

DISTRIBUTION OF LITHIUM
IN THE GRANITIC ROCKS
OF THE
PREISSAC - LACORNE AREA, QUEBEC

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By

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SCOPE AND CONTENTS: An investigation was made of the distribution of lithium in the rocks and minerals of the Preissac, Lamotte and Lacorne batholiths of north-western Quebec. Spectrochemical methods were used; and for this purpose two working curves were constructed using the following analysis lines: Li 3232, Li 6103 and Li 6707. The analysis results show that lithium concentrates in ferro-magnesian minerals, especially biotite; the feldspars and quartz being low in lithium content and hornblende being intermediate. Averages for the lithium content in the various rocks are as follows: amphibolite (lithium not detected); hornblende monzonite, 7 p.p.m.; granodiorite, 53 p.p.m.; granite 153 p.p.m.

Acknowledgements

I would like to express my sincere thanks and gratitude to Dr. D. M. Shaw for his kind assistance and direction; also to Mr. R. E. Jones for first suggesting this study and for his subsequent interest and helpful suggestions. I am indebted to Dr. J. E. Hawley of Queens' University for supplying me with most of the specimens used in this study, and also to the Quebec Department of Mines for giving me the opportunity to work in the thesis area. To all other faculty members and students who aided me with discussions and helpful suggestions, I express my thanks.

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Abstract

Three batholiths with associated lithium-bearing pegmatites are located in the Preissac - Lacorne area of north-western Quebec. Results of previous workers have indicated that the rocks of the batholiths represent a differentiation sequence. These rocks and their constituent minerals were analyzed spectrographically for their lithium content, for the purpose of studying the distribution of lithium during magmatic crystallization.

Two working-curves were constructed for the analyses, one for minerals and the other for rocks. The curve for mineral analysis covered a concentration range of 3 to 3160 p.p.m. Li, whereas the curve for rock analysis covered the concentration range of 25 to 500 p.p.m. Li. Sodium was used as internal standard for mineral analyses, the spectral line Na 6160 being used with the spectral lines Li 6707 and Li 6103. For rocks, indium was the internal standard, the spectral line In 3258 being used with the analysis line Li 3232.

Analyses of the rocks show that the lithium content increases with the acidity of the rocks, that is most probably with increasing differentiation. Averages for the various rocks are as follows: amphibolite (lithium not detected); hornblende monzonite, 7 p.p.m.; granodiorite, 53 p.p.m.; granite, 159 p.p.m. Analyses of the minerals show that quartz and feldspar usually contain much less than 100 p.p.m. lithium. Hornblende, on the other hand, averages about 208 p.p.m. and micas are even richer, some exceeding 3200 p.p.m.

Strock's (1936) theory for the increase in the $\frac{\text{Li} \times 100}{\text{Mg}}$ ratio in rocks with increasing differentiation is found to hold true for the batholithic rocks of the Preissac - Lacorne area. Furthermore, the results suggest that as a result of the increase of lithium with increasing differentiation, the last major differentiate of the batholiths (biotite-muscovite granite) was parental to the lithium-bearing pegmatites found in the area.

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I. INTRODUCTION

Three batholiths occurring close together in the Preissac-Lacorne area of northwestern Quebec are of interest because of associated mineable deposits of lithium and molybdenum. A differentiation sequence from amphibolite through hornblende monzonite to biotite granodiorite to biotite-muscovite granite and ending in spodumene-bearing pegmatites has been recognized by Tremblay (1950) in the Lacorne batholith. In addition, Halferdahl (1955) has suggested that the rocks of all three batholiths, the Lacorne mass, the Lamotte mass, and Preissac mass are unusually high in lithium.

Strock (1936) has pointed out that lithium is concentrated in the end stages of a differentiation sequence, because reduction of the early high concentration of magnesium permits substitution of lithium for magnesium in the later-crystallizing products. The batholiths of the Preissac-Lacorne area are well exposed and accessible and provide material for testing Strock's hypothesis.

The writer spent the summer of 1955 as senior assistant on a Quebec Bureau of Mines party under Mr. R. E. Jones, mapping in north-east Lamotte township over part of the Lamotte mass, one of the three batholiths. Brief visits were made to a few outcrops of the other two masses, the Lacorne mass and the Preissac mass, but specimens were not collected at that time for analysis. Specimens from points spaced at regular intervals across all three masses had been collected by Halferdahl and were obtained for the present study through the kindness of Dr. J. E. Hawley.

The specimens were analyzed by a spectrochemical method

sensitive to 20 p.p.m., then separated into component minerals and analyzed by another spectrochemical method sensitive to 3 p.p.m. Li. Halferdahl was interested only incidentally in lithium but had previously analyzed these rocks spectrochemically by a method with a sensitivity of about 150 p.p.m.

The analyses in this study were made to investigate the following topics:

1. the distribution of lithium in a series of differentiated igneous rocks and their constituent minerals,
2. the correlation of the rocks of the three batholiths on the basis of their lithium content,
3. the possibility that there is a relationship between the trace quantities of lithium found in the granitic rocks, and the economic lithium-bearing pegmatites in the area,
4. the verification of the theory suggested by Strock (1936), that there is an increase in the ratio $\frac{\text{Li} \times 100}{\text{Mg}}$ with increasing differentiation.

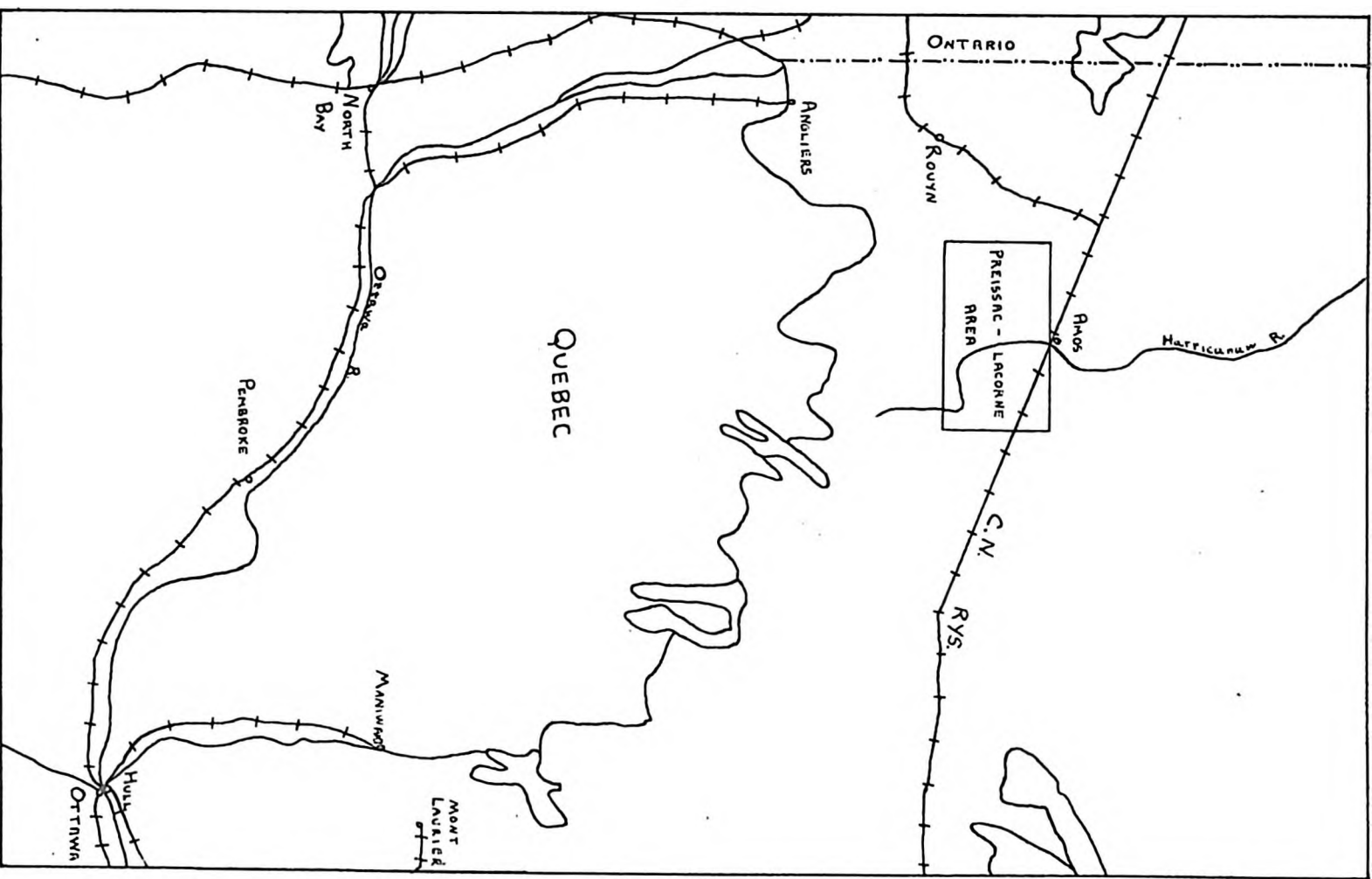


Fig.1 INDEX MAP OF PREISSAC - LACORNE AREA

II. PREISSAC - LACORNE AREA

LOCATION AND ACCESS

The Preissac - Lacorne area is situated in Abitibi county, north-western Quebec, about 250 miles northwest of Ottawa. The area lies roughly half way between the towns of Amos and Val d'Or. Figure 1 is an index map showing the location of the area. The following townships comprise the area: Lacorne, Lamotte, Preissac, Fiedmont, Cadillac, Malartic, Vassan, Senneville, Figuery and Villemontel.

The area is readily accessible by road and rail from Toronto, Ottawa and Montreal, and by air from Toronto and Montreal. Within the area itself, provincial highways, secondary roads and logging roads provide easy access to all parts of the area except the interior of Lacorne township.

THE LACORNE, LAMOTTE AND PREISSAC BATHOLITHS

Three batholithic masses outcrop within the area. They are called the Lacorne, Lamotte and Preissac batholiths, in order of decreasing size respectively. The Lacorne batholith is somewhat circular in outline, with an average radius of roughly eight miles. The Lamotte and Preissac masses are elliptical in plan with their major axes trending east-west, the major axis of the Lamotte mass being approximately ten miles long, and that of the Preissac five. These batholiths are bounded on the south by the Cadillac fault and on the north by the Manneville fault, both of which strike approximately east-west. The batholiths themselves are crossed by two sets of regional tension

fractures which have (in some cases) been filled by gabbroic dikes.

Five rock types outcrop in the Lacorne batholith, ranging in composition from basic to acidic. They are as follows: amphibolite, hornblende monzonite, biotite granodiorite, biotite-muscovite granite and pegmatite. However, in the Lamotte and Preissac batholiths only the acid types are found, namely, biotite granodiorite, biotite-muscovite granite and pegmatite. In 1902, Johnston's discovery of molybdenum on Indian Peninsula in Kewagama Lake, and subsequent discoveries of spodumene and beryl deposits have aroused interest in the batholithic rocks of the area.

PREVIOUS WORK

The earliest geological investigation of the granitic rocks in north-western Quebec was made in 1872 when McQuat made a reconnaissance of the region between Lakes Timiskaming and Abitibi. During the succeeding 40 years a series of reconnaissance surveys added to the geological knowledge of the area, but contributed little to the understanding of the batholiths. Detailed work in the area began in 1913 with Wilson's memoir on the Kewagama lake area. His map included the western part of the Preissac - Lacorne area and showed a distribution of granitic rocks similar to that on more recent maps. Cook, James and Mawdsley (1931) compiled a geological map which included the entire area underlain by the batholithic rocks. Subsequent field investigations have made few changes in the batholithic contacts.

Gerrie in 1927 was the first to publish chemical analyses of the batholithic rocks, taken from the area adjoining molybdenite showings. Ten years later Gussow (1937) published petrographic descrip-

ions and analyses of the batholithic rocks. He divided the rocks into two distinct types: hornblende granodiorite and garnetiferous muscovite leucogranite. Norman in 1944 published a preliminary report on the Lamotte map-area which comprises the western half of the Preissac - Lacorne area. He described the batholithic rocks as a diorite-syenite-granodiorite-granite group, which he believed to be a differentiation series from a common parent magma. Norman stated that the various members of the group were not all of the same age, but that the general order of decreasing age was toward the lighter-coloured and more siliceous members. Six years later Tremblay (1950) published a report on the Fiedmont map-area, which covers the area underlain by the Lacorne batholith. Tremblay recognized six main rock types in the Lacorne batholith: hornblende monzonite, amphibolite, biotite-hornblende granodiorite, biotite granodiorite, biotite-muscovite granite and pegmatite. He considers the biotite-hornblende granodiorite to be a hydrothermally altered phase of the hornblende monzonite. The other rocks however, he describes as the Lacorne differentiation sequence decreasing in age as follows: hornblende monzonite, amphibolite (a basic differentiate of the monzonite, probably separated at depth before injection), biotite granodiorite, biotite-muscovite granite and pegmatite.

The following geologists of the Quebec Dept. of Mines, Ingham (1949), Latulippe (1953, 55), Jones (1955), mapped in detail various sections of the Preissac - Lacorne area, but did not appreciably change the petrographic relationships of the batholithic rocks. Rowe of the Geological Survey of Canada published in 1953 a detailed report on the pegmatitic beryllium and lithium deposits in the area. In the following year Dawson, also of the Federal Survey, published a report on the

structural features of the three batholiths, mentioning a more detailed, petrographic report to follow later. Halferdahl (1954) a graduate student of Queen's University who had worked as an assistant with Dawson made a study of the trace-element distribution in the batholithic rocks. His results led him to conclude as others had (Norman, Tremblay, Dawson, Rowe) that the three batholithic masses were in reality segments of one large mass, having been derived from a common parent magma at depth.

