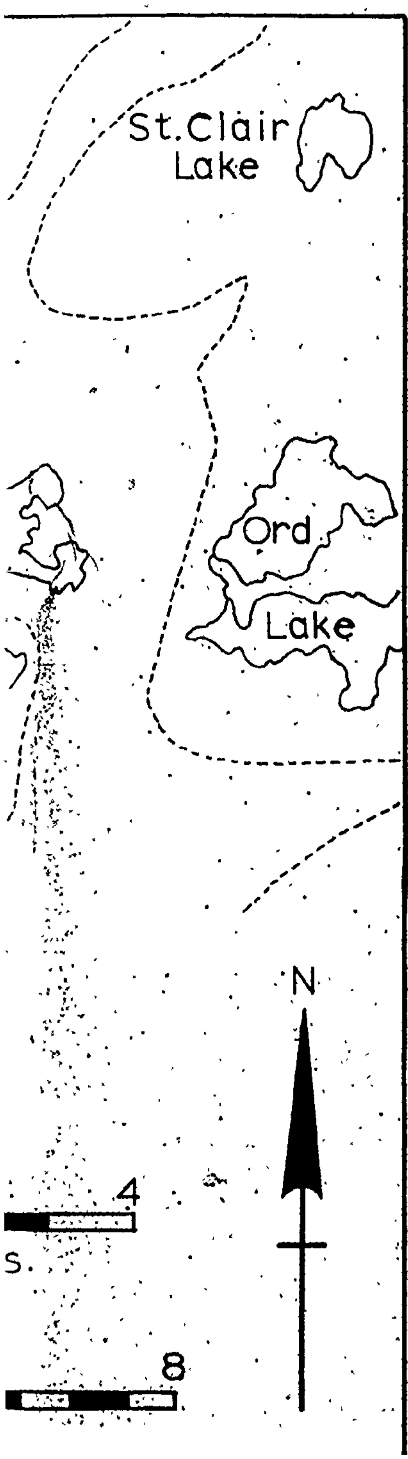

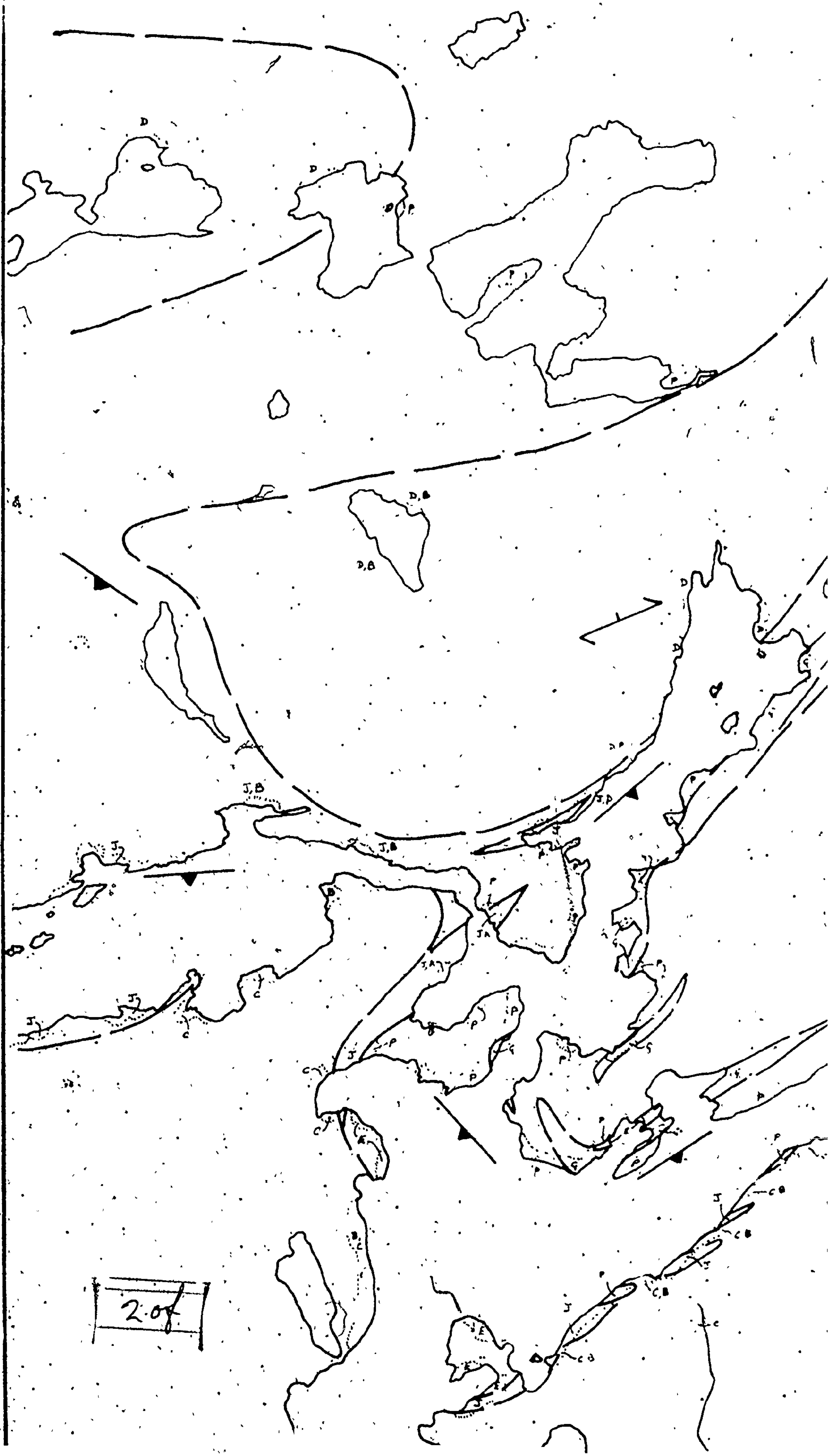

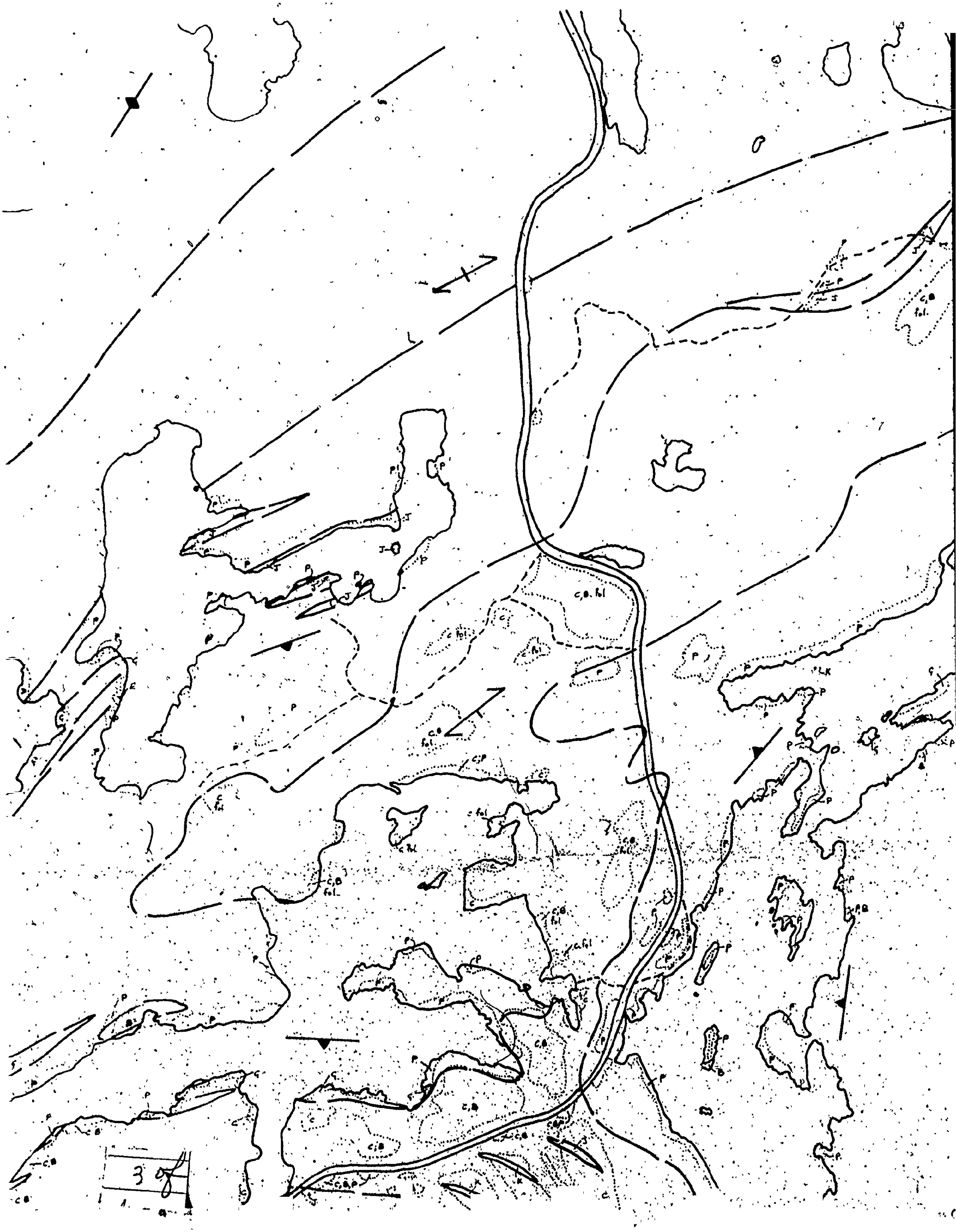

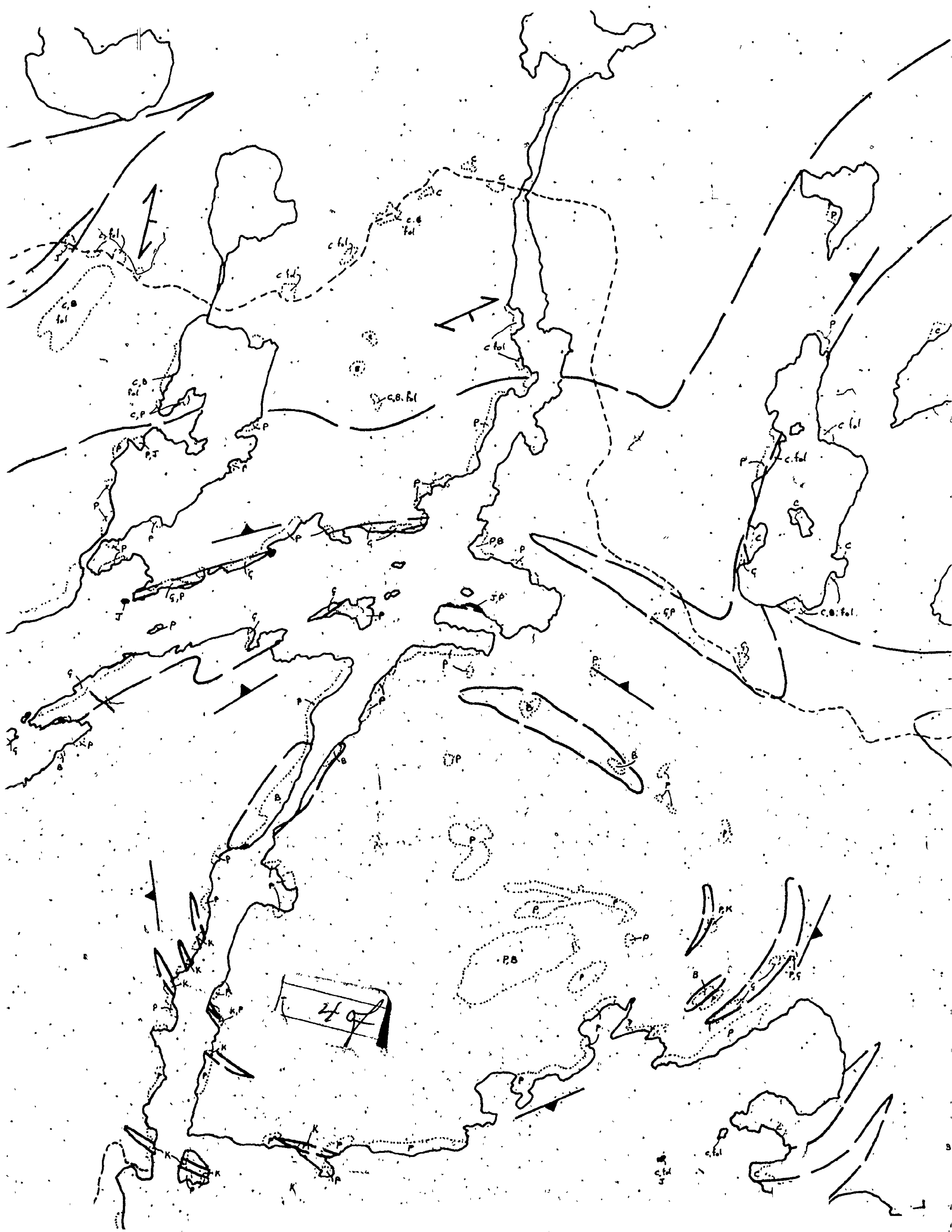
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