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DEPARTMENT OF ENERGY, MINES AND RESOURCES

STUDY OF PEGMATITE BODIES AND ENCLOSING ROCKS, YELLOWKNIFE–BEAULIEU REGION, DISTRICT OF MACKENZIE

R. Kretz

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PREFACE

Pegmatites are of considerable interest and economic importance as they may contain minerals rich in elements such as tantalum, niobium, lithium, beryllium, uranium, and the rare earths.

The Yellowknife–Beaulieu region, one of the principal mineral-producing areas of northern Canada, contains many pegmatite masses, some of which are of economic interest.

This report presents field and laboratory data concerning pegmatite masses and draws preliminary inferences regarding their mode of formation. These results form a basis from which more detailed studies can be made, thus leading to a greater understanding of the pegmatite-forming process which in turn will assist prospecting for minerals of rare but strategic value.

Y. O. FORTIER,
Director, Geological Survey of Canada

OTTAWA, March 30, 1965

BULLETIN 159 — Eine Untersuchung der Pegmatitkörper und der sie umschliessenden Gesteine in der Yellowknife-Beaulieu-Region des Mackenziedistrikts

Von Ralph Kretz

БЮЛЛЕТЕНЬ 159 — Исследование залежей пегматита и вмещающих пород, Йеллонайф—Болье область, территория Макензи.

Автор: Ральф Кретц

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STUDY OF PEGMATITE BODIES AND ENCLOSING ROCKS, YELLOWKNIFE–BEAULIEU REGION, DISTRICT OF MACKENZIE

Abstract

Pegmatite bodies are found in muscovite–biotite granite plutons, dated at 2550 m.y. and in biotite-, cordierite-, and garnet-bearing schists that form broad aureoles about the plutons. Most of the pegmatite bodies consist of quartz, albite, potash feldspar, and muscovite, and some contain notable amounts of beryllium, lithium, and niobium–tantalum minerals.

Most of the pegmatite dykes found in the Sparrow Lake granite pluton and in its contact aureole are several centimetres or a few metres thick and dip steeply in different directions. Data on the geometry of some of these dykes suggest that they are fracture-controlled dilation dykes. Tourmaline, beryl, and spodumene are found within the dykes at progressively greater distances from the granite pluton.

The distribution of minerals within individual dykes is normally irregular and the composition of minerals is variable. In one large dyke, albite crystals near the centre contain less sodium and more potassium than those near the margin, whereas crystals of muscovite near the centre contain more sodium and less potassium than those near the margin.

The granite and schist adjacent to some pegmatite dykes have been altered. In granite, muscovite, tourmaline, and apatite have crystallized at the expense of potash feldspar and biotite, and in schist, tourmaline, quartz, and apatite have crystallized at the expense of biotite and plagioclase. These mineral reactions were accompanied by an addition to the country rocks of boron and phosphorus, and a removal of potassium.

The pegmatite and the muscovite–biotite granite were evidently derived from a common source. The pegmatite-forming matter was relatively mobile and capable of transport for great distances through the country rocks. At numerous structurally favourable sites, the pegmatite minerals proceeded to crystallize, causing enlargement of the pegmatite bodies. The various chemical and physical processes that were involved are not clearly understood.

Résumé

Des massifs de pegmatite se retrouvent dans les plutons de granite à muscovite–biotite qui datent de 2,550 millions d'années, et dans des schistes à biotite, à cordiérite et à grenat, formant de larges auréoles autour des plutons. La plupart des massifs de pegmatite sont formés de quartz, d'albite, de feldspath potassique et de muscovite; quelques-uns contiennent des quantités assez considérables de béryllium, de lithium, et de minéraux de niobium–tantale.

La plupart des dykes de pegmatite que l'on trouve dans le pluton de granite de Sparrow Lake et dans son auréole de contact ont une épaisseur de plusieurs centi-

mètres à quelques mètres et un pendage accentué dans diverses directions. Les données sur la forme de quelques-uns de ces dykes portent à croire qu'il s'agit de dykes qui se sont dilatés dans le sens des fractures. Dans les dykes à des distances de plus en plus grandes du pluton de granite, on trouve de la tourmaline, du béryl et du spodumène.