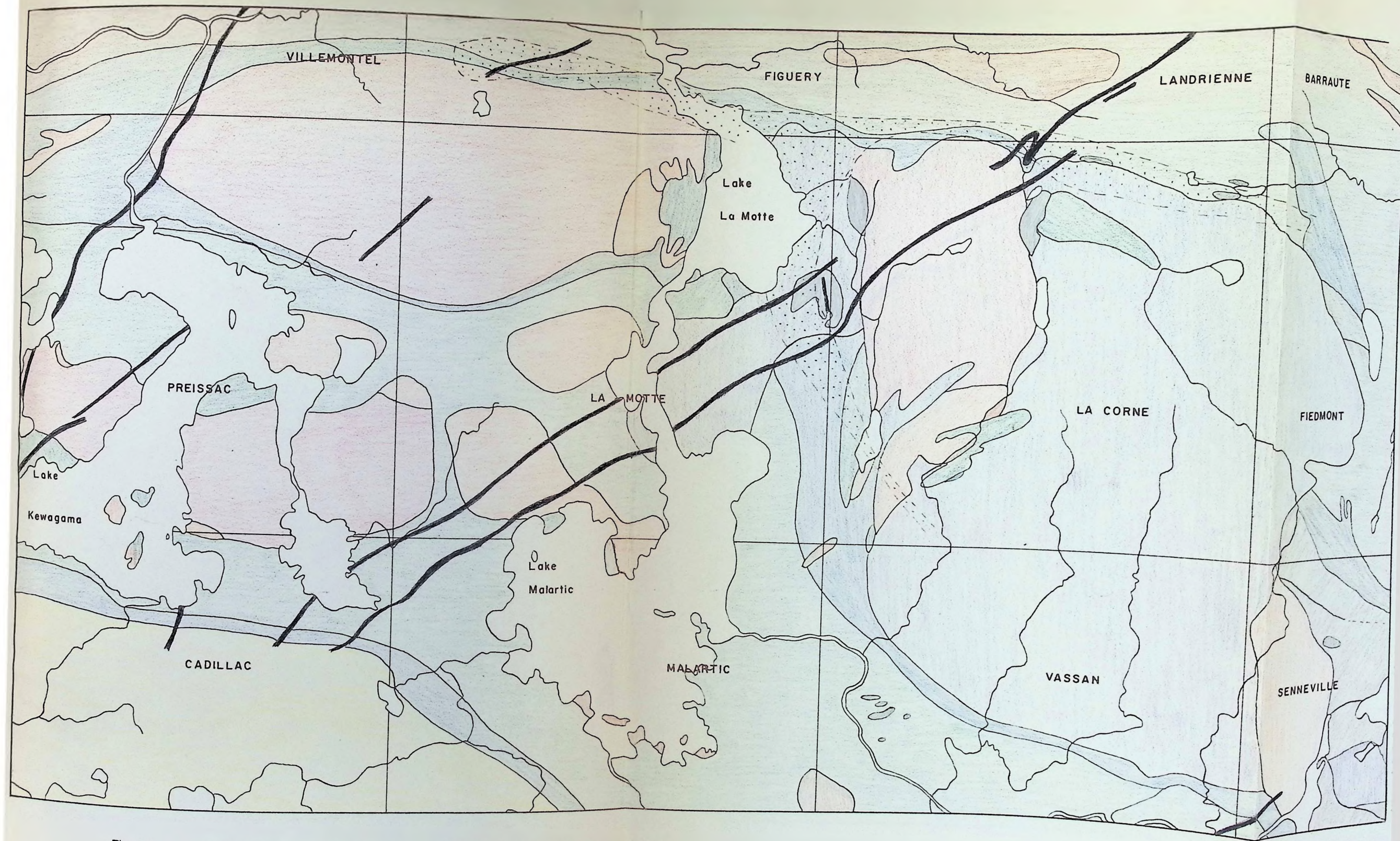
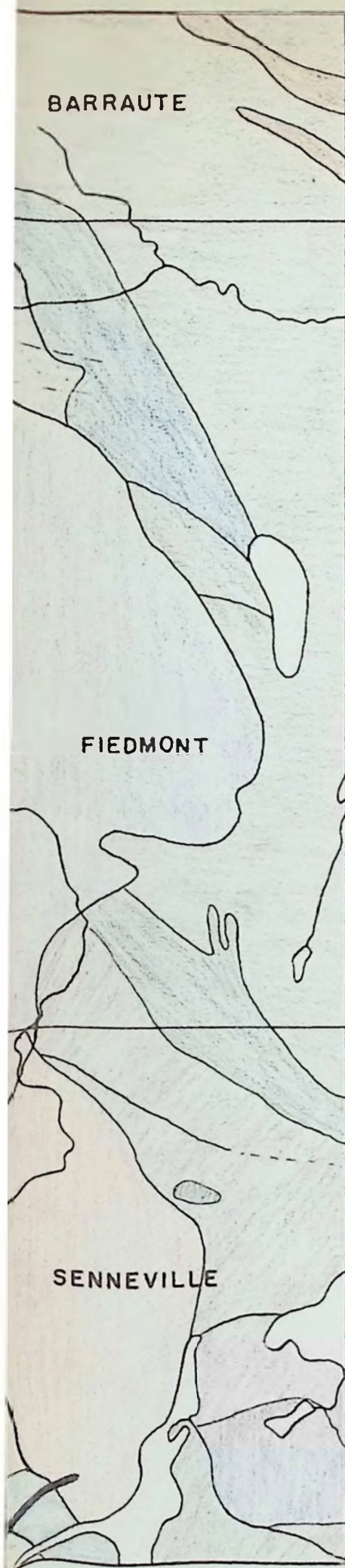



Fig. 10 GEOLOGICAL MAP OF PREISSAC - LACORNE AREA




LEGEND

8


LATE PRECAMBRIAN

 Olivine diabase, quartz diabase

EARLY PRECAMBRIAN


 Biotite - muscovite granite

 Biotite granodiorite, 9a Malartic Stock

 Hornblende monzonite, 8a biotite - hornblende granodiorite


 Amphibolite

BASIC TO ACIDIC INTRUSIVE ROCKS

 Albite granite, granodiorite, quartz - feldspar porphyry

 Amphibolite, peridotite, diorite

BLAKE RIVER GROUP

 Altered basic to acidic lavas and pyroclastics, minor greywacke

KEWAGAMA GROUP

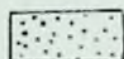
 Greywacke, and derived biotite schist, conglomerate, minor lava

MALARTIC GROUP

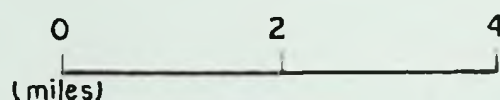
 Basic to acidic lavas and derived hornblende schist, agglomerate, some peridotite

KINOJEVIS GROUP

 Basic and minor acidic lavas and derived hornblende schist

 LITHIUM ZONE (Rowe 1953)

SCALE (1" = 2 miles)



Sources Of Information

1. TREMBLAY (1950)
2. HALFERDAHL (1954)
3. JONES (1956)

III. GENERAL GEOLOGY

All the consolidated rocks of the Preissac - Lacorne area are of early Precambrian age. These rocks are part of a wide belt of Archaean sedimentary, volcanic and intrusive rocks that extend 150 miles east of the Ontario-Quebec border. In the Preissac - Lacorne area these rocks consist of east-west trending sedimentary and volcanic formations, which include basic to silicic lavas, pyroclastics with altered counterparts and also sediments consisting chiefly of greywacke and biotite schist. These formations have been folded and invaded by numerous masses of intrusive rocks of various types.

The rocks of the Lamotte and Lacorne batholiths are intrusive into the Kewagama sediments, which form an almost complete envelope around the two batholiths. These sediments now consist almost entirely of quartz-biotite schist with a little sandstone and conglomerate. Tremblay believes that the original rock was an argillaceous to arenaceous greywacke which has completely recrystallized under the effects of metamorphism.

The batholithic rocks of the area are very similar petrographically; however, since there are three distinct masses, they will be described separately, and a special section at the end will be devoted to pegmatites and aplites.

LACORNE BATHOLITH

The Lacorne batholith outcrops in the eastern half of the Preissac - Lacorne area. It constitutes all the area of Lacorne township and adjoining parts of Fiedmont, Senneville, Vassan and Lamotte

townships. More than three-quarters of the batholith consists of hornblende monzonite. Small areas in the western and south-eastern part of the batholith consist of biotite granodiorite, and the north-western corner of the batholith is biotite-muscovite granite. As mentioned earlier, six main rock types are found in the batholith, however, since it is believed (Tremblay, 1950) that the hornblende-biotite granodiorite is only a hydrothermal alteration of the hornblende monzonite, this granodiorite will not be described with the other rock types below.

Hornblende monzonite

The hornblende monzonite is a dark-coloured rock with a uniform medium grain. It is almost wholly composed of feldspar and hornblende, both of which are easily recognized in hand specimen. Feldspar constitutes over 60% of the rock and two thirds of it is plagioclase. The plagioclase is white, has an elongated habit and appears to be more calcic at the margin of the mass than at the centre, varying in composition from An 16 to An 26. The remainder of the feldspar is potassic, being mainly interstitial and appearing to replace both plagioclase and hornblende. Elongated greenish-black grains of hornblende constitute approximately 35% of the remainder of the rock.

Amphibolite

A few, irregularly-shaped bodies of amphibolitic rock up to a half square mile in area occur in the hornblende monzonite of the Lacorne batholith. This rock is brownish-green in colour, coarse to very coarse grained and almost wholly composed of hornblende. Feldspar and biotite are interstitial and the latter was formed in part as an alteration product of the hornblende. Hornblende is present in grains up to 1 inch across and in most specimens constitutes up to 80% of the rock.

In thin section the hornblende is green and very similar to the hornblende of the monzonite. It has two distinctive parts, a core of altered and bleached hornblende, and an outer zone or rim of hornblende which is entirely fresh and free of alteration products. Most of the feldspar in the rock is a calcic oligoclase (An_{28}), showing albite polysynthetic twinning. A little microcline is present; it is unaltered and appears to replace both hornblende and plagioclase.

Tremblay considers these amphibolite bodies to be basic differentiates of the hornblende monzonite, formed by an early accumulation of hornblende crystals.

Biotite granodiorite

The granodiorite is a light grey gneissic rock of fine to medium grain. In hand specimen quartz, feldspar and biotite are easily recognizable. Tremblay has determined the feldspar, which constitutes over 50% of the rock, to be oligoclase of composition An_{18-23} . Interstitial microcline is present but forms only 5% of the rock. Quartz is an abundant mineral in the rock averaging around 27%. Black, minute flakes of biotite which give the rock a gneissic appearance amount to 10%.

Biotite-muscovite granite

The granite is a light-coloured rock with grain-size averaging 3 to 6 mm. The rock is composed of the following minerals: feldspar, quartz, muscovite, biotite and euhedral garnet. Feldspars constitute approximately 64% of the rock, and Tremblay has revealed by staining that 1/3 of the feldspar is potassic. Quartz is quite abundant making up to 33% of the rock. Muscovite and biotite are commonly

found intergrown and usually comprise 5% of the rock.

An important feature of the granite is the presence of much intimately associated pegmatitic material, which in places constitutes up to 50% of the rock, which could properly be termed a pegmatite-granite.

Lacorne Differentiation Sequence

Of the three batholiths, only the Lacorne mass has a complete differentiation sequence from basic to siliceous rocks. This can best be seen by the variation diagram for the Lacorne rocks presented by Tremblay.