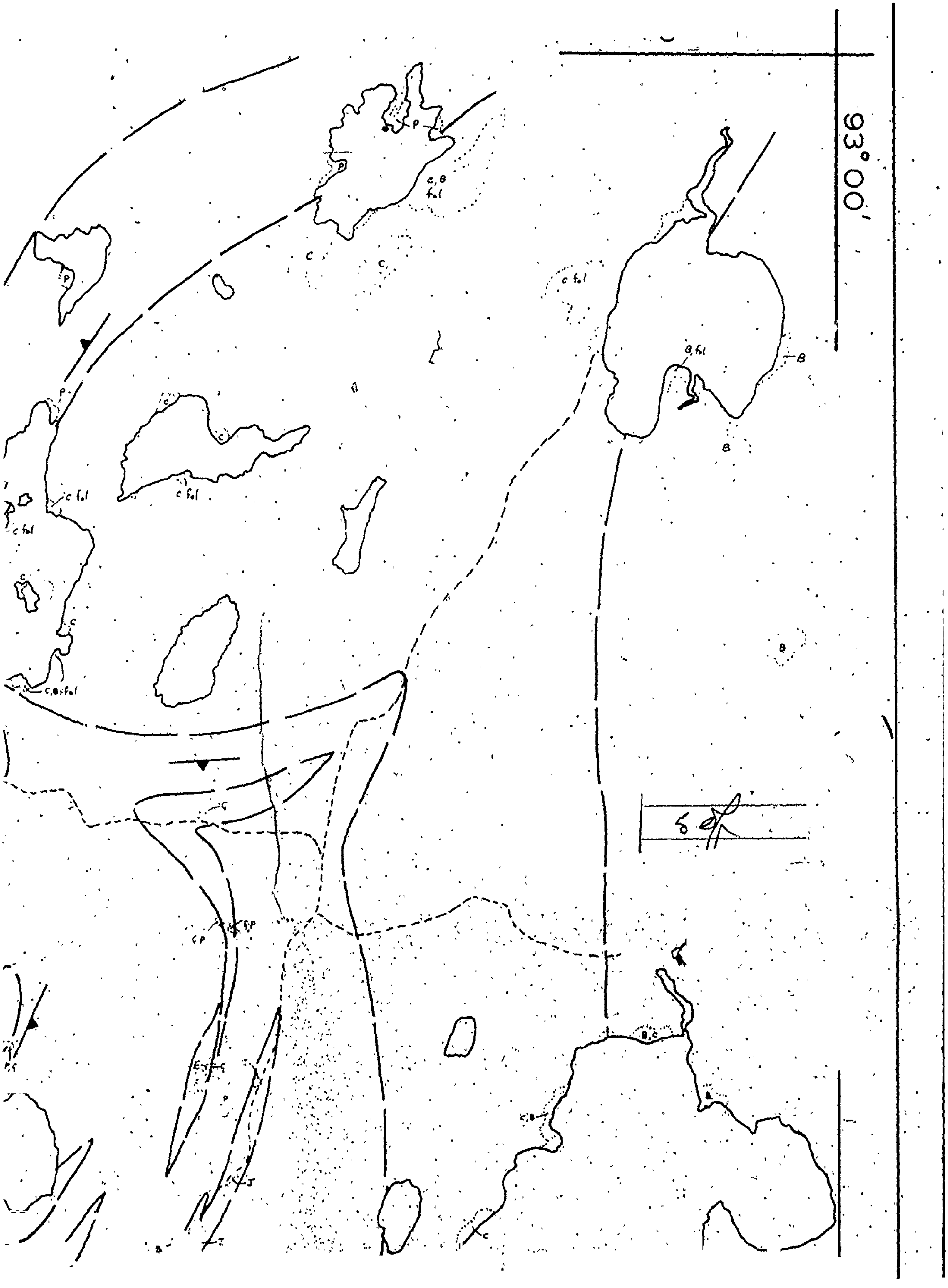
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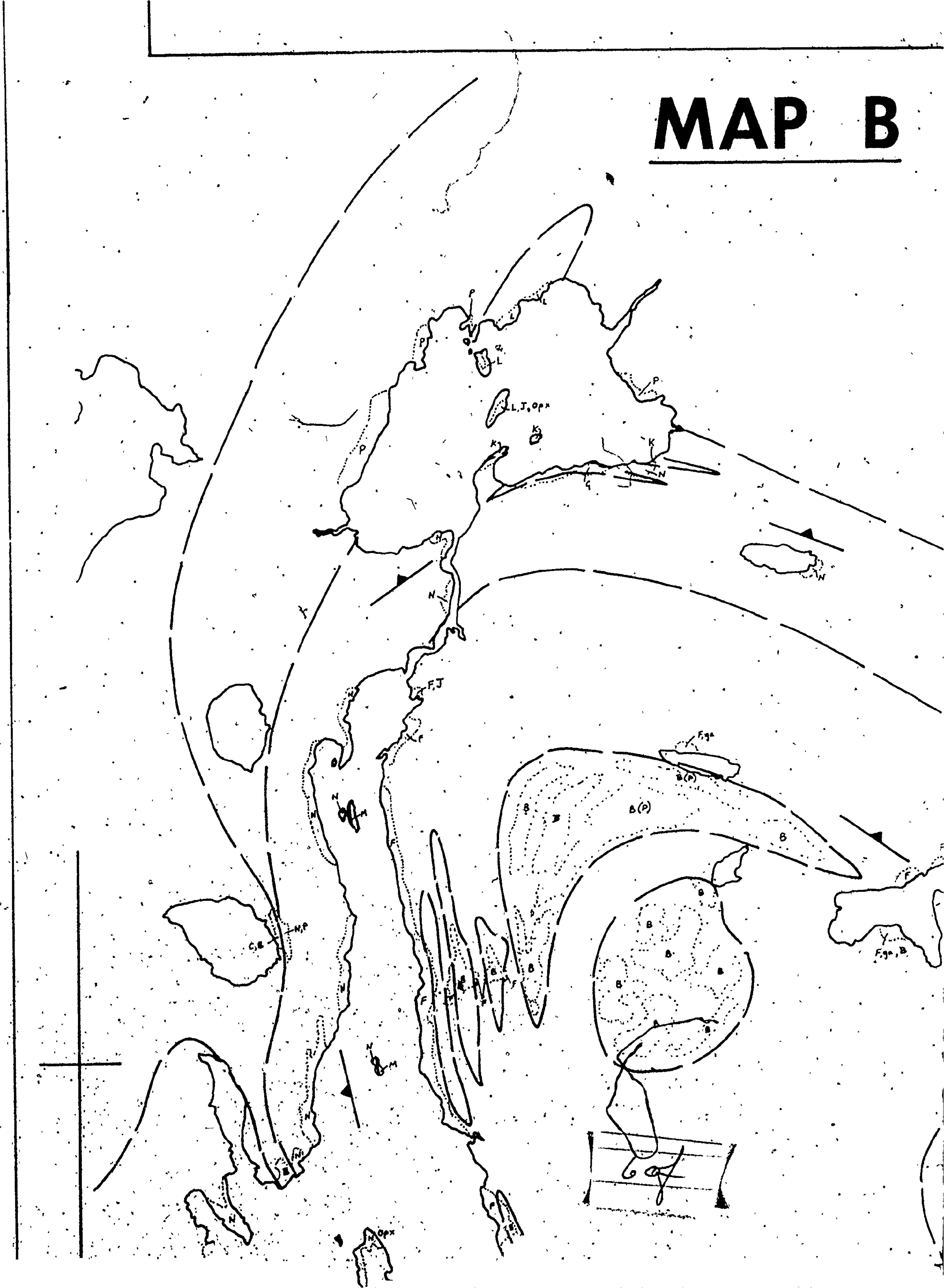
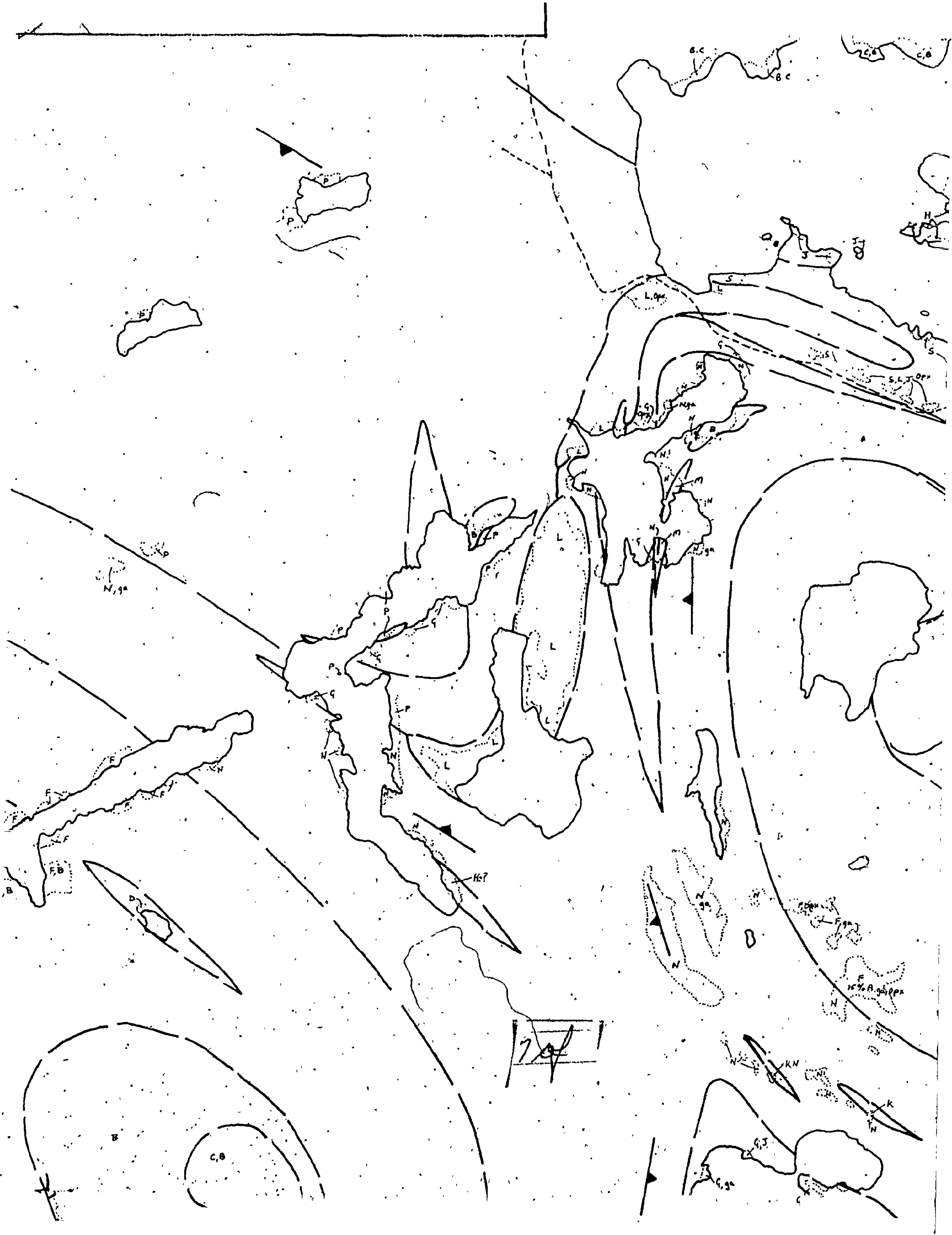
MAP B





