PETROGENESIS OF THE LAC TURGEON GRANITE AND URANIUM OCCURRENCES NEAR BAIE JOHAN BEETZ, QUEBEC

A Thesis Submitted To
The Faculty of Graduate Studies,
The University of Manitoba

(In partial fulfillment of requirements for
the degree, Masters of Science)

By

Bruce Wayne Mackie
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Department of Earth Sciences
University of Manitoba
Winnipeg, Manitoba
Canada

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Figure 1

Frontispiece

View of north end of Lac Turgeon looking SE.

ABSTRACT

The Lac Turgeon granite near Baie Johan Beetz, Quebec, is located in a supracrustal group of metasediments and intrusive gabbroic sills, known as the Wakeham Bay Group, part of the eastern Grenville Province. The body is approximately 55 square miles in extent and regional geology indicates that the granite occurs in the fold nose of a major anticlinorium. Detailed field mapping and radiometric surveys, as well as thin section work were used in order to determine the granite and its associated U mineralization petrogenesis.

Peak metamorphic conditions in the metasediments appear transitional between the upper amphibolite and lower granulite facies at temperatures between 650-800°C with minimum water pressures of 4-5 kbars. The concordant edges of the Lac Turgeon granite with the surrounding metamorphic rocks along with granite compositions which fall within the low temperature trough in the system Qz-Al-Or-An-H_2O suggests that the granite originated by anatexis of the Wakeham Bay Group metasediments.

The uranium mineralization occurs in the coarse-grained granitic and associated pegmatitic rocks and is concentrated in the axial planes and in fold noses, and was deposited post-crystallization, syntectonically by late stage hydrothermal solutions.

ACKNOWLEDGEMENTS

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Many thanks are also due to Mr. T. J. Beesley who supervised the field season programme and whose support and suggestions aided the author in his writing of the thesis.

TABLE OF CONTENTS

TABLE OF CONTENTS
(Continued)

LIST OF FIGURES

LIST OF FIGURES
(Continued)

LIST OF FIGURES (Continued)

LIST OF FIGURES
(Continued)

LIST OF TABLES

LIST OF MAPS

INTRODUCTION

GENERAL STATEMENT

Interest in large tonnage, low-grade uranium deposits in granites and granitic pegmatites was renewed by the discovery of the Rossing deposit in southwest Africa (Berning et al, 1976). Detailed exploration by numerous companies in or near the Lac Turgeon granite has found several highly radioactive zones.

The Lac Turgeon granite was originally interpreted to be igneous in origin (Cooper, 1957). Recent detailed geological mapping involved in an exploration programme for uranium during 1974-1975 by Urangesellschaft Canada Limited indicates that the granitic rocks are conformable with the surrounding metamorphic belt: the alternative hypothesis for its origin, granitization of the pre-existing country rocks, is thus suggested. Field and thin section data indicates that alkali metasomatism occurred during the early stage of metamorphism, which cumulated in the anatexis of the metamorphic rocks. culminated

Rocks displaying typical granitic textures (perthitic microcline, myrmekitic intergrowths, anhedral interlocking grain boundaries), although variable in composition (probably still reflecting the original rock composition), lie within the low temperature trough of the system Qz-Ab-Or-An-H_2O.

Metamorphic mineral assemblages in the metasediments indicate that temperatures reached 650-800°C with minimum water pressure of 4-5 kbars.

Uranium was first noted in the Johan Beetz area in 1955 (Baldwin, 1970). Field radiometric and geologic mapping indicate that anomalous radioactivity is restricted to coarser-grained (pegmatitic) granitic rocks. Uranium is usually associated with brick-red alteration of plagioclase, but shows an antipathy for pegmatitic rocks with graphic textures (potassium-feldspar-rich).

Structurally the Lac Turgeon granite and practically all anomalous radioactivity in the Wakeham Bay Group is in the axial zone of a regional anticlinorium. The granite formation took place syntectonically. On a more detailed scale, low pressure zones (fold axis) caused by deformation are shown to be more suitable for the development of pegmatitic material and anomalous radioactivity.

LOCATION AND ACCESS

The claim group lies entirely, or in part, within the Lac Turgeon granite. The property is situated 7 miles northwest of the village of Baie Johan Beetz, which is located on the north shore of the Gulf of St. Lawrence (see Map 1). A tractor trail connects the village to parts of the claim group. Float planes (or ski-equipped bush planes in winter) can land on the two largest lakes (Lac Turgeon and Lac Tanguay) found on the property.

Baie Johan Beetz is approximately 35 miles downstream of Havre St. Pierre, the nearest airbase for sea planes, and 150 miles down the coast from the port of Sept-Iles. Access to Baie Johan Beetz is via coastal shipping freighter or by chartered float-equipped planes out of Havre St. Pierre. A winter road also connects the village to Havre St. Pierre.

Commercial air flights into Mingan (near Havre St. Pierre) are flown on a regular schedule by Quebecair. An all-purpose paved road runs between Sept-Iles and Havre St. Pierre.

PHYSIOGRAPHY

The area is characterized by gently rolling hills with the maximum relief rarely exceeding two hundred feet. The valleys are covered with glacial till while the hills are generally free of glacial debris except for the occasional erratic boulder.

The ridges are found to be underlain by granitic or pegmatitic rocks and are thus resistant to erosion. Approximately 30 percent of the claim group occurs as outcrop.

The lowlands are either covered by spruce and fir trees with lesser amounts of birch and alder or form muskeg swamps.

The main drainage system in the property is by the Corneille River which drains with Lac Turgeon and Lac Tanguay into the Gulf of St. Lawrence. Numerous rapids and falls make passage along the river difficult.

PREVIOUS WORK

The Lac Turgeon granite and surrounding region was previously mapped during 1951-1952 by G. E. Cooper, on the scale one mile to the inch, for the Quebec Department of Mines (Cooper, 1957). The area to the west of the property was investigated by J. Depatie for the Quebec Ministry of Natural Resources (Depatie, 1966).

Exploration for uranium within the granite was undertaken in 1967-1968 as a follow-up to several radiometric anomalies formed in an airborne survey in 1966. The claim group was previously prospected by the Redrock Uranium Syndicate during this period and was optioned by Urangesellschaft following the results of the G.S.C. Skyvan airborne spectrometer survey.

The granitic rocks on the adjacent Denison Mines Limited property were studied by Hauseux (1976) for a M.Sc. thesis at McGill University (published in CIM, 1977).

Reports and maps can be obtained in the assessment file of the Quebec Department of Natural Resources in Quebec City.

WORK PROGRAMME

The entire property was mapped on the scale of one inch equals 800 ft., both radiometrically and geologically, using airphotos for control. The radiometric survey consisted of traverses over areas of outcrop spaced at 20 ft. intervals, taking continuous readings with the Scintrex BGS-1S scintillometer. Anomalies (areas with greater than 400 cps or four times background) were flagged and plotted on base maps.

Four zones of anomalous radioactivity were delineated and were subsequently mapped on more detailed scales; one inch equals 200 and 50 ft. Here grids were cut with line spacings every 400 ft. in order to pinpoint locations.

A more detailed account of the exploration programme is available in the report for the Assessment Office.

REGIONAL GEOLOGY

All the consolidated rocks in the Lac Turgeon region are of Precambrian age and lie within the eastern portion of the Grenville Province. The oldest rocks are a sequence of metasediments, the Wakeham Bay Group, which occupy a large north-south trending synclinal basin. The rocks plunge gently to the south (Grenier, 1957). Close to the coast the belt suddenly swings in a SW direction (Cooper, 1957) forming an anticlinorium structure (see Map 1).

The sedimentary succession has been divided into three units (Grenier, 1957). The lowermost unit consists primarily of meta-quartzites, with minor amounts of quartz mica schist, banded hematite, meta-quartzite with rutile, and biotite gneiss. The middle unit is comprised almost exclusively of a fine-grained white meta-quartzite. The uppermost member is characterized by a calcareous meta-quartzite with lesser amounts of phyllite and interstratified white meta-quartzite. Total thickness of the Wakeham Bay Group has been estimated at between 15,000-25,000 ft. (4.5-7-6 km).

Intruded into the metasediments, penecontemporaneous with folding, are a series of gabbro sills, the largest of which is approximately 3 km thick and has a minimum strike length of 2 km (Cooper, 1957). The gabbroic sills have usually undergone alteration and metamorphism resulting in a variety of derivatives ranging from uralitic gabbro to amphibolites.

The Lac Turgeon granite is approximately 140 km^2 (55 $miles^2$) in area, and occurs within the axial zone of the regional anticlinorium. It was interpreted by Cooper to be igneous in origin.

Metamorphism in the belt is stated to be greenschist to amphibolite facies (Cooper, 1957). However, the meta-sediments to the west of the Lac Turgeon granite have been extensively migmatized and are gneissic in structure (Depatie, 1966).

The age of the Wakeham Bay Group has been ascribed by various authors to be Proterozoic (Retty, 1944) or Neohelikian (Stockwell, 1964) based on its relationship to the nearby Lac Allard anorthosite. Unlike the Grenville Supergroup of southeastern Ontario and western Quebec, the metasediments of the Wakeham Bay Group appear to be less metamorphosed; this lead Grenier (1957) to postulate that the group was younger than the supracrustal rocks further to the southwest.

The dominant N-S tectonic lineaments differ from those of the rest of the Grenville (Wynne-Edwards, 1972) which trend in a NE-SW direction. Similar N-S trending tectonics are a characteristic of the Nain Province in Labrador.

FIELD GEOLOGY

INTRODUCTION

The Lac Turgeon granite was mapped by Cooper (1957) and was described as a circular granitic pluton surrounded by belts of gneisses, metasediments, migmatites and pegmatites. More detailed geological mapping during the exploration for uranium indicates that such a theory is improbable and that far more complex geological processes were involved in the formation of the body, including the metamorphism, metasomatism and finally the anatexis of the existing supracrustal rocks.

METASEDIMENTS

The most striking feature of the area is the abundant metasedimentary and amphibolitic material present within the granitic rocks. These rocks occur as remnant fragments (enclaves) ranging in size from a few feet in diameter to bodies measuring hundreds of feet in length (Figure 2 and 3). The metasediments range in composition from quartzites, sandstones and arkoses to biotite schists and gneisses. Banding (original sedimentary bedding?) is quite common and is usually concordant with the regional structural trend. In some areas of abundant metasedimentary material, these migmatitic rocks form mappable units, and can further be traced into the adjacent granitic rocks by their occurrence as xenoliths.

The surrounding metamorphic rocks, including the metasediments and amphibolites, pass gradationally into the granite through an intermediary zone of migmatites and abundant pegmatitic material.

Figure 2

Meta-Sedimentary Raft (R) in Pegmatitic Granite (Peg)

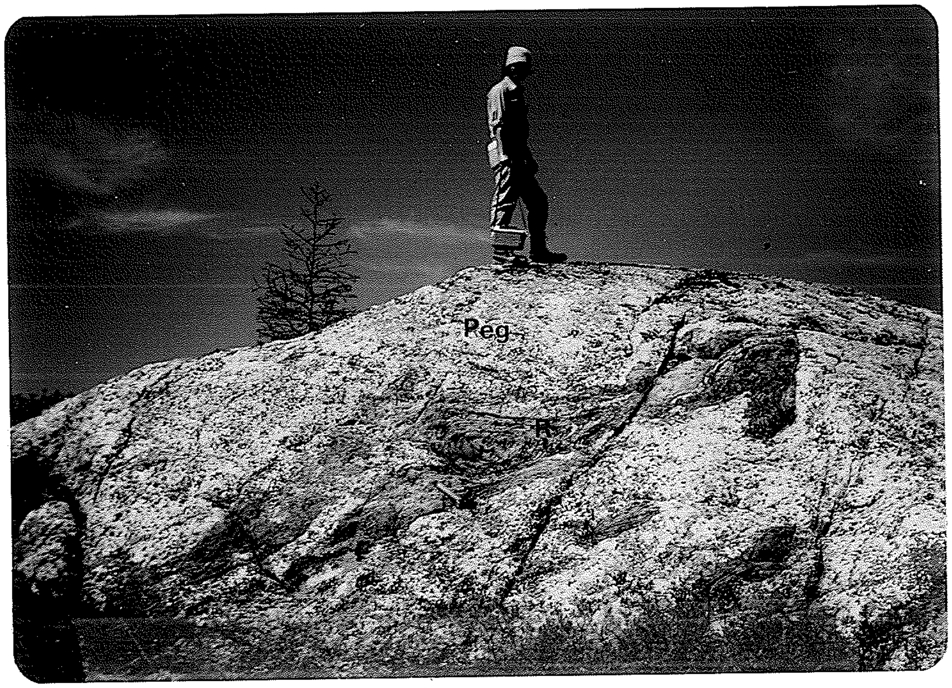
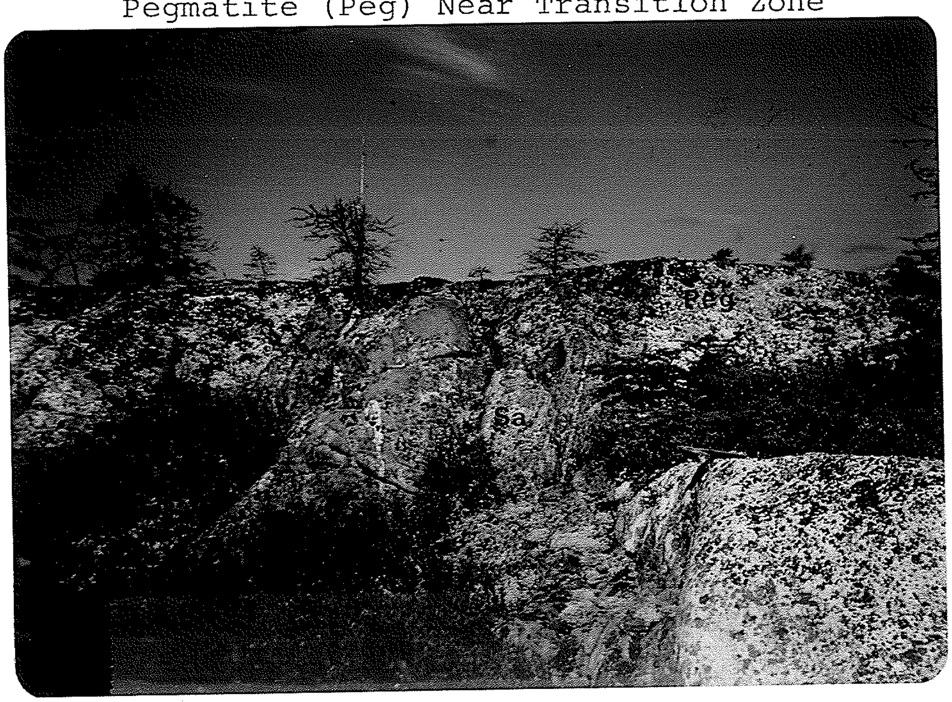


Figure 3

Large Conformable Sandstone Unit (Sa) in Granitic Pegmatite (Peg) Near Transition Zone



The contact relations between the inclusions and the host granites are often sharp, but sinuous, with the pegmatoidal material showing convex forms against concave points of the enclave. Mehnert (1968) describes this feature as one characteristic of migmatites (Figure 5), usually with the development of a thin mafic selvage edge (melanosome) consisting of biotite and/or hornblende (Figure 29). In arkosic rocks the boundary is much less definite, with one grading into the other. Thin section work showed that the transition was due to a change in texture; the meta arkose displays typical metamorphic granular texture which gradually changes to one more characteristic of granites (Figure 30).

AMPHIBOLITES

Amphibolites occur in much the same manner as the metasediments. They consist primarily of hornblende and plagioclase. In some cases they are compositionally gradational to adjacent biotite schists, suggesting that they are paramphibolites. In other areas (Lac à l'Ours) detailed mapping indicates a discordant relationship between the amphibolites and surrounding rocks, indicating an igneous origin. In all probability these hornblende-rich rocks represent both para and orthoamphibolites.

GRANITIC ROCKS

The granitic rocks in the Lac Turgeon area are heterogeneous in grain size and in composition. Borders between various phases are often nebulous to say the least. However, five phases have been recognized and in some cases relative ages determined. They are: (1) Biotite Granite,

(2) Medium-Grained Granite, (3) Massive Medium-Grained Granite, (4) Pegmatitic Granite, and (5) White Pegmatitic Granite. The distribution of these subdivisions of the Lac Turgeon granite is shown in Map 2 (pocket).

Biotite Granite

The biotite granite was found to be one of the oldest phases. It is fine to medium-grained in appearance, usually light gray in colour, and often displays a well-defined biotite foliation. Its average composition as determined by modal analysis is 21% potassium feldspar (microcline), 30% quartz, 40% plagioclase (An 10-18) with 9% mafic minerals, predominantly biotite and magnetite.

Abundant pegmatitic material (with grain size greater than 2 cm) is present within the phase, with one unit grading into the other. The boundary between the two was defined as when the pegmatoidal material constituted greater than 50% of the rock. This coarse-grained fraction can occur interlayered with granite, in some cases measuring up to 600 ft. across with a minimum strike extension of 3 to 4 miles. More commonly, it occurs as an admixture with the finer-grained phase. This feature suggests that the two formed synonymously. However, the occurrence of angular rafts of biotite granite in pegmatitic rocks suggests that the hydrous solutions and pegmatite development were still active after the formation of the granite.

Medium-Grained Granite

The medium-grained granite is very similar to the biotite granite in texture and grain size although in some areas it tends to be coarser-grained. It is generally pinkish in colour due to the hematization in plagioclase. The boundary between the biotite granite and medium-grained granite in the field was based on the biotite content of the rock (biotite granite contained more than 5% biotite). Mineralogically it is slightly more leucocratic than the biotite granite (32% microcline, 29% quartz, 36% plagioclase [An 5-15] and 3% combined mafics).

It appears in places to be in part later than the biotite granite (due to the occurrence of xenoliths of the latter [Figure 6]). The medium-grained granite also contains abundant pegmatitic material in much the same manner as previously discussed.

Late stage fractures filled with epidote (± chlorite) are common.

Massive Medium-Grained Granite

Although similar in appearance and in composition to the medium-grained granite (33% microcline, 32% quartz, 33% plagioclase [An 3-8] with 2% mafics), as its name implies the massive medium-grained granite displays no biotite marked foliation. It has a limited occurrence, restricted to the western portion of the claim group in the axial region of an overturned antiform. Not only is it more massive in appearance but it is much more homogeneous in composition.

There is also a lack of pegmatitic material and xenoliths of country rock. The pegmatites which do occur are mainly as discordant linear "dyke"-like bodies which crosscut the granite in a random fashion.

Pegmatitic Granite

By far the most abundant rock type in the area is a coarse-grained (greater than 2 cm) "pegmatite", consisting of variable amounts of quartz, plagioclase and potassium feldspar with minor amounts of biotite and magnetite. Crystal sizes vary from fine-grained aplite to giant megacrysts of plagioclase and microcline measuring up to 10 ft. or more in diameter (Figure 7). These coarser-grained rocks are generally reddish in colour due to the oxidation of iron in plagioclase. The term "pegmatite" is used; however, it does not necessarily imply an igneous origin. The term is used solely to describe a coarse-grained rock of acidic composition.

The relation of the pegmatites to the granites has been previously described. On the regional scale they tend to be concordant with the regional structure although widely local variations do occur. In areas where the fold axes plunge there is usually a buildup of pegmatitic material which crosscuts the existing stratigraphy (an example is the Turgeon East Zone). The reason for this is clear if one assumes that the pegmatitic material was carried in a hydrous phase. Such a fluid phase would tend to migrate with a pressure gradient into low pressure zones. Ramberg (1951) cited that areas of high mobility are more conductive to granitization and migmatitic development.

The fact that abundant pegmatitic material is found as an admixture with the granites indicates that water pressures were fairly high at their time of formation so that the aqueous pegmatitic phase coexisted with the granitic phase (Jahns and Burnham, 1969). Such aqueous solutions could be responsible for the alteration, corrosion and recrystallization of the granitic rocks by the process of autometamorphism (Figure 8).

The occurrence of blocks of both biotite granite and the medium-grained granite within the pegmatites meant that hypogene activity and pegmatitic formation continued after formation of the finer-grained granitic phases. This idea is supported by the cross-cutting relations already mentioned. It is these hydrous solutions which probably altered (and presumably leached) the granites and formed the replacement textures later described.

More detailed examination of the pegmatites on both outcrop and in hand specimens indicates that several varieties of pegmatites can be discerned on a mineralogical basis. Some pegmatites are made up by roughly equal amounts of quartz, plagioclase and perthitic microcline, while in others one of the feldspars will dominate, forming megacrysts which are supported in a finer-grained matrix. Microcline, where dominant, is granophyric or graphic. No anomalous radioactivity was found associated with graphic pegmatite. The internal structure and segregation of pegmatites is reviewed by Jahns and Tuttle (1963), although zoning was not prevalent in the pegmatites studied.

White Pegmatitic Granite

Mineralogically similar to the pegmatitic granites, the white pegmatitic granites, as their name implies, display no brick-red discolouration. They usually contain muscovite (and locally garnet) and are often gradational in nature to the pegmatitic granites. Field mapping indicates that they have a close spatial relationship to amphibolites although the nature of this relation is not yet understood.

Whether rocks of basic composition could produce such a great portion of acidic material through granitization (by either anatexis or metasomatism) seems unlikely especially if one assumed that most of the amphibolite is igneous in origin as described by Cooper (1957). These initially dry rocks would tend to act as a "sink" for water to produce the hydrous minerals hornblende and biotite, rather than act as a source for such fluids.

But, the most important feature is that the plagioclase crystals, while still highly sericitized, have not been hematized. This suggests that the deuteric aqueous solutions were not as oxidizing as they were in the pegmatitic granites. This may explain why no appreciable anomalous radioactivity was found to be associated with this rock type.

STRUCTURAL GEOLOGY

Biotite foliation, sedimentary banding, drag folds and lineations were used to define the regional structural geology. The subsequent result is inconsistent to a flow pattern produced by an intrusive igneous body but is explained in terms of a multiphase deformational history which took place synchronously to the granitic and pegmatitic formation.

As previously mentioned, one striking characteristic of the inclusions of metasediments and amphibolites is that their foliations and usually their long axes are concordant to the regional structure. This, along with the foliation developed within the granites, suggests that the rocks were deformed plastically (Kretz, 1967). Once the fragmentary nature of the metasediments and amphibolites is recognized by their occurrence as rafts, one can see that the structure of the granite is conformable to the surrounding metamorphic rocks. The metamorphic rocks are found to protrude well into the granite and pass gradationally from metasediments to migmatites to remnant rafts with increasing amounts of granitization.

Contacts in the south and northeastern part of the claim group generally dip southward at an angle between 50° and 80°. In the northwest section the dip is to the north or northeast. Strike and dip directions are shown in Figure 4, along with secondary foliation directions.

Three main phases of folding were discerned in the course of regional mapping. The first phase (f_1) trends NW and forms a series of isoclinal folds, the plunges and dips of which are variable due to the superposition of later fold events. The second phase (f_2) runs NE-NNE and plunges between 20° and 30°N. It forms slightly more open folds than the f_1 phase. The last phase (f_3) strikes E-W and gives the granite its "plutonic" shape.