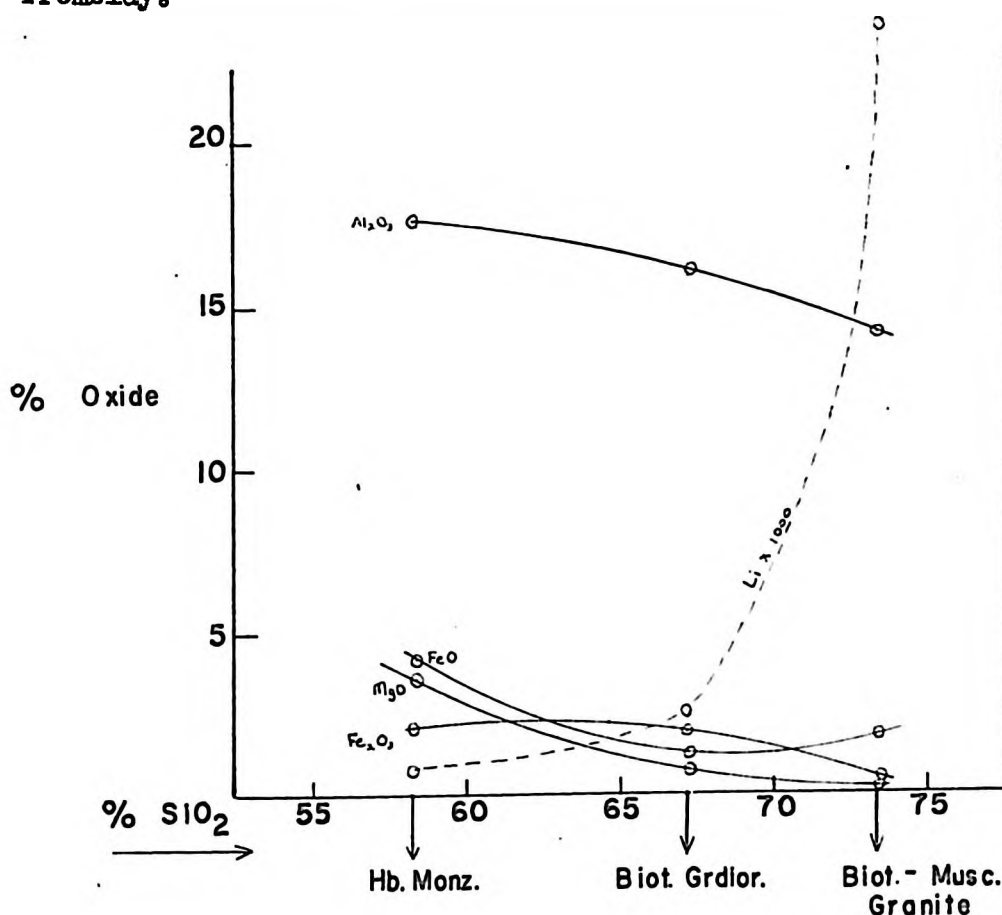
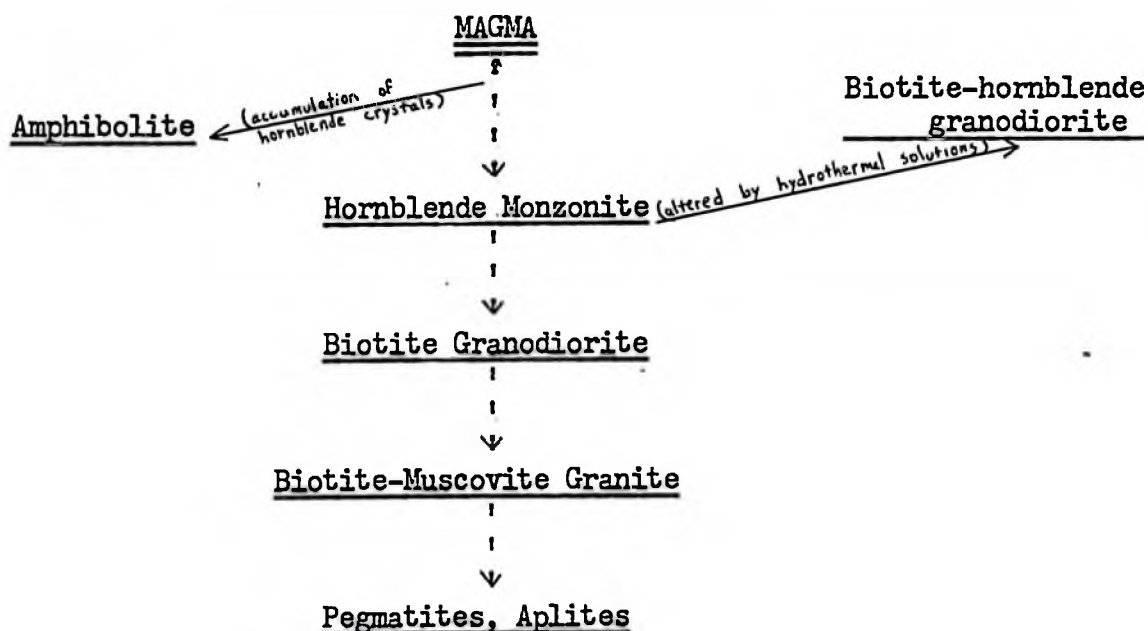


Fig. 3 VARIATION DIAGRAM FOR LACORNE BATHOLITH

(after Tremblay, 1950), with Li data from this thesis

Tremblay (1950, pp. 52) compares the above variation diagram to one drawn for Daly's average andesite, dacite and rhyolite. He took Daly's results to represent the normal liquid line of descent during the differentiation of a magma of basaltic composition. There is a great deal of similarity between the two variation diagrams. Tremblay assumed that the parent magma of the Lacorne batholith was basaltic in composition, and that it differentiated in a reservoir at great depth. He explains the differentiation by fractional crystallization, which started at depth with the formation of hornblende and calcic plagioclase, and continued in part where the intrusive masses were emplaced. He believes that the Lacorne series of rocks are characterized by two periods of intrusion, one giving rise to the hornblende monzonite and its associated basic differentiate (amphibolite) and the other giving rise to the biotite-granodiorite and the biotite-muscovite granite. A more complete outline of the differentiation history may be found in Tremblay (1950, pp. 52-54). A diagrammatic sketch of the differentiation sequence is shown below.



LAMOTTE BATHOLITH

The Lamotte batholith outcrops in adjoining parts of the following townships: Lamotte, Preissac, Figuery and Villemontel. All of the batholith consists of granitic rock, 9/10 of the mass being biotite-muscovite granite with the eastern extremity being biotite granodiorite. These rocks are very similar petrographically to their counterparts in the Lacorne mass and therefore only brief descriptions need be given.

Biotite granodiorite

This granodiorite is a light, grey massive rock of medium to fine grain. Feldspar, quartz and biotite are the main constituent minerals. Jones (1956) reports that the feldspar is zoned plagioclase with inner zones ranging in composition from calcic oligoclase An_{25} to Labradorite An_{60} and outer zones changing to oligoclase (An_{18-25}).

Biotite-muscovite granite

This rock is light-coloured and massive with medium grain-size. Feldspar, quartz, muscovite, biotite and euhedral garnet are easily recognized in hand specimen. Feldspar is the most abundant mineral, forming as much as 60% of the rock. Jones (1956) reports the feldspar to be albite-oligoclase Ab_{89-87} , and prefers to call the rock a quartz monzonite. Clear, glassy quartz grains make up to 30% of the rock, muscovite, biotite and euhedral garnet comprising the remainder. Like its counterpart in the Lacorne mass, this granite has also much intimately associated pegmatitic material.

Jones found that the origin and age of the rocks in the eastern part of the batholith could not be directly determined. However, he states that the similarity to rocks described by Tremblay in the Lacorne

mass suggests that the Lamotte rocks are the result of an injection of a later differentiation product from a common parent magma of both batholiths.

Preissac Batholith

The Preissac mass, smallest of the three batholiths, outcrops in Preissac township. Like the Lamotte mass, it too only contains two rock types, biotite granodiorite which forms the northern quarter of the mass, and a biotite-muscovite granite which constitutes the remaining $3/4$ of the batholith. Because these rocks are petrographically similar to those described above they will not be described further here. It will suffice to say that they may be regarded as a separate injection of a differentiation product from the parent magma of the three masses.

Pegmatites and Aplites

Pegmatite and aplite bodies are associated with the batholithic rocks of the Preissac - Lacorne area. Landes (1933) has classified pegmatites into two main groups, simple and complex, the latter containing minerals such as spodumene, columbite-tantalite, beryl, lepidolite and other rare minerals. In the Preissac - Lacorne area both types of pegmatites are found, however, no complex pegmatites have been reported associated with the Preissac mass. Rowe (1953) recognizes a general zonation of the complex pegmatites about the Lacorne and Lamotte batholiths. Beryl seems to occur in greatest concentration in pegmatites within the batholiths, spodumene in pegmatites within the batholith near the contact and in metamorphic rocks adjacent to the contact.

Pegmatites vary in size to about 1000 feet in length and 200 feet in width. Rowe states that the pegmatites examined by him averaged 20 feet or less in width. Tremblay has observed that pegmatites in the centre of the batholith or in the metamorphic rocks adjacent to it are regular in shape and have sharp wall-rock contacts, whereas those within the batholith, but near the wall-rock contact are irregular in shape and have gradational contacts. The pegmatites of economic interest are tabular or flatly lenticular in shape and have sharp contacts with their walls. Most of the pegmatites consist only of the common rock-forming minerals, feldspars, quartz and muscovite. Feldspars (generally white) are the most abundant constituents and include both albite and microcline. Quartz occurs in all of the pegmatites, varying in colour from colourless to milky white to light and dark grey. Muscovite is generally present but is not an important constituent. It

varies in pegmatitic grain size from very fine to medium and is pale green or greyish in colour. The economic minerals found in the pegmatites are spodumene and beryl. Many other minerals have been reported and include the following: lepidolite, spessartite, columbite, tantalite, microlite, betafite, bismuthinite, hematite, powellite, phenacite, molybdenite and lithophyllite, (Rowe 1953). However, none of these minerals are sufficiently abundant to be of economic importance and are regarded as accessories.

The aplite bodies found in the batholiths are similar to the pegmatites in mineralogy, and for that reason will not be described separately. The aplites are often found associated with and grading into the pegmatites, the main difference between them being in grain size.

Tremblay suggests that the pegmatites are late differentiates of the biotite-muscovite granite. He presents the following facts to support this suggestion (a) the pegmatites are closely associated spatially with the biotite-muscovite granite, (b) many of them grade into the granite, and (c) they both contain essentially the same minerals, any difference being a matter of grain-size rather than composition. Tremblay also found a few grains of spodumene in two thin sections of the granite, which he interpreted as showing a direct compositional relationship between the granite and the lithium-bearing pegmatites.

IV. ANALYTICAL PROCEDURE

SAMPLING AND PREPARATION

Since the purpose of this thesis was to study the distribution of lithium in the differentiated rocks of the three batholiths, samples were taken of the various rock types in the three batholiths (excepting the biotite-hornblende granodiorite of the Lacorne mass). The zoning plan of Rowe (1953) for the distribution of the associated lithium-bearing pegmatites in the area was also kept in mind; and with the hope of tracing trends for lithium concentration within the rocks of the batholiths, samples were taken to give traverses north-south and east-west across the biotite-muscovite granite and the hornblende monzonite, the main rock types of the three masses.

The specimens used were portions of those used by Halferdahl (1953) in his study of the trace-element distribution in the granitic rocks of the area. Figure 10 shows localities from which these specimens were taken. Halferdahl's sampling pattern covered each rock type adequately, except for the central portion of the hornblende monzonite in Lacorne township, where the scarcity of outcrop makes sampling difficult.

The sampling procedure carried out by Halferdahl was as follows: at each sampling site fresh rock was broken off from the outcrop, and four to fifteen pounds were taken. Chips from this sample were taken to give a sample of one to one and a half pounds. These chips were crushed to a grain size of 2 to 4 mm. and then quartered. One quarter was used for analysis, the remainder of the sample was retained by Queens' University.

The samples received from Queens' University weighed approximately 100 grams. These were quartered; one quarter was used for rock analysis and one quarter for mineral analysis. The quarter for rock analysis (25 grams) was ground to a fine powder in a Fisher automatic agate mortar. The quarter for mineral analysis was crushed in a stainless steel mortar and the powder obtained was then screened in stainless steel sieves. The 100-200 mesh portion was retained.

Using a Frantz-Isodynamic Separator biotite, muscovite and hornblende were separated from quartz, feldspar and minor constituents. It was found that rolling the mineral grains on a piece of paper was a good means of separating micas from the other minerals. To be assured of having a high grade of purity, each mineral sample was handpicked under a binocular microscope. Visual inspection and grain counts gave estimates of impurities averaging 1-2 percent. This mineral sample was then crushed to a fine powder in an agate mortar.

SPECTROCHEMICAL METHODS

The spectrochemical methods used in this study are standard and are summarized in Tables I and II on pages 20, 23. Further details of the method can be obtained in Ahrens (1954, pp. 70-85) and Ahrens (1950, pp. 121-134).

TABLE 1. SPECTROCHEMICAL ANALYSIS PROCEDURE FOR MINERALS (EXCEPT FELDSPARS)

Instrument -	21 foot Jarrell-Ash grating spectrograph (1st order dispersion 5.2 Å/mm.)
Condensing Optics -	Arc focussed on an adjustable diaphragm by a 10 cm. spherical lens. Diaphragm focussed on the slit by a 6.7 cm. cylindrical lens with axis vertical and focussed on spectrograph mirror by a 45 cm. cylindrical lens placed at the slit with axis horizontal.
Anode -	1/8" crater graphite electrode (National Carbon Co. Special Grade)
Cathode -	1/8" graphite electrode (National Carbon Co. Special Grade)
Electrode Gap -	10 mm.
Wave Length Range -	5600-6900 Å
Current -	7 amperes D.C.
Exposure Time -	40 seconds
Step Sector -	8 steps (intensity ratio $\log I_0/I = 0.2$)
Density Filter -	Metal screen, mesh #150
Slit Width -	30 μ
Slit Length -	5 mm.
Optical Filter -	Yellow, Corning #3486, Cut-off about 5000 Å
Photographic Plates-	Eastman Kodak, type III - F
Buffer -	1 part NaCl to 9 parts SiO ₂ (Na as internal standard)
Sample -	9 parts buffer to 1 part mineral, mixed for 2 minutes in a Wigglebug.
Sintering -	Filled electrodes were dried and sintered to a red heat for 10 to 15 seconds in a blow-pipe flame.
Plate Calibration -	Iron electrodes, 10 second exposure at 3.5 amperes, the other parameters as above.
Processing -	3 minutes in Kodak D-19 developer at 20 C (constant manual agitation), 10 seconds in 2.5% acetic acid stopbath, 10 minutes in acid fix, 20-30 minute continuous-flow water bath; plates were dried at room temperature in a dust-free enclosure.