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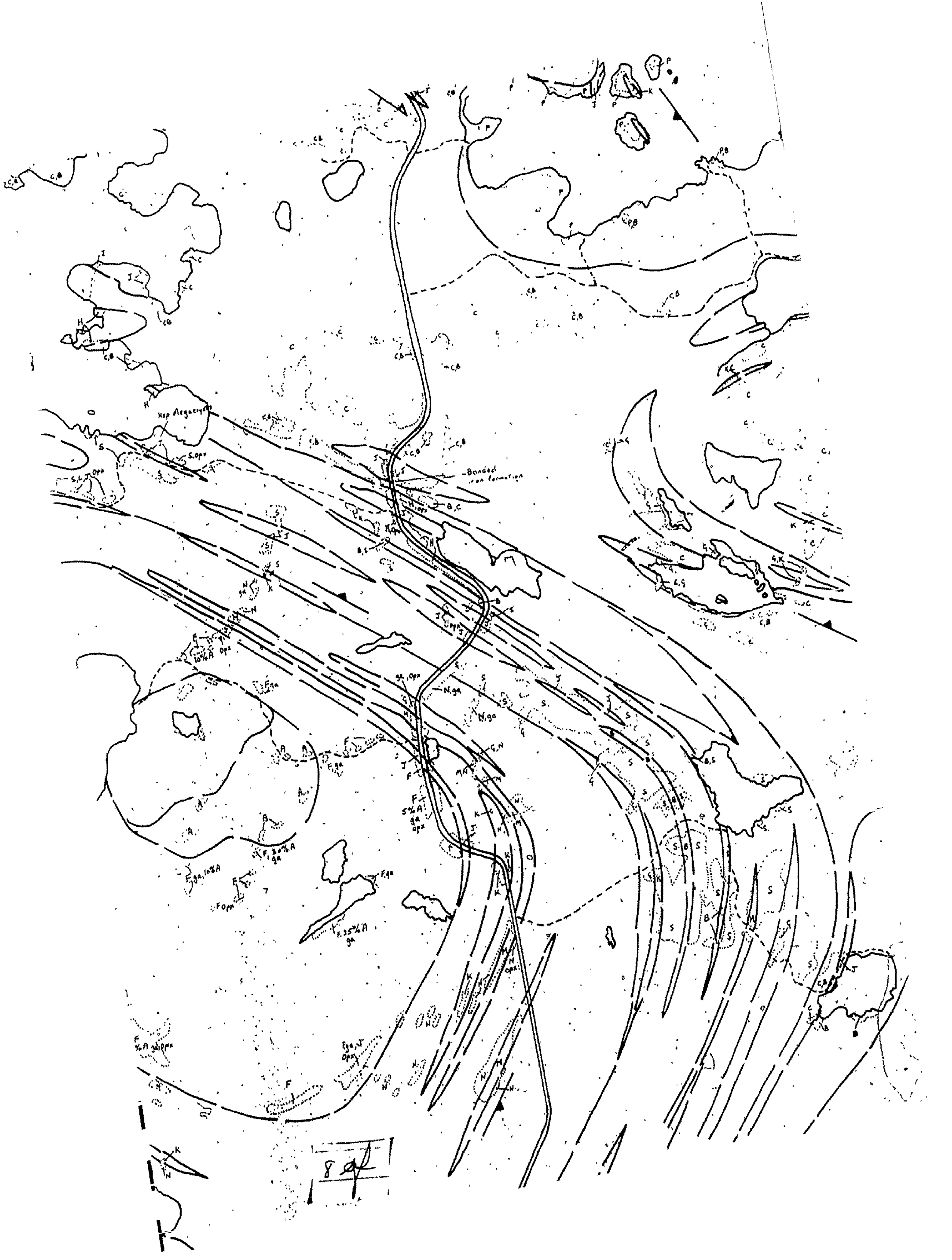
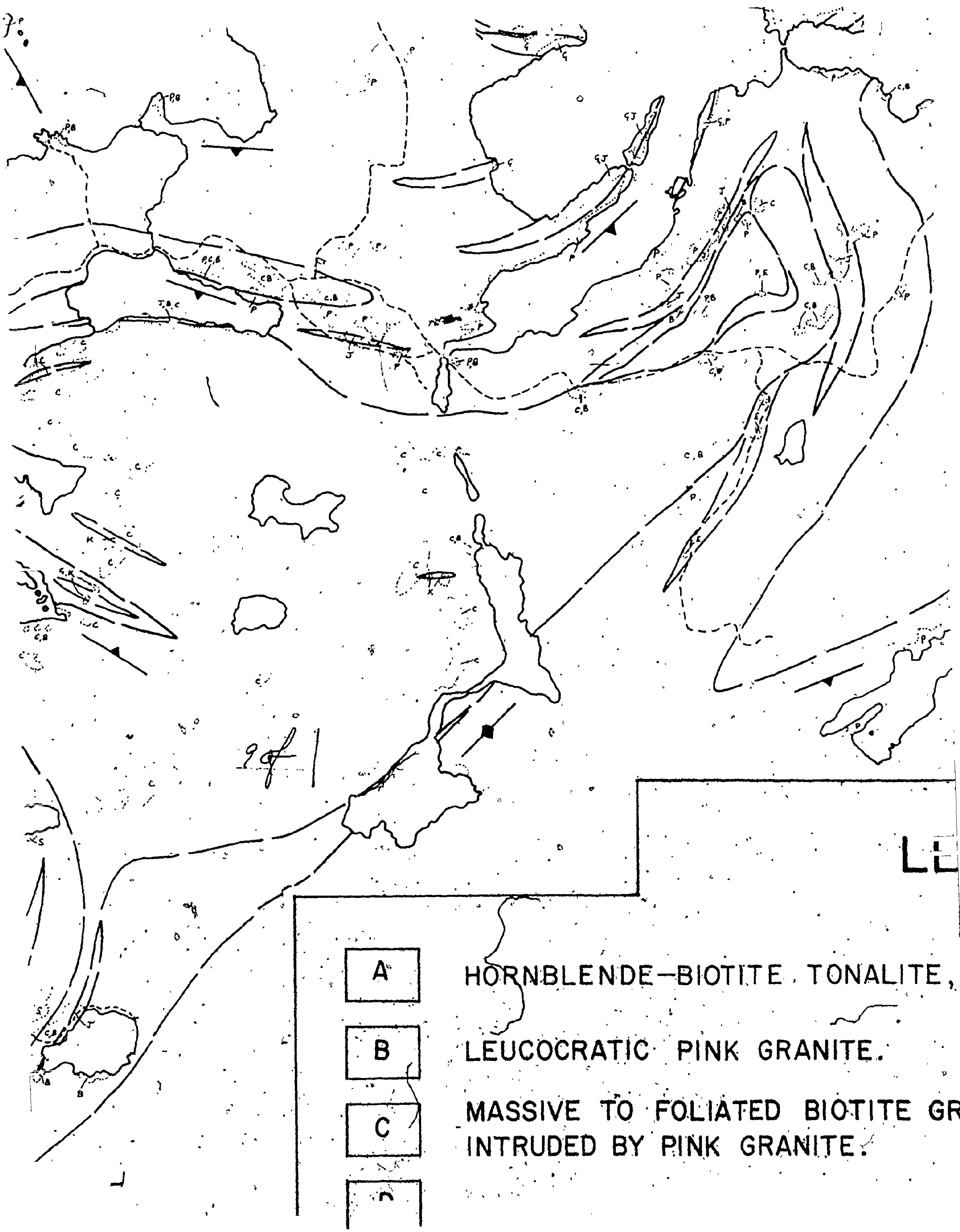
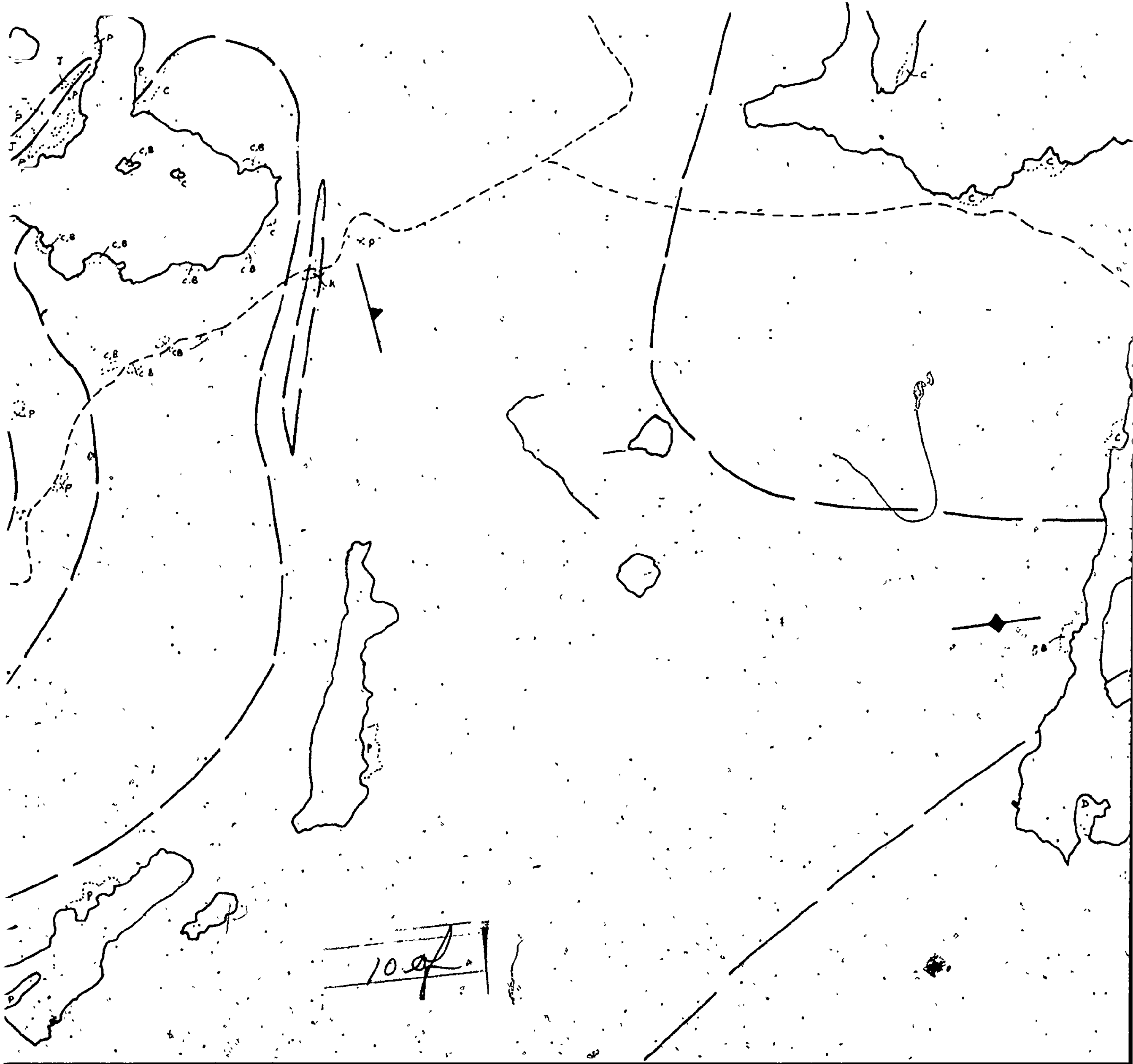


Ksp Megacrysts
Banded iron formation



LE
A
HORNBLENDE—BIOTITE TONALITE,
B
LEUCOCRATIC PINK GRANITE.
C
MASSIVE TO FOLIATED BIOTITE GR
INTRUDED BY PINK GRANITE.