No faults were observed near the transition zone between the granitic and surrounding metamorphic rocks. A north-south trending fault is suggested along Lac Turgeon by the disconformable dips, offsets and the aeromagnetic patterns.

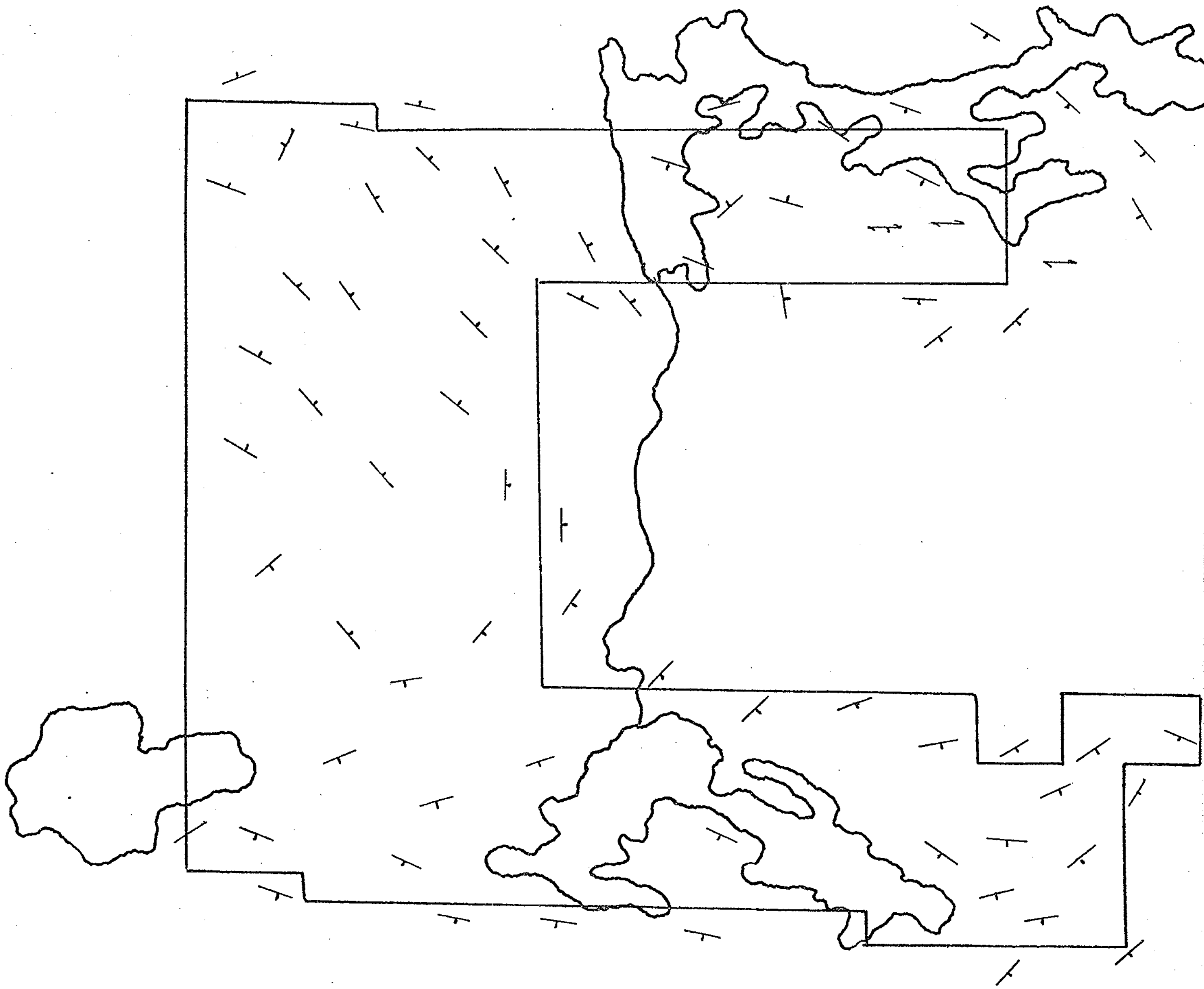
Jointing is common in the granitic rocks and are near vertical. They show a random orientation and are thus probably not associated with any deformation event.

Ptygmatic folds in migmatites are also widespread.

<u>Figure 4</u>

Regional Foliation

(Showing strike and dip directions of foliations and lineations)



Scale in miles

0 1 2 3

Figure 5

Pegmatitic Stringer (Peg) in Quartzite (Qu)
Note Convex Borders

Figure 6

Raft of Biotite Granite (Bio) in
Medium-Grained Granite (MG)

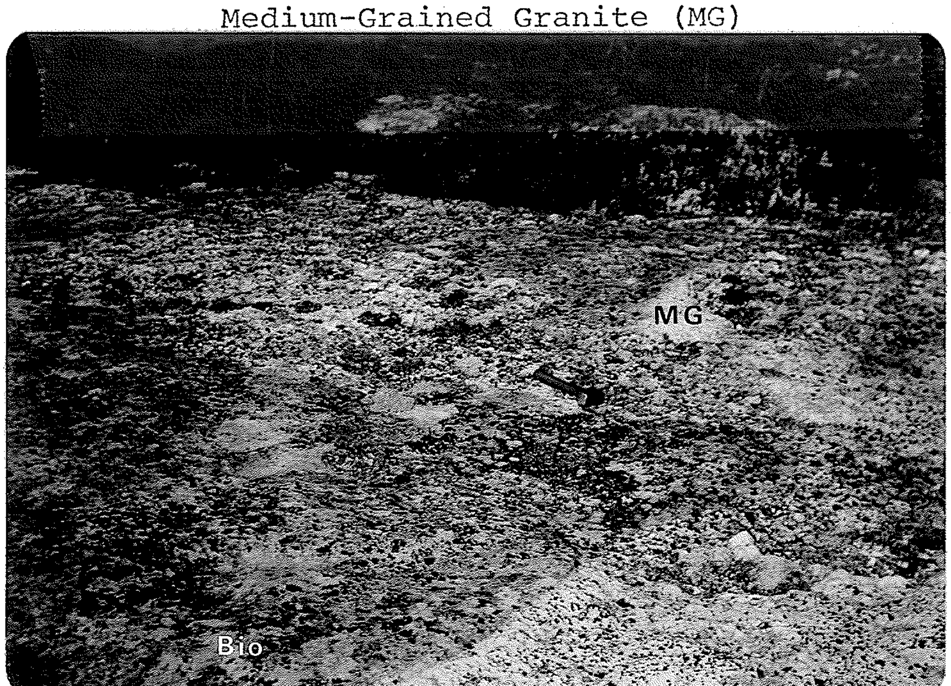


Figure 7

Plagioclase Megacrysts (Plag) in
Finer-Grained Matrix (Mat)

Figure 8

Admixture of Pegmatitic Granite (Peg)
and Medium-Grained Granite (MG)

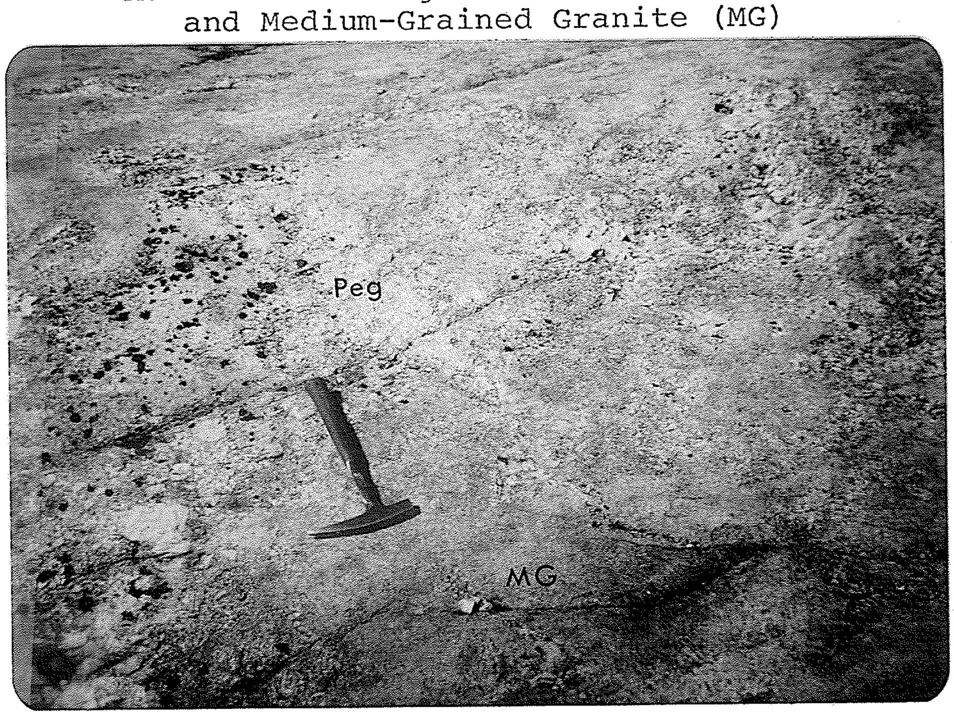


Figure 9

Radioactive Pegmat~~oidal~~itic Pod (Peg) in
Medium-Grained Granite (MG)
Note the brick-red alteration of feldspars and smoky quartz.

GEOPHYSICS

The Geological Survey of Canada performed an airborne magnetic survey of the Lac Turgeon area from 1967-1968 (Maps 5129G, 5130G - 1960) with east-west line spacings approximately every one half mile. The results of the survey are shown in Figure 10. The area near Lac Turgeon displays a unique magnetic pattern compared to the rest of the terrain near Baie Johan Beetz. The magnetic signature is one of low relief and large amplitude.

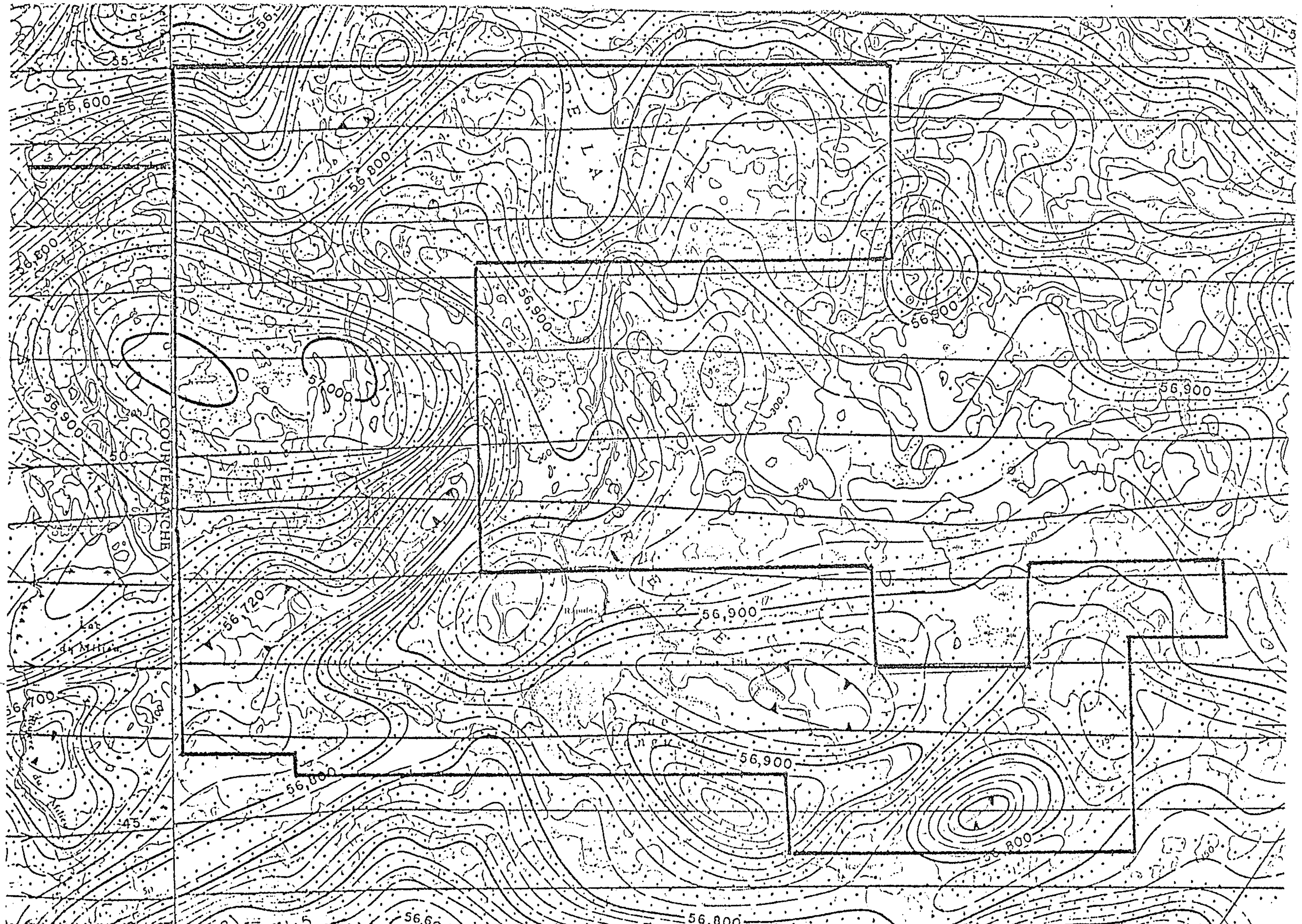
Several major features recognizable in the aeromagnetic pattern closely follow the ground geology. The major east-west fold west of the Corneille River shows up as a domal structure on the aeromagnetic maps consisting of a series of concentric elliptical contours. The two areas of massive medium-grained granite show up as local lows. The large high near the southeast corner of Lac Turgeon proved to be due to a large inclusion of magnetite-rich amphibolite. The fact that other areas of magnetite bearing amphibolite do not show as anomalies on the map suggests that they may occur as relatively thin horizontal lenses in the granitic and pegmatitic material (a fact supported by drill results).

A major break in the aeromagnetic pattern appears near Lac Turgeon. Such a phenomenon is best explained by a fault. Geological mapping indicates that there has been some displacement along this zone.

A regional gravity map done by the Earth Physics Branch and its correlation to the regional geology (Thomas, 1974) indicates that the Wakeham Bay Group and associated granites lie in a triangular area of a positive Bougeur anomaly believed to have its origin at depth. No petrogenetic relations to the Lac Turgeon granite can be derived from this data due to the regional nature of the survey.

Airborne Geophysics

Figure 10



Scale 1" = 1 Mile

Claim Boundary

RADIOACTIVITY

All anomalous radioactivity is restricted to the coarser-grained granitic material and the pegmatites, with most significant radioactivity in the rock unit pegmatitic granite. The uranium mineralization, primarily in the form of uraninite, occurs as disseminations along grain boundaries or along microfractures. It also occurs in metamictic zircons associated with magnetite (Hauseux, 1976). Rarely was any anomalous radioactivity found along macroscopic fractures and none was found in the metasediments.

Uranium-thorium ratios are variable ranging from 1:1 to 15:1 but with a mean of 4-5:1. Wedepohl (1969) states that such high U:Th ratios usually mean that the uranium is not juvenile but has been remobilized.

Four zones, Tanguay Zone, Turgeon East, Central and West Zones, of concentrated radioactive anomalies were delineated on the regional scintillometer survey and were investigated more thoroughly by detailed geological and radiometric mapping (see Figure 11).

TANGUAY ZONE

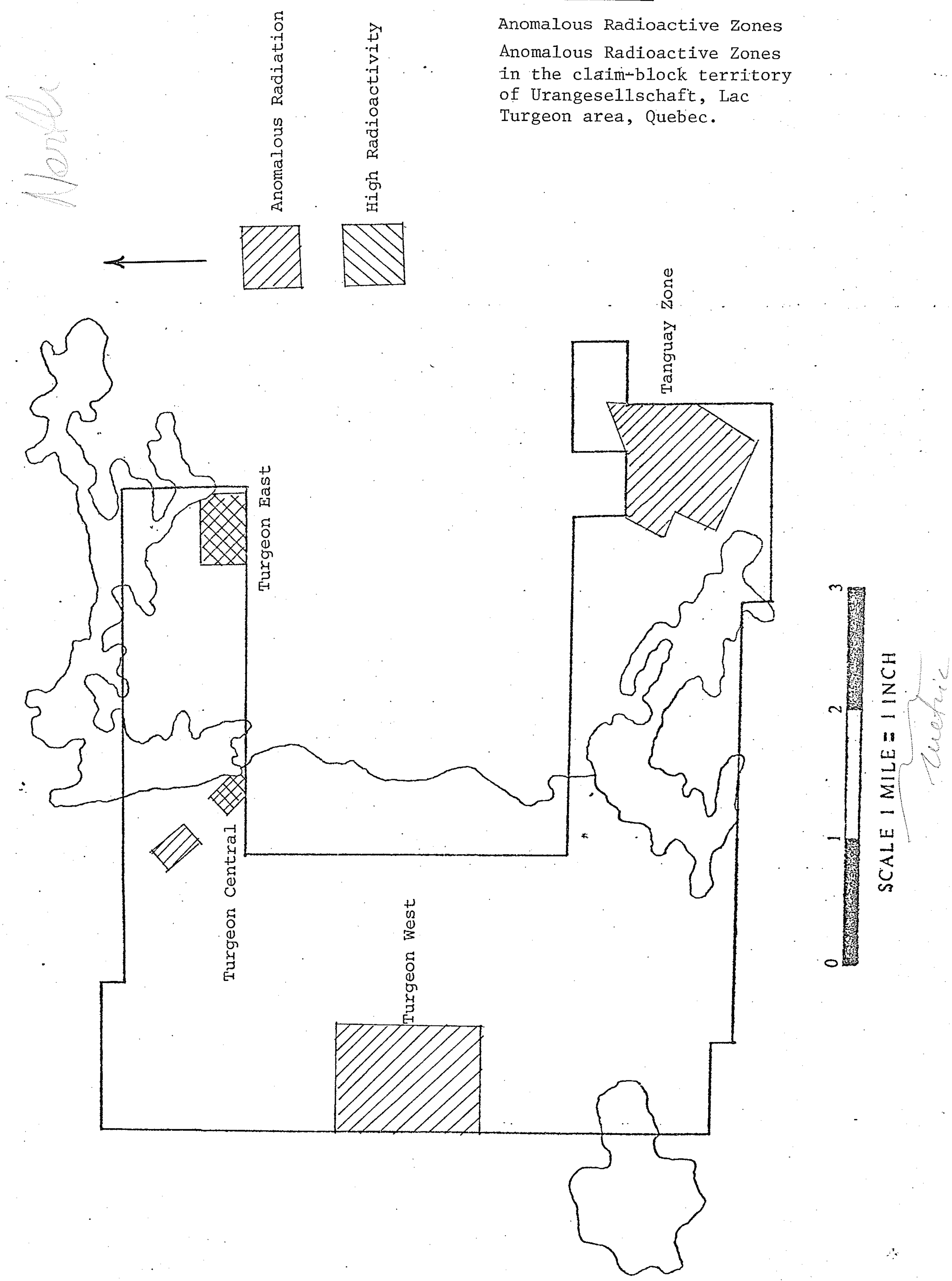
The Tanguay Zone, although the largest, is actually made up of several small areas of high scintillometer counts. The anomalous radioactivity forms irregular-shaped pods with their long axes generally conformable to the regional structure. The host rock, pegmatitic granite, displays the brick-red colouration of plagioclase. Smoky quartz is also present as well as magnetite (see Figure 9).

Detailed geological mapping indicates that the radioactivity is concentrated in the axial regions of small secondary folds.

Figure 11

Anomalous Radioactive Zones

Anomalous Radioactive Zones
in the claim-block territory of Urangesellschaft, Lac Turgeon area, Quebec.



TURGEON WEST ZONE

Here again the radioactivity is restricted to rocks rich in pegmatitic material. It occurs in the axial zone of an f_3 fold (see Map 2). Follow-up work was limited due to the shallow dips of the rock units. Such geology would not make the area amenable to open pit mining techniques.

TURGEON CENTRAL ZONE

The Turgeon Central was one of the two zones drilled (along with the Turgeon East Zone) as a result of the detailed scintillometer and spectrometer surveys. Geologically the zone consists of interlayered pegmatitic granite and biotite granite. The areas of anomalous radioactivity in the zone range in size from "spot" anomalies (less than 25 sq. ft.) to irregular linear pods whose lengths may exceed 150 ft. The mineralization occurs in a coarse-grained phase of the biotite granite which, as in the other two zones discussed, are brick-red in colour. In thin sections the anomalous biotite granites are riddled with numerous micro-fractures filled with quartz, albite and zoisite. Plagioclase crystals are completely altered and hematized and biotite was altered to form chlorite and (epidote?). This zone is actually an extension of a high uranium zone on the Denison property; their mapping also shows it lying along a fold axis.

Although yielding some of the highest U_3O_8 assay values in drilling, the mineralization appears to be restricted to various horizons.

TURGEON EAST ZONE

The radioactivity in the Turgeon East Zone is much more uniform and evenly distributed than in the other zones. The host rocks are an admixture of various pegmatitic material including muscovite bearing white pegmatites, "blocky" pegmatites (with megacrysts of plagioclase in a finer-grained quartz monzonite matrix) and aplite.

High scintillometer and spectrometer readings show that uranium shows a strong affinity to magnetite. Xenoliths of country rock material are comprised mostly of amphibolite with lesser amounts of biotite schist. The anomalous zone occurs again in a fold nose.

From the above case histories a strong argument can be made for the structural control of the uranium mineralization. In each case the anomalous radioactivity lies in the axial zone of a fold (see Figure 11, Map 2). This along with the occurrence of uraninite in microfractures and in crystal defects (Hauseux, 1976) suggests that the uranium mineralization was concentrated and affixed, at least in part, post crystallization but syntectonically.

PETROLOGY

METHOD OF STUDY

Two hundred and fifty thin sections cut from samples taken from outcrops were examined. Samples were taken from various locations in order to be representative of the various rock types throughout the claim group. Mineral modes were point counted for 36 granitic specimens, using the rock slabs from which the thin sections were cut. The An content of the plagioclase was determined in the corresponding thin section by the Michel-Levy or Albite-Carlsbad method (Ayres, 1976). This method was preferred due to the coarse-grained nature of the granites; point counting on the slabs allowed a larger surface area to be examined and hence give a more accurate analysis.

Thin sections of forty-five metasediments were also point counted.

Amphibolites

Amphibolites and hornblende biotite schists and gneisses occur as xenoliths within the granitic rocks or as large remnant bodies often associated with white pegmatitic granite.

In hand specimen, amphibolites may display a strong foliation of biotite and hornblende crystals; the larger bodies tend to be more massive, with the mafic minerals (hornblende, sphene and magnetite) often forming clots ranging in size from 1 to 5 cm. in diameter.

In thin section, the amphibolites display a simple mineralogy, generally consisting of varying amounts of hornblende, plagioclase, biotite, potassium feldspar (orthoclase), quartz, magnetite, ilmenite and sphene with lesser amounts of rutile, zircon, apatite, epidote, tremolite, zoisite, allanite, calcite and scapolite. No pyroxene minerals were identified in the course of thin section analysis nor any pseudomorphs recognized.