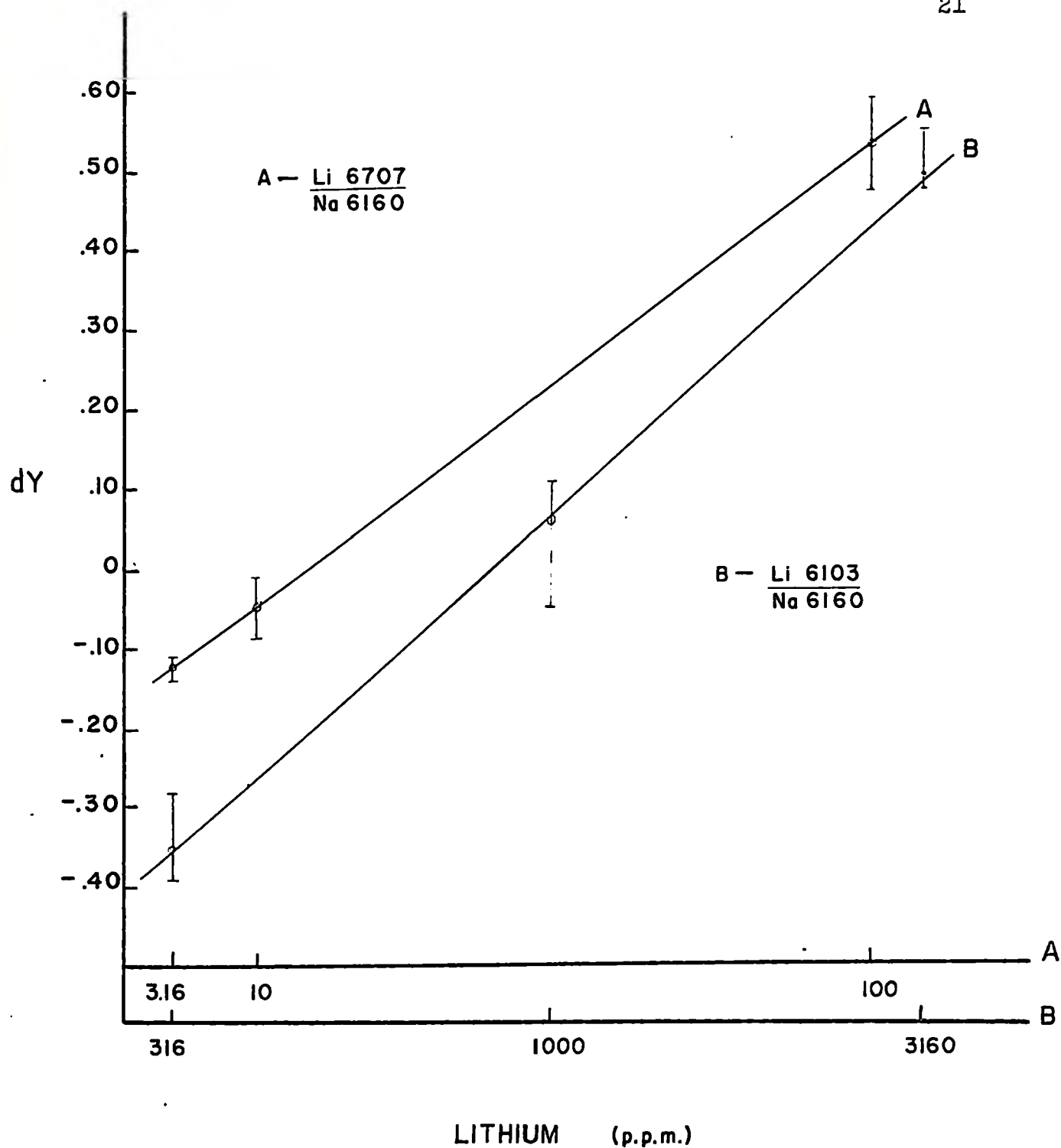


Fig. 4 WORKING - CURVES FOR MINERALS (Plot of log concentration versus dY values for artificial standards)

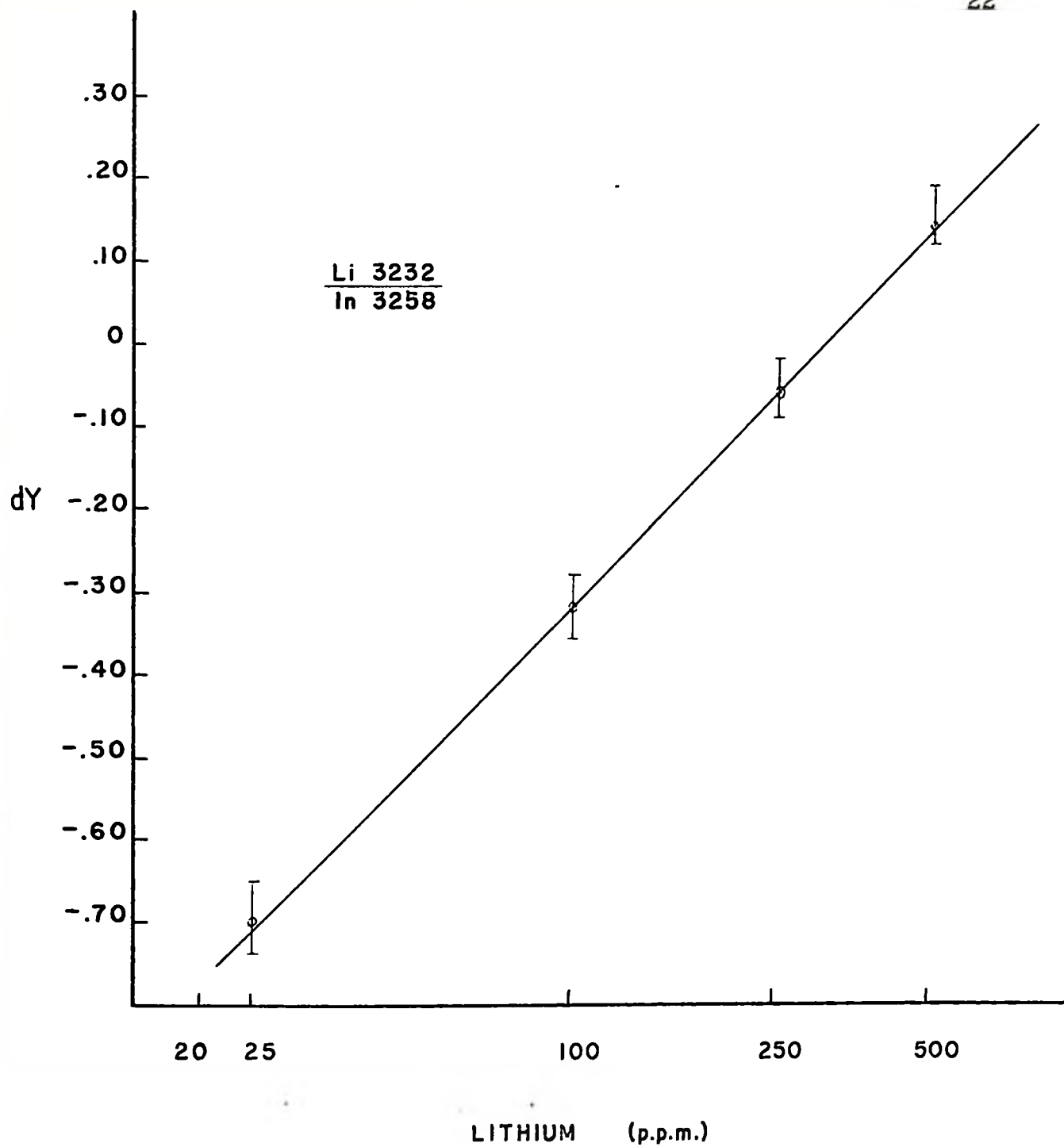


Fig. 5 WORKING - CURVE FOR ROCKS (Plot of log concentration versus dY values for artificial standards)

LEGEND

— range
● average

The method used for rocks and feldspars was a modification of that used by Webber (1952). The difference in parameters from the method for minerals is found in Table 2 which follows.

TABLE 2. SPECTROCHEMICAL ANALYSIS PROCEDURE FOR ROCKS AND FELDSPARS

Wave Length Range -	2200 - 3500 Å
Current -	4 amperes D.C.
Exposure Time -	90 seconds
Filter -	None
Photographic Plates -	Eastman Kodak, type S.A.I.
Buffer -	NaCl containing 0.25% In as In ₂ O ₃ (Internal Standard)
Sample -	1 part Buffer to 9 parts rock.
Processing -	4 minutes at 22 C. in Kodak D19 (constant manual agitation): other details as before.

PHOTOMETRY

Spectral line blackness was measured on an Applied Research Laboratories densitometer. Background readings averaged 95% transmission (clear plate reading 100% transmission), therefore background in most cases was considered negligible and ignored. No problem was encountered with line coincidences.

Spectral lines used for analysis and as internal standards were as follows (Harrison 1939):

Minerals (except Feldspars)

Analysis Line Li 6707.844 Å
(3-100 p.p.m.)

Analysis Line Li 6103.642 Å
(316-3160 p.p.m.)

Internal Standard Na 6160.760 Å
Line

Rocks and Feldspars

Analysis Line Li 3232661 Å
(25-500 p.p.m.)

Internal Standard In 3258.56 Å
Line

Plate calibration curves were initially plotted for each plate from the iron spectrum using the two-step method recommended by Harvey (1950). However, the curves were found to be of similar slope and it subsequently proved unnecessary to calibrate each plate.

Transmission readings of the analysis lines were converted to log relative intensity Li/Na and Li/In (dY values) according to the method of Honerjager-Sohm and Kaiser (1944).

Working curves were constructed by arcing samples of an artificial mafic mineral base containing from 3.16 to 3160 p.p.m. Li, and of an artificial granite base containing from 25 to 500 p.p.m. Li. All chemicals used were "Specpure" Johnson-Matthey products. The points plotted on Figures 4 and 5 are averages of 5 analyses or more. The compositions of the artificial bases are as follows:

Mafic Mineral Base

Wt%

SiO ₂	-	36
Al ₂ O ₃	-	18
MgO	-	14
CaCO ₃	-	18 (9% CaO)
Fe ₂ O ₃	-	<u>14</u>

100

Granite Rock Base (Webber 1952)

Wt%

Pyroxene	-	5.56
KCl	-	5.56
Al ₂ O ₃	-	14.44
SiO ₂	-	<u>74.44</u>
		100.00

A gap exists between the range 100-316 p.p.m. Li in the working-curves for the minerals. The four analyses which fell in this range were therefore re-analyzed by the method used for rocks, which covers this gap.

CONTAMINATION

Contamination can be a major source of error in the spectrochemical analysis of trace elements in rocks and minerals. In this study all possible sources of contamination of the samples were considered and thoroughly investigated. The reagents used in the buffers and the artificial bases were separately analyzed along with the electrodes used to contain the analysis samples. None of these materials was found to contain detectable amounts of lithium (ie. more than 3 p.p.m. Li). Furthermore, during all separating, grinding, weighing and mixing operations extreme care was exercised to avoid any possible contamination.

PRECISION AND ACCURACY

To check the accuracy and precision of the working curves, samples of known standards (G1,W1) were analyzed and checked with the results recommended by Ahrens (1954). Also an artificial standard (Spex Industries G1) of 1000 p.p.m. Li was used. It was decided that the limited number of samples did not warrant treatment by statistical methods.

Accuracy

CURVE I (3.16 - 100 p.p.m. Li)

<u>Granite G1 (p.p.m. Li)</u>		<u>Diabase W1 (p.p.m. Li)</u>	
<u>Ahrens</u>	<u>Siroonian</u>	<u>Ahrens</u>	<u>Siroonian</u>
22	32	9	11
	29		8.5
	29		9.5
	<u>26</u>		
	Av. 29		Av. 9.7

CURVE II (316 - 3160 p.p.m. Li)Spex Mix (G1) p.p.m. Li

1000

Siroonian (G1) p.p.m. Li

985

985

Av. 985

V. CONTROLS ON LITHIUM DISTRIBUTION DURING MAGMATIC CRYSTALLIZATION

The following discussion assumes a magmatic origin for common plutonic igneous rocks:

Various workers in the past have found that the following controls are operative in determining the distribution of lithium during magmatic crystallization: the original content of lithium in the magma; ionic size and electrical charge of lithium; Mg^{+2} , Fe^{+2} , and Fe^{+3} content in the magma; the mineralogy of the crystallizing rocks; the temperature of the cooling magma. Each of these factors is important and is related in some way to the others. It is the interaction of these various controls which determines the nature and the extent of lithium distribution.

The first control, the original content of lithium in the magma is an obvious one. The greater the original content of lithium in a magma, the greater the concentration of lithium in the resulting rocks and minerals. A natural supplement to this statement is that the less the concentration of the replaceable ion or ions in the magma, the more lithium will be able to act as a substituting ion.

Following from this is the second control, the ionic size and electrical charge of the lithium ion. This control is best explained by referring to the two rules formulated by Goldschmidt (1934), which may be given as follows:

(a) If two ions have the same electrostatic charge (of the same sign), the ion of smaller radius will enter a given crystal lattice more readily than the ion of larger radius.

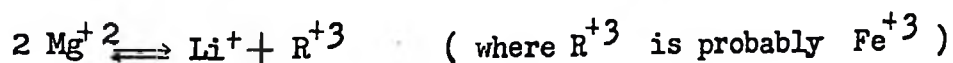
(b) If two ions are of similar size but of different electrostatic charge (of the same sign), the ion of higher electrostatic charge will enter a given crystal lattice more readily than the ion of lower electrostatic charge.

From these two rules a terminology has been derived to describe the nature of minor element substitution. When a trace element has the same electrostatic charge and similar ionic radius to a given major element the trace element will be "camouflaged" in the crystal lattice containing the major element. When a trace element has a similar ionic radius but higher electrostatic charge than that of a given major element the trace element is said to be "captured" by the crystal lattice containing the major element. Finally when a trace element has a similar ionic radius but a lower electrostatic charge than that of a given major element it is said to be "admitted" into the crystal lattice containing the major element.