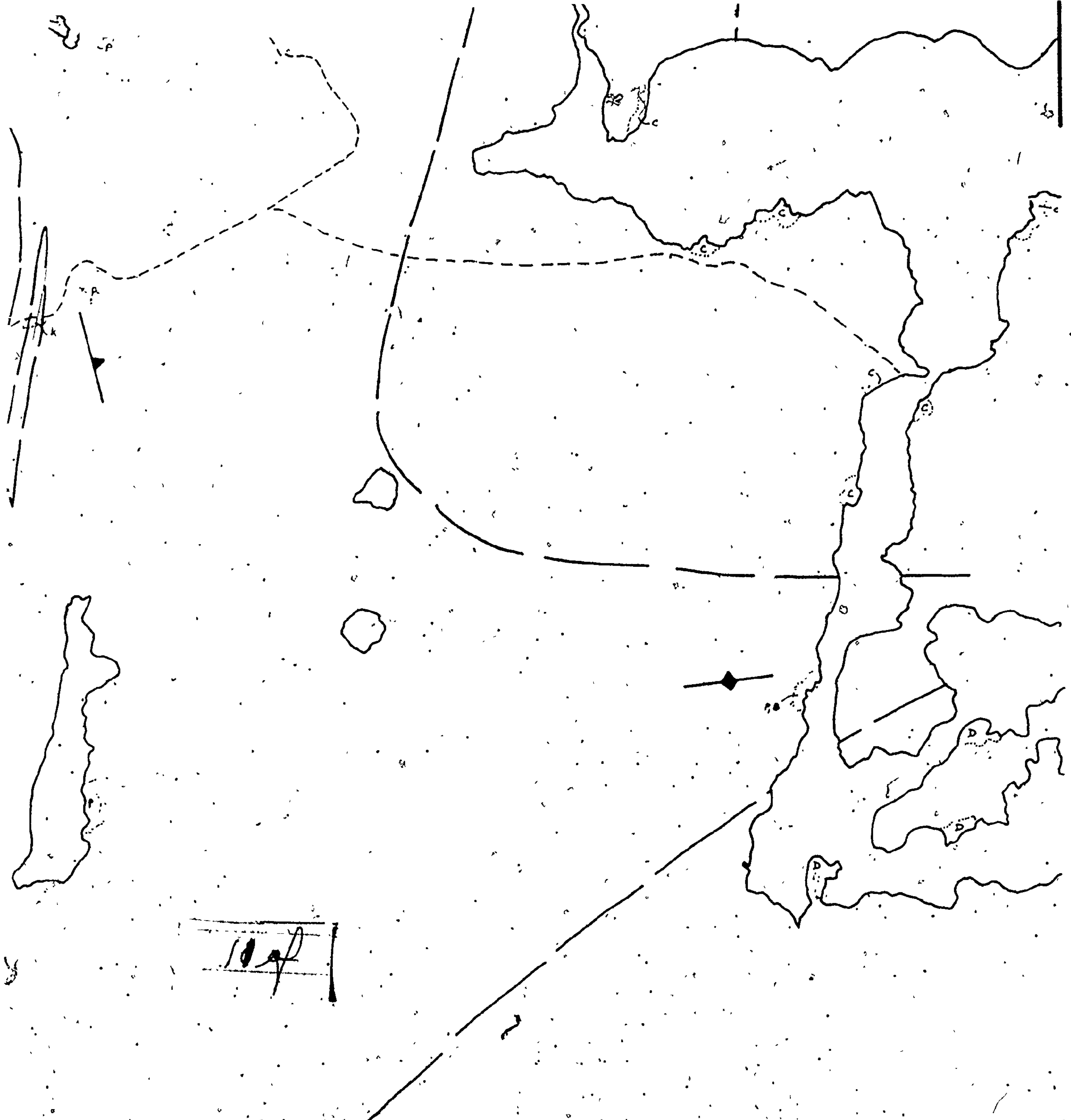


LEGEND

NALITE, ABUNDANT GARNET—BIOTITE GNEISS INCLUSIONS.

E.

CLIFF LA



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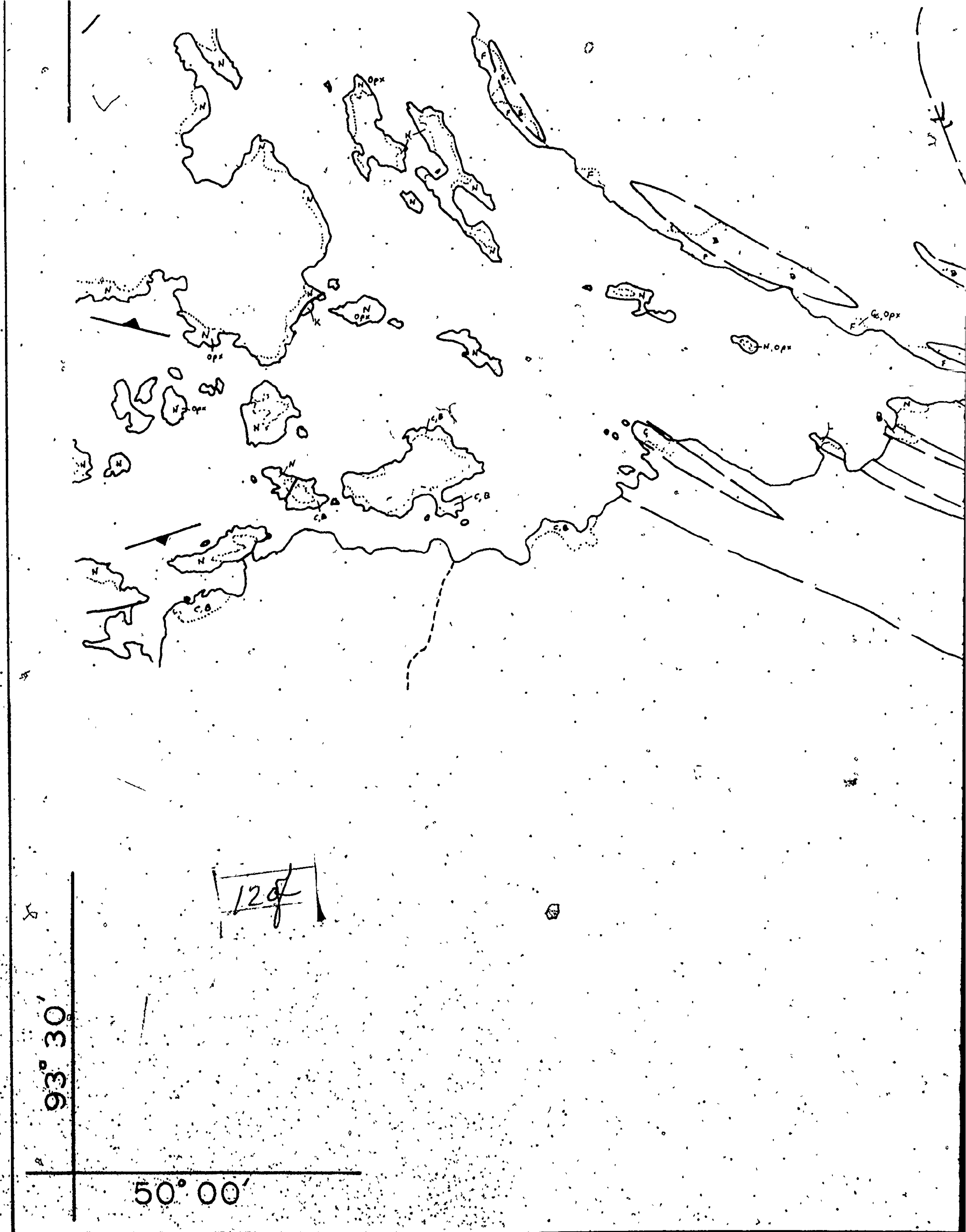
IT GARNET—BIOTITE GNEISS INCLUSIONS.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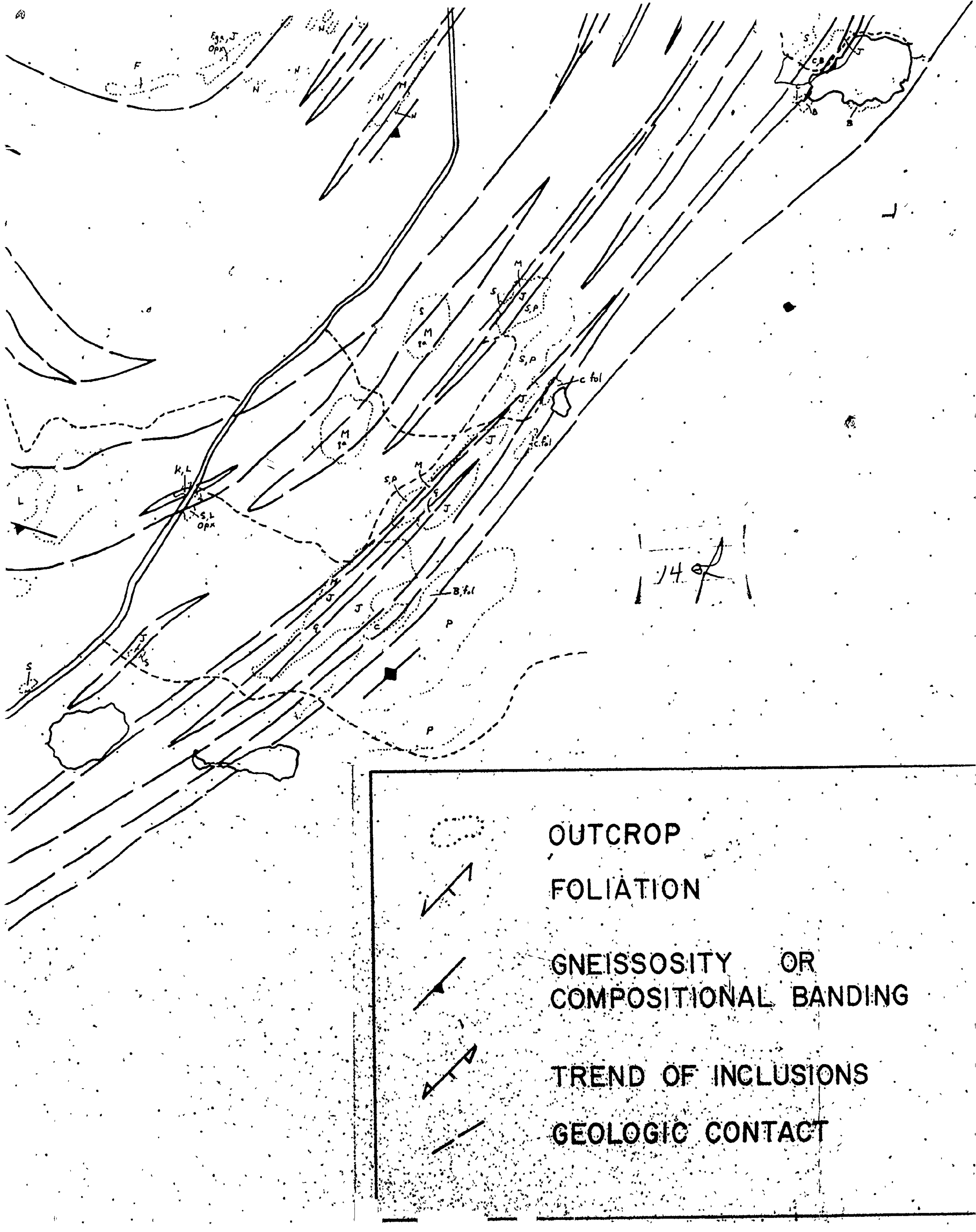
OUTCROP
FOLIATION
GNEISSOSITY OR
COMPOSITIONAL BANDING
TREND OF INCLUSIONS
GEOLOGIC CONTACT

C — MASSIVE TO FOLIATED BIOTITE GRANODI
INTRUDED BY PINK GRANITE.

D — WEAKLY FOLIATED BIOTITE TONALITE

E — FOLIATED BIOTITE—HORNBLENDE QUARTZ

F — BANDED GARNET—BIOTITE GNEISS. ABUND
LOCAL CONCORDANT BIOTITE TONALITE I

G — HORNBLENDE—BIOTITE GNEISS WITH MINO

H — PYROXENE—BIOTITE—HORNBLENDE GNEISS.
COMMON AMPHIBOLITE.

I — AMPHIBOLITE : STRONGLY BANDED, MIN

J — AMPHIBOLITE : UNBANDED, LOCAL AGMA

K — COARSE GRAINED, FOLIATED, PYROXENE—HO
RARE MICROCLINE MEGACRYSTS.

L — STRONGLY FOLIATED GARNET—BIOTITE T
RARE MAFIC INCLUSIONS.

M — STRONGLY FOLIATED, INTERBANDED BIOTI
LOCALLY GNEISSIC, MINOR MAFIC INCLUS

N — STRONGLY FOLIATED TO GNEISSIC BIOTI
COMMON MAFIC INCLUSIONS.

O — TONALITIC TO GRANODIORITIC GNEISS,

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:ANODIORITE WITH MICROCLINE MEGACRYSTS, } CLIFF LAKE INTRUSION

.ITE TO GRANODIORITE.

RTZ DIORITE TO GRANODIORITE.

ABUNDANT QUARTZ–FELDSPAR VEINS, MINOR AMPHIBOLITE,
.ITE INTRUSIONS ———————— TWILIGHT GNEISS

MINOR AMPHIBOLITE INCLUSIONS.