La répartition des minéraux au sein des dykes est normalement irrégulière et leur composition peut varier. Dans un énorme dyke, les cristaux d'albite près du centre contiennent moins de sodium et plus de potassium que ceux situés près de la bordure, tandis que les cristaux de muscovite près du centre contiennent plus de sodium et moins de potassium que ceux près de la bordure.

Le granite et les schistes contigus à certains dykes à pegmatite se sont altérés. Dans le granite, la muscovite, la tourmaline et l'apatite se sont cristallisées aux dépens du feldspath potassique et de la biotite; dans les schistes, la tourmaline, l'apatite et le quartz se sont cristallisés aux dépens de la biotite et du plagioclase. Une addition de bore et de phosphore aux roches encaissantes et l'enlèvement du potassium ont accompagné ces réactions minérales.

Il est évident que la pegmatite et le granite à muscovite–biotite proviennent d'une source commune. Le matériau produisant la pegmatite était relativement mobile et capable d'émigrer sur des grandes distances à travers les roches encaissantes. Les minéraux pegmatitiques ont cristallisé à plusieurs endroits à structure favorable, occasionnant ainsi un grossissement des amas de pegmatite. On ne comprend pas très bien les divers procédés chimiques et physiques qui ont provoqué cette réaction.

Chapter I

INTRODUCTION

Background and Scope of the Present Study

The Yellowknife–Beaulieu region has played an important role in the development of northern Canada and requires little introduction. An understanding of the geology and mineral deposits of this region has evolved during the past 30 years, due largely to several field and laboratory investigations by the Geological Survey of Canada.

The pegmatite masses in the Yellowknife–Beaulieu terrain were first reported by Jolliffe (1936), who later estimated that those containing tantalum, niobium, lithium, beryllium, and tin minerals are common within 1,000 square miles of this terrain (1944). Investigations of these pegmatite masses have concentrated on their distribution in relation to regional geology (Jolliffe, 1942, 1946; Fortier, 1947), on rare element minerals (Jolliffe, 1944), and on the internal and regional distribution of pegmatite minerals (Rowe, 1952, 1954; Hutchinson, 1955; and Mulligan, 1962). Certain geochemical data and discussions have recently appeared (Boyle, 1961). Despite these studies, much remained to be done when the present study was initiated in 1960.

The aim of the present work is to record field and laboratory-derived data concerning pegmatite bodies of the Yellowknife–Beaulieu terrain and to draw preliminary inferences regarding the pegmatite-forming process. Attention was focused on certain areas within the terrain that, because of their clear exposure or simplicity of geological setting, were likely to yield the maximum information. It is expected that these data may form a suitable foundation for more detailed studies, leading eventually to greater understanding of the pegmatite-forming process.

Methods Employed

General geological information collected in the field was plotted directly on transparent paper superimposed on enlarged aerial photographs. The scales used were about 6 inches to one mile (enlarged 2x) and 12 inches to one mile (enlarged 4x). Greater detail was obtained by using a plane-table or by taking offsets from an extended chain. Fine detail of pegmatite contacts and other features were recorded

MS. received December 1964.