Lithium is an alkali metal and therefore we might expect it to be "camouflaged" in the mineral structures of alkali minerals. However this is not the case generally, for the only other alkali metal with a radius sufficiently similar to that of lithium (0.78 Å) is sodium (0.98 Å). The difference in size between the two radii is approximately 20%, which is more than the normally accepted tolerance limit of $\pm 15\%$. Therefore we can expect only a limited substitution of lithium for sodium in minerals. Since there are no other singly charged cations of suitable ionic size for which lithium can substitute in minerals we must turn to more highly charged cations which have radii similar to that of lithium. The following elements fall in this category:

Mg⁺² (0.78), Fe⁺² (0.82), Al⁺³ (0.63), Ti⁺⁴ (0.64). Since lithium has only a single charge, according to Goldschmidt's rules it cannot be expected to enter the early crystallizates of any of these elements except in very subordinate amounts. The geochemical experience of past workers has proven that, of the elements mentioned above, lithium is most closely associated with magnesium in rocks and minerals.

Strock (1936) in his study of the geochemistry of lithium first clearly enunciated the relationship between magnesium and lithium in magmatic rocks and minerals. He found that there is an increasing ratio Li/Mg in the magma and the crystallizates during the sequence of fractional crystallization. Both Li and Mg are six co-ordinated in silicate structures, and magnesium (because of its higher charge and greater abundance) acts as a protective element to lithium. Strock attributed the increase of Li/Mg in the course of the differentiation sequence to the decrease in magnesium during differentiation and also to the increase in the amount of trivalent iron. In order to affect the substitution of Li for Mg, the electrical balance of the mineral structure must be maintained. Strock offered the following equation to explain the substitution of Li for Mg:



Many subsequent workers have verified Strock's findings so that it may be safely said that an important controlling factor for lithium distribution in a cooling magma is the magnesium content.

Another control for the distribution of lithium during magmatic crystallization is the mineralogy of the crystallizing rocks. Strock found that lithium tended to concentrate more in the ferro-

magnesian minerals rather than in the feldspars and aluminous minerals. In the ferro-magnesian minerals he found that lithium concentrates more in later-formed minerals of the differentiation sequence than in earlier ones, i.e. the micas were more enriched than the pyroxenes or amphiboles. In view of the relationship between Li and Mg described in the preceeding paragraph, the preference for lithium to concentrate in the later-formed ferro-magnesian minerals (micas) of a crystallizing magma is easily understood.

The enrichment of lithium in micas shows how the last control mentioned, the temperature of the cooling magma is an effective factor in controlling the lithium distribution in a magma. The effect of temperature can be best explained by referring to Rankama and Sahama (1949, pp. 426-427) who state:

"Another point of importance is that during the replacement of Mg by Li the mineral structure suffers a loss in energy. When the Li ion with a lower charge than Mg^{+2} is admitted, the bonds in the structure become weakened. Therefore, no considerable replacement can take place until a relatively low temperature has been reached, i.e. toward the later steps in the main stage of crystallization. It is thus evident that the dark minerals of the granites, especially the micas, will be the richest in lithium."

All of the above controls have been operative to a lesser or greater degree in determining the distribution of lithium in the rocks and minerals of the Preissac, Lamotte and Lacorne batholiths. This will be shown in the interpretation of the analysis results which is to follow.

VI RESULTS AND INTERPRETATION

GENERAL

The analysis results for lithium in the various rocks of the three batholiths present a basis for comparison or correlation of the three batholiths. Although only the Lacorne mass has all the rocks of the complete differentiation sequence, nevertheless each batholith contains the more acid members of the sequence. The analytical results also served in the examination of Tremblay's hypothesis on differentiation and at the same time presented an opportunity to check the validity of Strock's theory for the changing Li/Mg ratio in a differentiating magma. The sampling procedure outlined earlier enabled the author to check Rowe's zoning plan for the pegmatites in the area, to see if the trace quantities of lithium in the rocks of the batholith were related to the loci of the lithium bearing pegmatites. In view of the numerous results of workers in other areas of the world, a comparison was made with these results and those of this study to try to determine if the batholithic rocks of the Preissac - Lacorne area had greater than average concentrations of lithium.

LITHIUM IN ROCKS OF ALL THREE MASSES

The analysis results for lithium in the rocks of the three batholiths may be seen in Table 3 and Figure 6. If the weighted average lithium content (see p. 33) of each batholith is compared (Figure 6) it can be seen that the Lamotte mass contains the greatest lithium content (121 p.p.m.) followed by the Preissac mass (82 p.p.m.) and lastly the Lacorne mass (42 p.p.m.). The explanation for this

variance in their lithium content is best explained in a later section dealing with the lithium-bearing pegmatites. Figure 6 also shows a steady increase in lithium in the batholithic rocks with increasing acidity up to the granite stage, then a decrease in the aplites. This trend suggests that lithium kept increasing in concentration in the magma until the pegmatitic and aplitic stage, and then was incorporated in the pegmatites leaving the aplites almost barren. From Table 3 this trend can be clearly seen in the rocks of the Lacorne batholith where all the members of the differentiation sequence are present. A similar but more limited trend can be seen in both the Lamotte and Preissac masses. In each case the granite contains a greater average lithium content than the (earlier) granodiorite of the same mass.

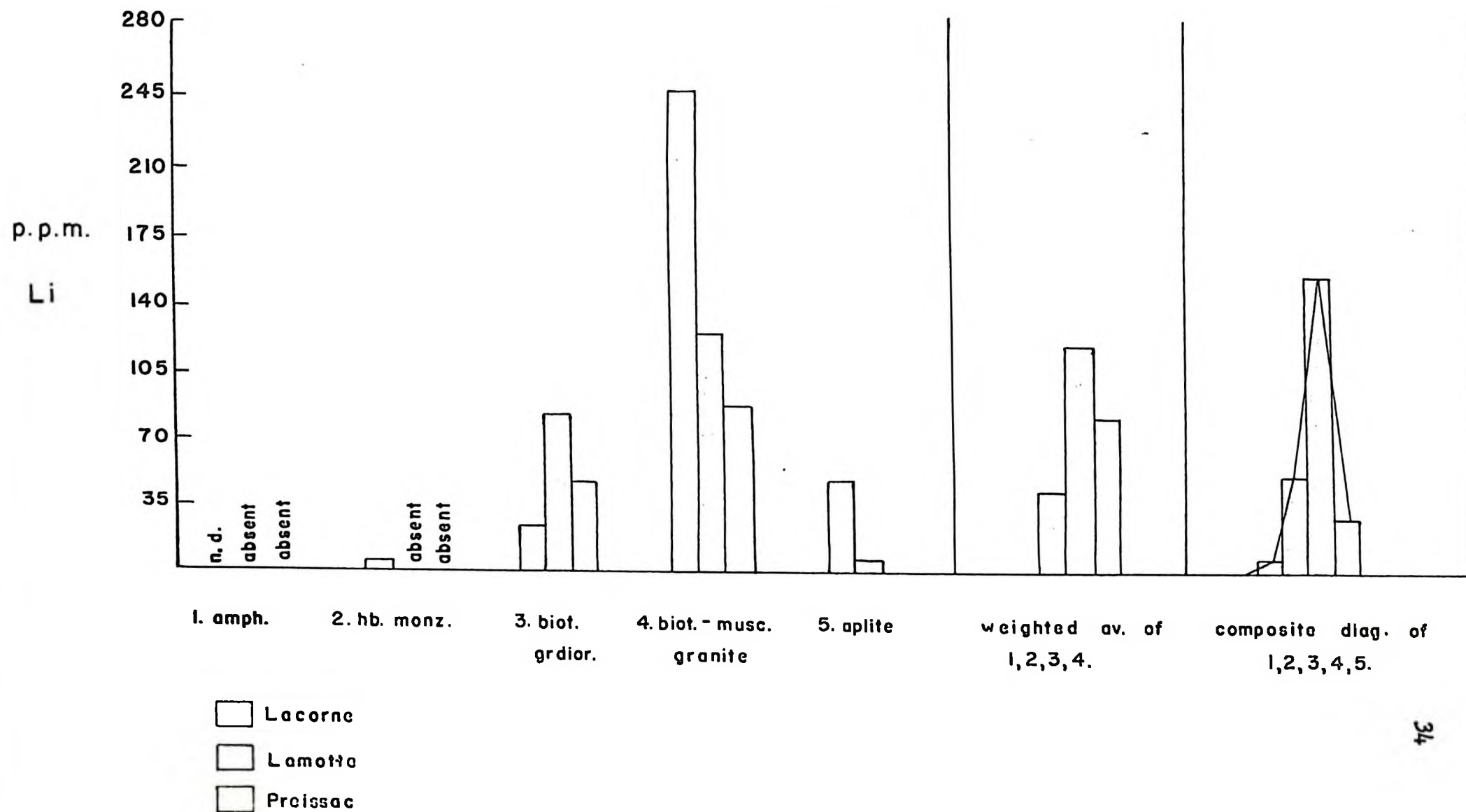
A comparison of the lithium content in the two rock types common to all three batholiths, (granite and granodiorite) reveals that for the granite there is a progressive decrease from 247 p.p.m. in the Lacorne mass through 126 p.p.m. Li in the same rock of the Lamotte mass to 87 p.p.m. in Preissac granite. This trend, however, is not repeated in the granodiorite of the three masses, since a maximum of 83 p.p.m. is reached in the Lamotte mass. However, this is possibly the result of an erratic high of 140 p.p.m. lithium recorded for one specimen of the granodiorite.

TABLE 3. LITHIUM CONTENT IN THE BATHOLITHIC ROCKS

BATHOLITH	LACORNE (A)			LAMOTTE (B)			PREISSAC (C)			AVERAGE of A,B,C.
ROCKS	Number of Samples	Li (p.p.m.)		Number of Samples	Li (p.p.m.)		Number of Samples	Li (p.p.m.)		Li (p.p.m.)
		Average	Range		Average	Range		Average	Range	
AMPHIBOLITE	3	n.d.	----	*	*	*	*	*	*	n.d.
HORNBLENDE MONZONITE	9	7	n.d.-23	*	*	*	*	*	*	7
BIOTITE GRANODIORITE	3	25	20-35	2	83	27-140	2	50	32-69	53
BIOTITE-MUSCOVITE GRANITE	6	247	89-390	14	126	23-325	4	87	25-175	153
APLITE	1	49	----	1	8	----	*	*	*	29
WEIGHTED AVERAGE (By area of outcrop)		42			121			82		82

* Absent

Fig. 6 DIAGRAM COMPARING THE LITHIUM CONCENTRATION
IN THE ROCKS OF THE THREE BATHOLITHS



LITHIUM IN THE LACORNE ROCKS

The lithium distribution in these rocks may be seen in Table 4, which shows a steady increase in lithium with increasing acidity.

TABLE 4. AVERAGE LITHIUM CONTENT IN LACORNE ROCKS (p.p.m.)

Increasing Silica Content →				
AMPHIBOLITE	HORNBLENDE MONZONITE	BIOTITE GRANODIORITE	BIOT.-MUSC. GRANITE	APLITE
not detectable	7	25	247	49

← Decreasing Magnesium Content

The marked increase in the biotite-muscovite granite strongly favours the theory that this rock is the source of the late-stage solutions which formed the lithium-bearing pegmatites. After the granite-forming stage, lithium reached such a high level of concentration in the resulting pegmatitic solutions that ultimately lithium minerals themselves were formed. Thus, these rocks provide us with an excellent example of the formation of rare-element minerals by the process of differentiation.

Strock (1936) used the ratio $\frac{\text{Li} \times 100}{\text{Mg}}$ as a means of determining how far an igneous mass had differentiated; the larger the ratio the greater the degree of differentiation. He also suggested that this ratio could serve as a means of ascertaining if a questionable rock-type belonged in a sequence of differentiated rocks or not.

Figure 7 illustrates the relationship between $\text{Li} \times 100$ and Mg in the rocks of the Lacorne batholith. The data for lithium are taken from Table 3 and the figures for magnesium and iron are taken from Gussow's (1937) analyses of the Lacorne rocks. Figure 7 shows

that as the acidity increases there is a corresponding increase in lithium and a decrease in magnesium. This illustrates the point mentioned earlier, that the magnesium content in a magma is an effective control against the concentration of Li ions in the minerals of the derived rocks. The figures for the $\frac{\text{Li} \times 100}{\text{Mg}}$ ratio in the Lacorne rocks show that differentiation has taken place to a marked degree, the trend being gradual from the monzonite to the granodiorite and then rapidly increasing to the granitic stage.

Strock thought the increase in the Li/Mg ratio during crystallization was accompanied by an increase in the $\text{Fe}^{+3}/\text{Fe}^{+2}$ ratio. He stated that Fe^{+3} was the most likely trivalent ion for the coupled replacement with lithium. Wickman (1943), however, disagrees with Strock on this point. He points out that the Fe^{+3} content does not materially change during differentiation because it is so immobile that it becomes incorporated in a suitable mineral structure. On the other hand the Fe^{+2} content decreases during differentiation, partly owing to the oxidation to Fe^{+3} , and he states that this is the process which is mainly responsible for the change in the $\text{Fe}^{+3}/\text{Fe}^{+2}$ ratio during differentiation. It is seen in Figure 7 that the $\text{Fe}^{+3}/\text{Fe}^{+2}$ ratio does increase from the monzonite to the granodiorite but then decreases markedly to give the lowest figure for the granite, which in theory should be the highest.