While mineralogically simple, the amphibolites display complex and variable textural relationships. The dominant amphibole is hornblende (with minor tremolite after hornblende), usually pleochroic (α = pale brown, β = green, γ = dark green). It occurs in a variety of forms, ranging from subhedral granoblastic aggregates to poikiloblasts with inclusions of plagioclase, quartz, apatite and sphene,to small anhedral intergrowths with magnetite, sphene and quartz.

Biotite occurs as a primary mineral and as an alteration product of hornblende. It is found as small anhedral laths interstitial to quartz and feldspars or as subhedral poikiloblasts (containing apatite and sphene). At least three separate stages of biotite crystal growth can be discerned in some thin sections. The earliest phase usually consists of moderate-sized, well-oriented, biotite flakes which gives the rock its foliation. The secondary stage consists of a weaker alignment of biotite grains which transgress the primary stage biotites. These secondary biotites, unlike their predecessors, are not bent and broken. The final stage of biotite formation consists of randomly-oriented flakes which appear to have grown in a period of little and no stress.

A similar multi-phase history can be found for hornblende with the earliest formed hornblende crystals being in some cases particularly annealed with the superposition of later hornblende growth.

Both potassium feldspar (orthoclase) and plagioclase can be found in the thin sections, although plagioclase is dominant. Both are highly fractured and have undergone some sericitization. Poikiloblastic plagioclases are anhedral and some display a highly seritized core with serrated edges (relict core?). Carlsbad and Albite twinning are common in the plagioclase crystals. Their compositions range from An20 to An42. In any thin section there is no observable difference in composition between porphyroblastic crystals and small ones in the groundmass.

The majority of the feldspars occur with quartz in a granulitic polygonal matrix that has many equigranular triple junctions (a texture showing complete recrystallization under equilibrium conditions, Spry, 1969).

Sphene often occurs as rims around magnetite and forms clusters consisting of numerous equant crystals. Although some of the sphene may be primary in origin, in other cases magnetite, encased in sphene, appears as remnant lamellae. If the amphibolites were originally igneous in origin, then the anorthite content in plagioclase would be considerably higher. The breakdown of the anorthite component in plagioclase during metamorphism could react with ilmenite to form sphene in oxidizing conditions.

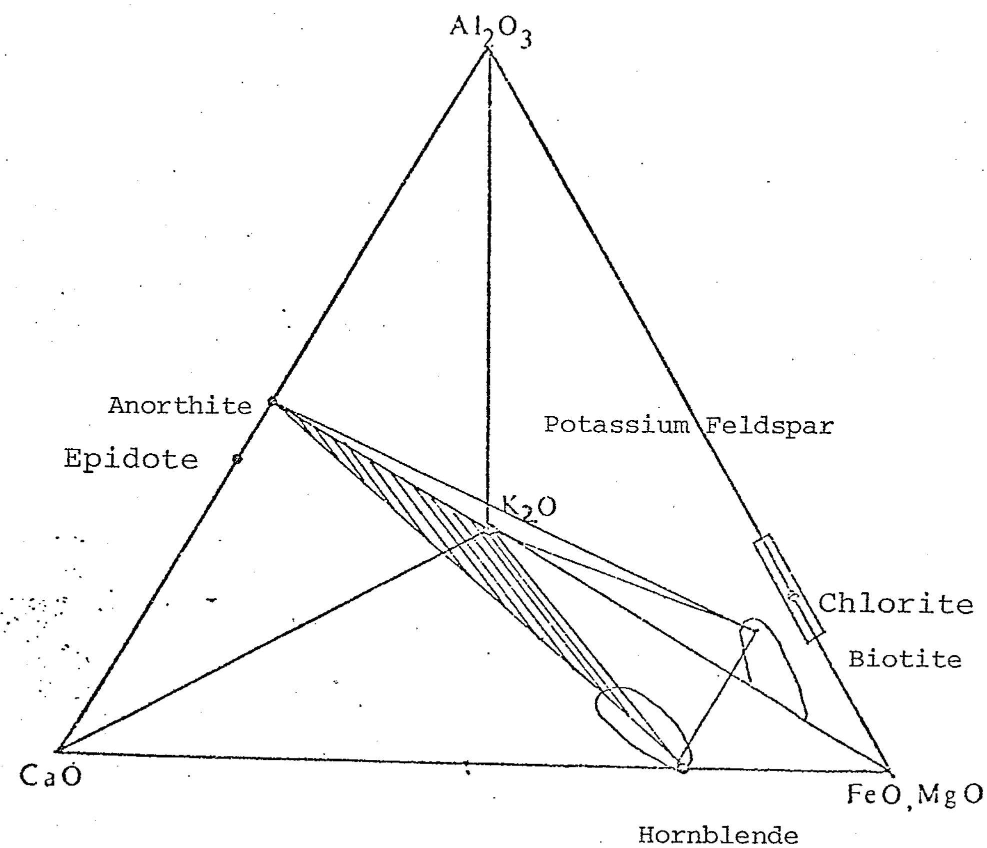
$$3Ca_{plag} + 3SiO_2 + 2O_2 + 3FeTiO_3 = 3CaTiSiO_5 + Fe_3O_4$$

The stability of sphene over ilmenite has been suggested by other authors to be characteristic of oxidizing conditions (see section on metamorphic conditions).

Mineral assemblages for amphibolites are plotted in Figure 12 and are typical in rocks of basic composition which have been metamorphosed to the mid to upper amphibolite facies.

Figure 12

Mineral Assemblages in Amphibolites



a) Potassium Feldspar, Plagioclase, Biotite, Hornblende.

b) Plagioclase, Biotite, Hornblende.

c) Potassium Feldspar, Plagioclase, Hornblende.

± Quartz, Sphene, Rutile, Zircon, Apatite, Epidote, Tremolite, Magnetite, Ilmenite, Zoisite, Allanite, Calcite, Scapolite.

Granulites

In thin section, the metasedimentary rocks are typically granulitic in texture. Biotite schists and gneisses are also present and rarely contain poikiloblastic feldspar crystals.

Mineralogically the granulites are made up of variable amounts of quartz, plagioclase (An 10-25), potassium feldspar (predominantly orthoclase) and biotite with lesser amounts of magnetite, ilmenite, rutile, sphene, zircon, apatite, muscovite, and chlorite. Anthophyllite, epidote, allanite , hornblende and andradite also occur, dependent on the bulk rock composition and physical conditions.

The texture developed among the quartz and feldspar crystals is one of an equigranular mosaic (Figure 23). Quartz is usually undulose in extinction. Away from the granitic rocks, the quartz and feldspar minerals in the metasediments contain numerous minute inclusions of magnetite, sphene, zircon and apatite. As one approaches the transition zone (between the surrounding metasedimentary rocks and the granite) the grains exhibit less tendency to be poikiloblastic showing that they have been more highly recrystallized.

Muscovite has a restricted occurrence as a primary mineral in the metasediments; its breakdown in the transition zone between the metasediments and granitic rocks roughly parallels the transition microcline-orthoclase. No alumina-silicate minerals were found.

Muscovite and microcline occur within the metasedimentary enclaves east of Lac Turgeon along a proposed fault zone (see Figure 31).

Both potassium feldspar and plagioclase (An 10-25) occur as large poikiloblasts , especially in the biotite schists and gneiss. This type of feldspathization has been interpreted to have formed by the addition of K and Na to the rocks (Misch, 1949; Jones, 1969). These anhedral feldspars display highly corroded edges. Perthitic textures were not identified in the metasediments and some of the plagioclase minerals have been sericitized.

Most of the metasediments are fairly rich in calcium, which is reflected by the presence of epidote, hornblende and in the highest metamorphic grade regions, andradite.

Hornblende rarely forms granoblastic aggregates as it does in the amphibolitic units. It usually occurs as anhedral poikiloblasts (Figure 21) with inclusions of sphene, quartz and apatite or as small equant grains interstitial to the feldspar and quartz crystals.

Epidote is commonly associated with hornblende and occurs as anhedral interstitial masses. Andradite in some localities replaces epidote forming poikiloblasts (Figure 24) containing quartz and magnetite. Associated with and intergrown with epidote in some of the metasediments is the mineral allanite (Figure 25). Vlasov (1966) and Deer, Howie and Zussman (1962, Vol. 1, pp 211-220) both report that this rare element-rich mineral commonly occurs in granitic pegmatites and associated skarns.

Biotite, pleochroic α = brown, $\beta = \gamma$ = dark brown, is present in almost all thin sections. Its habit is either as small anhedral interstitial laths or it forms subhedral poikiloblasts. In the latter case the biotite flakes define the rock foliation and are often bent or broken.

A later development of biotite grains is present; these usually grow in random fashion. Zircon inclusions within the biotite do not exhibit any pleochroic haloes. Some of the biotite has been altered to chlorite.

Sphene usually occurs as equant crystals. Some of the sphene has been altered to leucoxene. Adams et. al. (1974) attributes the formation of leucoxene from titaniferous minerals to the deuteric alteration in oxygen-deficient ground waters. Anthophyllite occurs as elongate porphyroblasts which have been microscopically fractured; iron staining is prevalent.

Modal counts for the metasediments are shown in Figure 13. From the dispersion of points it is evident that the metasedimentary rocks are of variable composition and the average composition contains more quartz and mafics than the average composition of the granite.

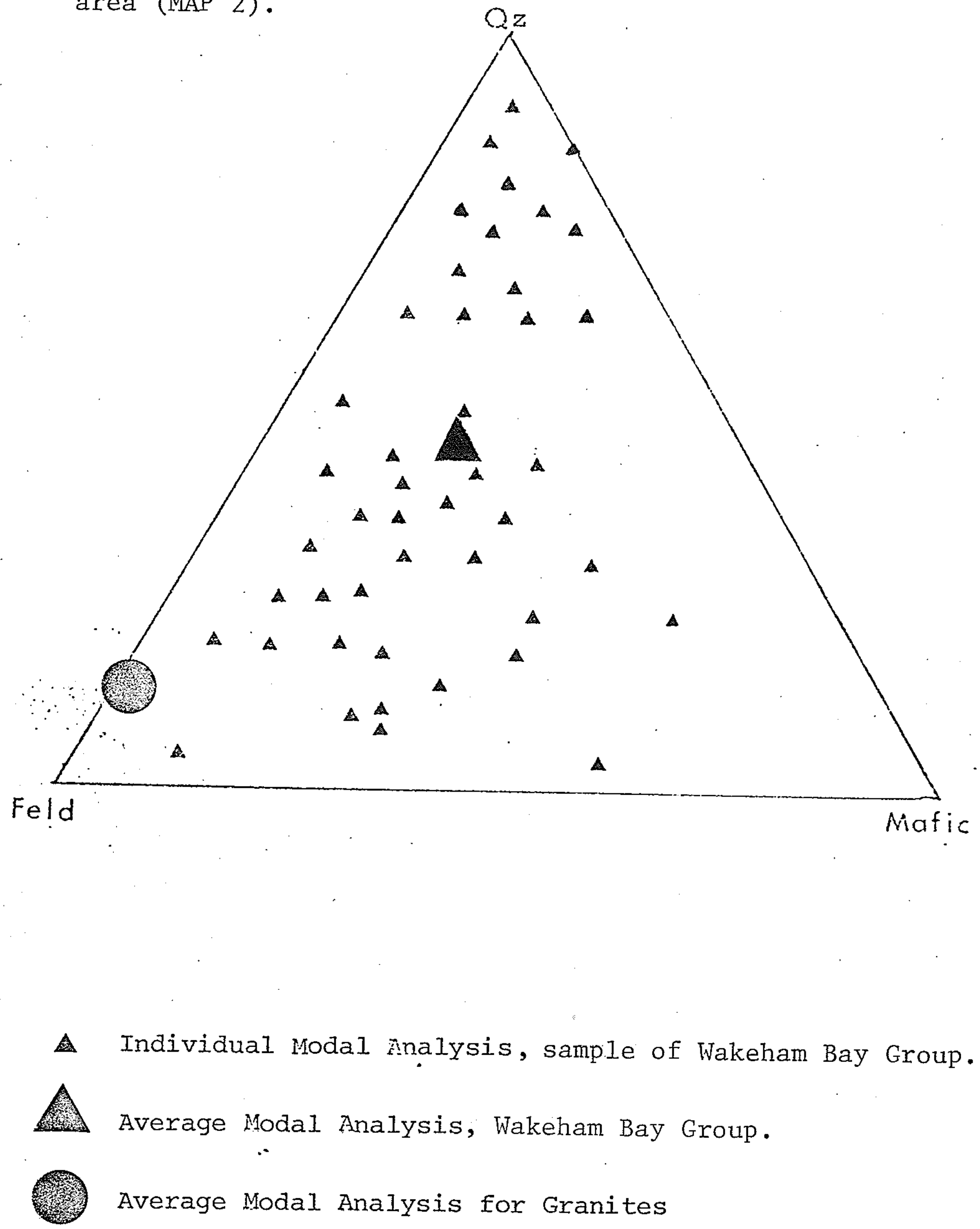
Mineral assemblages observed in the granulites are listed in Table 1 and are displayed diagrammatically in Figures 14, 15 and 16. Figure 14 shows the mineral assemblages observed in the presence of muscovite. Figure 15 represents those assemblages believed stable below the upper stability limit of epidote, while Figure 16 indicates the highest grade metamorphic mineral assemblages. The triangles represent the projection planes of the tetrahedron, K_2O, Al_2O_3, CaO and (Fe, Mg) O. Projection points are through muscovite in Figure 14 and through potassium feldspar in Figures 15 and 16 (see Thompson, 1957, for a detailed description of such graphical analyses).

Note that in some cases the tie lines cross each other, or an extra mineral phase is present. This feature does not represent disequilibrium conditions but is merely due to components not represented. For example, Fe and Mg are treated as one component, H_2O pressure is assumed equal to load pressure and the sodic component of anorthite is ignored.

For example in the system Al_2O_3, CaO, (Fe, Mg) O, with variable pressure and temperature, Gibbs' phase

Figure 13

Relative modal concentrations (by volume) of the minerals quartz (Qz) - feldspars (Feld) - dark minerals (Mafic), for rock samples of the metasedimentary rocks of the Wakeham Bay Group and Lac Turgeon granites, from the Urangesellschaft claim area (MAP 2).



rule, $f = c - p + 2$ (where f = degrees of freedom, c = number of components, p = number of mineral phases present), the predicted maximum number of stable minerals present for bivariant equilibrium is:-

$$f = c - p + 2$$
$$2 = 3 - p + 2$$
$$p = 3$$

Four phase mineral regions, such as biotite + hornblende + epidote = plagioclase, should represent a disequilibrium assemblage suggesting a reaction relationship. If, however, one realized that Fe and Mg are actually independent variables and that pH_2O adds another degree of freedom then the maximum number of mineral phases allowed is 5 not 3.

Granites

The granites are wholly crystalline rocks and are composed of roughly equal portions of quartz, potassium feldspar (microcline) and plagioclase (An 3-10), with lesser amounts of biotite, apatite, zircon, rutile, sphene, magnetite and muscovite. Muscovite is found only locally as a primary mineral, but often occurs as an alteration product of feldspars. Other secondary minerals include zoisite, scapolite, epidote and chlorite. Orthoclase is rare or more generally absent. According to Ayres (1974), (classification of granitic rocks for the Ontario Department of Mines) the granites fall into the quartz monzonite and albite quartz monzonite fields of composition.

Texturally the grain boundaries are lobate and interlocking and are quite distinct from the granulites.

Table 1 - Mineral Assemblages in Granulites

All assemblages include: potassium feldspar, quartz $\pm$ apatite, sphene (zircon, magnetite, ilmenite).

Below decomposition of muscovite:

(1) mus + bio + plag
(2) mus + bio + epid + plag

Upper stability limit of muscovite:

(3) bio + plag
(4) bio + epid + plag
(5) bio + horn + epid + plag
(6) anth + bio + plag
(7) epid + plag
(8) horn + plag
(9) horn + bio + plag

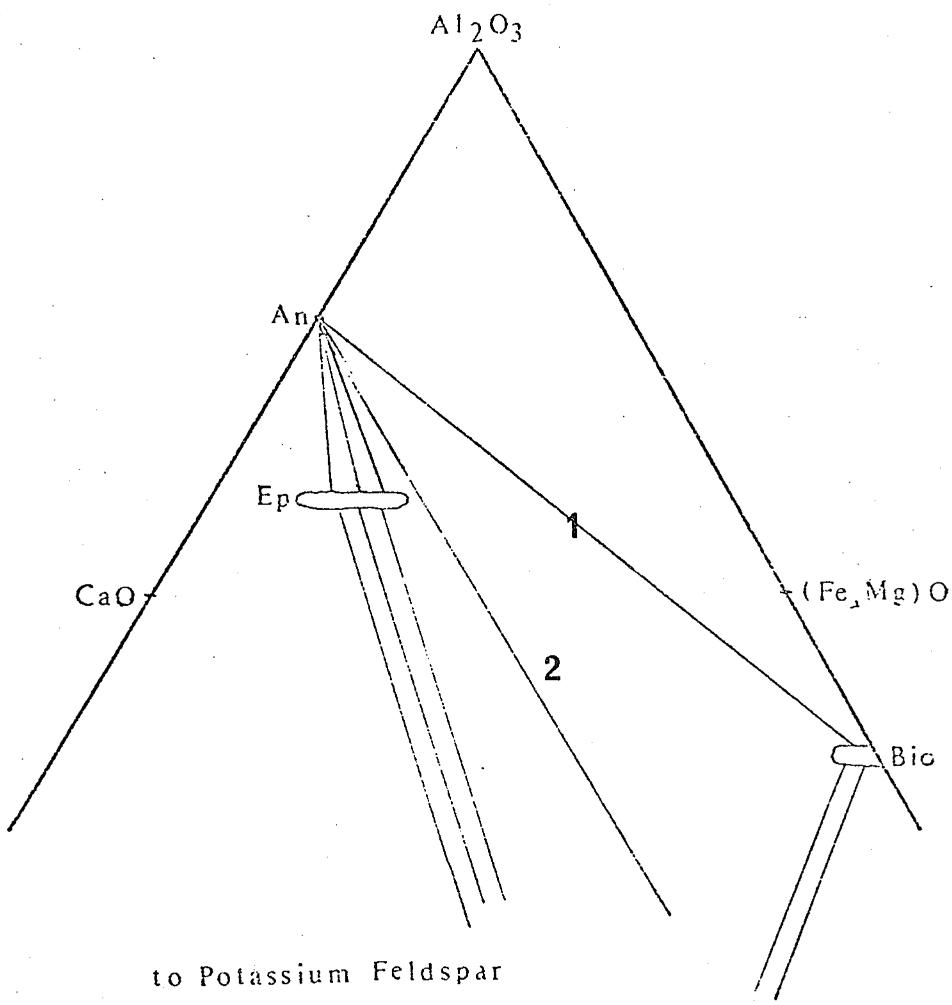
Upper stability limit of epidote:

(10) bio + horn + and + plag
(11) anth + bio + plag

mus - muscovite
bio - biotite
plag - plagioclase
epid - epidote
horn - hornblende
anth - anthophyllite
and - andradite

Figure 14

Mineral Assemblages in Metasediments
Below the Upper Stability Limit of Muscovite



(1) Muscovite + Biotite + Plagioclase

(2) Muscovite + Biotite + Epidote + Plagioclase

+ Potassium Feldspar, Quartz, Apatite, Sphene, Zircon, Magnetite, Ilmenite

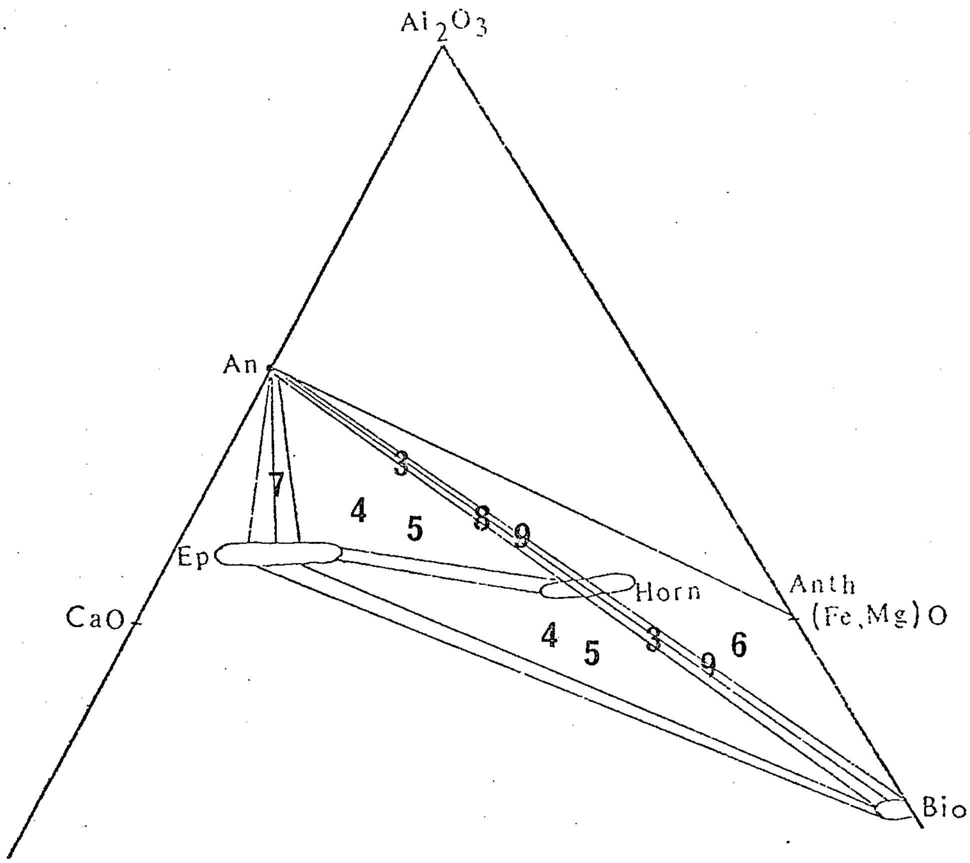
An - Anorthite

Bio - Biotite

Ep - Epidote

Figure 15

Mineral Assemblages in Metasediments
Below the Upper Stability Limit of Epidote



3 - Biotite + Plagioclase
4 - Biotite + Epidote + Plagioclase
5 - Biotite + Hornblende + Epidote + Plagioclase
6 - Anthopyllite + Biotite + plagioclase
7 - Epidote + Plagioclase
8 - Hornblende + Plagioclase
9 - Hornblende + Biotite + Plagioclase

+ Potassium Feldspar, Quartz, Sphene, Apatite, Zircon, Magnetite, Ilmenite

An - Anothite

Anth - Anthophyllite

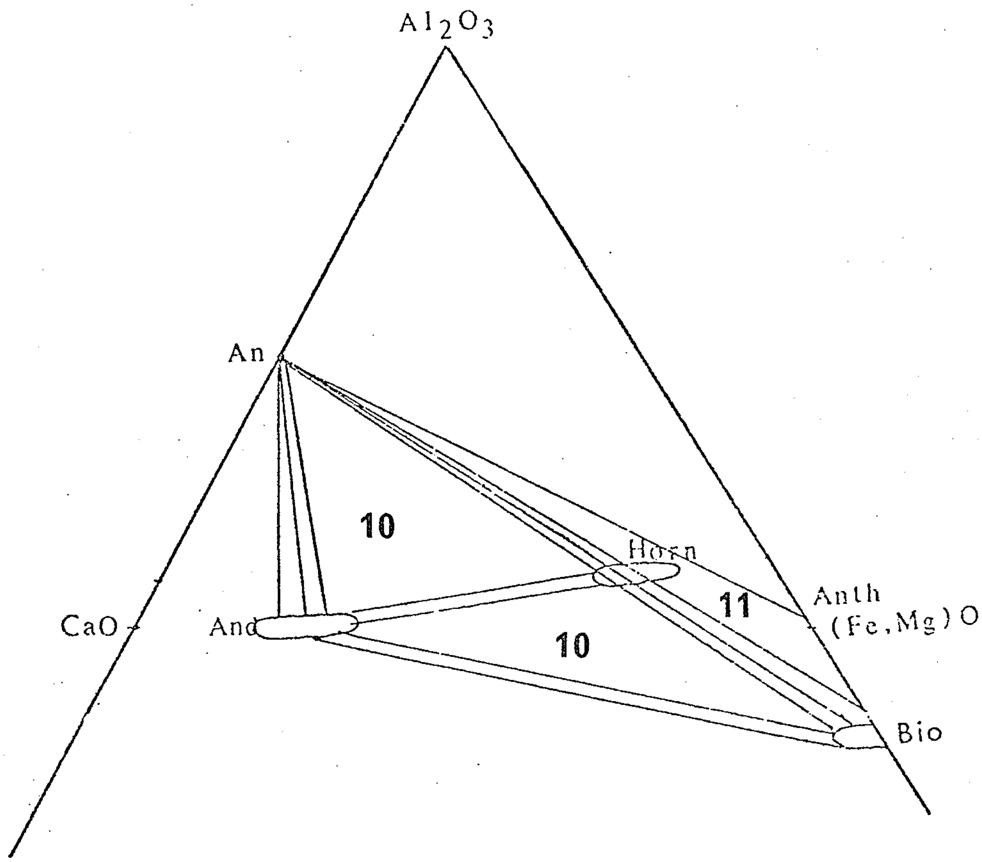
Bio - Biotite

Ep - Epidote

Horn - Hornblende

Figure 16

Highest Metamorphic Grade Mineral Assemblages



(10) Biotite + Hornblende + Andradite + Plagioclase

(11) Anthophyllite + Biotite + Plagioclase

+ Potassium Feldspar, Quartz, Apatite, sphene, Zircon, Magnetite, Ilmenite

An - Anothite

And - Andradite

Bio - Biotite

Horn - Hornblende

A list of the modal analysis of the granitic rocks are in Table 2. In the system Quartz-Plagioclase-Potassium Feldspar (normalized to 100%) and the system Quartz, total Feldspar and Mafics, the sample locations are shown in Fig. 17. The results are plotted in Figures 18 (a), (b), 19 and 20.