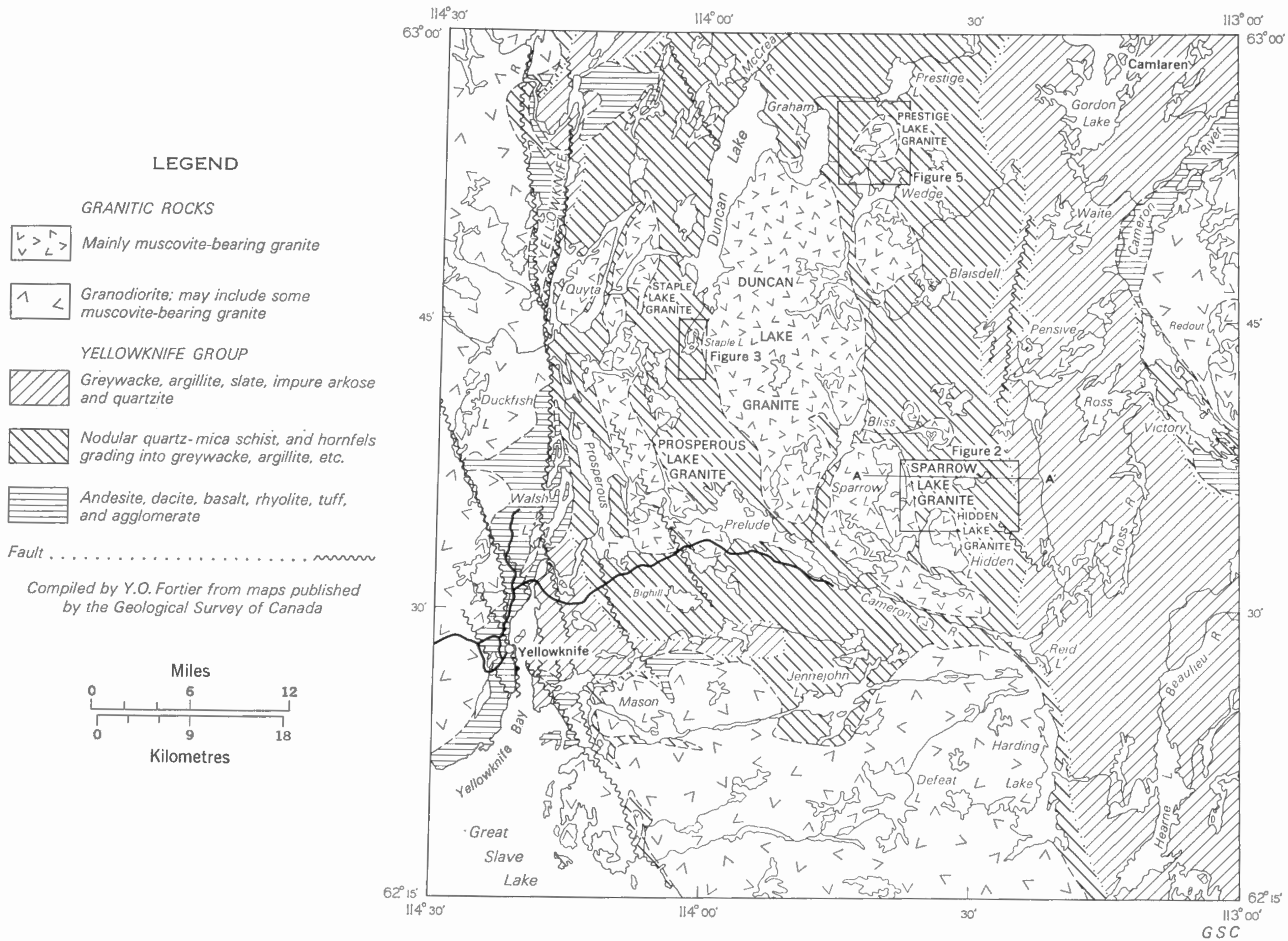


FIGURE 1. Part of Yellowknife–Beaulieu region showing distribution of principal rock units and location of Figures 2, 3, and 5.

photographically, or by tracing them directly onto transparent paper taped to the outcrop.

Most of the minerals encountered could be readily identified in the field; it was, however, difficult to distinguish between albite and potash feldspar. To overcome this difficulty the sodium cobaltinitrite test for potash feldspar was successfully applied directly to rock outcrops.

Numerous specimens were collected and these, as well as large- and standard-sized thin sections cut from them, were examined microscopically. These examinations revealed certain minerals that could not be recognized or identified in the field. The sodium cobaltinitrite test was also applied to many of these specimens. Some of the textures observed in thin sections were photomicrographed; others were projected onto a sheet of paper and traced in pencil. The figures produced by the latter method were refined by a detailed survey of the thin sections. In certain thin sections of schist, quartz could be distinguished from untwinned plagioclase if the sections were submerged for a few seconds in hydrofluoric acid.

A few minerals were identified or their identity was confirmed by use of the X-ray powder method.

Sodium, potassium, lithium, and beryllium analyses were carried out in the chemical laboratories of the Geological Survey of Canada. Other sodium and potassium analyses were performed by the writer in the geochemistry laboratory of Queensland University.