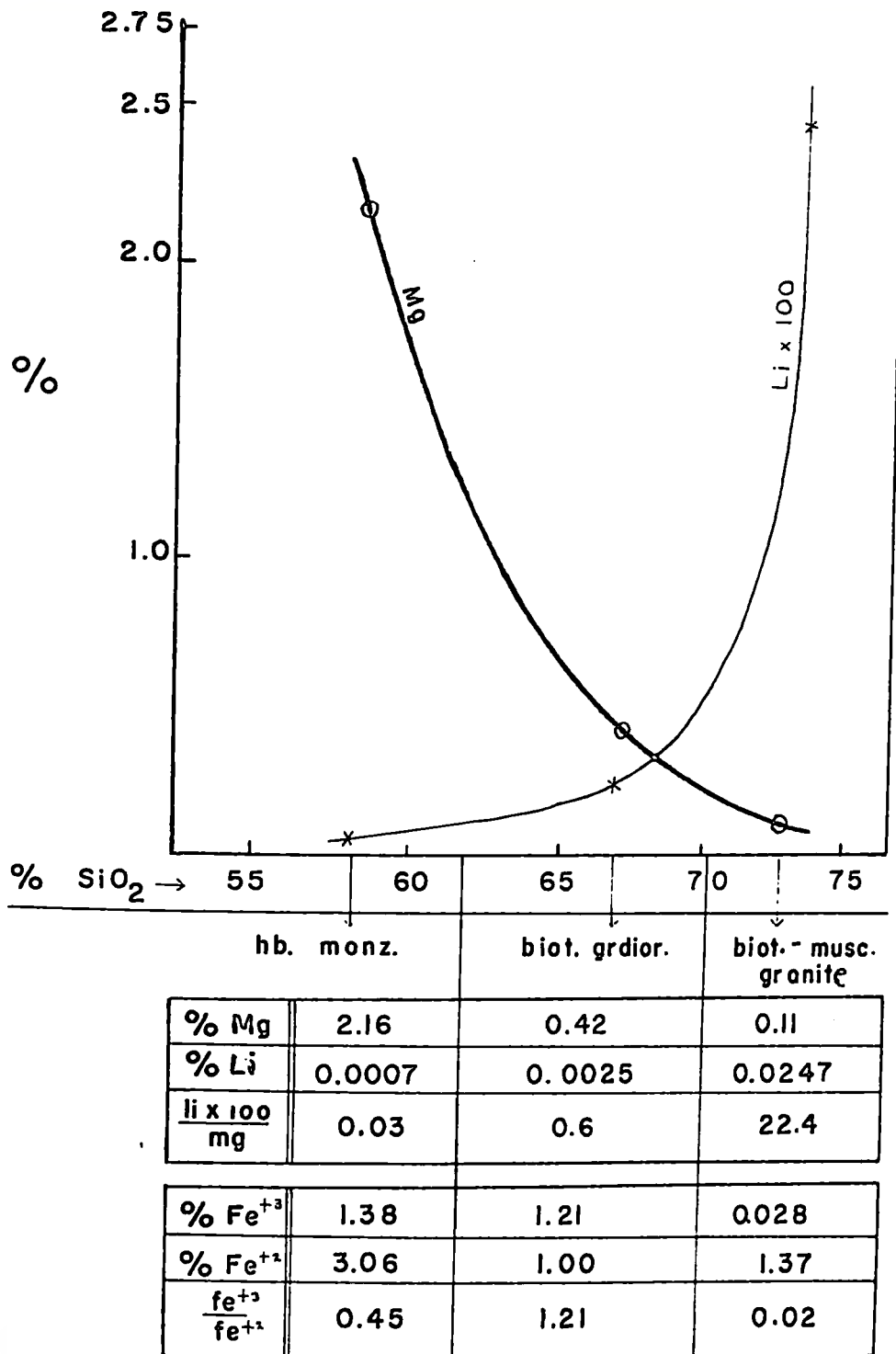


Fig. 7 THE Li-Mg RELATIONSHIP IN THE ROCKS
OF THE LACORNE BATHOLITH

LITHIUM IN MINERALS

General

In minerals separated from rocks of the Preissac, Lamotte and Lacorne batholiths there is a clear tendency for lithium to be concentrated in ferro-magnesian minerals, particularly biotite. This is shown in Table 5 below, in which the average and range of analyses of specific minerals from various parts of all three batholiths are arranged in order of increasing lithium content. Feldspar, quartz, garnet and epidote have low Li concentrations with little departure from average in their ranges. Muscovite and biotite on the other hand show much greater concentrations and also greater ranges. Hornblende is intermediate between these two groups. Since the micas showed such a range of Li content, the geographic and lithological distribution of the variation was examined,

TABLE 5. LITHIUM CONTENT IN PREISSAC - LACORNE MINERALS

MINERAL		MICROCLINE	QUARTZ	FELDSPAR (Plag. Pot.)	GARNET
Li (p.p.m.)	Average	n.d.	45	73	140
	Range	---	17-89	22-220	---
Number Of Samples		3	4	4	1
MINERAL		EPIDOTE	HORNBLENDE	MUSCOVITE	BIOTITE
Li (p.p.m.)	Average	23	258	2506	2418
	Range	---	88-442	633-3200	270-3200
Number Of Samples		1	6	22	25

Minerals Of The Lacorne Sequence

Since the Lacorne batholith contains all the rocks of the differentiation sequence, it was decided that the minerals in these rocks would best illustrate the distribution of lithium in the various mineral families during magmatic crystallization. A representative sample of each rock type was chosen on the basis that the representative sample should have approximately the same lithium content as the average value for the rock. The results of the analyses are listed in Table 6 and are also presented in Figure 8.

The high lithium values for quartz cannot be accounted for except as the result of inclusions. The concentration of lithium increases from the granodiorite to the granite, and then decreases in the aplite and pegmatite stages.

No lithium could be detected in potash feldspars, illustrating how lithium differs geochemically from other alkali metals. Table 6 shows low lithium values in sodic plagioclase (mixed feldspars), except for a marked enrichment in the biotite-muscovite granite. The latter parallels the behaviour of quartz.

The hornblende from the amphibolite contains less lithium than the monzonite, which is to be expected since the amphibolite is considered to be a basic differentiate of the monzonite. This again illustrates how a decreasing Mg content in a magma aids in increasing Li substitution.

Since the micas will be discussed separately in the next section, they will not be discussed in detail here. It may be seen however, from Table 6, that the biotite from the granite contains considerably more lithium than that from the gran odiorite. A high point of

concentration is reached in the micas of the granite, those in the subsequent aplite and pegmatites having considerably less lithium, presumably since most of the lithium was used in forming the lithium minerals of the pegmatites.

TABLE 6. LITHIUM .CONTENT. OF MINERALS FROM THE LACORNE ROCKS

ROCKS	LITHIUM (p.p.m.)								
	Quartz	Feldspar (Plag. Pot.)	Microcline	Garnet	Epidote	Hornblende	Muscovite	Biotite	Chlorite
AMPHIBOLITE	A	*	*	A	*	105	A	A	*
HORNBLLENDE MONZONITE	A	22	n.d.	A	23	165	A	A	A
BIOTITE GRANODIORITE	52	22	*	A	36	A	A	393	A
BIOT.-MUSC. GRANITE	89	220	*	*	A	A	3200	3200	A
APLITE	17	27	*	140	A	A	677	A	A
PEGMATITE (simple)	22	*	n.d.	*	A	A	967	A	A
PEGMATITE (spodumene)	*	*	n.d.	A	A	A	1191	A	A

* - no analysis.

n.d.- Lithium not detected.

A - mineral absent.

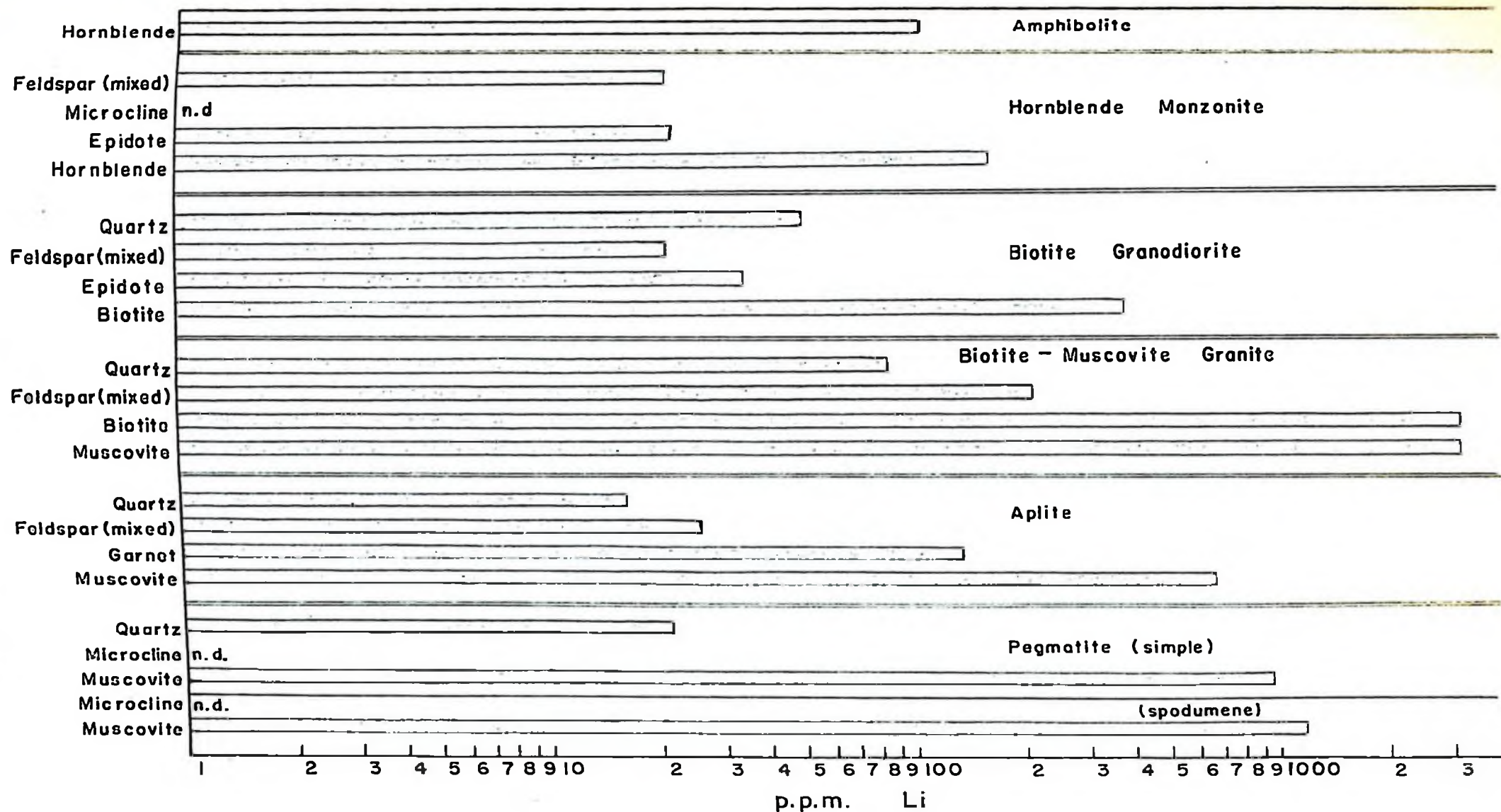


Fig. 8 BLOCK DIAGRAMS OF THE LITHIUM CONTENT IN
THE MINERALS OF THE LACORNE ROCKS

Micas

The distribution of lithium in the micas is shown in Table 7. It can be seen that the Lacorne micas are the richest in lithium, followed by the Lamotte, while those of the Preissac mass contain the least lithium. A comparison of muscovite and biotite in each granite shows that in the Lacorne and Lamotte masses the muscovite and biotite have approximately the same Li concentration, while in the Preissac mass there is a considerable difference, the biotite containing almost twice as much as the muscovite. These trends in the micas are generalizations: more detailed trends will be discussed in the following paragraphs.

The biotite granodiorite comprises only a small part of each batholith, and few analyses of the biotite were made. The results (Table 7) show that lithium has concentrated to the greatest degree in the biotite in the Lacorne granodiorite. This trend is similar to that of the general trend for all micas from the three batholiths.