EISS. ABUNDANT QUARTZ–FELDSPAR VEINS,
———————— TRAIL LAKE SERIES

), MINOR EPIDOTE RICH PODS.

AGMATITE.

NE–HORNBLENDE–BIOTITE TONALITE,

ITE TONALITE TO GRANODIORITE,

BIOTITE TONALITE AND BIOTITE GRANODIORITE,
NCLUSIONS. } CLAY LAKE GRANITOID SUITE

BIOTITE TONALITE TO GRANODIORITE,
———————— TRANSITIONAL SEQUENCE

:ISS, ABUNDANT MAFIC INCLUSIONS. ———————— CEDAR LAKE GNEIS

C.J. WESTERMAN. 19/

TE WITH MICROCLINE MEGACRYSTS, } CLIFF LAKE INTRUSION

GRANODIORITE.

ITE TO GRANODIORITE.

QUARTZ–FELDSPAR VEINS, MINOR AMPHIBOLITE,
JSIONS ———— TWILIGHT GNEISS

MPHIBOLITE INCLUSIONS.

NDANT QUARTZ–FELDSPAR VEINS,
———— TRAIL LAKE SERIES

EPIDOTE RICH PODS.

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LENDE–BIOTITE TONALITE,

ITE TO GRANODIORITE, } CLAY LAKE GRANITOID SUITE

ONALITE AND BIOTITE GRANODIORITE,

12 of 17

ONALITE TO GRANODIORITE,
———— TRANSITIONAL SEQUENCE

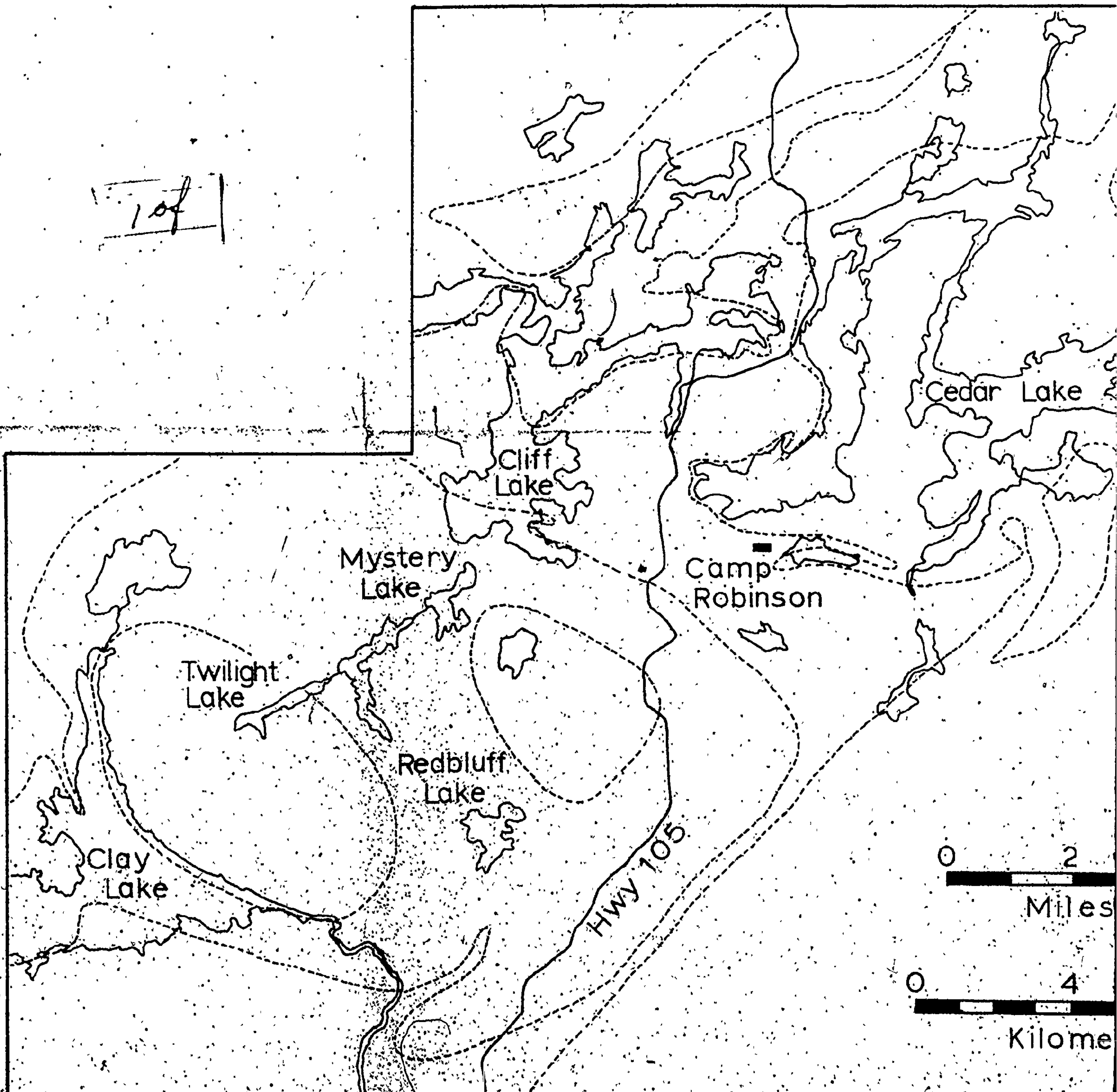
NDANT MAFIC INCLUSIONS. ———— CEDAR LAKE GNEISS

C.J. WESTERMAN, 1975.

MINOR STRUCTURES

CEDAR LAKE — CLAY LAKE

1 of



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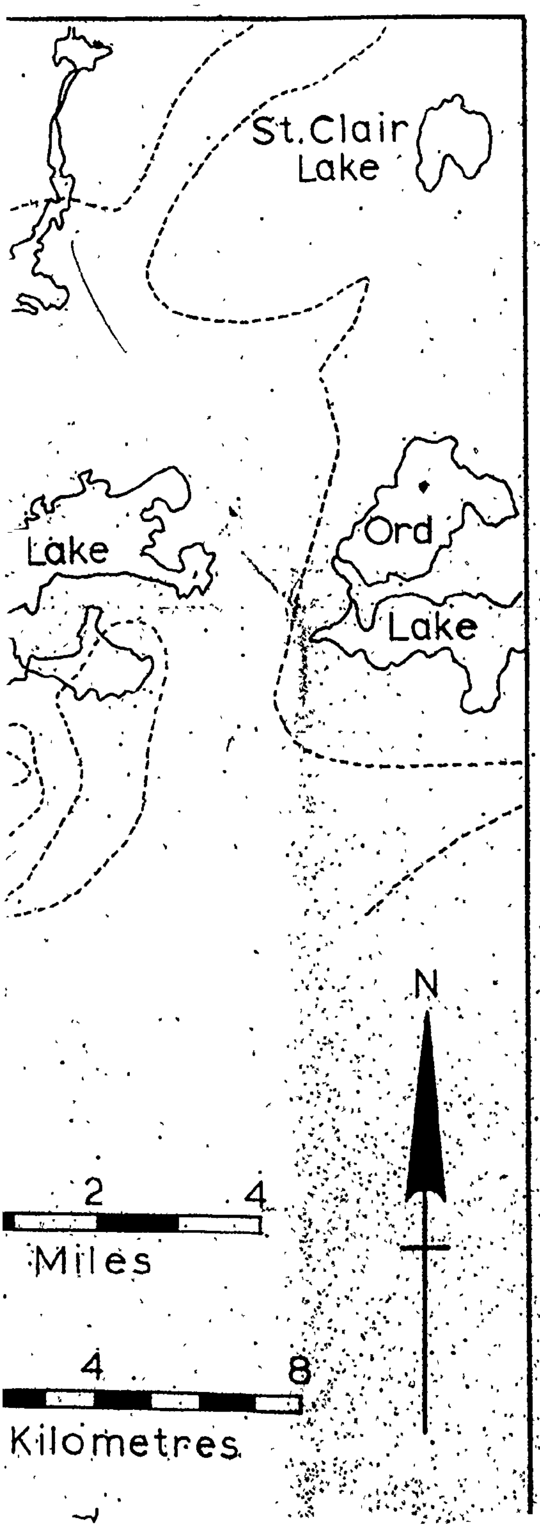