Included in Diagrams 19 and 20 are the results obtained from the normative mineralogy in the adjacent Denison Mines property (Hauseux, 1976).

The granites display a different texture than that of the granulites. The grains are anhedral and interlocking (although remnant metamorphic textures can be observed in some sections). Microcline and plagioclase both form anhedral poikiloblasts with inclusions of quartz, apatite, sphene and biotite. Microcline can occur as late stage crystals which completely encase pre-existing perthite, microcline, plagioclase and quartz. They also occur as anhedral grains along with quartz to constitute the matrix material. Anorthite content among the plagioclase is variable in any given granitic rock unit; however, there is a general decrease in Ca content going from the biotite granite (average An, 12.5) to the medium-grained granite (An 9.5) to the massive medium-grained granite (An 5). No zoning was evident in the plagioclase crystals and the poikiloblasts shows roughly the same composition as those plagioclase crystals which were in the matrix. The presence of zoned plagioclase, according to Mehnert (1968), is a dominant characteristic of igneous rocks, while zoning in pegmatoidal (migmatitic) plagioclases will only occur if the leucosomes originate from paleosomes of widely different compositions. While zoning may not be evident among the plagioclase, there are numerous crystals which show remnant cores, often broken or bent. Unfortunately, these cores were too highly sericitized to obtain their composition.

Table 2 - Mineral Mode Analyses (in Volume %)

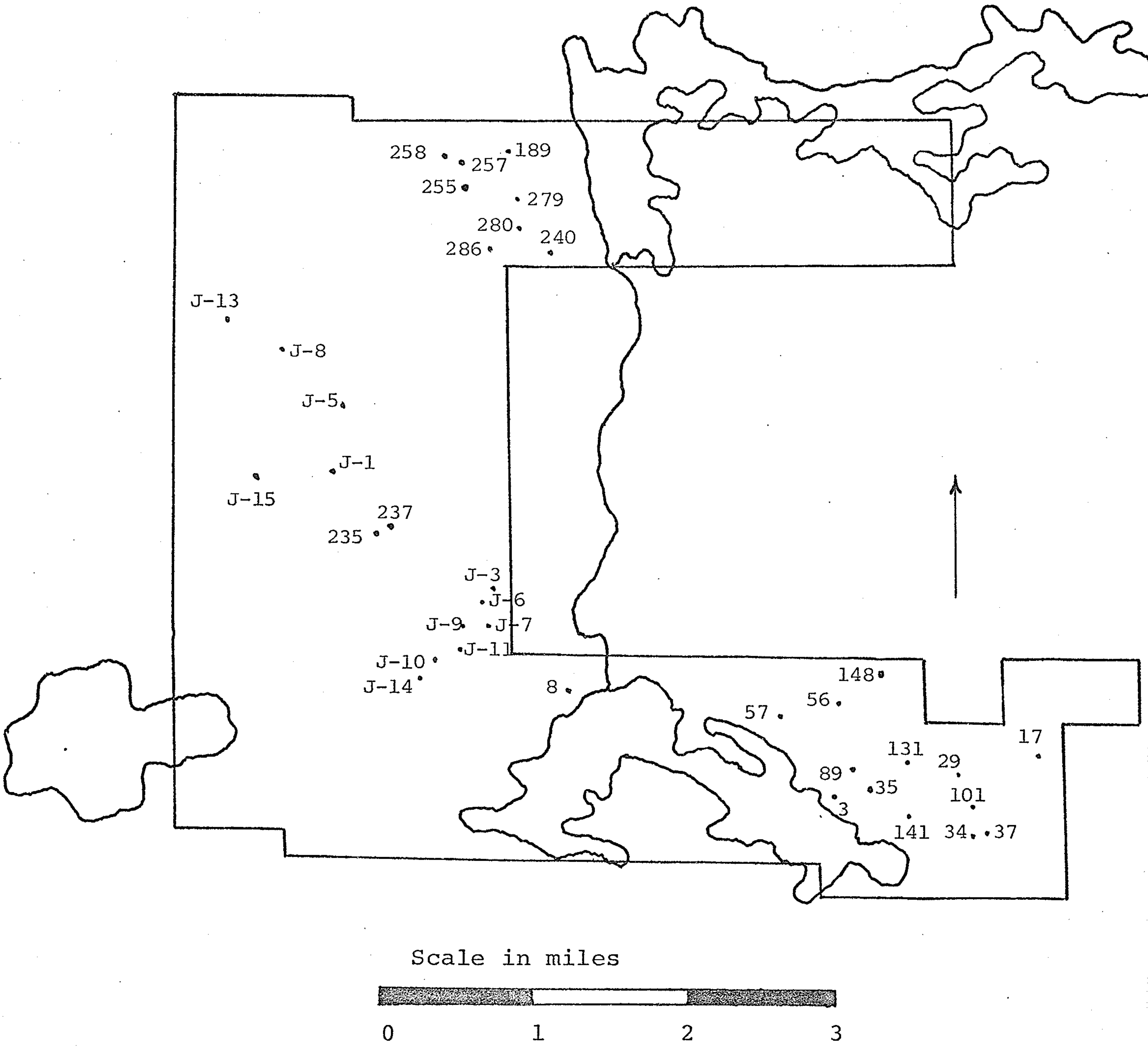
Sample No.	System: Quartz - Potassium Feldspar - Plagioclase normalized to 100%			System: Quartz - Total Feldspar - Mafics		
	Quartz,	Plagioclase,	Potassium Feldspar,	Quartz,	Total Feldspars,	Mafics
Biotite Granite						
8	21.4	49.9	28.7	19.2	70.7	10.1
189	28.6	43.4	28.0	25.8	64.4	9.2
240	40.0	40.8	19.3	35.9	53.9	10.2
279	28.4	39.3	32.3	26.0	65.6	8.4
280	31.2	43.6	25.2	28.4	62.7	8.9
285	37.5	52.3	20.1	34.0	56.6	9.4
J-3	29.2	37.8	32.9	26.2	63.4	10.3
J-6	26.1	47.1	26.8	23.4	67.6	10.0
J-7	29.2	45.6	25.4	27.7	61.6	11.7
J-9	42.3	38.5	20.1	38.4	52.3	9.3
J-10	28.5	48.0	24.8	24.5	62.7	12.8
J-11	33.3	44.3	22.5	30.9	61.9	7.3
J-14	33.4	41.7	25.1	30.5	61.0	8.6
Medium-Grained Granite						
35	32.5	35.0	32.6	32.0	66.5	1.6
148	34.3	30.2	35.5	33.5	63.9	2.6
235	29.8	39.0	31.2	28.9	71.2	2.9
237	33.4	35.1	31.5	32.6	65.2	2.2
J-1	8.6	21.4	69.7	8.7	89.6	1.7
J-5	32.6	40.2	27.1	31.7	65.3	3.0
J-8	30.7	34.3	35.0	30.7	65.2	5.9
J-13	28.2	37.2	34.6	27.3	69.6	3.1
J-15	30.7	39.7	29.6	23.0	66.0	4.9
Massive Medium-Grained Granite						
255	40.2	26.2	33.6	39.8	59.1	1.1
257	42.9	27.6	29.5	42.3	56.3	1.5
258	41.4	27.1	31.5	40.9	57.8	1.3
Pegmatitic Granite - Lac Tanguay Area						
3	39.4	27.5	33.1	37.2	57.3	5.6
17	43.8	22.6	33.6	43.1	55.4	1.5
29	30.3	41.2	28.3	28.9	66.3	4.7
34	34.4	26.0	29.5	33.1	63.0	3.8
37	33.9	39.0	27.1	33.5	65.3	1.3
56	33.0	28.7	38.6	32.3	66.0	1.6
57	32.9	31.9	35.1	32.1	65.5	2.3
89	32.5	21.5	46.1	31.9	66.3	1.9
101	41.2	31.9	26.7	40.1	57.0	2.9
131	31.0	26.8	42.4	30.0	67.2	2.9
141	40.0	58.5	1.5	39.1	58.7	2.2

Method: Counting at least 600 points on a grid of 0.5 mm. line spacing.

Figure 17

Sample Locations

(For Mineral Mode Analyses)



Another common feature of the feldspar minerals is partial rims of albite which seem to occur along the boundary between microcline and plagioclase (see Figure 27). Ramberg (1962) interpreted this to be a replacement phenomena while Rodgers (1961) argues that the albite is a direct product of crystallization during the later stages of magma solidification in deuteric and hydrothermal action.

Microcline is thought by some (Goldsmith and Laves, 1954) to form from pre-existing monoclinic orthoclase. Marmo (1962) argues that microcline can crystallize directly as a triclinic feldspar at relatively low temperatures. The microcline in the granites is often perthitic. Bowen and Tuttle (1950), with their experiments into the liquidus-solidus and sub-solidus relations among the alkali feldspars, showed that alkali feldspars form complete series of solid solutions at higher temperatures. Upon cooling, a miscibility gap appears between the two end members with the formation of the resultant perthitic texture. Michot (1961) showed that the exsolution temperature must pass through the solvus at temperatures between 660-715°C, depending on the water pressure and An content of plagioclase for the formation of mesoperthites. An ex-solution origin is also suggested by Mackenzie and Smith (1962).

Buddington (1948) concluded that perthitic textures were characteristic of crystallization from a magma. Granites formed by metasomatism contained single feldspars, microcline or orthoclase. This idea seems to argue with the petrological evidence from this area as perthites are restricted to the granitic rocks and are absent from the metasediments.

Both myrmekitic and graphitic (granophyric) textures were noted and occur interstitially to all other crystal phases. The classic theory to the origin of myrmekite is attributed to Becke (1908) who interpreted it as the replacement of potassium feldspar by plagioclase (which contains less SiO_2). However, Mehnert (1968) points out this replacement reaction is well known in petrography and normally it does not lead to the formation of myrmekitic structures. Further controversy lies in the origin of graphic intergrowths. Vogt (1928) thought the intergrowths were due to the simultaneous growth of quartz and feldspar at the eutectic. Augustithis (1962) puts forth an opposing view: because of the wide variance in the quartz/feldspar ratios in such growths it is claimed that they could not represent eutectic conditions. He prefers the idea that they are due to late replacement by hydrothermal solution. A detailed review of feldspar textures is given by Smith (1974). Many feldspar grains have been fractured and filled with quartz, albite $\pm$ zoisite.

In general, the various textures exhibited by feldspars have been interpreted as either primary (due to the crystallization sequence) or late stage hydrothermal replacement (authometamorphism). These textures are lacking in the metasedimentary rocks; thus it appears that the granitic rocks have a different crystallization history than the metamorphic rocks. Due to the corrosive appearance of some feldspars and fracture fillings by quartz and albite, it appears that some low temperature replacement occurred. The fact that such features are not present in the metasedimentary rocks suggests that the late stage hydrothermal activity was primarily restricted to the granitic rocks. This probably explains why orthoclase, not microcline, is the stable potassic feldspar in the metamorphic rocks.

Biotite forms subhedral laths, interstitial to quartz and feldspar. It may also form poikiloblasts containing inclusions of magnetite, sphene, quartz and zircon (which are usually metamictic). In most cases, biotite has been, at least in part, altered to chlorite.

Quartz rarely is poikilitic; usually it occurs as anhedral grains in the groundmass and it is highly undulose but rarely fractured.

Numerous apatite inclusions occur in both quartz and feldspars. Unlike igneous apatites, these are fairly equant having elongation ratios 3:4:1, a ratio Mehnert (1963) suggests is more common to granitoid migmatites rather than igneous granites which will have an elongation ratio of 5:1 or greater.

Hauseux (1976) did a detailed study on the zircon population of the granitic rocks. She found most had elongation ratios varying from 1:1 to 2:1 and they often showed growth zoning. Quoting work done by Poldervaart and Eckelmann (1955), who showed that zircons displaying growth patterns were characteristic of autochthonous granites, and Saxena (1966), who thought that euhedral zircons could form by authigenesis, Hauseux suggested that the zircons in the granitic rocks were recrystallized from original sedimentary material.

Epidote, chlorite and zoisite occur as secondary alteration products. Chlorite occurs due to the alteration of biotite. While, as mentioned, epidote and zoisite along with quartz and albite fill numerous fractures which occur in the granites, much of the plagioclase has been sericitized and has abundant hematitic staining.

Figure 18(a)

Modal Analysis

Qz-Plag-Potassium Feldspar

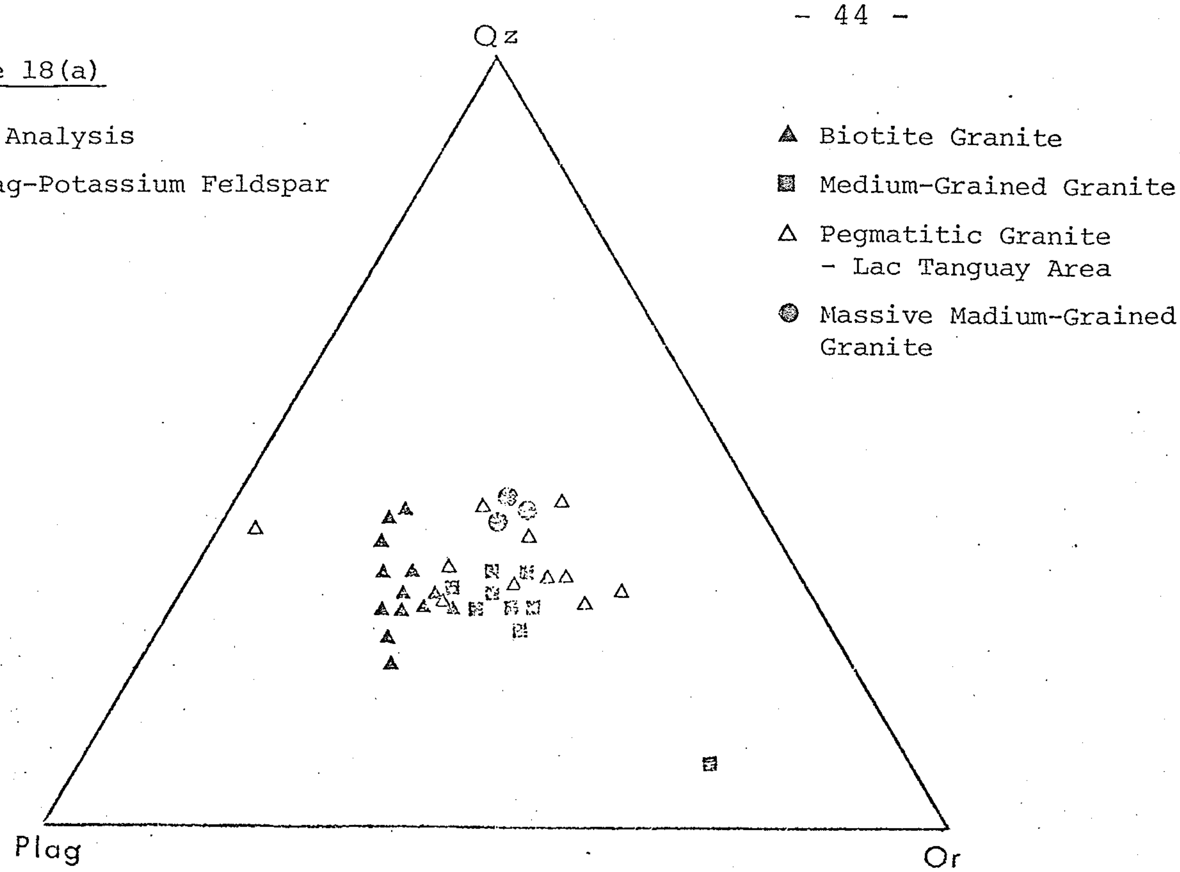


Figure 18(b)