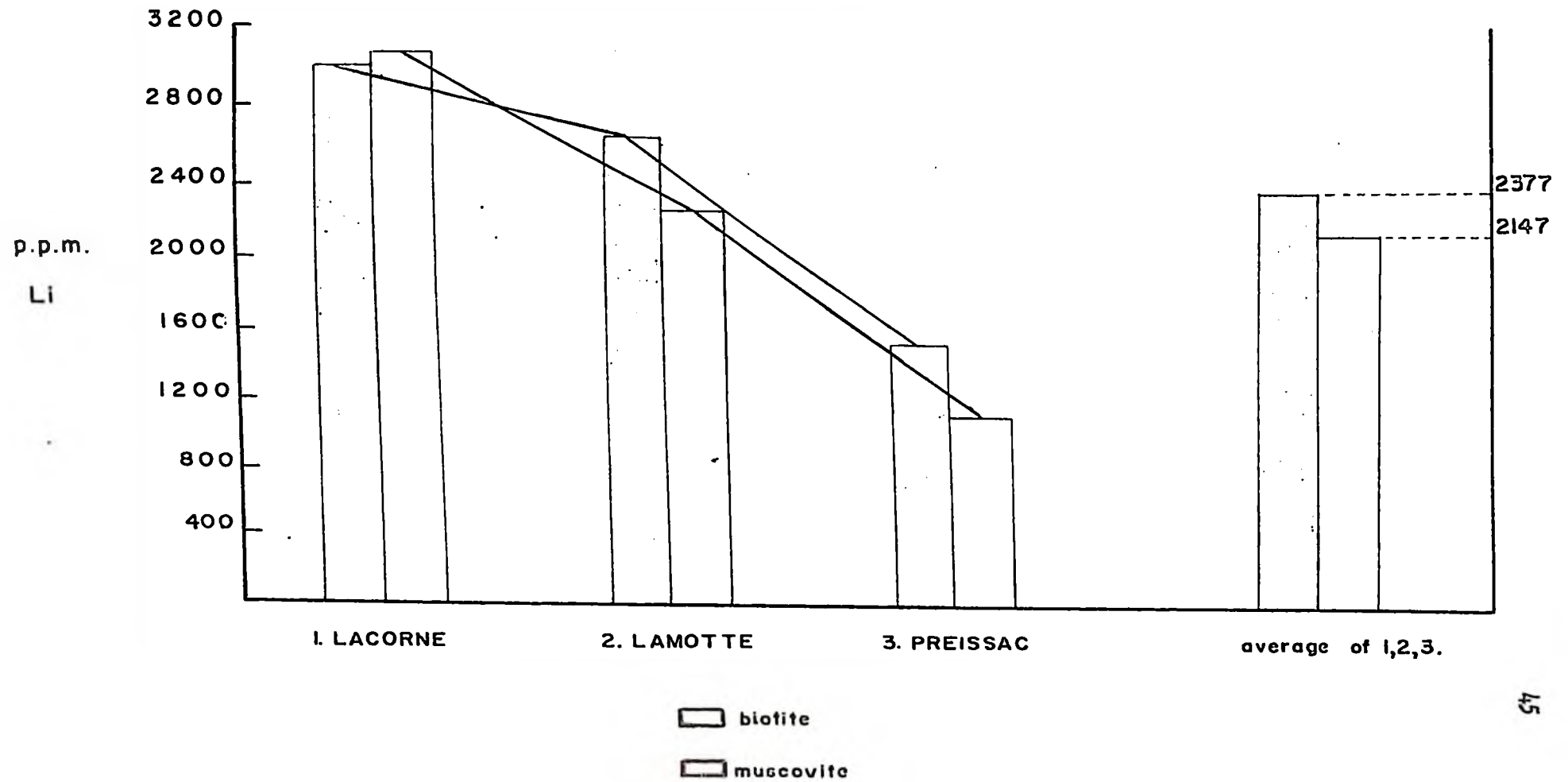
The results of the analyses of micas from the granites are shown in Table 7 and in Figure 9. Both biotite and muscovite show a regular decrease in lithium content from the Lacorne through the Lamotte to the Preissac rocks. The decrease is more marked in the muscovite. The Lacorne micas have very similar lithium contents whereas in the Lamotte and Preissac granites lithium is preferentially enriched in the biotites, this being particularly evident in the Preissac rocks. The average micas from all three granites examined show a slight lithium enrichment in biotite (Figure 9).

TABLE 7. LITHIUM ANALYSES FOR HORNBLLENDE, BIOTITE, MUSCOVITE

BATHOLITH	LACORNE			LAMOTTE			PREISSAC		
MINERALS	Number Of Samples	Li (p.p.m.)		Number Of Samples	Li (p.p.m.)		Number Of Samples	Li (p.p.m.)	
		Av.	Range		Av.	Range		Av.	Range
HORNBLLENDE									
(Amphibolite)	1	105	---	*	*	*	*	*	*
(Monzonite)	5	229	88-442	*	*	*	*	*	*
BIOTITE									
(Granodiorite)	2	2421	1642- 3200	2	575	490-660	1	270	---
(Granite)	7	2957	1583- 3200	13	2642	520- 3200	2	1533	---
MUSCOVITE									
(Granite)	11	3062	2425- 3200	8	2265	960- 3200	3	1113	633-2042

* - Absent

Fig. 9 THE AVERAGE LITHIUM CONTENT IN THE MICAS
OF THE BIOTITE-MUSCOVITE GRANITE



LITHIUM-BEARING PEGMATITES

One of the aims of this study is to try to determine from the analytical data the probable source of the spodumene-bearing pegmatites in the area and to explain their mode of occurrence on a geochemical basis. The views of previous workers as to the origin of the lithium-bearing pegmatites may be summarized as follows:

1. Derry's (1946) observations led him to conclude that the minerals in the lithium-bearing pegmatites had crystallized directly from a melt;
2. Tremblay (1950) suggested a genetic relationship between the biotite-muscovite granite and the lithium-bearing pegmatites on the basis of the fact that:
 - a. the biotite-muscovite granite and the lithium-bearing pegmatites are closely associated spatially,
 - b. many of the pegmatites grade into the granite and contain essentially the same minerals;
 - c. a few grains of spodumene were identified in two thin sections of the granite;
3. Rowe (1953) states that the field evidence suggests that the batholithic rocks and pegmatites are differentiates of a single magma.
4. Halferdahl (1955, p 75) states:

"Some unknown process, possibly due to the relatively high amount of potash concentrated these metals (lithium, beryllium, molybdenum) in average or above average amounts in the original magma, to a greater extent than normal."

ation

Evidence presented in the present study shows a marked enrichment of lithium in the later minerals and rocks of the differentiation sequence, reaching a maximum in the last plutonic rock, i.e. the granite. This is particularly clear when Li/Mg ratios are considered. The magma or residual solutions from the crystallization of the granite might be

expected to maintain or even increase this lithium enrichment. These residual solutions might be expected to give aplite and pegmatite deposits.

Halferdahl (1955) presents figures which show that the Lacorne mass contains three times as many lithium-bearing pegmatites as the Lamotte mass. Since the Lacorne granite contains twice as much lithium as the Lamotte granite, this data provides additional evidence concerning the source of the pegmatites. The reason for the greater concentration of lithium in the Lacorne granite is the result of the difference in its differentiation pattern from that of the Lamotte mass. The Lacorne mass is almost three times as large as the Lamotte mass, and whereas the Lacorne batholith is essentially a hornblende-bearing rock, the Lamotte batholith is entirely a mica-bearing rock. It was seen earlier that the micas contained much more lithium than the hornblendes. Therefore, in the Lamotte mass much of the lithium in the magma was concentrated during crystallization in the rocks formed, thereby depleting the residual solutions. Since most of the Lacorne mass is composed of hornblendic rocks, more lithium remained in the magma until the later differentiates - the granite and the pegmatites crystallized. Further evidence to support this thesis is the fact that the Lacorne mass has a much lower overall lithium content than the Lamotte mass - most of the lithium in the Lacorne mass having been concentrated then drawn off into the pegmatites.

A possible source of lithium which should not be ignored are the Kewagama sediments, which envelope the batholithic rocks. Two samples of these sediments were analyzed, one contained a high concentration of

lithium and the other a very low concentration. However, since field evidence shows that inclusions of sedimentary material were only very local features it is likely that the introduction of lithium into the original magma by contamination was very limited.

The observations of past workers and the data of this study all support the idea that the lithium-bearing pegmatites were derived from the biotite-muscovite granite. Halferdahl attributes their origin to some unknown process connected with the high amount of potash in the batholithic rocks. The author does not see the need to invoke an unknown process to explain the origin of the lithium-bearing pegmatites when they can be adequately accounted for on the basis of normal differentiation.

The loci of the lithium-bearing pegmatites are necessarily connected with their origin, therefore an attempt will be made to explain this problem. Rowe (1953) stated the following:

"A detailed study made by Tremblay of the strikes and dips of the pegmatite bodies in Lacorne township has suggested that these bodies are related to structural features associated with the Preissac-Lacorne batholith. Near the contact zones of metamorphic rocks and muscovite granite or hornblende monzonite, the pegmatites strike either parallel with, or at right angles to the contacts, suggesting that the intrusion of the pegmatites was controlled by longitudinal and cross joints. The orientation of pegmatites within the batholith also suggests control by joint systems. Tremblay has observed that the more important pegmatite deposits appear to have formed in areas of intense fracturing close to the batholithic contacts, an observation that seems to be especially applicable to certain spodumene deposits. Diamond drilling has shown that the spodumene rich pegmatites south of Lake Lortie and Lake Roy dip 40 to 65 degrees south and strike parallel with the batholithic contacts. It is possible that these pegmatites are structurally controlled by longitudinal joints or by marginal fissures or marginal thrusts."

ation

In this study the analytical data seems to support Tremblay's

explanation for the loci of the lithium-bearing pegmatites. Figure 10 shows the analytical data plotted with the geographic location of the specimen. In the Lamotte mass a definite trend is seen for an increase in the lithium content of the rock towards the north-east corner of the batholith. This is the area where the larger lithium-bearing pegmatites are located and it also coincides with Rowe's "lithium rich zone". No definite trend can be distinguished in the small mass of biotite-muscovite granite in the Lacorne batholith. It might be noted, however, that there is a slight increase in the lithium content in the north-eastern corner of the monzonite towards the zone of pegmatites. Also there is a conspicuous absence of lithium in the monzonite in the southern half of the batholith - an area devoid of lithium-bearing pegmatites. These data agree with the hypothesis that lithium-rich solutions from the biotite-muscovite granite were drawn off into joints and fractures which had developed along the northern rim of the batholiths.

It may be concluded therefore, that the lithium-bearing pegmatites associated with the batholithic rocks of the Preissac - Lacorne area are a late stage differentiate of the biotite-muscovite granite, and that their loci were structurally controlled by the joint systems developed in the batholiths and the surrounding rocks.

ration

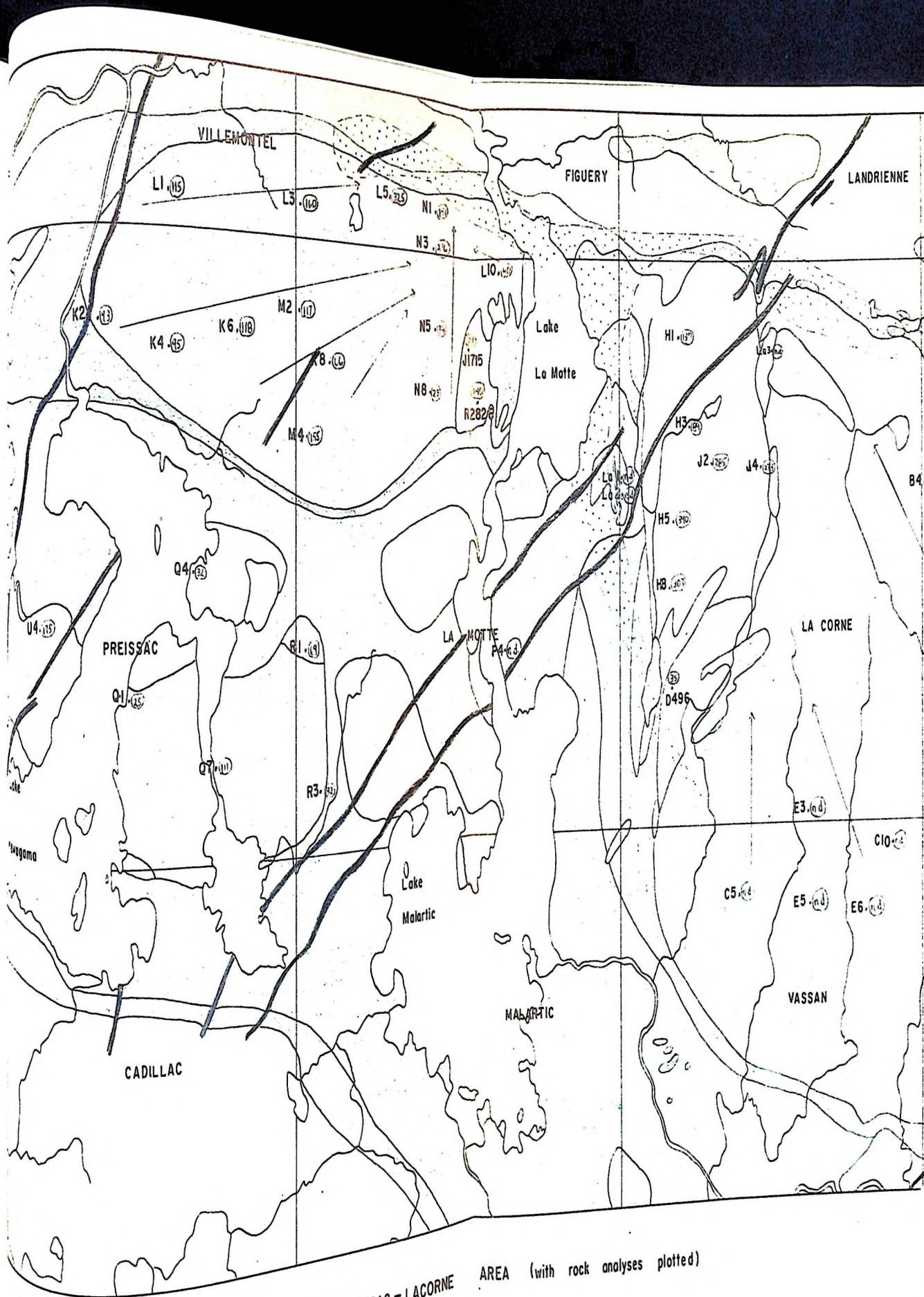



Fig. 10 GEOLOGICAL MAP OF PREISSAC - LACORNE AREA (with rock analyses plotted)


LEGEND

50


LATE PRECAMBRIAN

 Olivine diabase, quartz diabase

EARLY PRECAMBRIAN


 Biotite-muscovite granite


 Biotite granodiorite, 9a Malartic Stock

 Hornblende monzonite, 8a biotite-hornblende granodiorite


 Amphibolite

BASIC TO ACIDIC INTRUSIVE ROCKS


 Albite granite, granodiorite, quartz-feldspar porphyry

 Amphibolite, peridotite, diorite


BLAKE RIVER GROUP

 Altered basic to acidic lavas and pyroclastics, minor greywacke


KEWAGAMA GROUP

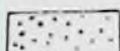
 Greywacke, and derived biotite schist, conglomerate, minor lava

MALARTIC GROUP

 Basic to acidic lavas and derived hornblende schist, agglomerate, some peridotite

KINOJEVIS GROUP

 Basic and minor acidic lavas and derived hornblende schist

 LITHIUM ZONE (Rowe 1953)

D2.65 - sample location and concentration of lithium in p.p.m.