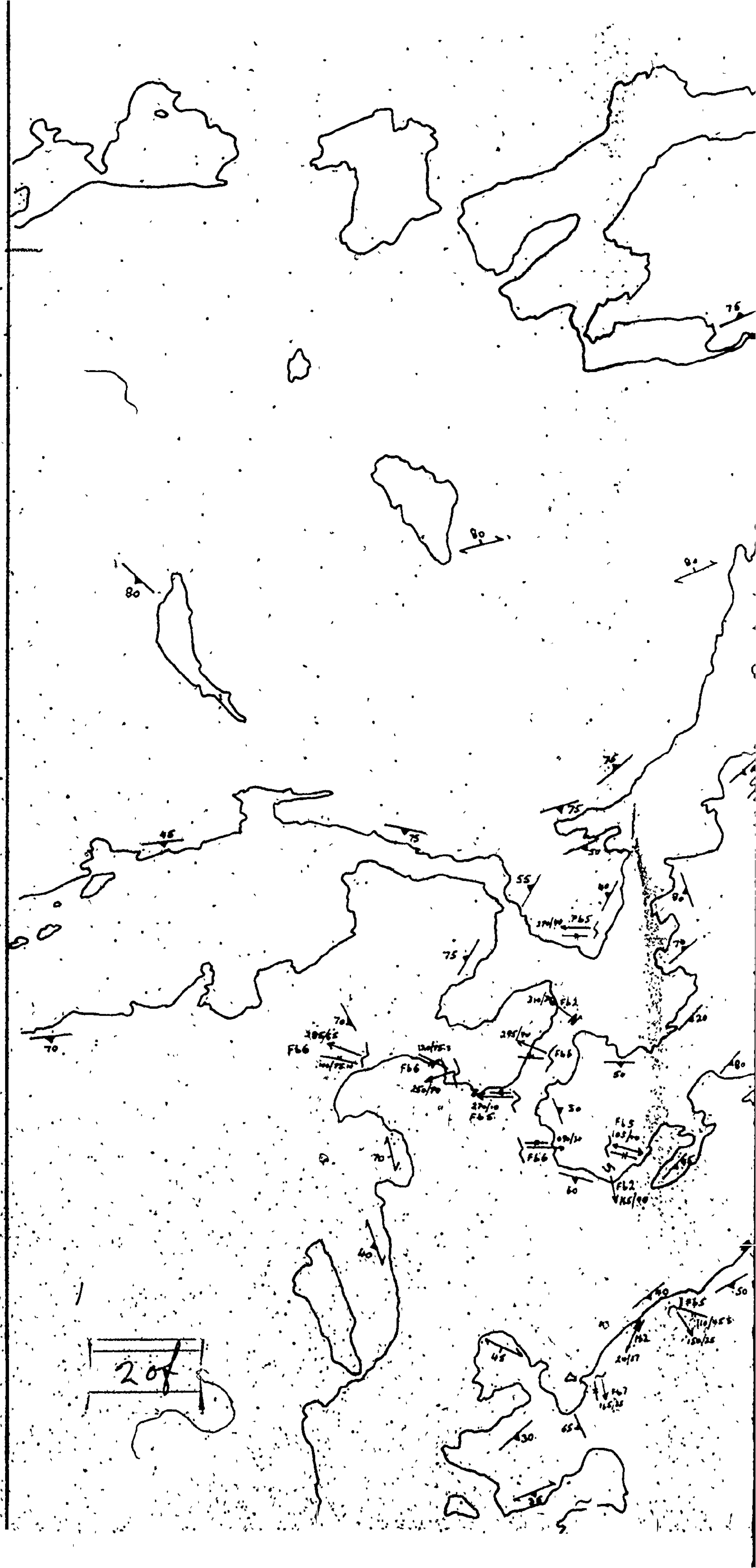

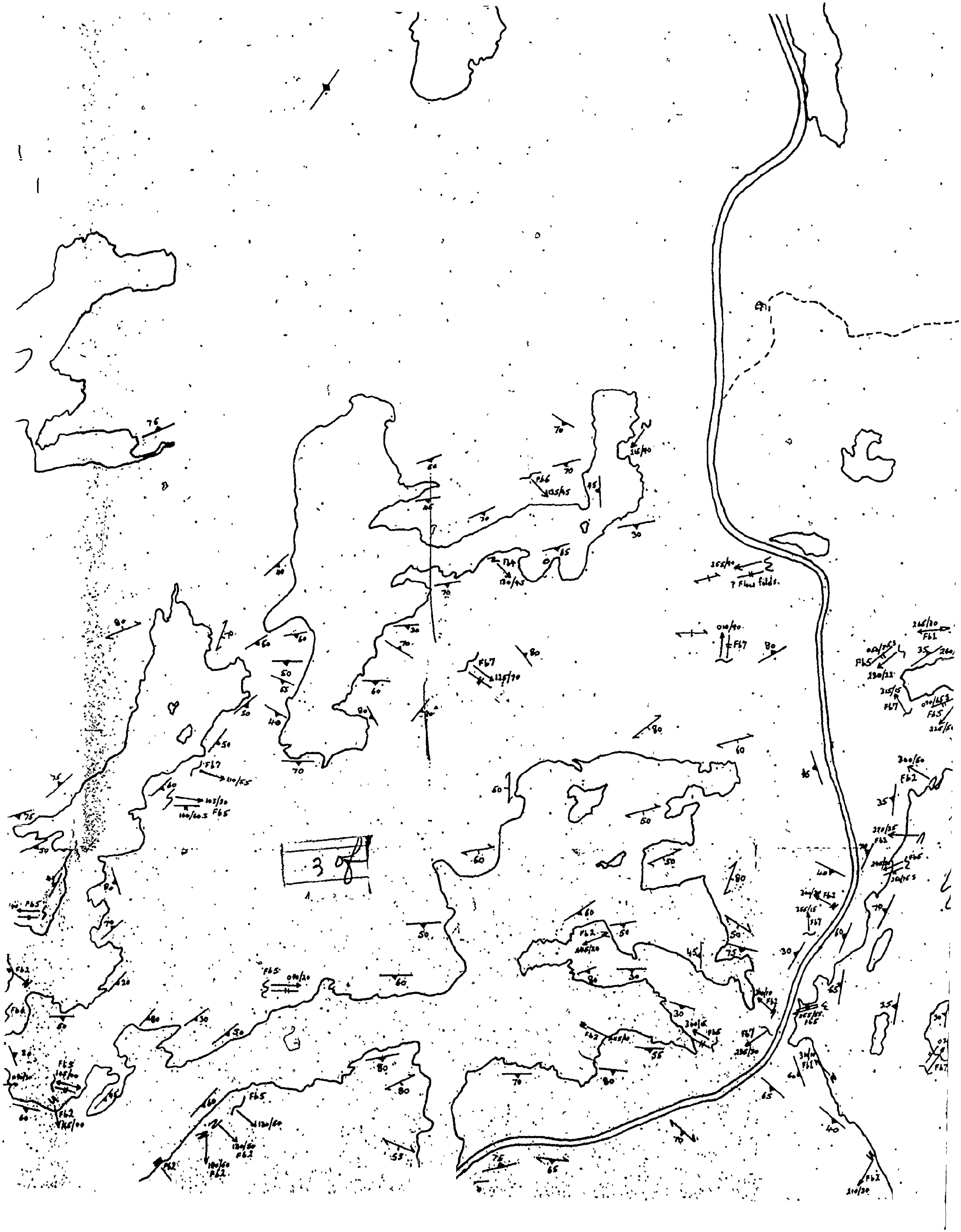
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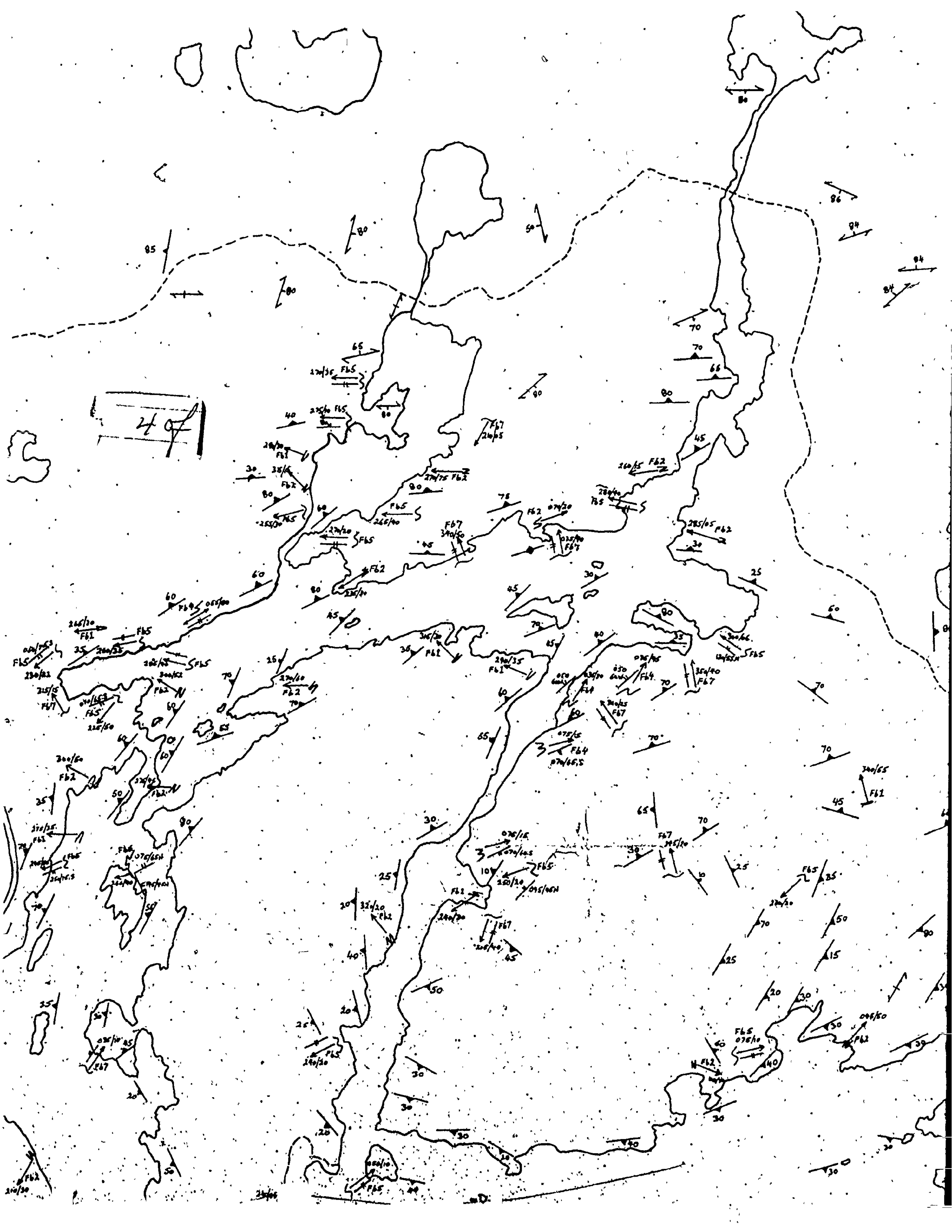
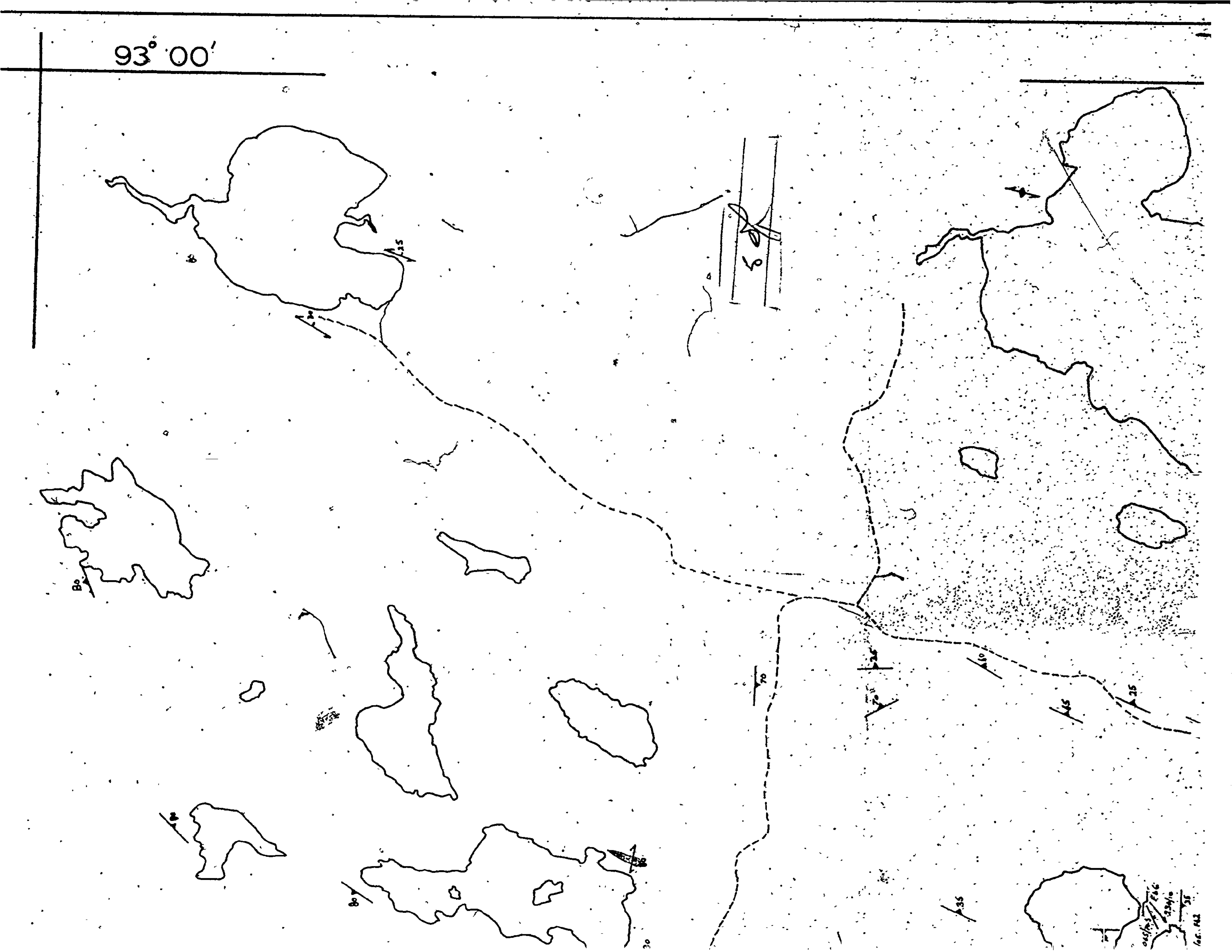
3 of