Acknowledgments

Officials of the Thompson-Lundmark Gold Mines kindly made their camp at Thompson Lake available to the writer. The study was completed at the University of Queensland, and the writer is indebted to Professor A. F. Wilson for courtesies extended. The assistance of my wife during one field season is acknowledged with appreciation.

Geological Setting

Regional geological investigations in the Yellowknife–Beaulieu region were carried out by Stockwell and Kidd (1932), Stockwell (1933), Jolliffe (1936, 1938, 1940, 1942, 1946), Henderson (1941, 1943), Henderson and Jolliffe (1941), Fortier (1947), Campbell (1947), and Henderson and Brown (1952). A summary of their work as well as a report on numerous features of general interest was prepared by Lord (1951). The principal rock units are listed in Table I, and their distribution is shown in Figure 1.

The oldest rocks, termed the Yellowknife Group, consist of a thick section of volcanic and predominantly detrital sedimentary rocks, variously metamorphosed (Jolliffe, 1942, 1946; Henderson and Jolliffe, 1941). The lower division of this group consists mainly of andesite and basalt, more generally referred to as greenstone.

Dykes and sills of similar composition are locally present, and small amounts of dacite, rhyolite, tuff, chert, breccia, and agglomerate are interlayered with the greenstones. The upper division of the Yellowknife Group consists of bedded greywacke, impure arkose and quartzite, slate, and argillite, and their metamorphosed equivalents. Conglomerate is locally present at the base of this division. Near granite plutons the sedimentary rocks have recrystallized to form various biotite, cordierite, staurolite, andalusite, and garnet-bearing hornfels and schist.

All rocks of the Yellowknife Group have been complexly folded. According to Henderson (1943) and Fortier (1946), folding occurred in at least two stages: the first was characterized by the formation of isoclinal folds and the second by the wrapping of these folds about near-vertical fold axes.

Several granitic plutons, partly concordant and partly discordant, underlie the Yellowknife–Beaulieu region (Henderson and Jolliffe, 1941; Jolliffe, 1942, 1946).

TABLE I *Principal Rock Units of the Yellowknife–Beaulieu Region*

Rock Units	Rock	Age (m.y.)	Reference
Diabase sills and dykes	dyke, N30°E, Yellowknife Bay area	1570	Burwash, *et al.*, 1963
	dyke, N30°E, Yellowknife Bay area	2230	Burwash, *et al.*, 1963
	dyke, E-W, Gordon Lake area	2250	Burwash, *et al.*, 1963
	dyke, N70°E, Prosperous Lake area	2310	Burwash, *et al.*, 1963
Granitic rocks			
	Moose Claim, Hearne Channel	2160±140	Shillibeer and Russell, 1954
pegmatite	Peg Tantalum Claim, Ross Lake	2495±125	Lowdon, *et al.*, 1963
	Prosperous L. granite	2330	Folinsbee, *et al.*, 1956
granite	Prosperous L. granite	2540±125	Lowdon, 1961
	Redout Lake granite	2555±125	Lowdon, *et al.*, 1963
granodiorite	Granodiorite at Mason Lake	2615±125	Lowdon, *et al.*, 1963
Yellowknife Group greywacke, arkose, impure quartzite, slate, argillite, minor conglomerate, and metamorphosed equivalents	cordierite-biotite gneiss, Germaine Lake	2365±125	Lowdon, *et al.*, 1963
andesite, basalt, dacite, rhyolite, minor pyroclastic rocks, and metamorphosed equivalents			

Various types of granitic rocks are present, ranging from hornblende-bearing granodiorite to muscovite-bearing granite. Two periods of granite emplacement were postulated by Henderson (1943), Jolliffe (1944), and Fortier (1946), an interpretation that is not confirmed by isotopic age determinations (Table I).

Undeformed diabase dykes and sills form the youngest rocks of the region, and at least two periods of emplacement are evident (Table I).

The present study is restricted to areas underlain by only four rock units, namely the Yellowknife Group sedimentary and metasedimentary rocks, certain muscovite–biotite granite plutons and dykes, pegmatite, and post-pegmatite diabase dykes.