 - direction of increasing lithium concentration

n.d. - lithium not detectable

SCALE (1" = 2 miles)

0 2 4
(miles)

BARRAUTE

B5.20

B7.20

FIEDMONT

SENNEVILLE

5.20

F6.20

TABLE 8. THE LITHIUM CONTENT OF VARIOUS GRANITES

ROCK TYPE	ANALYST	CONCENTRATION (p.p.m. Li)	AGE
Transgressive Granophyre	Wager and Mitchell (1951)	20	Tertiary
Acid Granite	Wager and Mitchell (1951)	13	Tertiary
Acid Rocks (Av.)	Nockolds and Mitchell (1948)	20	Caledonian
Ademellite	Nockolds and Mitchell (1948)	40	Caledonian
White Mtn. Granite (U.S.A.)	Webber (1952)	48	Mississippian
Finnish Granites (Av.)	Webber (1952)	44	Precambrian
German Granites (Av.)	Strock (1936)	179	Precambrian
Irish Lavas (Granitic)	Patterson (1951)	74	
Sweden (Granitic)	Lundegardh (1946)	70	Precambrian
North American Granites	Ahrens (Deleon and Ahrens) (1957)	44	
Yugoslavian Granites	Deleon and Ahrens (1957)	34	
Lacorne Granite	Siroonian (1958)	247	Precambrian
Lamotte Granite	Siroonian (1958)	126	Precambrian
Preissac Granite	Siroonian (1958)	87	Precambrian
Average Granite (World)	Strock (1936)	150	
Average Granite (World)	Horstmann (1957)	40	
Av. Granite (Preissac-Lacorne)	Siroonian (1958)	153	Precambrian

LITHIUM IN VARIOUS GRANITES

Table 8 presents Li analyses of granitic rocks from various parts of the world. A comparison of the results shows that the values are less than 100 p.p.m. and average around 50 p.p.m. Li if the German granites and the granites of this study are excluded.

The value of 150 p.p.m. Li given by Strock for the average granite seems too high in the light of more recent results. Horstmann, the most recent worker on the problem, gives a figure of 40 p.p.m. Li which seems much more reasonable. If the world average is taken somewhere in the range 40-50 p.p.m. Li, the Preissac - Lacorne granites are clearly very rich in lithium. This fact is indeed borne out by the economic deposits of lithium found in the area.

CONCLUSIONS

From the results of this study, several conclusions may be drawn regarding the significance of the distribution of lithium in the batholithic rocks of the Preissac - Lacorne area.

A comparison of the granites of the three batholiths is possible on the basis of their average lithium content. The granite of the Lacorne batholith having the highest concentration of lithium followed in decreasing order by the Lamotte and Preissac granites. Table 8, comparing the results of other investigators, shows that the granites of the Preissac - Lacorne area contain much more lithium than most granites elsewhere in the world, except for certain German granites which are also rich in lithium.

Tremblay (1950) presented geological, petrographic and chemical data showing that the Lacorne rocks represented a differentiation sequence. The evidence obtained in this study on the distribution of lithium in these rocks agrees well with Tremblay's theory of differentiation. Furthermore the results indicate that the lithium-bearing pegmatites associated with the batholiths are a late stage differentiate of the biotite-muscovite granite. The loci of these pegmatites were determined by structural features, - the joint systems in the batholiths.

Strock (1936) and others have shown that during the differentiation of a magma, lithium is concentrated in the ferro-magnesian minerals, and especially in the micas. The micas from the granites (especially the biotites) contain more lithium than any other mineral, excluding the

lithium minerals in the pegmatites, Strock also found that the ratio $\frac{\text{Li} \times 100}{\text{Mg}}$ increased with increasing differentiation in a magma. This also was confirmed in the present study.

APPENDIXLACORNE BATHOLITH

<u>No.</u>	<u>Location</u>			<u>Analysis Results</u> (p.p.m. Li)			<u>Average</u>
<u>Amphibolite</u>							
La 1	m, 3,	Vll	Lac.	n.d.	n.d.	n.d.	n.d.
La 2	m, 3,	Vll	Lac.	n.d.	n.d.	n.d.	n.d.
La 3	n, 34,	1X	Lac.	n.d.	n.d.	n.d.	n.d.
<u>Hornblende Monzonite</u>							
B 4	m, 1,	Vll	Fied.	27	22	20	23
B 5	m, 6,	VI	Fied.	20	20	20	20
B 7	m, 12,	V	Fied.	20	20	20	20
C 5	n, 26,	1X	Vass.	n.d.	n.d.	n.d.	n.d.
C 10	e, 53,	X	Vass.	n.d.	n.d.	n.d.	n.d.
E 3	s, 41,	1	Lac.	n.d.	n.d.	n.d.	n.d.
E 5	m, 40,	1X	Vass.	n.d.	n.d.	n.d.	n.d.
E 6	w, 54,	1X	Vass.	n.d.	n.d.	n.d.	n.d.
P 4	m, 41,	1V	Lam.	n.d.	n.d.	n.d.	n.d.
<u>Biotite Granodiorite</u>							
Da 496	m, 11,	111	Lac.	28	42		35
F 5	m, 5,	Vll	Senn.	20	20	20	20
F 6	n, 6,	VI	Senn.	20	20	20	20

n - north	w	54	1X	Lac	Fied. - Fiedmont	Senn. - Senneville
s - south	↓	↓	↓	↓	Vass. - Vassan	Fig. - Figuery
e - east	west	lot	range	town-	Lac. - Lacorne	Preis. - Preissac
w - west	end			ship	Lam. - Lamotte	Vill. - Villemontel
m - middle						

<u>No.</u>	<u>Location</u>	<u>Analysis Results</u>			<u>Average</u>	
		<u>(p.p.m. Li)</u>				
<u>Biotite-Muscovite Granite</u>						
H 1	n, 14, 1X Lac.	125	130	155	137	
H 3	s, 16, Vlll Lac.	92	86	90	89	
H 5	m, 13, VI Lac.	380	370	420	390	
H 8	m, 11, V Lac.	310	300	310	307	
J 2	m, 21, Vlll Lac.	280	280	290	285	
J 4	m, 30, Vll Lac.	290	260	270	273	
<u>Aplite</u>						
Ap H1	n, 14, 1X Lac.	52	46	50	49	

LAMOTTE BATHOLITH

Biotite Granodiorite

J 1715	n, 36, 1X Lam.	23	37	20	27
R 2826	e, 34, Vlll Lam.	175	115	130	140

Biotite-Muscovite Granite

K 2	m, 26, 1X Preis.	94	92	92	93
K 4	m, 37, 1X Preis.	86	100	100	95
K 6	m, 48, 1X Preis.	105	115	135	118
K 8	s, 7, 1X Lam.	56	70	72	66
L 1	m, 37, 1 Vill.	115	100	130	115
L 3	m, 1, 1 Fig.	175	125	180	160
L 5	n, 19, 1 Fig.	295	350	330	325
L 10	w, 45, X Lam.	32	50	37	40
M 2	n, 1, 1X Lam.	115	125	110	117
M 4	n, 2, Vll Lam.	145	160	160	155
N 1	n, 28, 1 Fig.	160	125	170	151

<u>No.</u>	<u>Location</u>	<u>Analyses Results</u>			<u>Average</u>
		<u>(p.p.m. Li)</u>			
N 3	s, 27, 1 Fig.	215	230	265	236
N 5	n, 28, 1X Lam.	72	80	70	74
N 8	e, 26, Vlll Lam.	21	20	28	23
<u>Aplite</u>					
Ap L2	m, 44, X Rreis.	n.d.	n.d.	25	8

PREISSAC BATHOLITH

Biotite Granodiorite

Q 4	n, 10, V Preis.	26	38	32	32
R 1	m, 22, 1V Lam.	74	64	70	69

Biotite-Muscovite Granite

Q 1	n, 29, 111. Preis.	27	30	20	25
Q 7	m, 44, 11 Preis.	105	74	155	111
R 3	s, 4, 11 Lam.	27	32	38	32
U 4	n, 13, 1V Preis.	190	155	180	175

THE LACORNE SEQUENCE

<u>Minerals</u>	<u>Analysis Results</u> <u>(p.p.m. Li)</u>			<u>Average</u>
<u>Amphibolite (La 3)</u>				
Hornblende	105	105		105
<u>Hornblende Monzonite (B 5)</u>				
Feldspar (Plag.+Pot.)	21	20	27	22
Microcline	n.d.	n.d.	n.d.	n.d.
Epidote	23	23		23
Hornblende	170	180	145	165
<u>Biotite Granodiorite (F 5)</u>				
Quartz	42	63		52
Feldspar (Plag.+Pot.)	25	22	20	22
Epidote	34	38		36
Biotite	390	390	400	393
<u>Biotite-Muscovite Granite (J 2)</u>				
Quartz	93	82	94	89
Feldspar (Plag.+Pot.)	210	230		220
Muscovite	>3200	>3200	>3200	>3200
Biotite	>3200	>3200	>3200	>3200
<u>Aplite (Ap H1)</u>				
Quartz	19	15		17
Feldspar (Plag.+Pot.)	29	31	20	27
Garnet	100	180		140
Muscovite	620	640	770	677

<u>Minerals</u>	<u>Analysis Results</u> <u>(p.p.m. Li)</u>			<u>Average</u>
<u>Pegmatite, simple (L 10)</u>				
Quartz	26	26	13	22
Microcline	n.d.	n.d.	n.d.	n.d.
Muscovite	1100	890	910	967
<u>Pegmatite, spodumene (L 11)</u>				
Microcline	n.d.	n.d.	n.d.	n.d.
Muscovite	1000	1175	1400	1191

LACORNE BATHOLITH

<u>No.</u>	<u>Mineral</u>	<u>Analysis Results</u> <u>(p.p.m. Li)</u>			<u>Average</u>
<u>Amphibolite</u>					
La 3	Hornblende	105	105		105
<u>Hornblende Monzonite</u>					
D 412	Hornblende	460	475	390	442
D 67	Hornblende	200	180	200	193
D 413	Hornblende	230	280	260	257
D 71	Hornblende	83	90	90	88
<u>Biotite Granodiorite</u>					
Da 496	Biotite	1625	1675	1625	1642
Da 499	Biotite	> 3200	> 3200	> 3200	> 3200
<u>Biotite-Muscovite Granite</u>					
H 1	Muscovite	2650	2650	> 3200 > 3200	2925
H 1	Biotite	> 3200	> 3200	> 3200	> 3200
H 2	Muscovite	2450	2100	> 3200 > 3200	2737
H 2	Biotite	> 3200	2950	> 3200	3116
H 3	Biotite	1500	1700	1550	1583
H 4	Muscovite	> 3200	> 3200	> 3200	> 3200
H 4	Biotite	> 3200	> 3200	> 3200	> 3200
H 5	Muscovite	> 3200	> 3200	> 3200	> 3200
H 5	Biotite	> 3200	> 3200	> 3200	> 3200
H 6	Muscovite	> 3200	> 3200	> 3200	> 3200
H 6	Biotite	> 3200	> 3200	> 3200	> 3200
H 7	Muscovite	1600	1700	> 3200 > 3200	2425
H 8	Muscovite	> 3200	> 3200	> 3200	> 3200

<u>No.</u>	<u>Mineral</u>	<u>Analysis Results</u> <u>(p.p.m. Li)</u>			<u>Average</u>
H 8	Muscovite	>3200	>3200	>3200	>3200
J 2	Muscovite	>3200	>3200	>3200	>3200
J 2	Biotite	>3200	>3200	>3200	>3200
J 3	Muscovite	>3200	>3200	>3200	>3200
J 4	Muscovite	>3200	>3200	>3200	>3200

LAMOTTE BATHOLITHBiotite Granodiorite

Da 228	Biotite	660	670	640	660
Da 546	Biotite	490	490	490	490

Biotite-Muscovite Granite

K 1	Muscovite	>3200	>3200	>3200	>3200
K 1	Biotite	>3200	>3200	>3200	>3200
K 2	Muscovite	>3200	>3200	>3200	>3200
K 3	Muscovite	1350	1300	>3200 >3200	2262
K 3	Biotite	>3200	>3200	>3200	>3200
K 4	Biotite	>3200	>3200	>3200	>3200
K 5	Muscovite	1650	1400	1400	1483
K 5	Biotite	1900	2050	2300	2083
K 6	Muscovite	3000	2500	3000	2833
K 7	Biotite	1800	1850	>3200 >3200	2512
K 8	Biotite	2800	>3200	>3200	3067
N 1	Muscovite	>3200	3000	>3200	3133
N 2	Biotite	1450	1625	>3200 >3200	2369
N 3	Biotite	>3200	>3200	>3200	>3200
N 4	Biotite	>3200	>3200	>3200	>3200

<u>No.</u>	<u>Mineral</u>	<u>Analysis Results</u> <u>(p.p.m. Li)</u>			<u>Average</u>
N 5	Biotite	2700	3100	>3200	3000
N 6	Muscovite	1050	930	1550 670	1050
N 6	Biotite	1750	1775	1350	1625
N 7	Muscovite	1050	930	900	960
N 7	Biotite	>3200	>3200	>3200	>3200
N 8	Biotite	620	420		520

PREISSAC BATHOLITH

Biotite Granodiorite

D 559	Biotite	255	300	255	270
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Biotite-Muscovite Granite

D 363	Muscovite	1825	2100	2200	2042
D 363	Biotite	1400	1725	1475	1533
D 572	Muscovite	660	670	660	663
D 2	Muscovite	640	640	620	633

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