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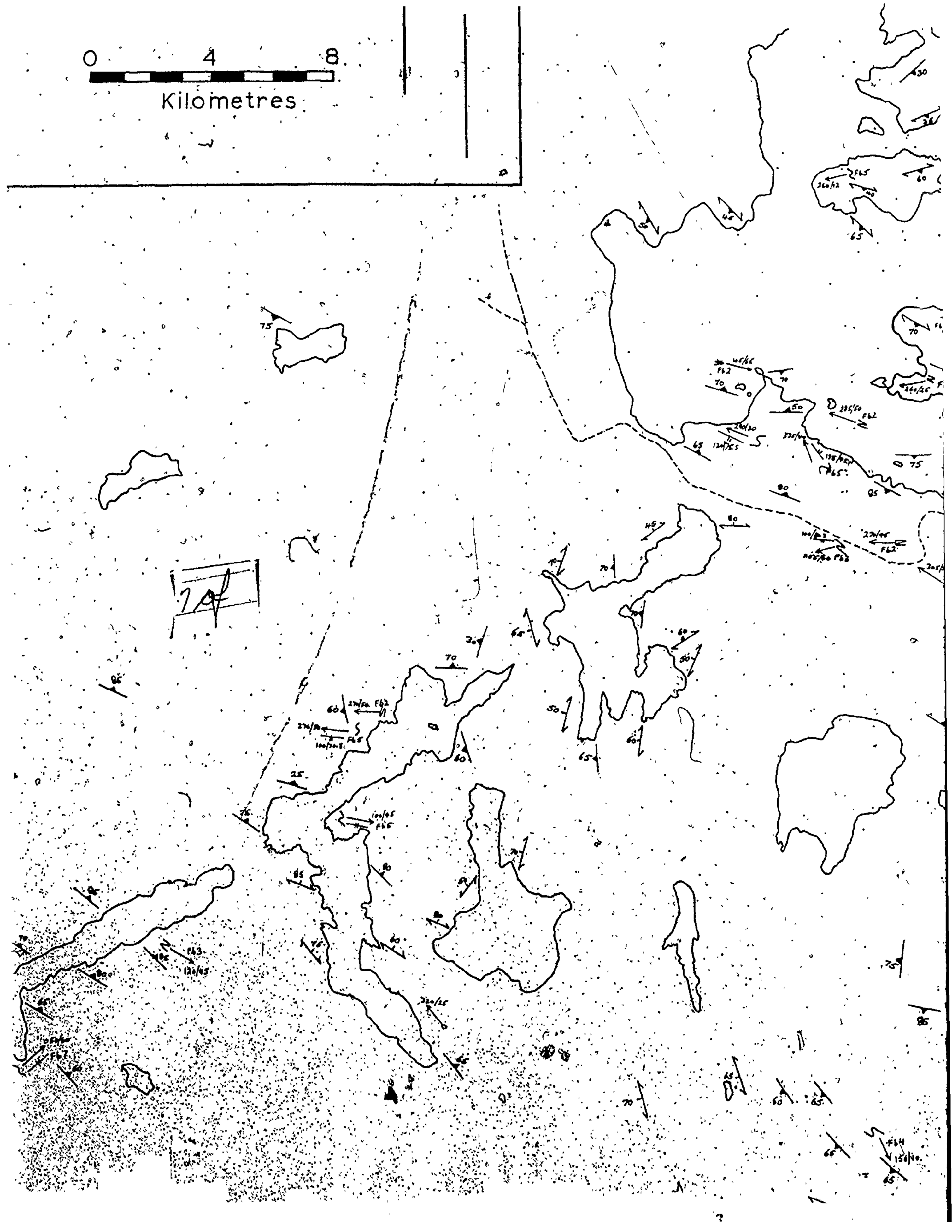
MAP C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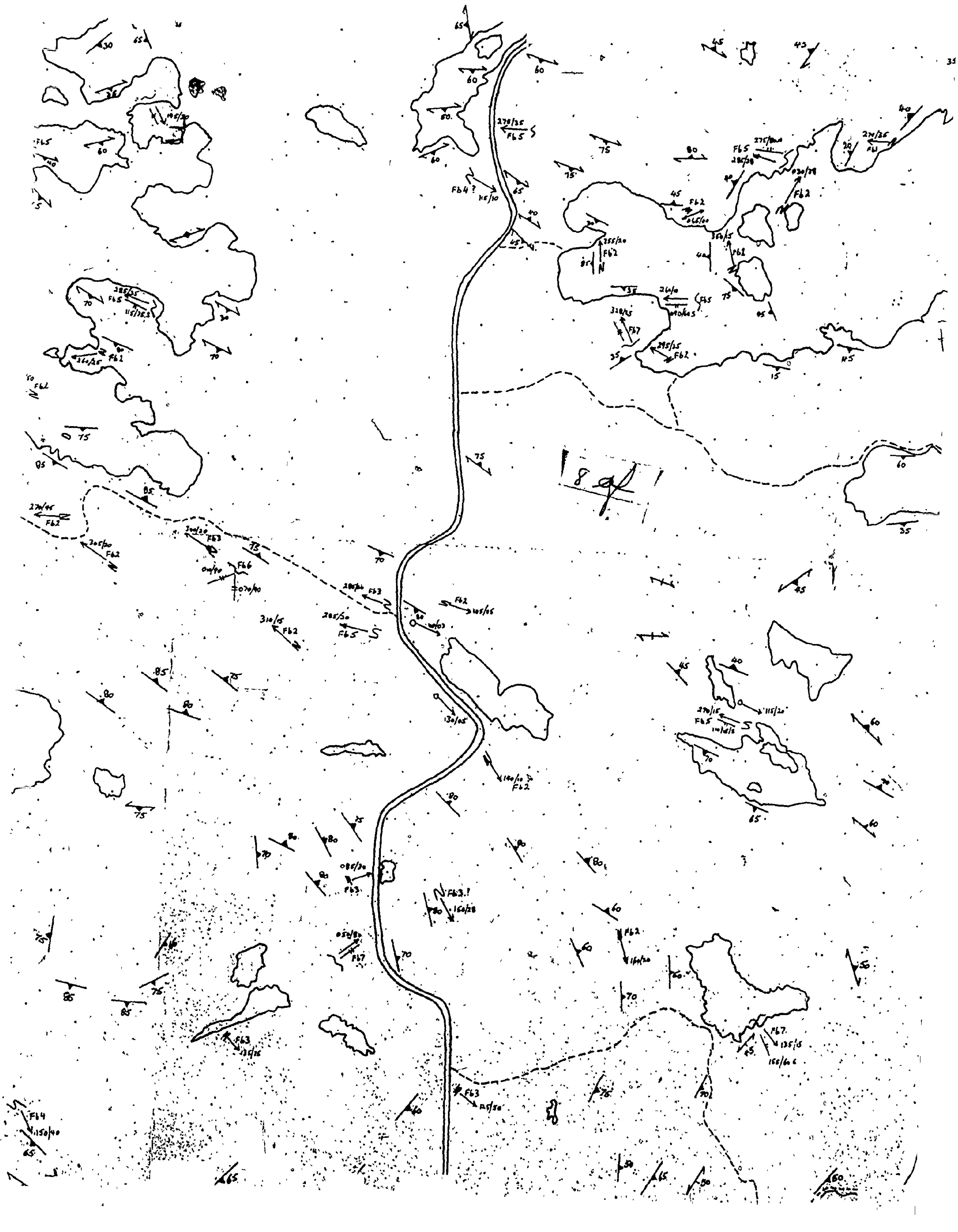

270/25 Fb5
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Fb4 ?
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285/20
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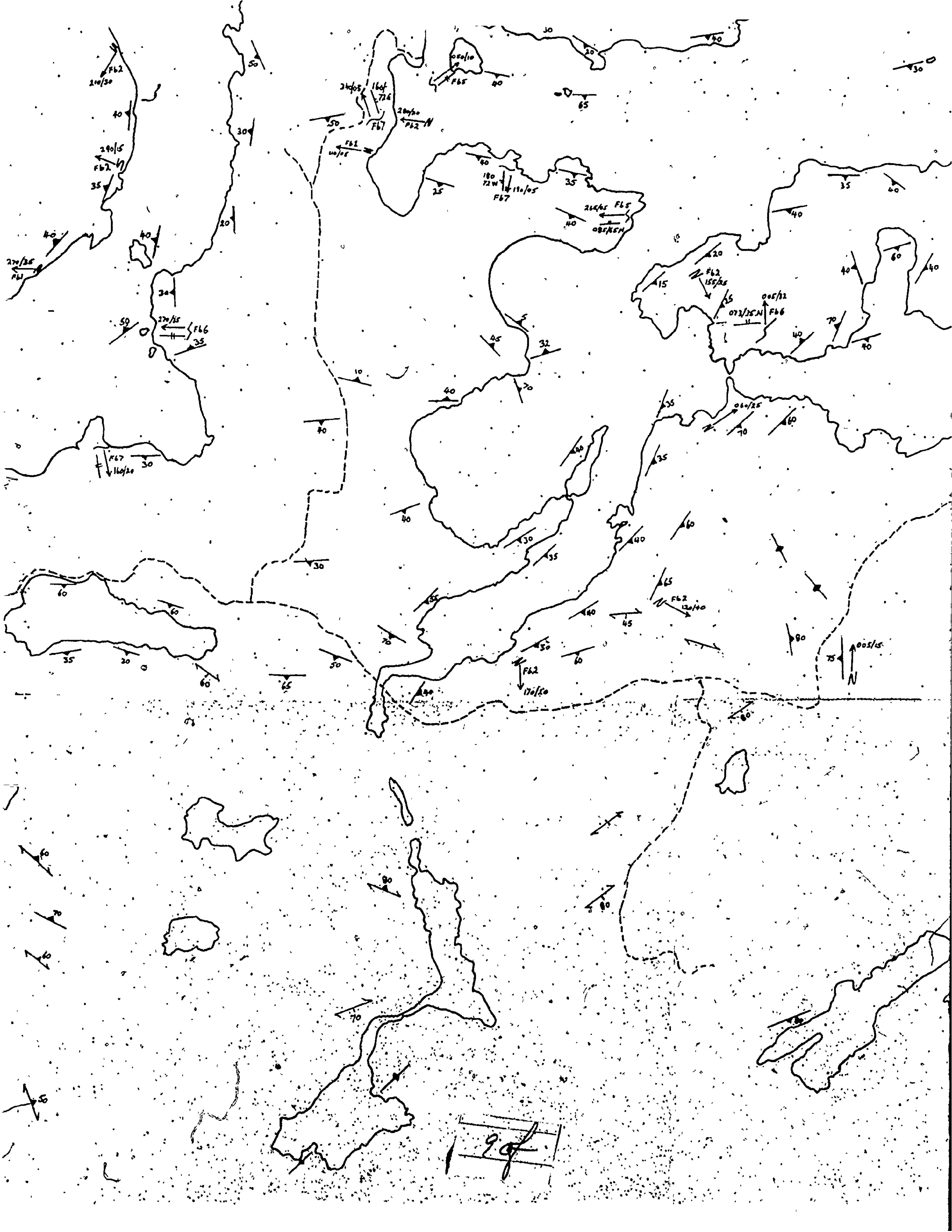

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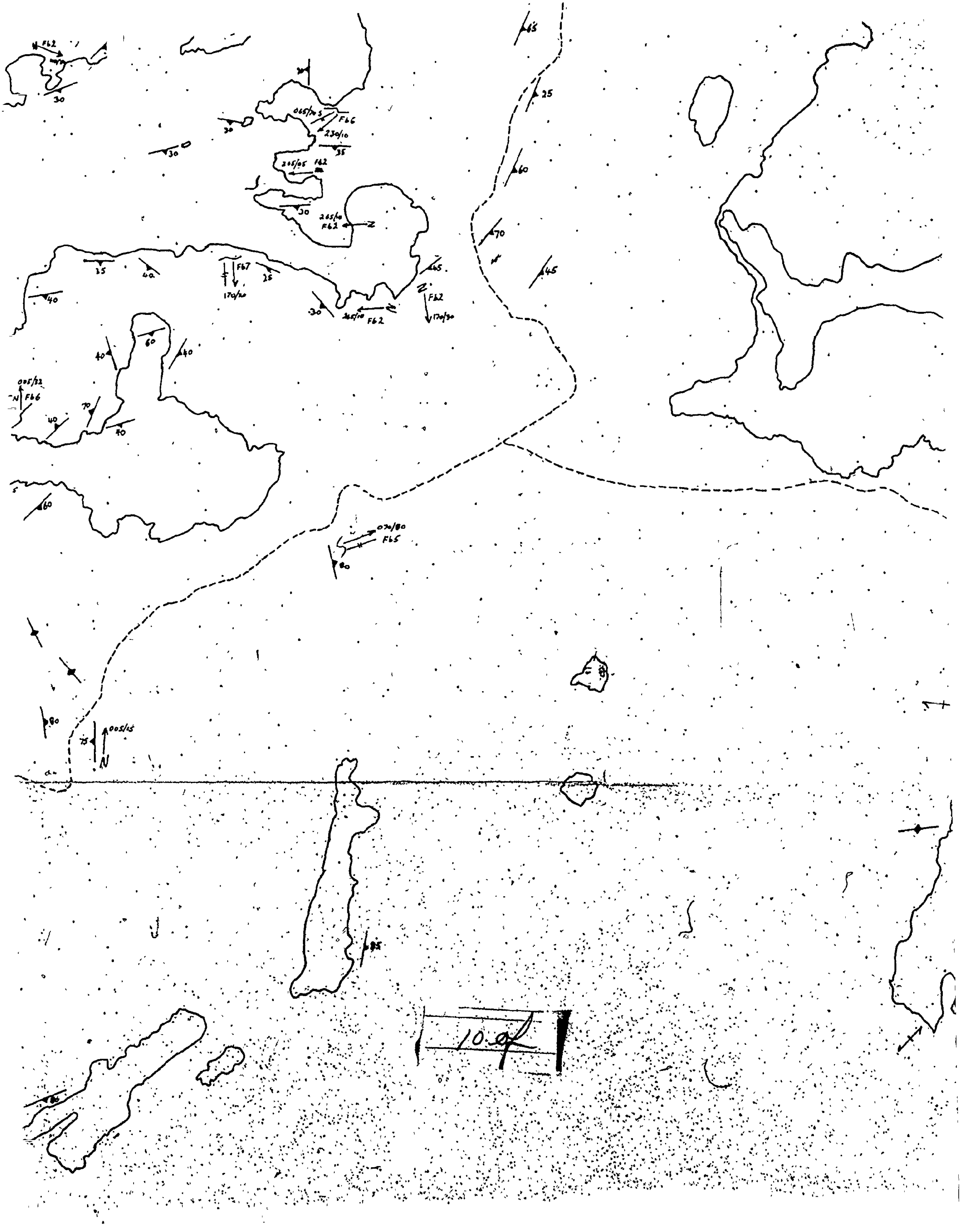