Chapter II

THE COUNTRY ROCKS

Pegmatite bodies of the Yellowknife–Beaulieu region are embedded in granitic rocks and in metasedimentary rocks of the Yellowknife Group, but only in rocks of relatively high metamorphic grade (Jolliffe, 1944; Fortier, 1947). A study of the regional distribution of pegmatite masses west of Redout Lake led Hutchinson (1955) to conclude that the pegmatite was derived from the Redout Lake granite pluton. Boyle (1961), however, concluded that at least some of the pegmatite of the region was derived from the metasedimentary rocks, presumably by a process of selective diffusion. These and other conflicting interpretations of the source of pegmatite-forming matter have urged the writer to examine the country rocks of the Yellowknife–Beaulieu terrain in the hope that new information would appear regarding the origin of the enclosed pegmatite masses.

Metasedimentary Rocks

The metasedimentary rocks display diverse mineral assemblages resulting from variations in rock composition and metamorphic grade. Although these rocks have been divided into two mappable units, as shown in Figure 1, a continuous gradation is found from little-altered greywacke, argillite, and minor other rock types to cordierite, andalusite and garnet bearing schist and hornfels, the last rocks forming aureoles about granite plutons. Rocks that were mapped as greywacke, argillite, etc. (Fig. 1) are referred to as rocks of low metamorphic grade, and those mapped as nodular quartz-mica schist and hornfels (unit 2, Fig. 1) as rocks of medium metamorphic grade.

Metasedimentary Rocks of Low Metamorphic Grade

The metasedimentary rocks of low metamorphic grade consist of interbedded greywacke, argillite, rocks intermediate between greywacke and argillite, and rarely arkose and quartzite. The beds range in thickness from minute to 10 feet, with an average of about 2 feet (Henderson, 1943).

The least altered rocks are well exposed at Gordon Lake (upper right-hand corner of Fig. 1), where Henderson (1941, 1943) reported the presence of greywacke composed of quartz and albite grains in a matrix of chlorite, white mica, feldspar, carbonate, and pyrite, and argillite composed of abundant chlorite and white mica.

The least altered rocks grade into more widespread biotite bearing rocks, composed of quartz, plagioclase, biotite, muscovite, and chlorite, with local and minor potash feldspar, graphite, apatite, ilmenite, pyrite, and pyrrhotite. Narrow lenses of an amphibole bearing rock are locally present.

Biotite-containing rocks of low metamorphic grade were examined by the writer east of Sparrow Lake (east-central part of Fig. 1), where greywacke retains much of its initial character while the more micaceous beds may now be referred to

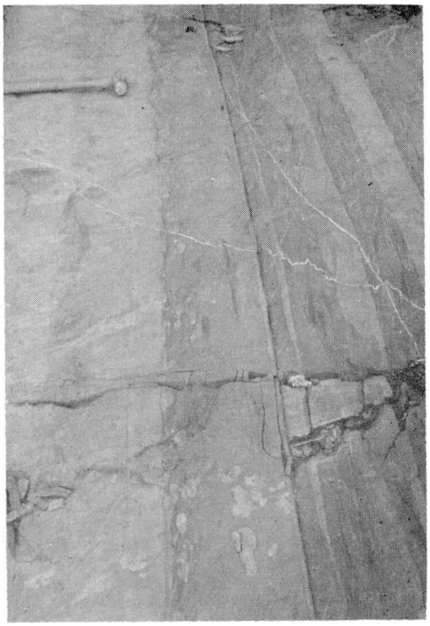
TABLE II *Mineral Assemblages of Metasedimentary Rocks of Medium and Low Metamorphic Grade, Sparrow Lake – Thompson Lake Area*