Modal Analysis

Qz-Feld-Mafics

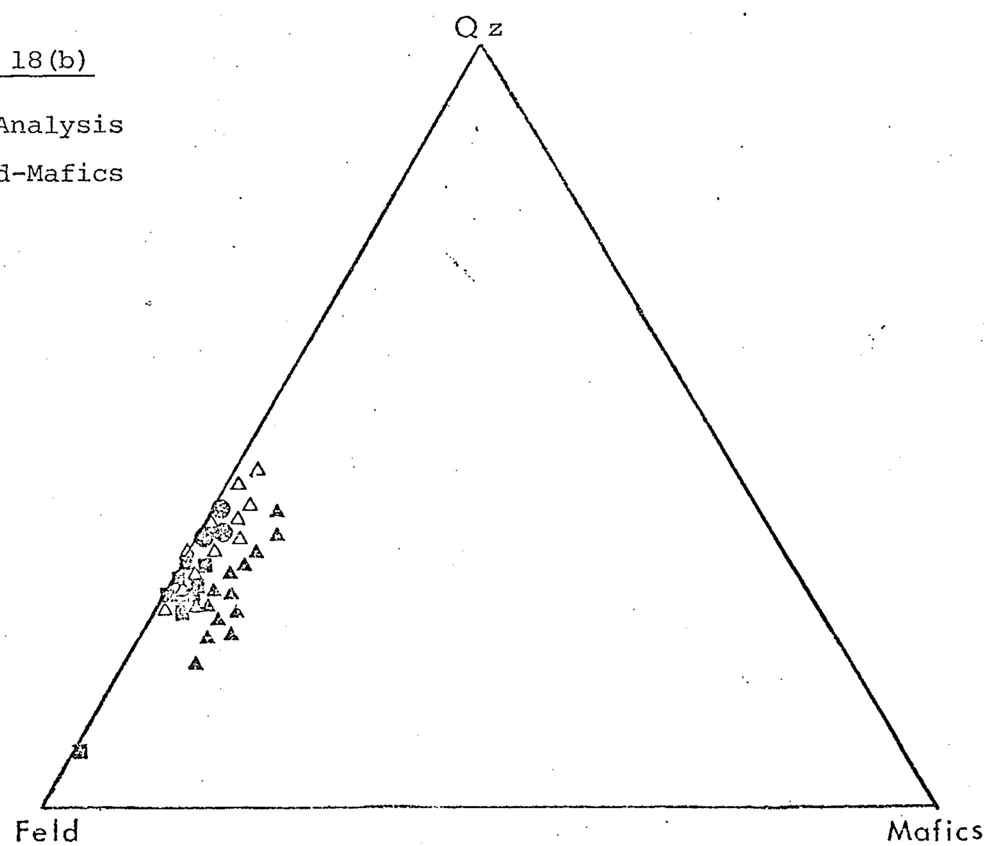


Figure 19

Modal Analysis An-Ab-Or

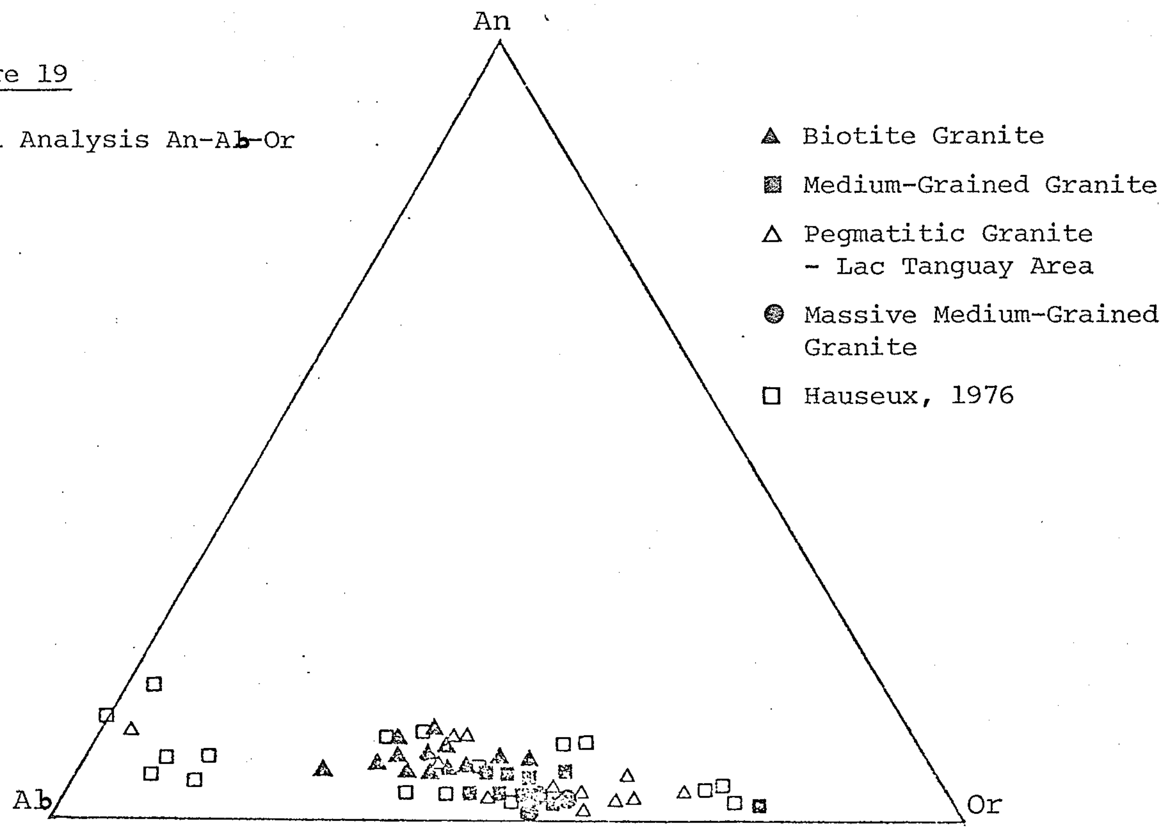


Figure 20

Modal Analysis Qz-Ab-Or

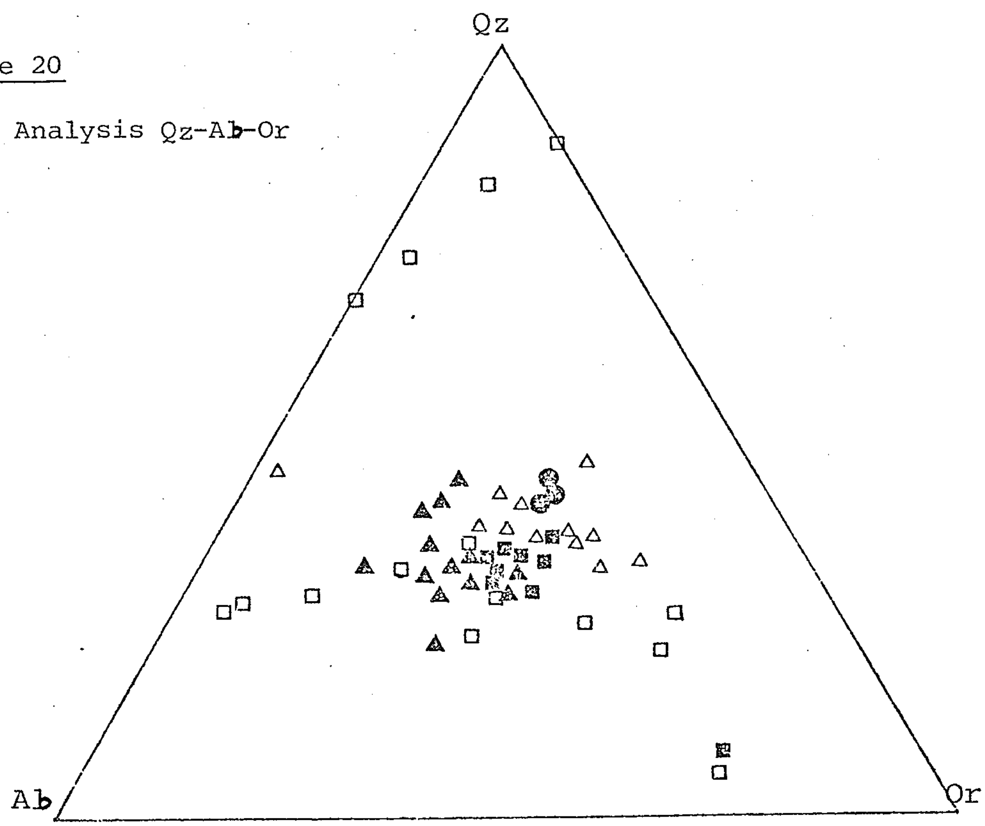


Figure 21

Poikiloblastic Hornblende(H) in Granulitic Matrix, Consisting of Quartz(Qu) and Feldspars (Feld)

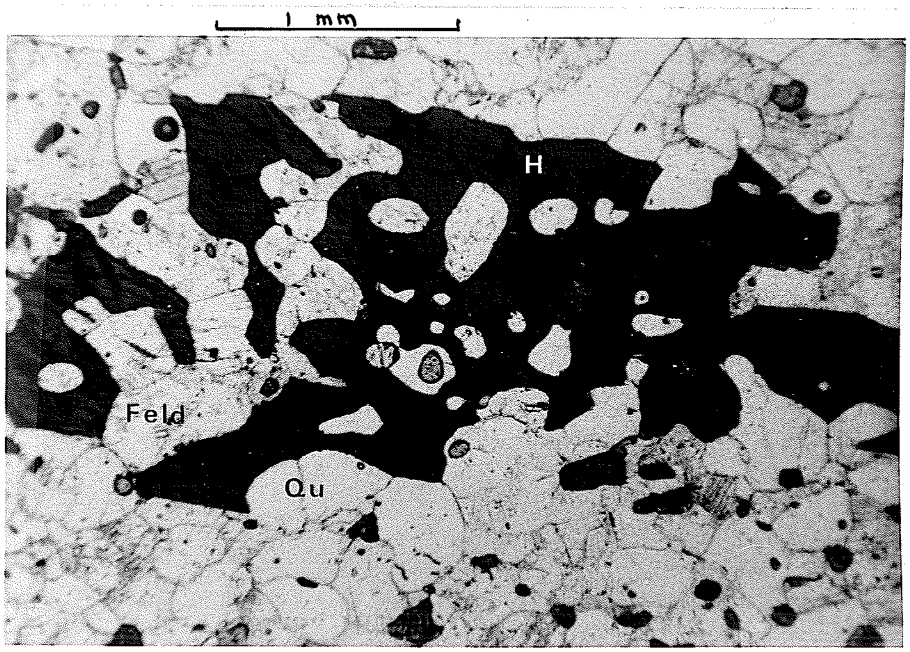


Figure 22

Magnetite (Mag) Rimmed by Sphene (Sph)

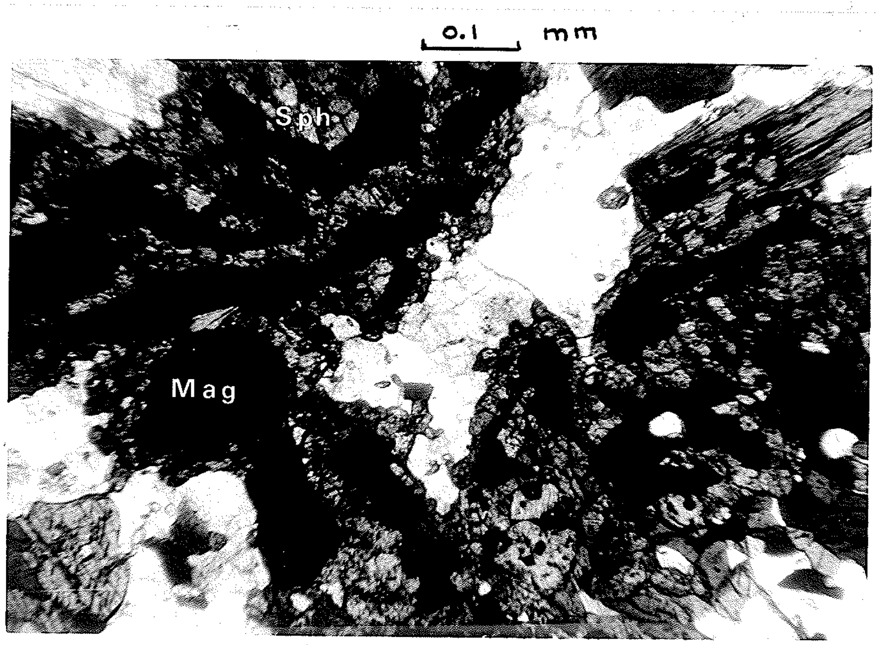


Figure 23

Granulitic Texture, Quartz (Qu), Feldspar (Fd), Hornblende (H)

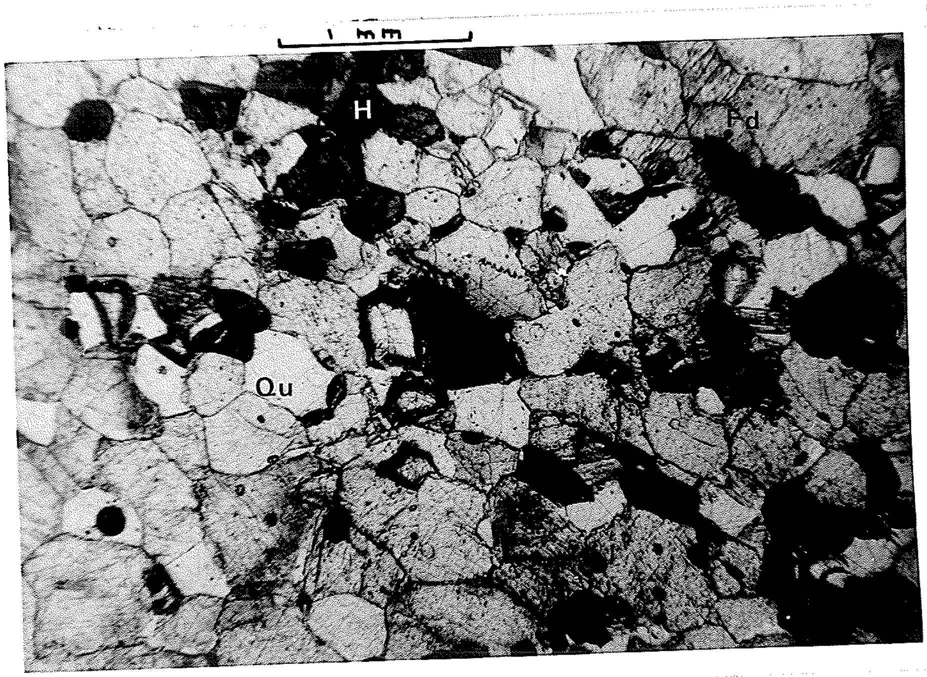


Figure 24

Poikiloblastic Andradite (And), Biotite (Bio), Hornblende (H)

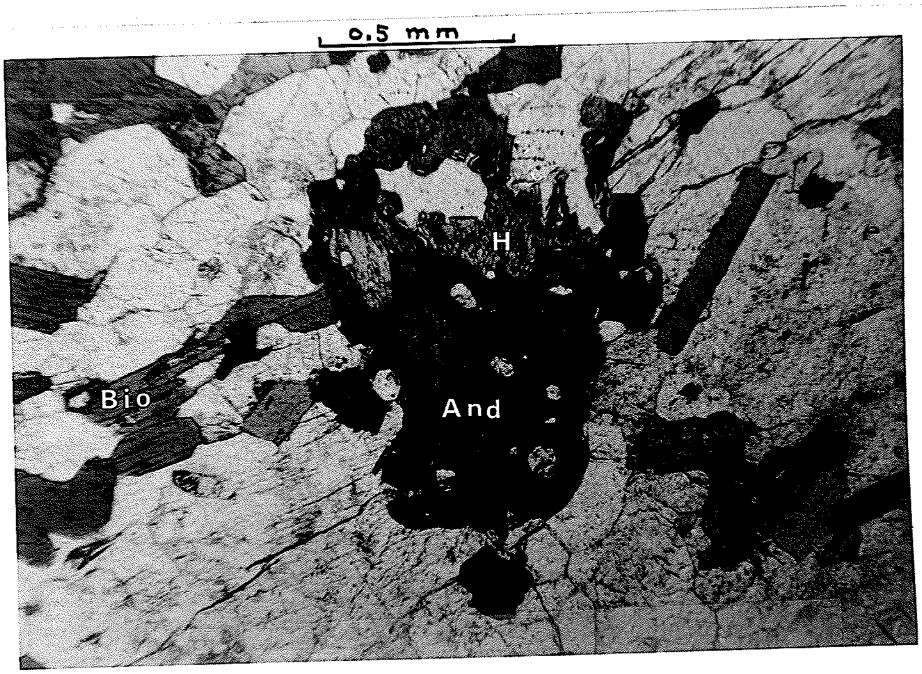


Figure 25

Allanite (Al) Rimmed by Epidote (Ep) as Inclusions in Biotite (Bio)

Figure 26

Metasomatic Plagioclase (Plag) in the Metasediments

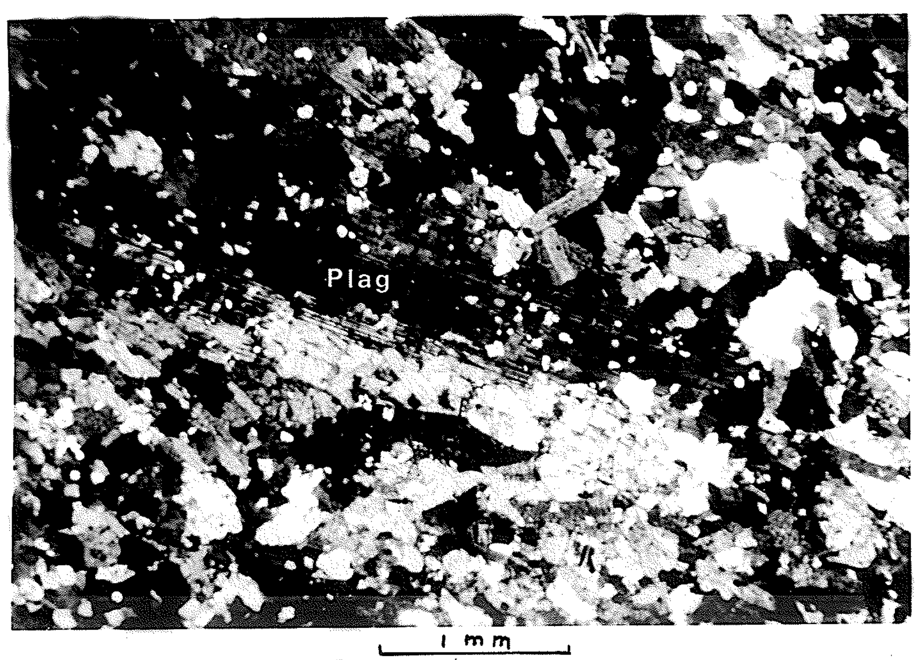


Figure 27

Microcline (Mic) and Plagioclase (Plag)
Showing Albite Rimming (Alb)

Figure 28

Corrosive Grain Boundaries Replacement by
Autometamorphism Perthite (P), Plagioclase (Plag)
and Quartz (Qu)

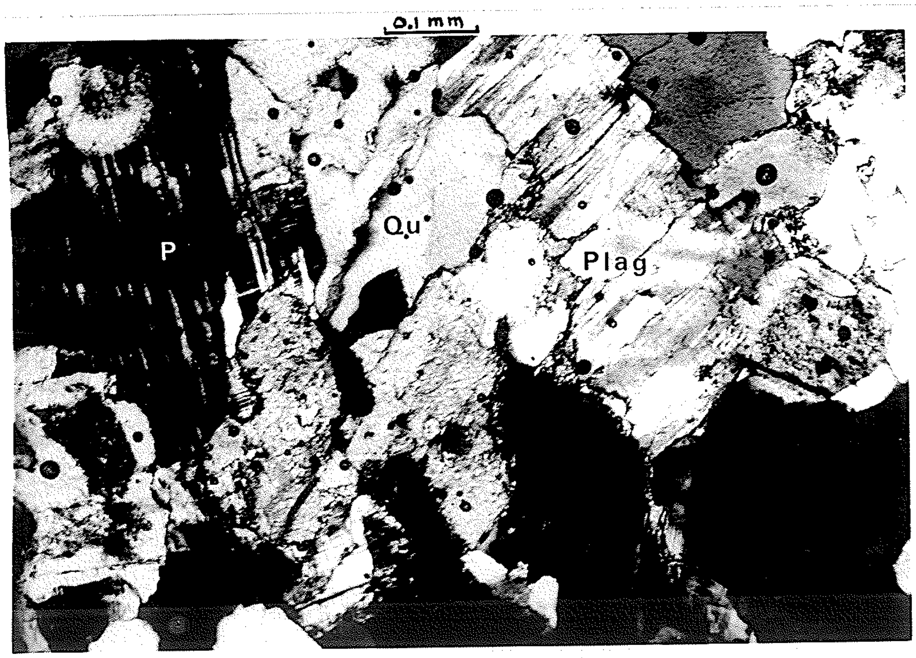


Figure 29

Biotite Selvage Edges (Bio) Separating Paleosome (Pal) on Left From Leucosome (Leuc) on Right

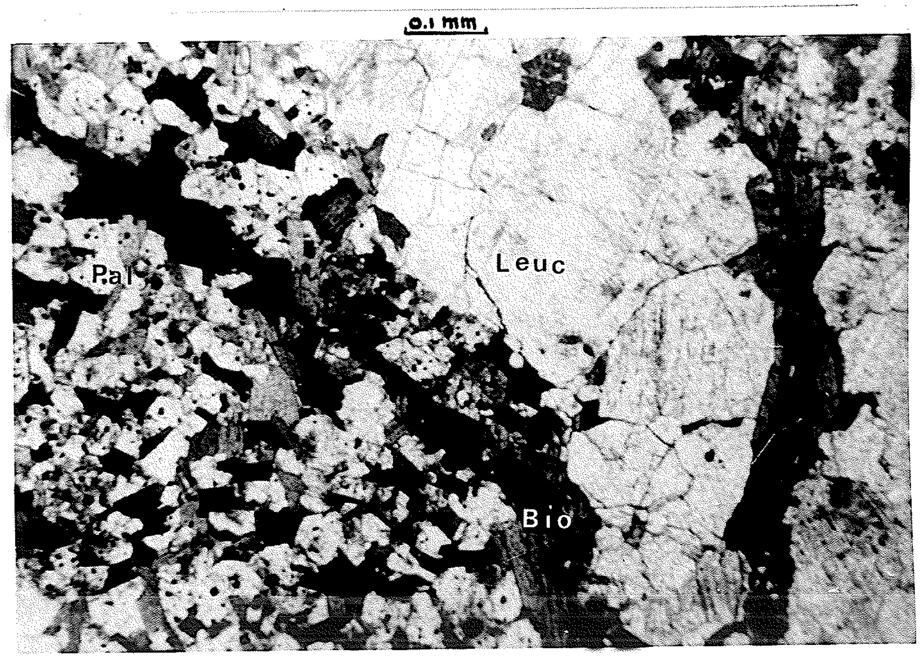
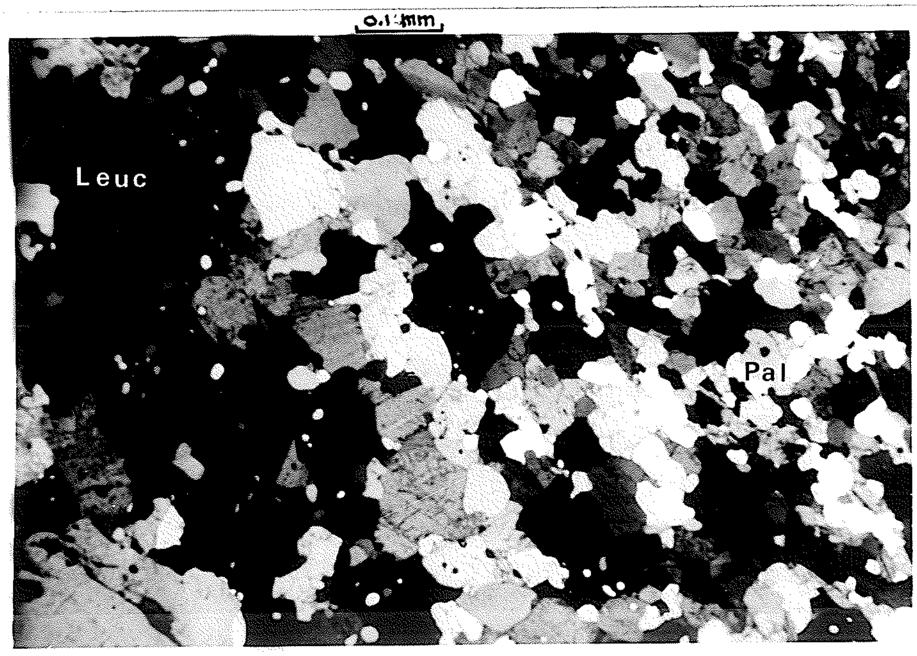


Figure 30

Microscopic Gradational Contact From Paleosome (Pal) To Leucosome
Note in this case no selvage edge is developed.



METAMORPHIC CONDITIONS

The objective in metamorphic petrology is to deduce from the observed mineral assemblages and their texture relationships the metamorphic conditions which prevailed during their formation.

PRESSURE AND TEMPERATURE

Pressure and temperature are the two main physical factors that control metamorphism. Mineral assemblages, stable under a specific pressure and temperature, for a given bulk rock composition, may become unstable if subjected to a different pressure, temperature regime. Thus the observed mineral assemblages will provide some indication to the physical conditions of metamorphism.

Problems arise with dehydration reactions; as a hydrated mineral stability field will depend on pH_2O and on the fluid phase composition as well as the load pressure (P_l) and temperature. Since the situation $P_f > P_l$ is not realized under metamorphic conditions (Winkler, 1974), two possibilities arise: $P_f = P_l$ or $P_f < P_l$. The effect of a variable fluid pressure, less than the load pressure, is twofold: (1) it lowers the temperatures for dehydration reactions and (2) it introduces another degree of freedom. Similar results can be obtained by the addition of another volatile component (O_2, CO_2) into the fluid phase. A detailed discussion of these effects can be found in Turner and Verhoogen (1960).

Further errors arise as mineral stabilities are often dependent on their compositions; most mafic minerals exhibit quite extensive solid solutions.

However, a comparison between various metamorphic indicators in the rocks studied yield consistent results to the degree of regional metamorphism in the Lac Turgeon area. These conditions must be taken into consideration when interpreting the genesis of the granitic rocks.

Although Cooper (1957) described the Wakeham Bay series as being metamorphosed to the greenschist and amphibolite facies, the metamorphic rocks within the granite and adjacent to the south appear to have reached peak metamorphic conditions more characteristic of a transitional facies between the upper amphibolite and lower granulite facies.

? means clastic?

Primary muscovite is found to be absent in the metasediments which occur near or in the granite, except on a north-south trending zone along the east side of Lac Turgeon. As mentioned, this is a zone of presumed faulting. This hypothesis is supported because while isogrades are concordant to the regional structure, these crosscut the existing trends in a N-S fashion along the line of the fault.