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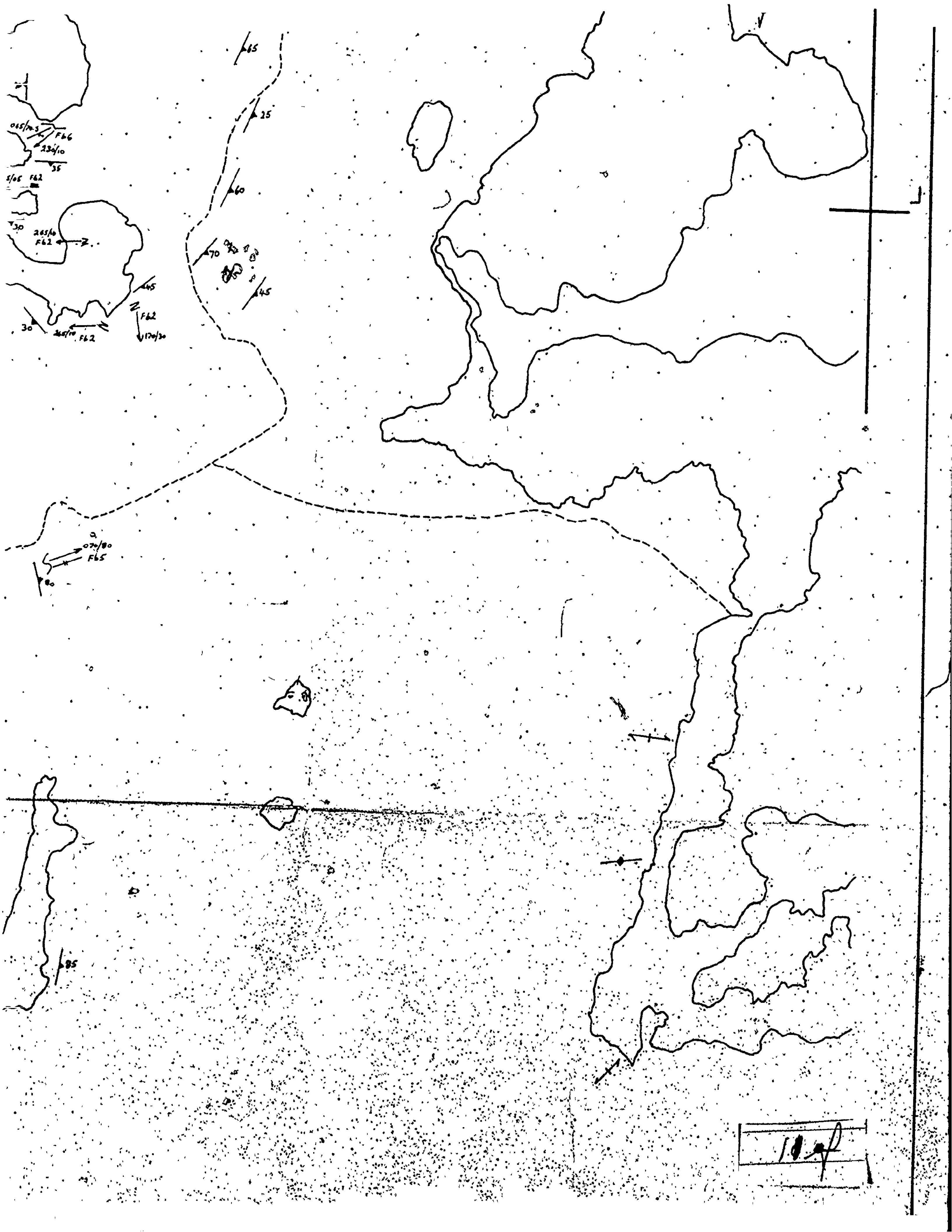
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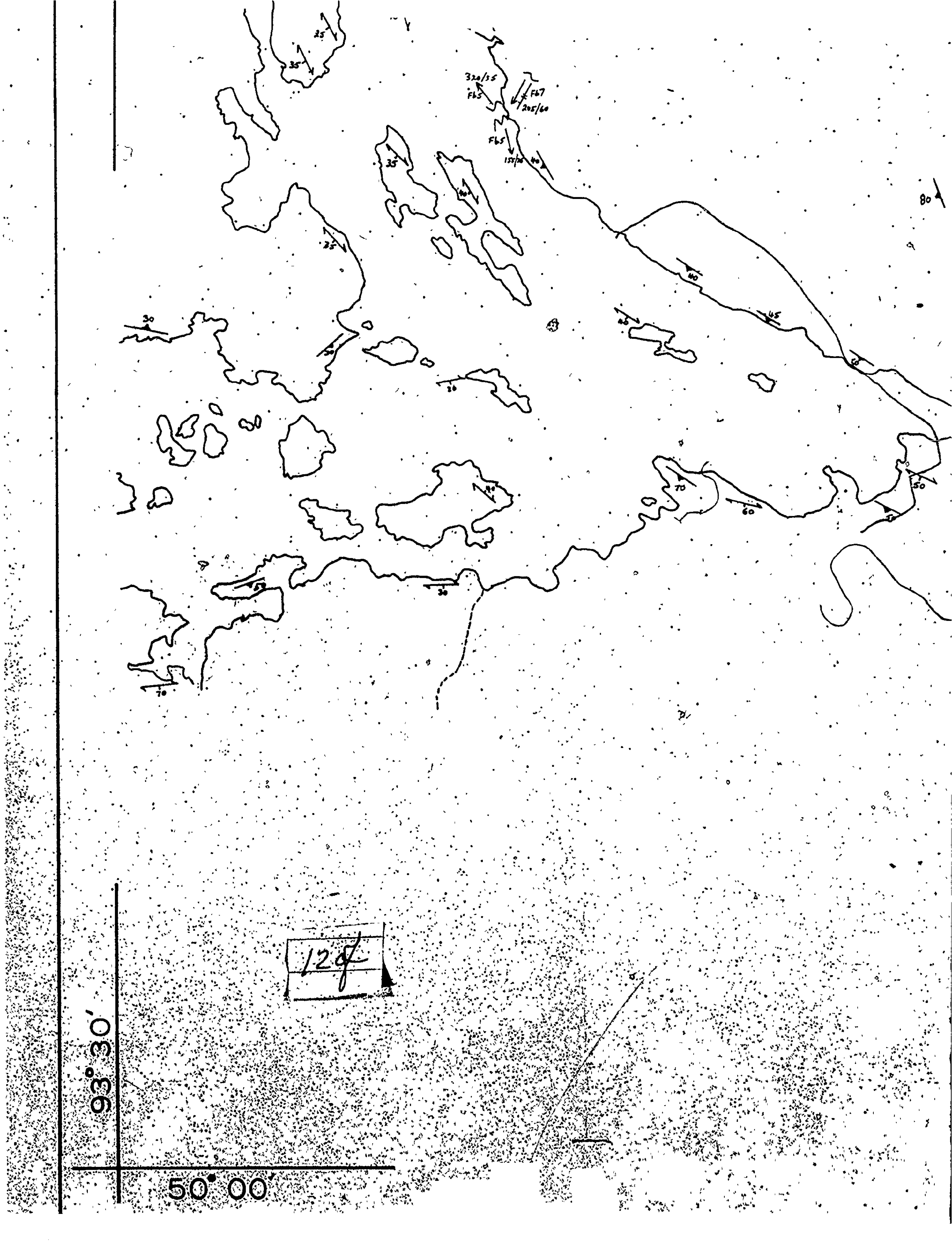

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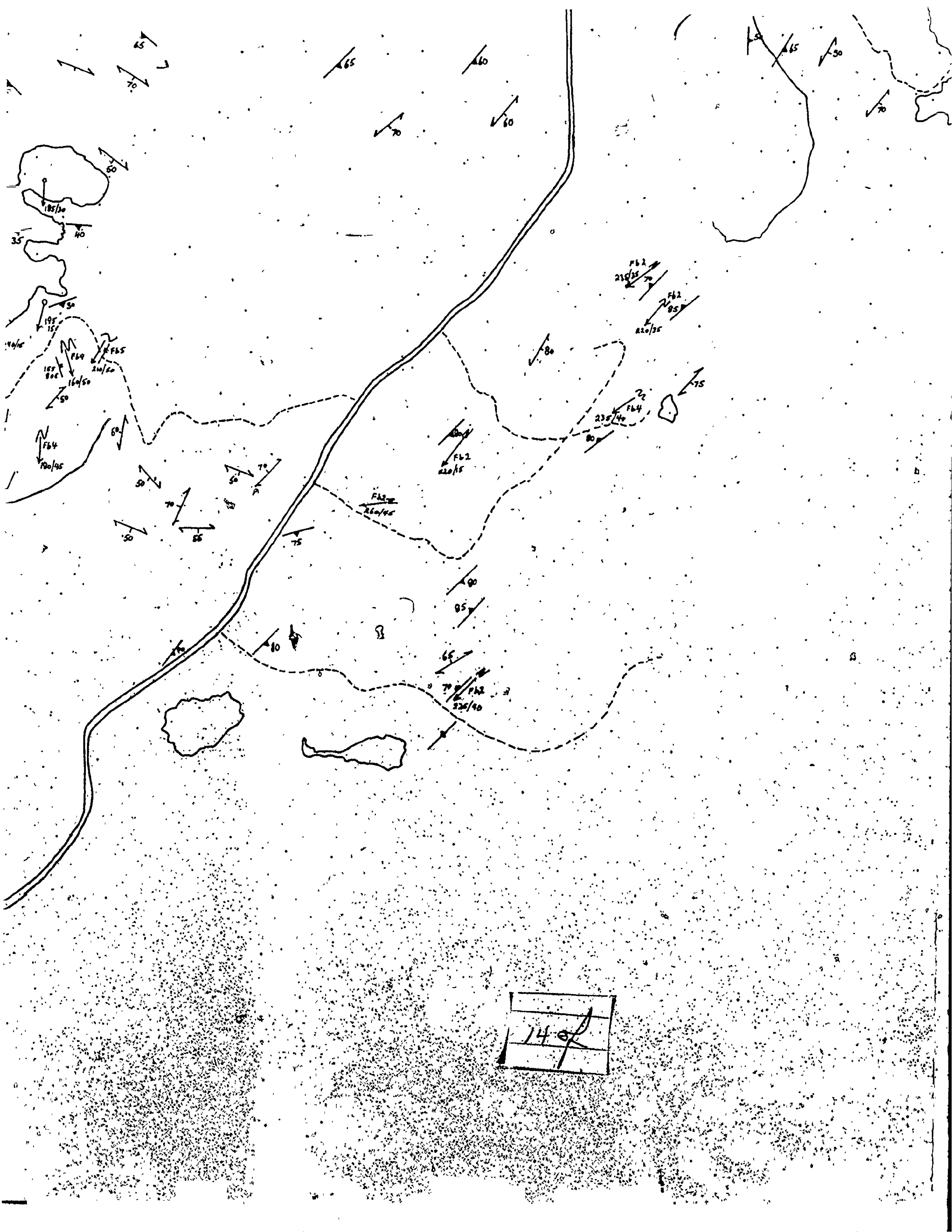
Fb2
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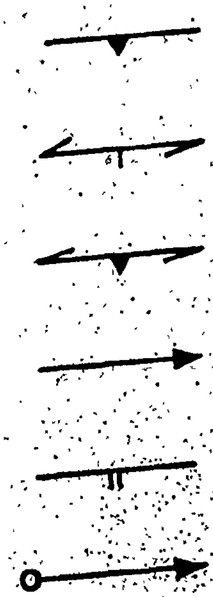
LEGEND



GNEISSOSITY OR COMPOSITIONAL BANDING

FOLIATION

TREND OF INCLUSIONS

MINOR FOLD AXIS

MINOR FOLD AXIAL PLANE

LINEATION