Reference No.	1	2	3	4	5	6	7	8	9	10	11	12	13
Specimen No.	120–61–5	137–60	372–61–11	139–60	339–61–2	142–60–1	447–61	235–60–1	235–60–2	461–61–2	462–61–2	463–61–2	463–61–3
Horizontal distance to granite in miles	0.025	0.066	0.14	0.22	0.28	0.66	1.9	3.1	3.1	4.4	5.0	5.7	5.7
quartz	+	+	+	+	+	+	+	+	+	+	+	+	+
plagioclase	+	+	+	+	−	+	−	+	+	+	+	+	+
biotite	+	+	+	+	−	+	−	+	+	+	+	+	+
cordierite	+	−	−	+	+	+	+	−	+	+	−	−	−
garnet	−	+	−	−	−	−	−	−	−	−	−	−	−
actinolite	+	−	+	−	−	−	−	−	−	−	−	−	−
cummingtonite	−	−	−	−	+	−	+	−	−	−	−	−	−
muscovite	−	−	−	−	−	−	−	+	+	−	+	+	+
chlorite	−	+*	+*	−	−	−	−	+*	+*	+*	+	+	+
tourmaline	−	+	+	+	−	+	−	+	+	+	−	+	+
apatite	−	+	+	+	−	+	−	+	−	+	−	+	+
ilmenite	+	+	+	+	−	−	+	−	+	+	+	+	+
magnetite	−	−	−	−	−	+	−	−	−	−	−	−	−
pyrrhotite	−	−	−	−	+	+	+	+	+	−	−	−	−
pyrite	−	−	−	−	−	−	−	−	−	−	−	−	−
Metamorphic grade					Medium							Low	

1. Narrow (5 cm) actinolite containing layer in common schist (site 120, Fig. 2).
2. Fine-grained garnet–biotite schist (site 137, Fig. 2).
3. Fine-grained biotite schist, containing about 2 per cent actinolite (site 372, Fig. 2).
4. Common nodular (cordierite) schist (site 139, Fig. 2).
5. Narrow (1½–2 cm) cummingtonite containing layer in common schist (site 139, Fig. 2).
6. Common nodular (cordierite) schist (site 142, Fig. 2).
7. Narrow cummingtonite containing layer, broken to form lath-shaped boudins enclosed by common schist (site 447, Fig. 2).
8. Common fine-grained biotite schist (site 235, Thompson–Lundmark mine, Fig. 2).
9. Common nodular (cordierite) schist (site 235, Thompson–Lundmark mine, Fig. 2).
10. Very fine grained rock, containing metacrysts of cordierite (site 461, Fig. 2).
11. Very fine grained schist (2.2 miles east of Thompson–Lundmark mine).
12. Fine-grained metagreywacke (2.8 miles east of Thompson–Lundmark mine).
13. Phyllite, tiny metacrysts of biotite macroscopically visible (2.8 miles east of Thompson–Lundmark mine).

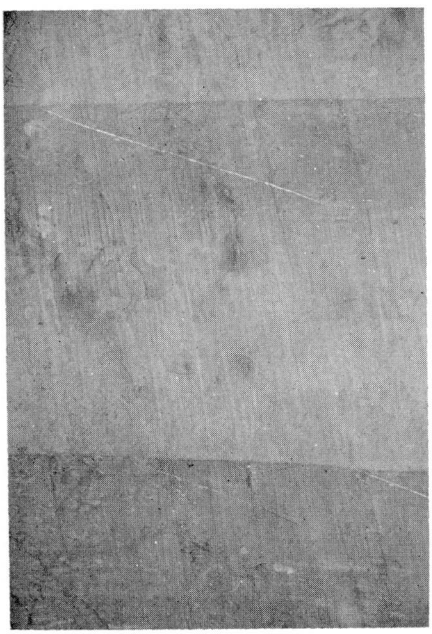
* product of retrograde crystallization
\+ mineral present
− mineral absent

as slate or phyllite. Three mineral assemblages from this terrain, which was previously examined by Fortier (1947), are listed in Table II, No. 11 to 13. Similar rocks are well exposed east of Yellowknife Bay (northeast of the town of Yellow-



Kretz, 16-5-60

PLATE I
Low-grade metasediments of the Yellowknife Group. Bed at centre of photograph is argillaceous greywacke, containing fragments of greywacke (light coloured) and lenses of argillite (dark coloured). Note presence of quartz veins (white). (East of Yellowknife Bay, lat. 62°29′N, long. 114°18′W.)



Kretz, 16-2-60

PLATE II
Glaciated surface showing graded bedding in low-grade metasediments of the Yellowknife Group. The bed shown is 50 cm (1.7 ft) thick and grades from relatively coarse-grained greywacke at bottom to argillite at top. Note position of quartz veins. (East of Yellowknife Bay, lat. 62°29′N, long. 114°18′W.)