The lack of any pyroxene minerals in any of the rocks implies that the peak metamorphic conditions did not reach the pyroxene (upper) granulite facies. The boundary between the amphibolite and granulite facies is often equated with the disappearance of hornblende in favour of pyroxenes (deWaard, 1965). Under these conditions, alumina-silicates would still be stable; their absence, along with the absence of muscovite, means that the breakdown of muscovite did not involve the reactions:

$$KAl_2\ (AlSi_3O_{10})\ OH_2 + SiO_2 = Al_2SiO_3 + KAlSi_3O_2H_2O$$

$$\text{Mus + Quartz} = \text{Alum-Sil + Kspar} + H_2O$$

(Evans, 1965), but was due to the partial melting of the metasediments with muscovite going into the liquid fraction. This would require temperatures in excess of 650°C with a water pressure of at least 5-6 kbars (Evans, 1965).

Figure 31 shows the isogrades present along with the transition microcline $\rightarrow$ orthoclase in the metasedimentary rocks.

In Figure 31 one notices that the disappearance of muscovite is closely related with the transition: microcline $\rightarrow$ orthoclase within the metasediments. Touret (1963), Heier (1956) and Bordet and Chaures (1965) equated the transition from the triclinic microcline to the monoclinic orthoclase at the boundary between the upper amphibolite and granulite facies.

Anthophyllite was noted in several thin sections along with quartz, biotite and feldspars. Its restricted occurrence is probably due to bulk rock composition rather than the metamorphic conditions. The lower and upper stability limit of anthophyllite can be defined by the following reaction:
4 forsterite + 9 talc = 5 anthophyllite + 4 H_2O
anthophyllite = 7 enstatite + 4 quartz + 4 H_2O (Greenwood, 1963).

Andradite (characteristic of skarn deposits) also is restricted in its occurrence; where it does occur it appears to be replacing epidote:
epidote = grandite (ss) + anorthite + hematite + quartz + H_2O (Liou, 1973).

Andradite thus appears to represent the highest grade metamorphic assemblages. Since epidote contains iron mainly in the ferric (oxidized) state its stability field is expanded under high O_2 fugacities. However, due to the ubiquitous presence of magnetite the reaction curve used is the one controlled by the QFM buffer.

The upper stability of andradite is defined by the reaction: andradite + 2 quartz = 2 hedenbergite + wollastonite + 1/2 O_2 (Liou et al, 1971).

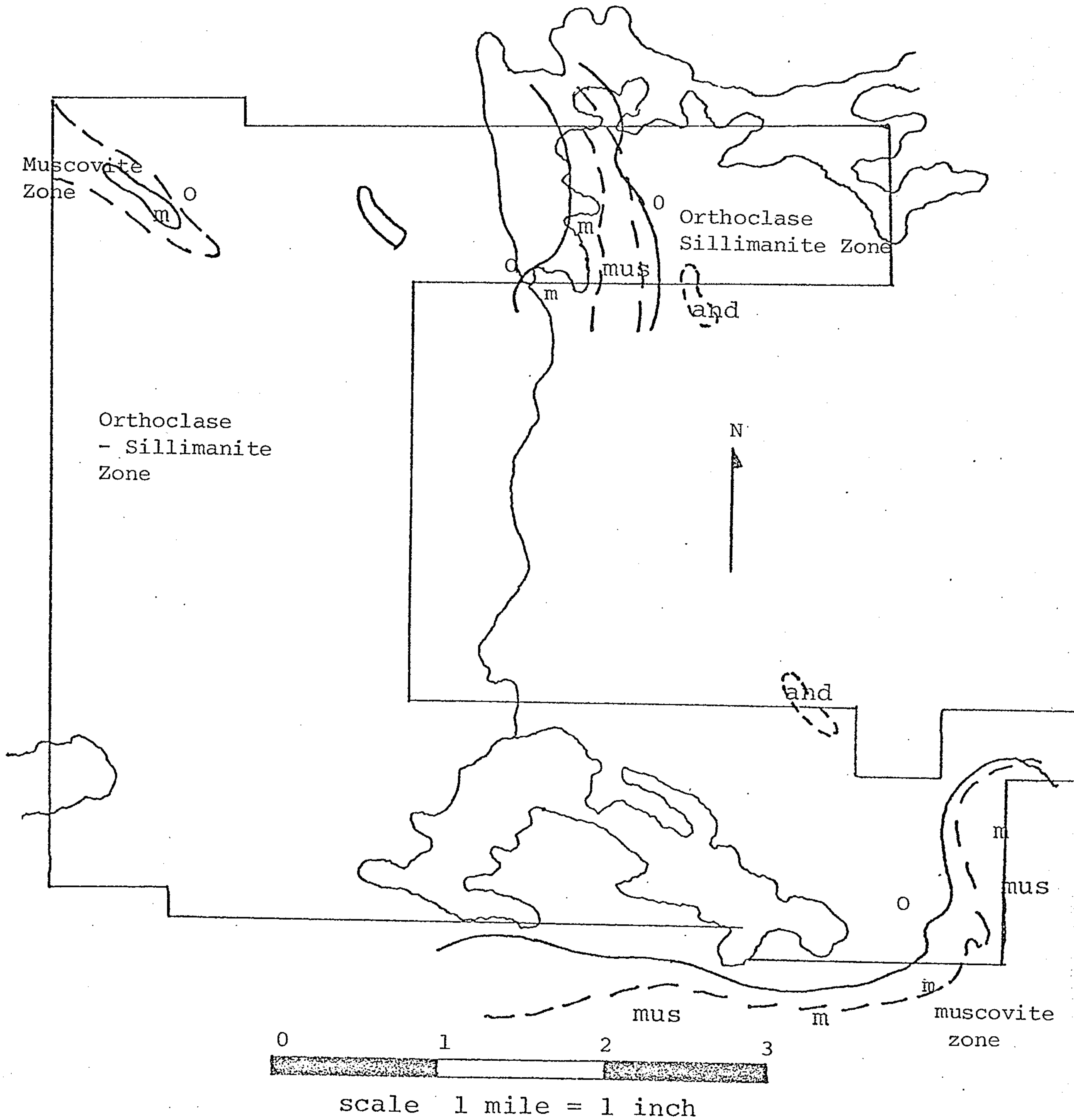


Figure 31

Map of Lac Turgeon Area Showing Metamorphic Zones and Isogrades
with Urangesellschaft's 1975 claim boundary outlined.

- transition, microcline (m) - orthoclase (o)
- muscovite (mus) stability field
- andradite stability field (and)

These reaction curves along with the minimum melting curve for granite (Bowen and Tuttle, 1958) and the aluminum-silicate phase relations (Richardson et.al., 1969) are shown in Figure 32.

The minimum metamorphic temperature is defined by curve numbers 1, 2 and 4 in Figure 32 representing respectively the minimum melting curve for granite and the lower stability limit for muscovite and anthophyllite in the presence of water. The maximum temperatures attained during regional metamorphism could not have exceeded the regions bounded by curve 5 (the upper stability limit of anthophyllite) and curve 7 (the limit of stability of andradite in the presence of quartz).

Since no alumina-silicate is present in the absence of muscovite, muscovite decomposed directly into the silicate melt. The minimum water pressure required for this to take place would be in the region above the point which curve 2 (the upper stability limit of muscovite) intersects the minimum melting curve of granite (curve 1).

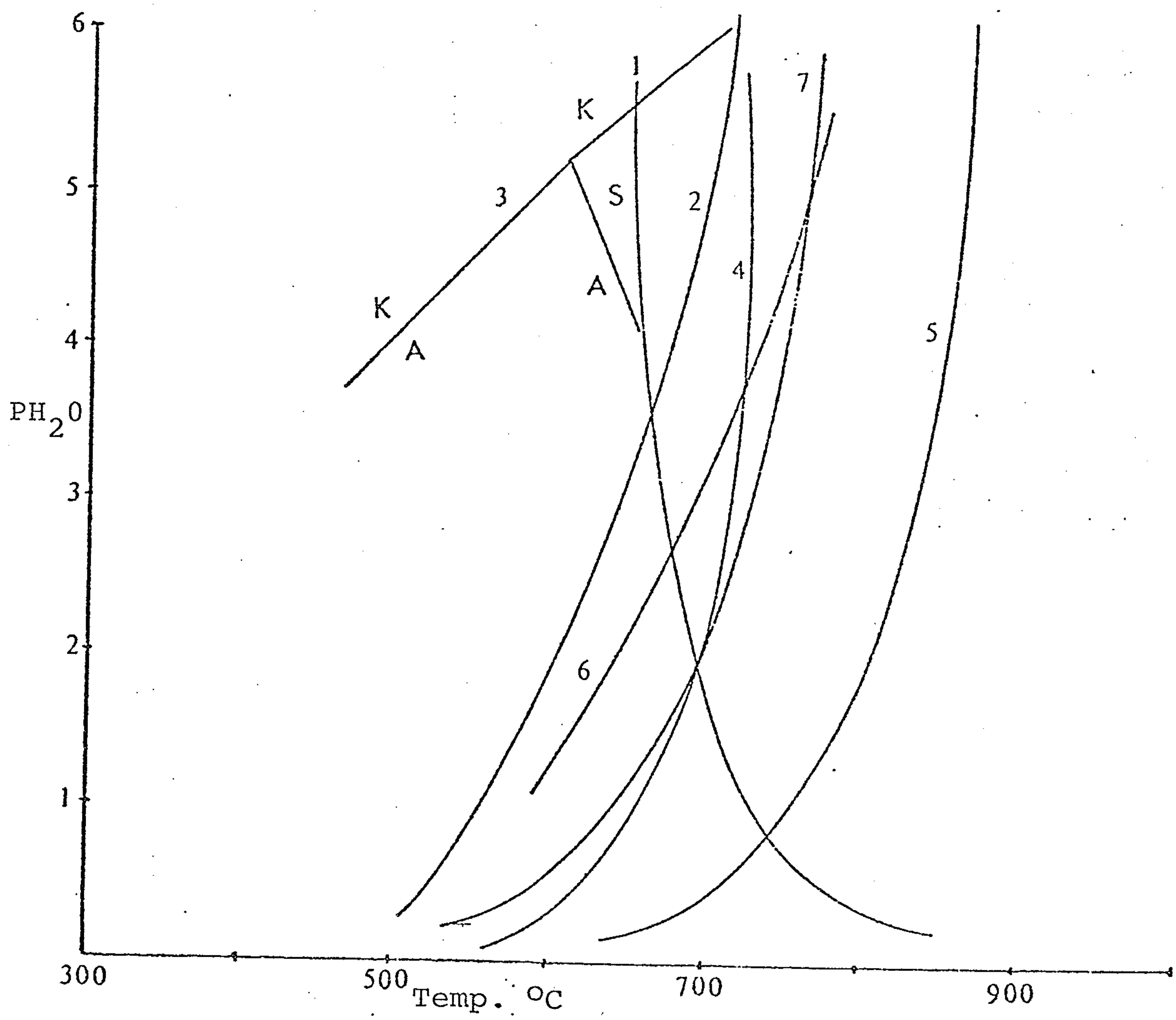
From these results one can estimate that peak metamorphic conditions in the Lac Turgeon area were at temperatures between 650 - 800°C with a minimum water pressure of 4 kbars, corresponding to the transition between the upper amphibolite and granulite facies.

Limited investigation in the surrounding country rocks indicates that peak conditions only managed to attain mid to upper amphibolite facies (muscovite was still stable, no primary chlorite or temolite was present).

This estimate agrees well with Hauseux's (1976) analysis of growth zoning in zircons which indicates temperatures between 525-750°C.

Figure 32

Pressure-Temperature Grid, with Mineral Reaction Curves



1 - Minimum Melting Curve for Granite (Bowen and Tuttle, 1958)

2 - Upper Stability Limit of Muscovite (Evans, 1965)

3 - Alumina Silicate Equilibrium Curve (Richardson et. al., 1969)

K - Stability Field Kyanite
A - Stability Field Andalusite
S - Stability Field Sillimanite

4 - 4Forsterite + 9Talc = 5Anthophyllite + $4H_2O$ (Greenwood, 1963)

5 - Anthophyllite = 7Enstatite + 4Quartz + $4H_2O$ (Greenwood, 1963)

6 - Epidote = $Grandite_{(SS)}$ + Anorthite + Hematite + Quartz + H_2O (Liou, 1973)

7 - Andradite + 2Quartz = 2Hedenbergite + Wollastonite + $\frac{1}{2}O_2$ (Liou et. al., 1971)

OXYGEN FUGACITY

Although adequate experimental data is lacking at metamorphic pressures and temperatures, at lower P,T conditions uranium in its hexavalent (oxidized) form is recognized to be quite mobile and can easily be transported in a fluid medium, while in its plus four oxidation state uranium is found to be more resistent to mobilization. If we want to assume that the uranium within the pegmatitic granites in the area was concentrated from the sediments through ultrametamorphism, oxidizing rather than more reduced conditions would be preferable.

The occurrence of sphene rims around magnetite and intergrowths of sphene with remnant magnetite lamellae (from the breakdown of ilmenite) has been reported by several authors (Buddington et al, 1963, Buddington and Lindsley, 1964, and Verhoogen, 1962). All authors agree that under high oxygen fugacities ilmenite is unstable with respect to magnetite and rutile. Buddington et al interpret that the presence of sphene in lieu of rutile is not a result of higher CaO content in the rock but was formed during regional metamorphism under slightly higher oxygen fugacities. As mentioned in the section on amphibolites, sphene could have been produced by the simultaneous decomposition of ilmenite and Ca-rich plagioclase in the presence of oxygen.

Further evidence for the presence of circulating oxygenized solutions is the development of hematization in the granitic plagioclases. The lack of any graphite or any significant sulphides in the metasediments and granite, although not conclusive, still support the hypothesis that the metamorphic conditions were oxidizing.

THE ORIGIN OF GRANITE

The origin of granite has been one of the most outstanding problems in geology for the past 150 years. The term 'granite' or 'granitic rocks' has been used extensively throughout this thesis. As suggested, it does not have any genetic implications but is used to describe any medium to coarse-grained crystalline rock consisting primarily of equal proportions of quartz, potassium feldspar and plagioclase, and whose composition lies near the low temperature eutectic in the system: Qz-Or-Ab-An-H_2O.

Theories ascribe the origin of granitic rocks to differentiation and crystallization of a primary magma, or to the process of granitization or transmutation, a term used by Keilhan (1838). He describes it as a process in which earlier rocks have been transformed into granite by slow and quiet processes. Granitization can occur by the partial melting of pre-existing metamorphic rocks (anatexis) or by metasomatism (the introduction of elements, mainly potassium and sodium, primarily in hydrous solutions). The main difference between the two processes is that in the latter case the transformation takes place with the rock essentially remaining in the solid state. Anatexis involves the formation of liquid melt.

The early magmatists included Scrope (1825), who thought that granites could form from the differentiation of a mafic primary magma. Bunsen (1851) suggested the existence of two primary magmas, one basic and forming basalts, the other acid responsible for the formation of granites. Rosenbusch (1901) postulated that fractional crystallization of a primary basic magma would produce a late granitic series of acidic rocks poor in Ca, Fe, Mg and enriched in Si, K and Na.

Bowen (1928) and Tuttle and Bowen (1958) in their experiments showed that the composition of granites corresponded to the ternary minimum in the system Or-Al-Qz-H_2O and thus they may represent the final crystallization phase of a basic magma or alternatively may represent the first formed phase of a partial melt.

Keilhan (1838) first recognized that granites occupied too large an area to be simply igneous in origin and thought that country rocks could be granitized with no deep-seated phenomena.

Extensive studies by Sederholm (1967) in the granite-gneissic belts of Fennoscandia proved that much of the granitic material was derived by the partial melting, a term he named anatexis, or pre-existing country rock. Holmquist (1910) named these composite rocks migmatites. Migmatites consisted of two or more petrographically different parts, one is the country rock in a more or less metamorphic state, the other is pegmatitic, aplitic granite or generally of plutonic appearance. Holmquist thought that these migmatites were formed during ultrametamorphism by the partial or complete recrystallization of pre-existing supracrustal material.

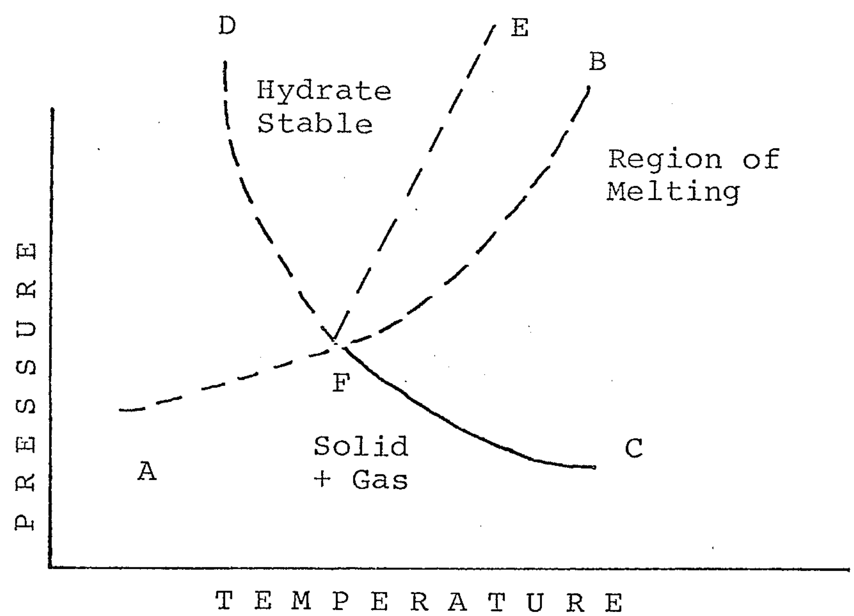
The hypothesis of partial melting within the earth's crust is plausible in light of recent geophysical data. The work of Tuttle and Bowen (1958) showed that water saturated granites can melt at temperatures of approximately 650°C at water pressures of 4-5 kbar. This minimum temperature may be reduced by the addition of a second volatile component (Li_2O, HF) by 50-90°C(Wyllie and Tuttle, 1964, Wyllie, 1969). Fyfe (1973a) points out that with the average geothermal gradient of 20°C/km (and up to twice that amount in mobile regions, Hyndman et al, 1968) partial melting can be expected to occur at depths of around 30 km, corresponding to the 600°C isotherm in the earth's crust and probably at even lesser depths in tectonically active zones. Berry and Fuchs (1973) give an average crustal thickness for the Grenville Province of 40-50 km.

Brown and Fyfe (1970) point out that granites do not form at the minimum pressure and temperature conditions as at such metamorphic conditions the rocks would be undersaturated with respect to water.

The temperature of fusion would depend rather on the vapour pressure of the hydrated mineral phases present, as illustrated in Figure 33.

Figure 33

Region of Partial Melting in the Presence of a Hydrous Phase



The vapour pressure curve of the hydrate (in the case of the Lac Turgeon granite the hydrated phase would be muscovite) lies along the line AFB. The water saturated melting curve of granite lies along CFD. The regions of total or partial melting is in the field EFD. The melting of material then actually buffers the dehydration reaction.

The resultant positive sloped melting curve method allows a granite to rise within the crust without crystallization. The refractary material from anatexis would be left behind as granulites (Fyfe, 1973b). This model would explain the depletion of such mobile elements as Rb, Cs, Th and U in granulite facies rocks (Heier, 1973). These as well as other elements would have been mobilized into the liquid phase.

The alternative process for granitization, metasomatism, also has support by various authors. Elements, especially potassium and sodium, are believed to be carried either by hydrous intergranular solutions (Wegmann, 1935) or by intragranular solid state diffusion (Ramberg, 1951). The fact that potassium metasomatism (feldspathization) is nearly universally present in granitized areas lends credibility to a metasomatic origin for such bodies. Ramberg (1951) also suggests that the source of the alkali-bearing solutions may be derived from the more highly metamorphosed granulite facies rocks which, upon dehydration, release their volatiles to the usually overlying rocks of the amphibolite facies.

Tuttle and Bowen (1958) argue against the metasomatic origin of granites saying that there are no physiochemical reasons to expect metasomatic rocks to form compositions which continually correspond to the low temperature trough of the system Qz-Ab-Or-H_2O. Experimental results from hydrous vapour phases in equilibria with granites and granite magmas by Luth and Tuttle (1969) support this argument.

Daly (1949) has written a review paper discussing in more detail the various shortcomings of the metasomatic theory while Marmo (1967) wrote a critical review paper on the whole granite problem.

The fact that granites occur in a number of different geological settings, ranging from small discordant bodies exhibiting a well-defined chilled margin, through large complex plutonic bodies which may or may not be discordant to the surrounding rocks to large areas of granitic-gneissic terrains exposed in the Precambrian. Read (1948, 1949, 1955) recognized the diversity in the mode of granite occurrences saying "there are granites and granites, all are members of one series genetically related". From this line of thinking he expounded his Granite Series:-

Time
Crustal Level

$\longrightarrow$

autochthonous granite, migmatites, metamorphites	para-autochthonous granites	intrusive magmatic granites	granitic plutons

Buddington (1959) classified granites according to their emplacement into the epizone, mesozone or catazone of the earth's crust and described their various characteristics:-

Zone	Depth In Miles	Contacts	Country Rocks	Granite Rocks
	0			
Epizone		Discordant Sharp	No concurrent regional metamorphism (meta). Some contact meta., genetically related to granitic emplacement.	Pluton No foliation
	4			
Mesozone	8	Discordant to concordant Sharp or locally gradational	Regional meta. Greenschist Well developed contact meta	Composite foliation, Lineations parallel to contact
Catazone		Concordant	Regional meta Amphibolite-granulite abundant migmatite	Foliation developed Augen Gneiss Porphyroblastic granulites, replacement features common
	?			

Finally, Mehnert (1968) in his book on migmatites and the origin of granitic rocks, put forth his own series of granitic rocks starting with first stage feldspathization with the final production of a granite extrusion:-

Increase in Metamorphism

(1) crystallization and crystalloblastic growth of potassium feldspar and/or plagioclase.

(2) formation of partial eutectic H_2O bearing melts (anatexis) which separates from the enriched in mafics.

(3) formation of predominantly molten material with little or no restites (diatexis).

(4) homogenity of the palingenetic melt and intrusion into foreign country rock, often with subsequent differentiation.

Mehnert placed the boundary between anatectic and magmatic melts at the point where the liquid leaves its place of origin.

The fact is, although such "series" may be useful as a guideline and different "hypotheses" may cover the spectrum for the mode of granitic genesis, each granite should be treated as unique. It has formed in its own environment under specific physical and chemical conditions. In order to evaluate a granite's origin field data, including its relationship to the surrounding rocks, its composition and structure should be gathered. From this cumulative knowledge one can derive its petrogenesis. The problem with granites is not in its habit but usually lies in the biased geologist who tries to "fit" its origin into a preconceived petrogenetic model.

SUMMARY AND CONCLUSIONS

INTRODUCTION

In order to understand the mode of the uranium occurrences, one must first deduce the petrogeneses of their host granitic and pegmatitic rocks. As mentioned in the section on origin of granites, three possible hypotheses can be put forth: (1) it is an intrusive igneous pluton; (2) it was derived by metasomatism of the pre-existing country rocks; or (3) it was produced by the anatexis of the same country rocks. Pertinent facts deduced both in field mapping and thin section petrography are discussed below.