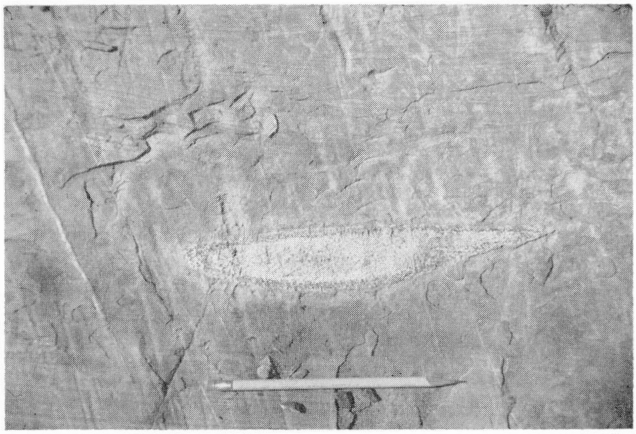


PLATE III
Amphibole-containing concretion in low-grade metasediments of the Yellowknife Group. Enclosing rock is metamorphosed argillaceous greywacke. (East of Yellowknife Bay, lat. 62°29′N, long. 114° 18′W.)

Kretz, 16-4-60

knife). The variation in bedding found in these rocks and the character of the contained quartz veins are illustrated in Plates I-III.

Henderson (1943) regarded the rocks of low metamorphic grade to have been affected by regional metamorphism only. Thus the least altered (biotite-free) rocks may be assigned to the lower half of the greenschist facies, and the biotite-containing rocks (which locally contain lenses of an amphibole-containing rock) may be assigned to the region that extends from the middle of the greenschist facies to the upper boundary of the epidote-amphibolite facies.

Metasedimentary Rocks of Medium Metamorphic Grade

The metasedimentary rocks of low metamorphic grade give way to rocks characterized by the presence of nodules, $\frac{1}{2}$ to 3 cm in diameter, composed of cordierite, less commonly andalusite, and rarely staurolite, or of aggregates of white mica and chlorite that are retrograde reaction products of these minerals. The boundary between rocks of low and medium metamorphic grade is referred to as the cordierite isograd. This boundary has been traced in considerable detail by Henderson and Jolliffe (1941), Jolliffe (1942, 1946), and Fortier (1947), and is shown in Figure 1. The nodular rocks extend to the margin of the granite plutons and form broad aureoles about them.

The most common rocks in this terrain are porphyroblastic (cordierite) schist or hornfels composed mainly of quartz, plagioclase, cordierite, and biotite, and even-grained schist or hornfels composed principally of quartz, plagioclase, and biotite (Henderson and Jolliffe, 1941; Jolliffe, 1942, 1946; Fortier, 1947). The porphyroblastic rock is a metamorphic equivalent of argillite and the even-grained rock of greywacke, as is clearly shown in some preserved graded beds. Lenses and layers, a few centimetres thick, composed principally of cummingtonite, quartz, and cordierite or plagioclase are locally present. Garnet may be present in the common metasedimentary rocks, especially in the northwestern part of the Yellowknife–Beaulieu terrain (Jolliffe, 1946). Other minerals found locally or in small amounts are muscovite, andalusite, sillimanite, staurolite, tourmaline, epidote, potash feldspar, zircon, apatite, magnetite, ilmenite, pyrite, pyrrhotite, carbonate, and chlorite.

Representative mineral assemblages from the Sparrow Lake – Thompson Lake area (Fig. 2, *in pocket*) and the Staple Lake area (Fig. 3, *in pocket*) are listed in Tables II and III respectively. Since all these rocks possess some foliation and lineation resulting from mineral grain orientation, the term schist is generally applicable.