(1) Relation to Surrounding Metamorphic Belt

The Lac Turgeon Granite is conformable to the surrounding metamorphic rocks. A gradational contact is present with the granitic rocks passing into the country rocks through a diffuse zone of migmatitic (pegmatoidal) material. Stratigraphic units, especially quartzites, can be traced well into the granitic rocks by their presence as xenoliths. No faults were found in the contact zone and no flow foliation features were noted. Such relations disclaim an intrusive origin to the granitic rocks. The introduction of granite material would cause the regional structure to wrap concordantly around the pluton (Heimlich, 1965; Pitcher et al, 1957). Even a passive intrusive mechanism ("stoping") would still cause discordant relations and a non-alignment of the xenoliths (Lovering and Goddard, 1950). Such features are in direct contrast to those found in the Lac Turgeon area. We are then left with the alternative granitization hypothesis. It now rests to determine whether metasomatism, partial melting, or some combination of both were involved in the formation of the Lac Turgeon Granite.

(2) . Degree of Metamorphism

The peak conditions of metamorphism appear to have been between the upper amphibolite and lower granulite facies. Based on experimental data for mineral reactions, maximum temperatures would have been between 650-800°C. The water pressures present are harder to estimate; however, since muscovite is not present as a primary mineral in the metasediments and no alumina-silicate is present one can assume that muscovite decomposed directly into a melt with the liquid portion acting as a buffer for the dehydration reaction.

Water pressures would have to be at least 5-6 kbars (depending on the position of the alumina-silicate triple point). At such temperatures and water pressures anatexis would be expected to occur.

(3) Metasomatism

As mentioned, alkali metasomatism is prevalent in the form of porphyroblasts of potassium feldspar and plagioclase in the metasedimentary rafts. These types of porphyroblasts are not found in the granitic rocks. They are commonly annealed and corroded. They could have been formed prior to the formation of the granitic rocks or if one takes the anatectic model they may have been formed during or after their formation by solutions expelled during crystallization. The fact that they have highly corroded edges, and orthoclase is the potassium feldspar present, not microcline as in the case of the granitic rocks, as well as the An content in the plagioclase being equal and more often greater than the anorthite content of the granitic plagioclases, proves that they formed earlier.

From this I conclude that alkali metasomatism took place before any partial melting would have taken place.

(4) Composition of Granites

Four basic types of textures can be recognized in thin sections: granular, porphyroblastic, granitic and pegmatitic. One of the hardest parts in the process of field mapping was the distinction between coarse-grained arkosic metasediments and granitic rocks. The former in thin section is typically granular in texture while the latter displays more characteristics of granites (see section on microscopy). Some sections display both textures and can be classified as hybrid rocks.

Modal counts for the granitic rocks are listed in Table 1 and plotted on Figures 19 and 20. The open square figures of the normative mineralogy derived by chemical analysis done by Hauseux (1976) shows an extremely wide variation in composition. Four points lying near the quartz apex are quartzite or sandstone in composition and may represent these hybrid rocks.

Figure 34 is taken from Tuttle and Bowen (1958), page 69, showing the low temperature melting trough in the system Qz-Ab-Or-H_2O at a pH_2O of 3,000 kg/cm^2. Plotting the results from the modal analysis, corrected for anorthite, one sees that nearly all points lie in or near the trough. Similarly, in the system An-Ab-Or-H_2O (Figure 35), the points lie near the ternary eutectic. The fact that the compositions do not lie on the equilibrium melting curve AB probably means that the composition of the granitic rocks was in part controlled by the original metamorphic rocks. Such effects have been experimentally investigated for the anatectic melting of greywackes and pelitic sediments (Kilinc 1972). Or, if melting took place and was fairly advanced (diatexis) either orthoclase or albite may have been completely consumed, a result of which would cause the composition of the liquid to move off the boundary curve away from the phase consumed. The alteration of the feldspar grains may have some minor effects; alteration processes would be as crucial in modal analysis as they would be in normative analysis.

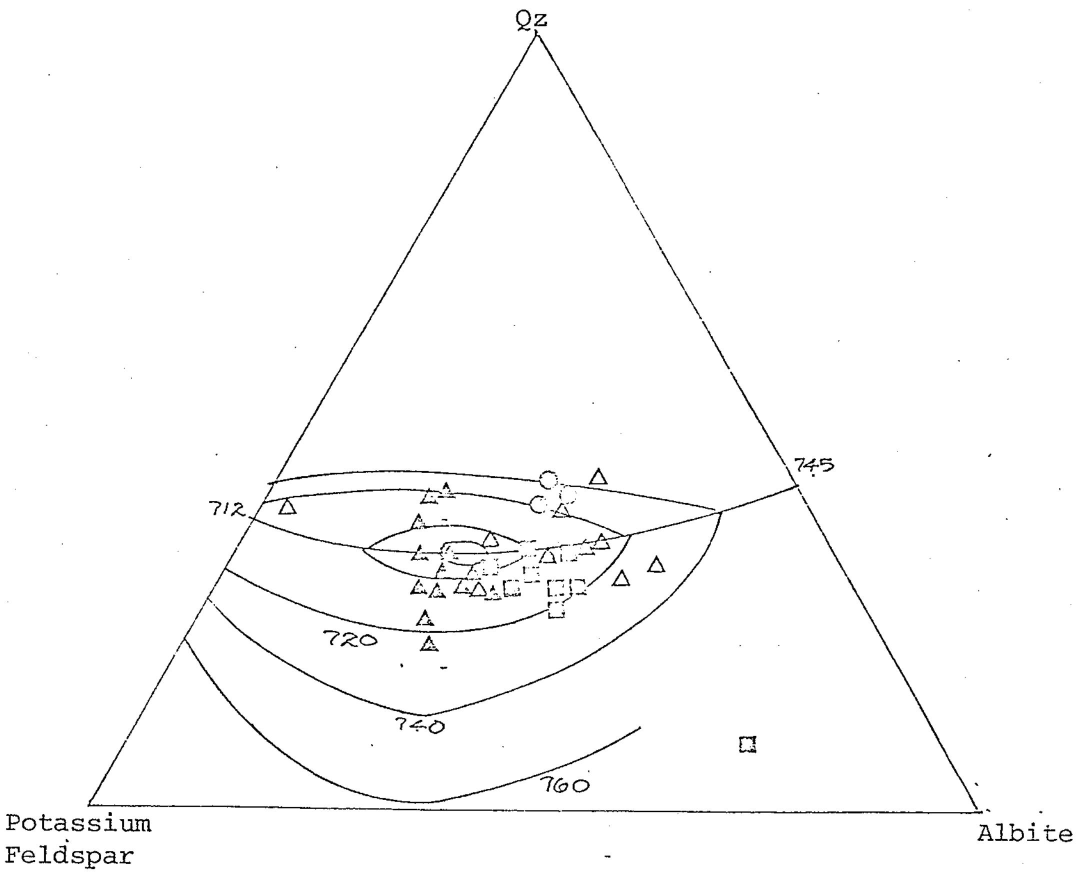
The fact that the composition of the granites are eutectic in nature suggests that they were derived by anatexis. Metamorphic conditions were high enough with sufficient amounts of water present to allow partial melting of the metasediments to occur. The granites display different textures as well as mineral relations (perthite microcline, myrmekite) than those in the metasediments. They are thus formed by a different process than solid state metamorphism; this process involved the formation of liquid silicate melt through ultrametamorphism.

(5) Differentiation of Granitic Rocks

Three phases of granite have been identified: biotite granite, medium-grained granite and the massive medium-grained granite. The biotite and medium-grained granite may be synchronous, although in some instances rafts of biotite granite were found in the medium-grained granite, suggesting that, at least in part, the latter is younger. Such an hypothesis is reflected in their compositions. The biotite granite contains more biotite and plagioclase with a higher anorthite content. However, their compositional fields do overlap. It is very difficult to say then whether the compositional differences are primary in origin, derived from different metamorphic rocks, or that some differentiation has occurred.

Figure 34

Low Temperature Melting Trough in System Qz-Ab-Or
at pH_2O = 3000 kg cm^2, and granitic compositions



▲ Biotite Granite

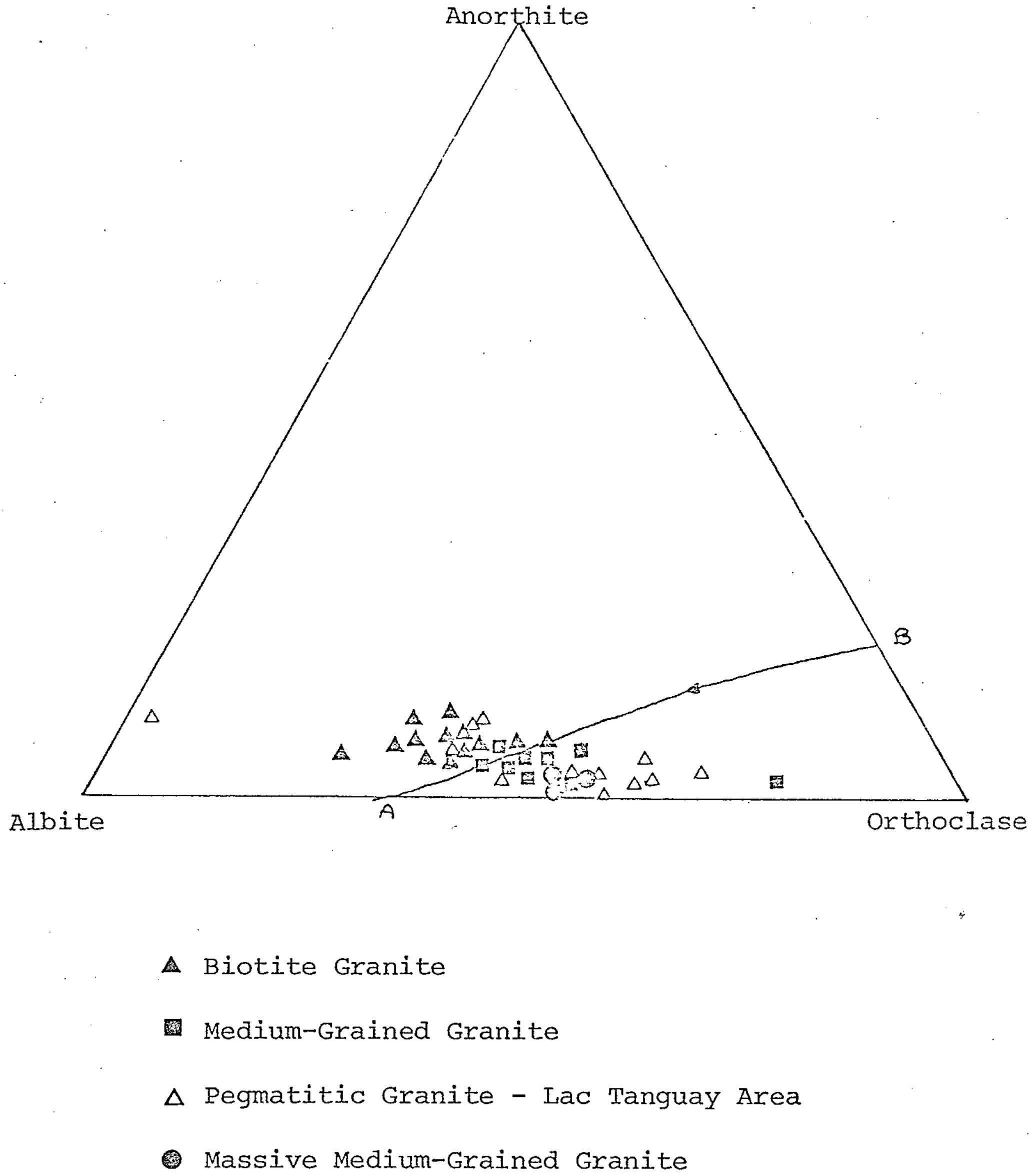
■ Medium-Grained Granite

△ Pegmatitic Granite - Lac Tanguay Area

● Massive Medium-Grained Granite

Figure 35

Granite Compositions and Eutectics in System Or-Al-An-H_2O



The massive medium-grained granite is definitely younger than the previous two phases. It occurs in the axial region of an overturned antiform. It lacks the foliation and abundant pegmatitic material present elsewhere. In thin section, microscopic deformation, fracturing and stress is not indicated. It is fairly homogeneous in composition being slightly more quartz-rich than the other phases. Its origin can best be explained by the later remobilization of the granitic material or perhaps it represents the last phase of an anatectic melt which has been squeezed out and migrated into the low pressure zone of the antiform.

If differentiation did take place then it can be assumed that the granitic rocks were just at the point of mobilization. This movement did not progress very far as the alignment of sedimentary rafts is mostly still intact. Differentiations suggests a more molten state.

The pegmatitic phases were the last to crystallize; they contain xenoliths of every other type of rocks and often crosscuts the granites.

(6) Nature of the Xenoliths

Abundant enclaves occur in the granitic and pegmatitic rocks. Their foliation is generally conformable with the regional trend and usually their long axes are also conformable (but they can be variable). Boundaries may be macroscopically sharp in thin section, often a thin selvage edge is developed or there is a rapid increase in grain size. Except for meta arkoses, the composition of the adjacent granite is different from the enclaves. The xenoliths are variable in composition ranging from meta quartzites to amphibolites. Figure 13 displays the modal analyses of 45 metasediments. Also the plagioclase content is more calcic in the xenoliths than in the country rocks (An_{10-25}) and in the metasediments (An_{20-42}); for the amphibolites and granitic plagioclases an average An content of 10.

These compositional and textural features suggest that the xenoliths are restites, that is material not assimilated by anatexis.

(7) Deformation

Three patterns of folding are recognized with NW, NE and E-trending axes in the granites and metamorphic rocks. The formation of the granitic rocks took place then syntectonically and were deformed by later tectonic events. The main deformation, NW-trending direction, corresponds to the axial plane direction of the Wakeham Bay anticlinorium. This infers that the folding in the Wakeham Bay Belt caused the synchronous formation by anatexis of the Lac Turgeon Granite within the axial zone.

URANIUM MINERALIZATION

Anomalous radioactivity occurs in the coarse-grained phases of the granite and in the pegmatitic rocks. It is associated with the brick-red alteration of plagioclase (caused by hematization) and development of smoky quartz and magnetite. It is usually in pod-shaped bodies and it tends to be concentrated along fold axes and fold noses. Uranium mineralization is rarely visible on the surface but secondary yellow staining is visible in drill samples.

No anomalous radioactivity was found in the metasediments and none was associated with major fractures.

Its occurrence along microfractures and in fold axes suggests that the uranium mineralization formed post-crystalline but syntectonically in late stage fluids.

PETROGENESIS

The model for the formation of the Lac Turgeon Granite and associated uranium mineralization is as follows:-

Deformation and metamorphism took place in the Wakeham Bay Group; folding along a NW axis formed the regional anticlinorium. Metasomatism and finally partial melting occurred in the axial region. Some differentiation may have taken place; however, the granitic rocks did not move much from their place of origin. The uranium was mobilized into the granitic melt from the sediments and concentrated into the hydrous phase after granite crystallization. The hydrous phase produced the pegmatitic rocks and caused the autometamorphism of the granites. It tended to migrate to areas of low pressure. Uranium, principally as uraninite, was one of the last minerals to form, precipitating out of solutions which filled fractures and caused the hematization of iron in plagioclase.

An interesting question still remains - how far did the metasomatic fluids migrate? Airborne spectrometer surveys show that the only anomalous regions are located in the axial region of the major regional fold. Other granitic bodies are to be found associated with the metamorphic rocks in the Wakeham Bay Group (Grenier, 1957). Yet these do not show ~~are~~ radioactivity-~~barren~~. If we assumed that they were formed by the same process, why should this be the case? Did the area around the Lac Turgeon Granite act as a "sink" for the expelled metamorphic fluids? Metamorphic conditions would appear slightly oxidizing as the metasediments in the belt contain no graphite and only trace amounts of pyrite (Cooper, 1953). Fletcher and Hofmann (1974) report that a combined diffusion and infiltration model for the transport in solutions would yield a rate of movement 10^{-2} km/yr., assuming a pressure gradient of 1 kbar/km. At such a rate, uranium could be concentrated in the Johan Beetz area during regional metamorphism.

If we draw on the field data collected, it was shown that hydrous solutions did migrate, supposedly by infiltration into fold axes and fold noses. To what regional scale can we extrapolate such processes? If the uranium was leached out of the sediments during metamorphism and the fluids migrated into the fold noses of the regional anticlinorium in the Johan Beetz area, this could explain why only this particular region has any considerable anomalous radioactivity.

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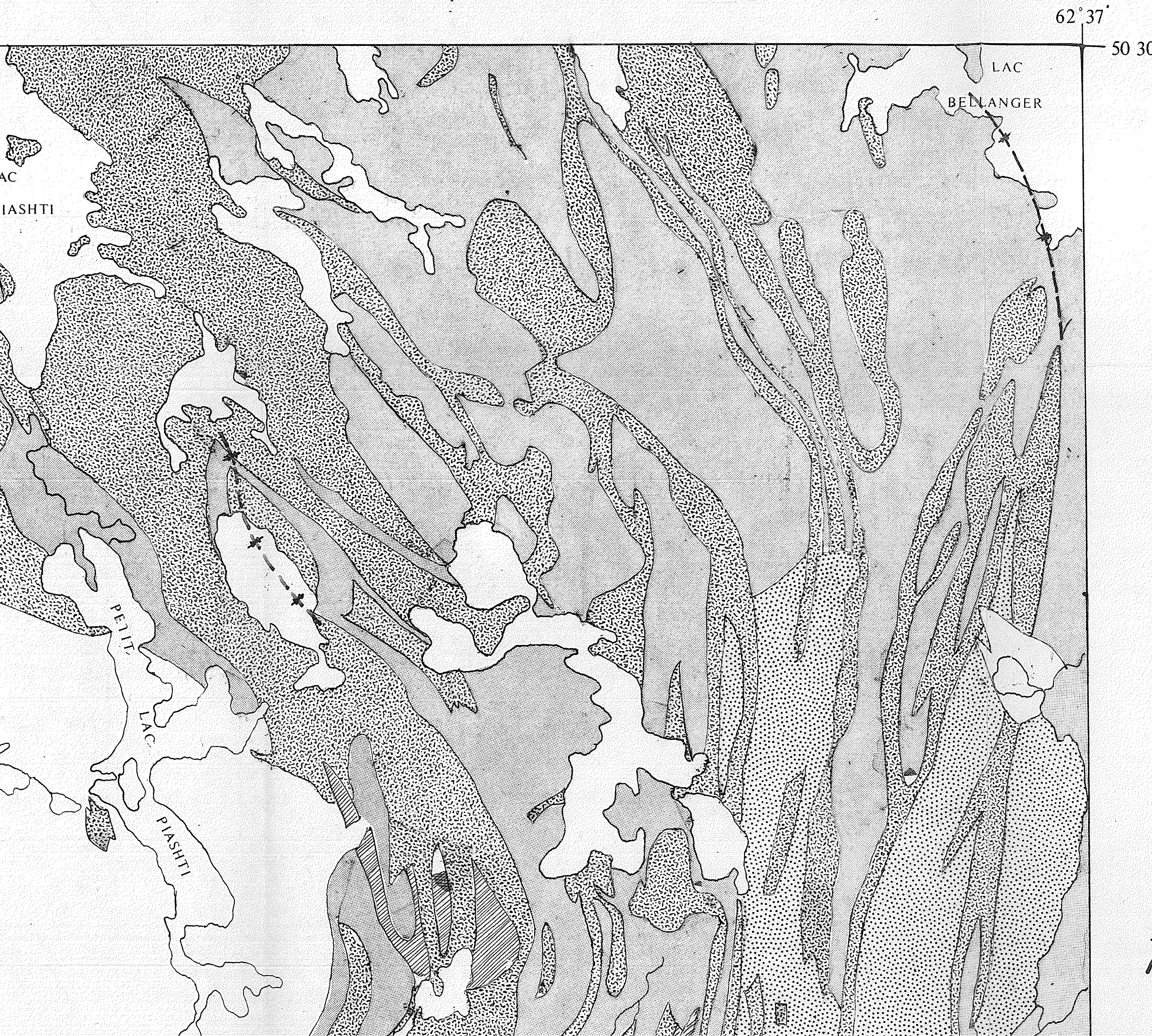


LEGEND

PLEISTOCENE

Glacial Till

PALEOZOIC

Limestone, Dolomite, Shale

PRECAMBRIAN

Pegmatite

Biotite Granite, Syenite

Gneissic Granite

Gabbro, Amphibolite

Migmatite, Augen Gneiss, Banded Gneiss

Grey Quartzite, Calcareous Quartzite, Conglomerate, Crystalline Limestone

Micaeous Quartzite, Quartz Biotite Schist, Quartz Biotite Gneiss

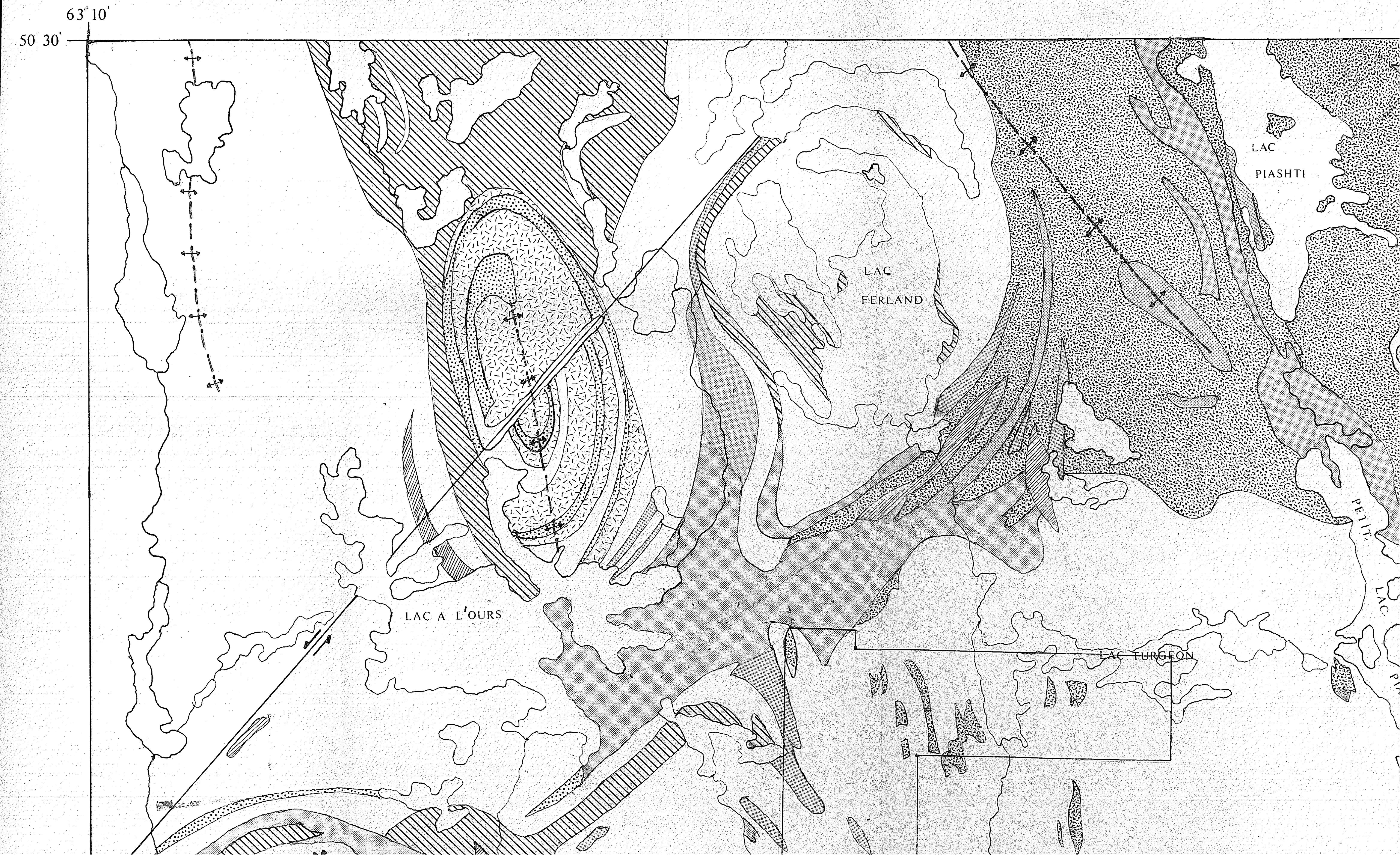
SYMBOLS

Geological Boundary

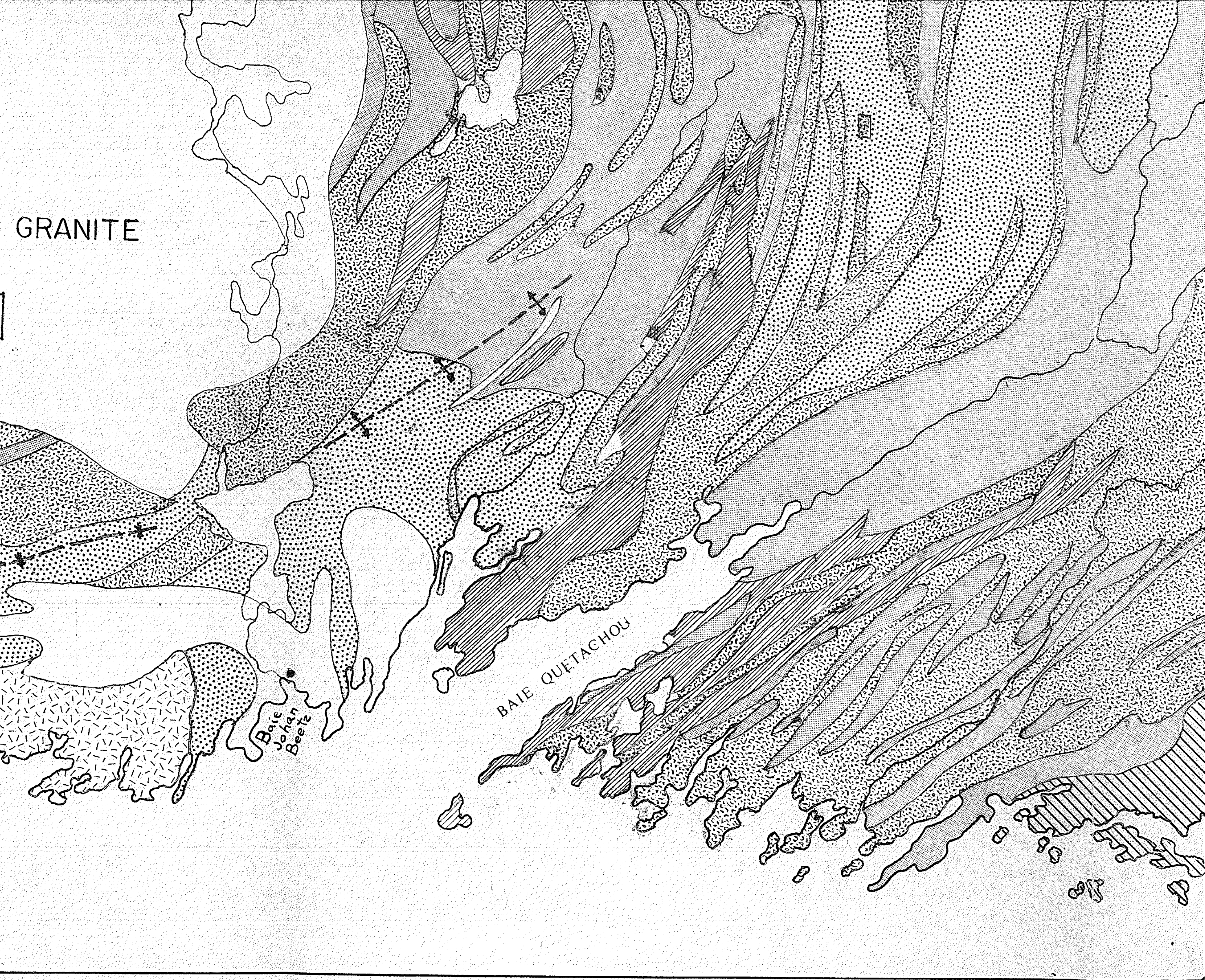
a b c d

Fold Axis: a) anticline b) syncline c) overturned anticline d) overturned syncline

Fault



63°10'
50 30'
LAC PIASHTI
LAC FERLAND
LAC A L'OURS
LAC TURGEON
PETIT LAC



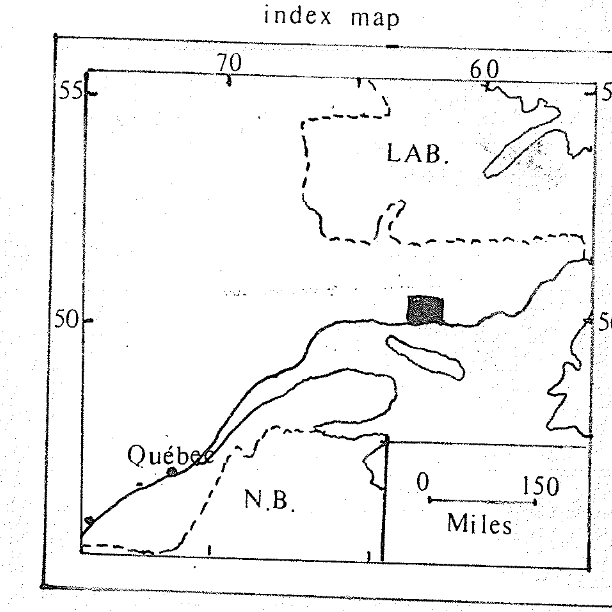
a b c d
Fold Axis: a) anticline b) syncline
c) overturned anticline d) overturned syncline

Fault

Geology by: G. Cooper 1951-2, J. J. Depatie 1964-5

Compiled by: B. Mackie 1975

index map

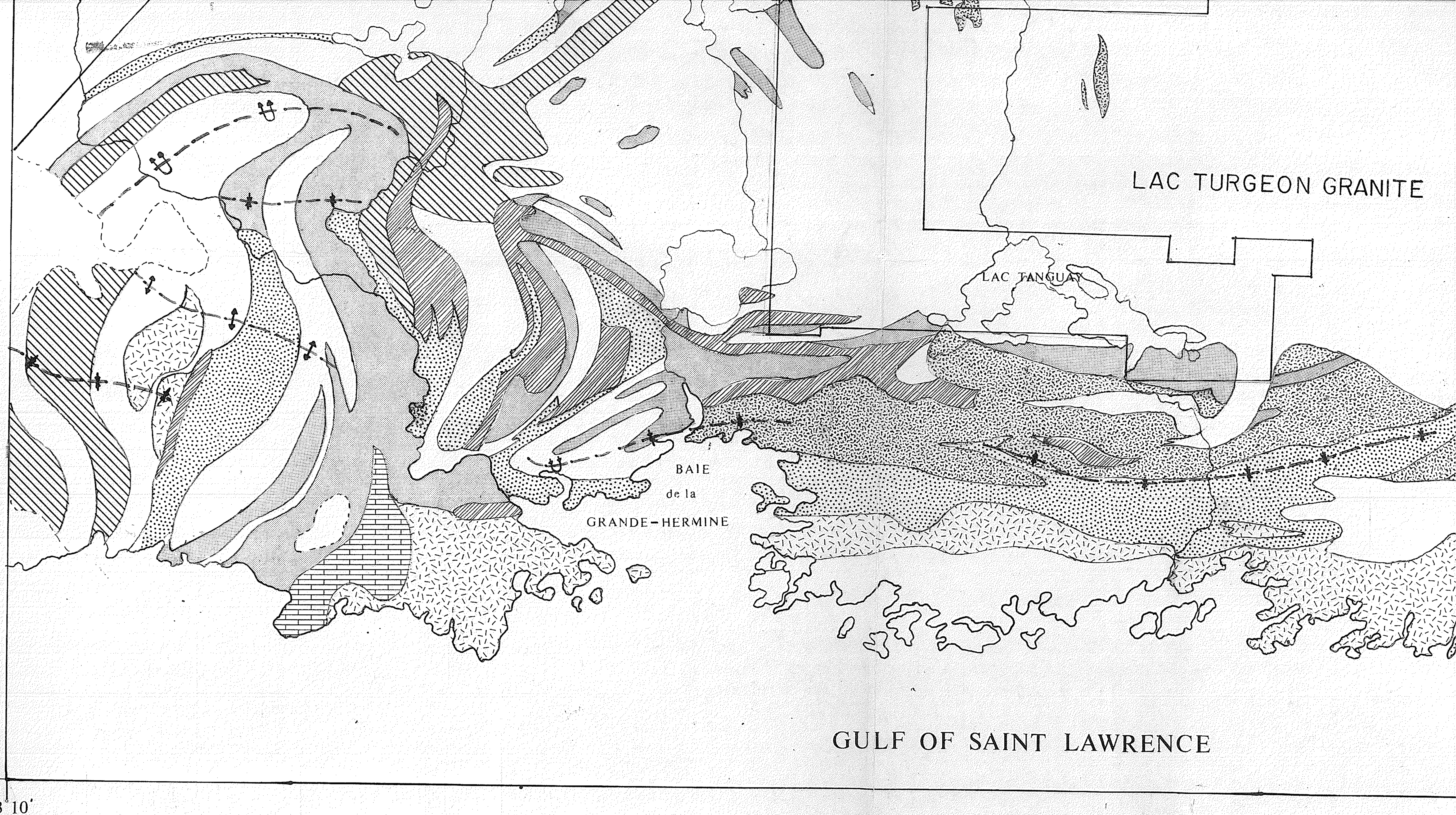


0 1 2 3

SCALE 1 MILE = 1 INCH

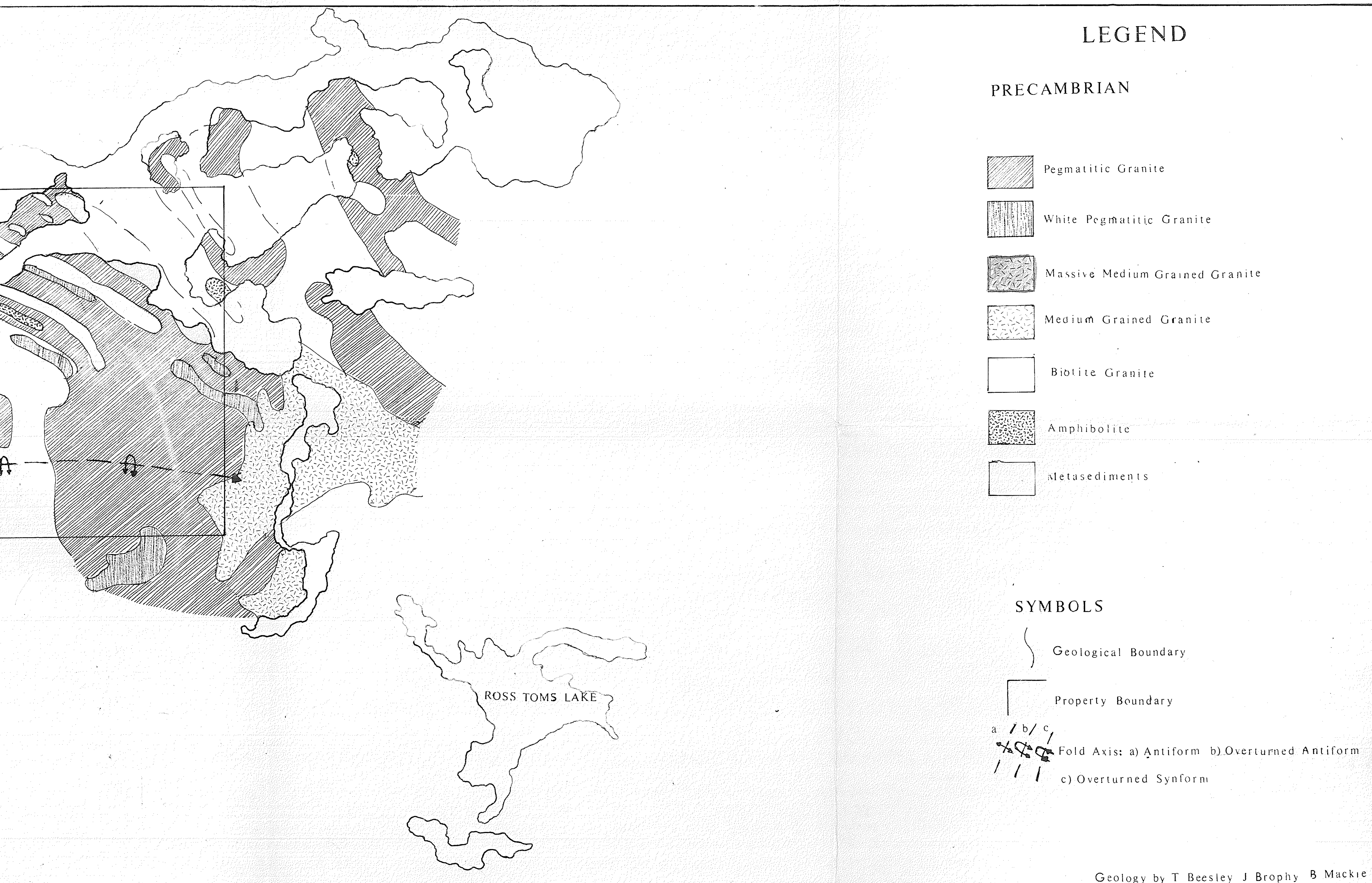
MAP 1

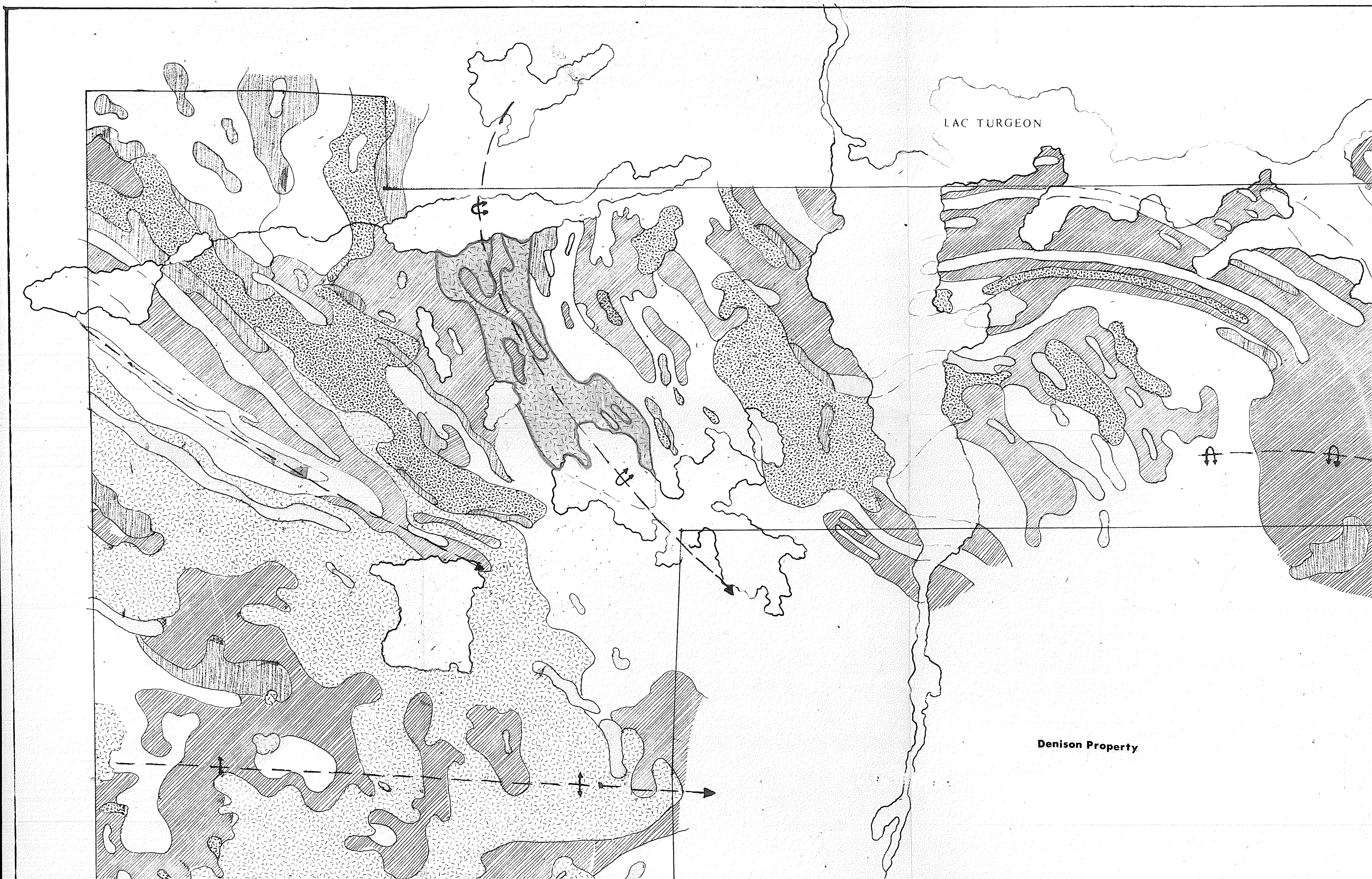
Compilation Map of the Geology
of the Johan Beetz Area, 78915-T
Quebec
to accompany the M. Sc. thesis
of B. W. Mackie



LAC TURGEON AREA

QUÉBEC


LEGEND
PRECAMBRIAN
Pegmatitic Granite
White Pegmatitic Granite
Massive Medium Grained Granite
Medium Grained Granite
Biotite Granite
Amphibolite
Metasediments
SYMBOLS
Geological Boundary
Property Boundary
a b c
Fold Axis: a) Antiform b) Overturned Antiform
c) Overturned Synform
ROSS TOMS LAKE
Geology by T Beesley J Brophy B Mackie


LAC TURGEON
Denison Property

Geology by T Beesley J Brophy B Mackie
L Owsciacki 1975-6

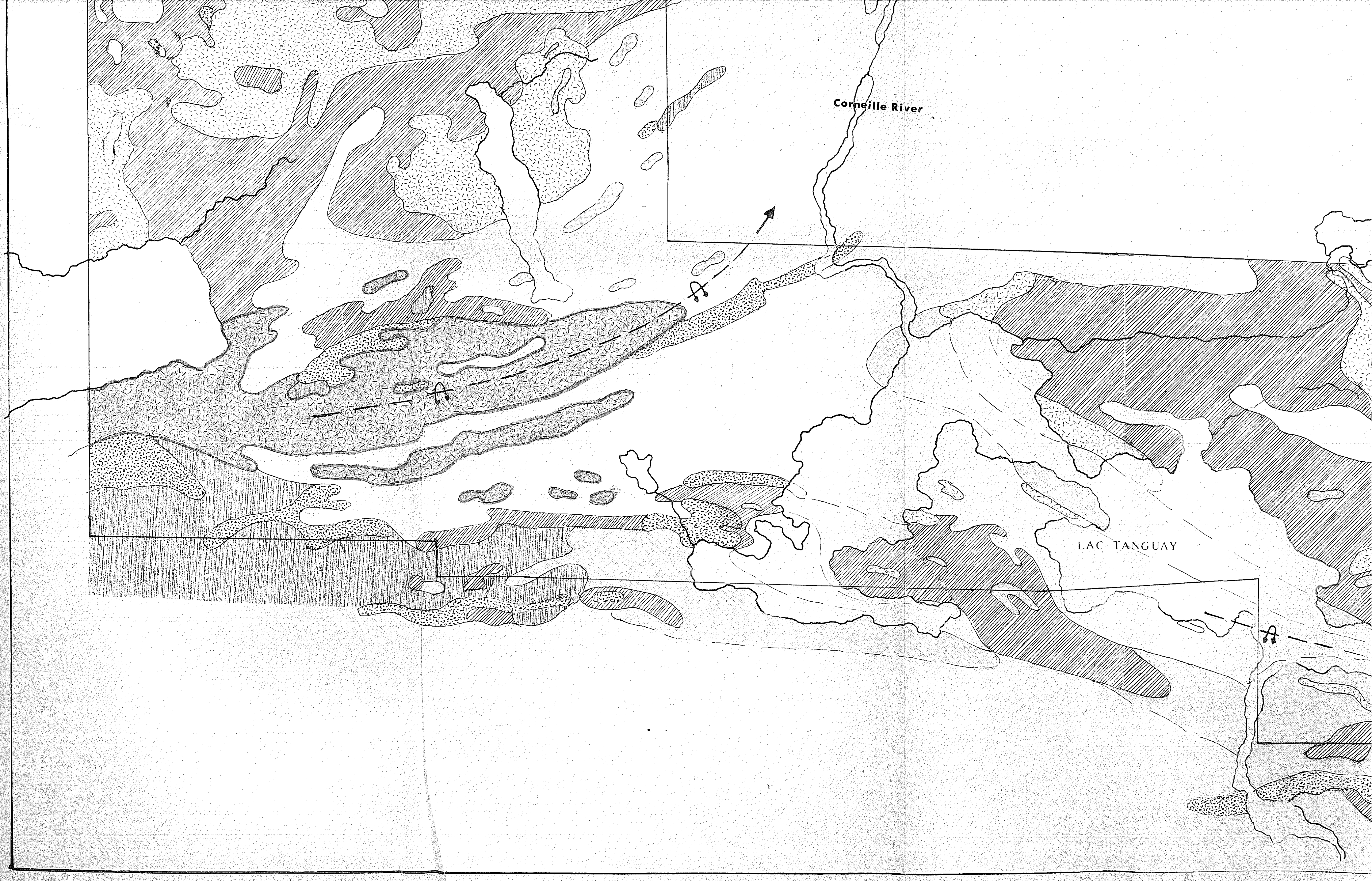
0 1600 3200 4800 6400 feet

Scale - 1" = 1600'

MAP 2

Geological Map of Thesis Area

Urangesellschaft claims,
Baie Johan Beetz area, Quebec


Corneille River
LAC TANGUAY