TABLE III — *Mineral Assemblages of Metasedimentary Rocks of Medium Metamorphic Grade at Staple Lake*

Specimen No.	296–61–1	296–61–2	263–61	302–61	271–61–1	296–61–3
Collecting site (Fig. 3)	296	296	263	302	271	296
quartz	+	+	+	+	+	+
plagioclase	+	+	+	+	+	+
biotite	+	+	+	+	+	–
cordierite	–	+	+	+	–	–
garnet	+	–	–	+	–	–
cummingtonite	–	–	–	–	–	+
andalusite	–	–	–	–	+	–
muscovite	–	+	–	–	+	–
chlorite	+	–	–	+	+	–
tourmaline	–	+	+	+	–	–
zircon	–	–	+	–	+	–
apatite	+	+	–	+	–	+
ilmenite	+	–	+	+	–	+
pyrrhotite	–	+	+	+	–	–
pyrite	–	–	–	–	+	–

\+ mineral present
– mineral absent

The following observations were made on the mineral content, texture, fabric, and structure of the rocks of medium metamorphic grade:

1. Two types of biotite grains are locally found in a rock. Relicts of irregular grains that contain many inclusions (occur locally in rocks of low metamorphic grade) are intersected by newly formed more regular grains (Pl. IV).

2. Aside from chlorite that is obviously an alteration product of cordierite, grains of chlorite, where present, almost invariably intersect biotite grains and lie at large angles to these grains (Pl. IV). Chlorite is therefore interpreted to be a retrograde reaction product.

3. Muscovite rarely forms more than about one per cent of the rock by volume, and commonly intersects biotite grains (Pl. V). It is found in schist adjacent to pegmatite dykes. Muscovite is therefore considered to have crystallized later than biotite and other minerals and to have resulted from the introduction of potassium and other elements into the rock.

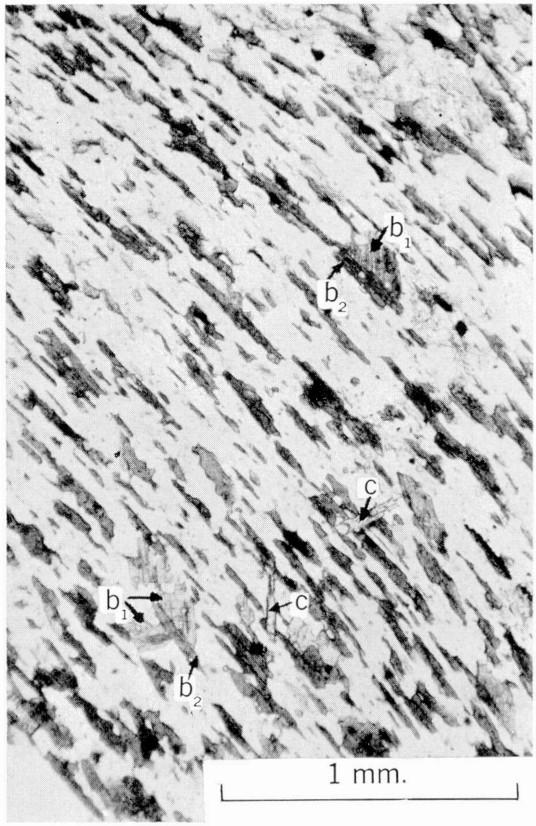


PLATE IV
Biotite schist of the Yellowknife Group showing relatively large biotite grains (b_1) intersected by biotite grains of parallel orientation (b_2), intersected by chlorite grains, products of retrograde metamorphism (c). (Site 235, Thompson Lundmark mine Fig. 2.)

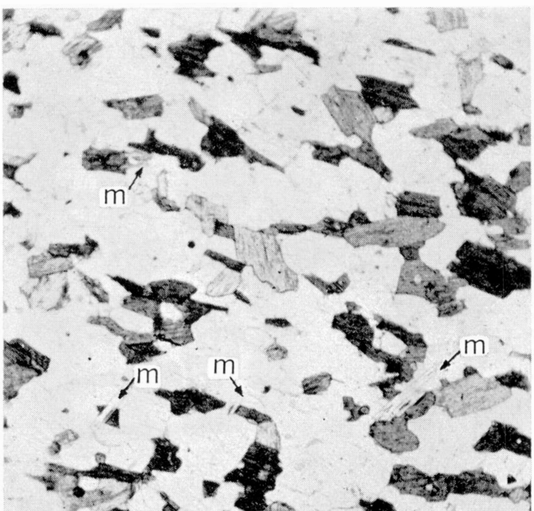


PLATE V
Metasedimentary rock of the Yellowknife Group containing minor muscovite (m) as grains 'cutting' biotite grains. Muscovite was presumably introduced into the rock. (Site 296, Fig. 3.)

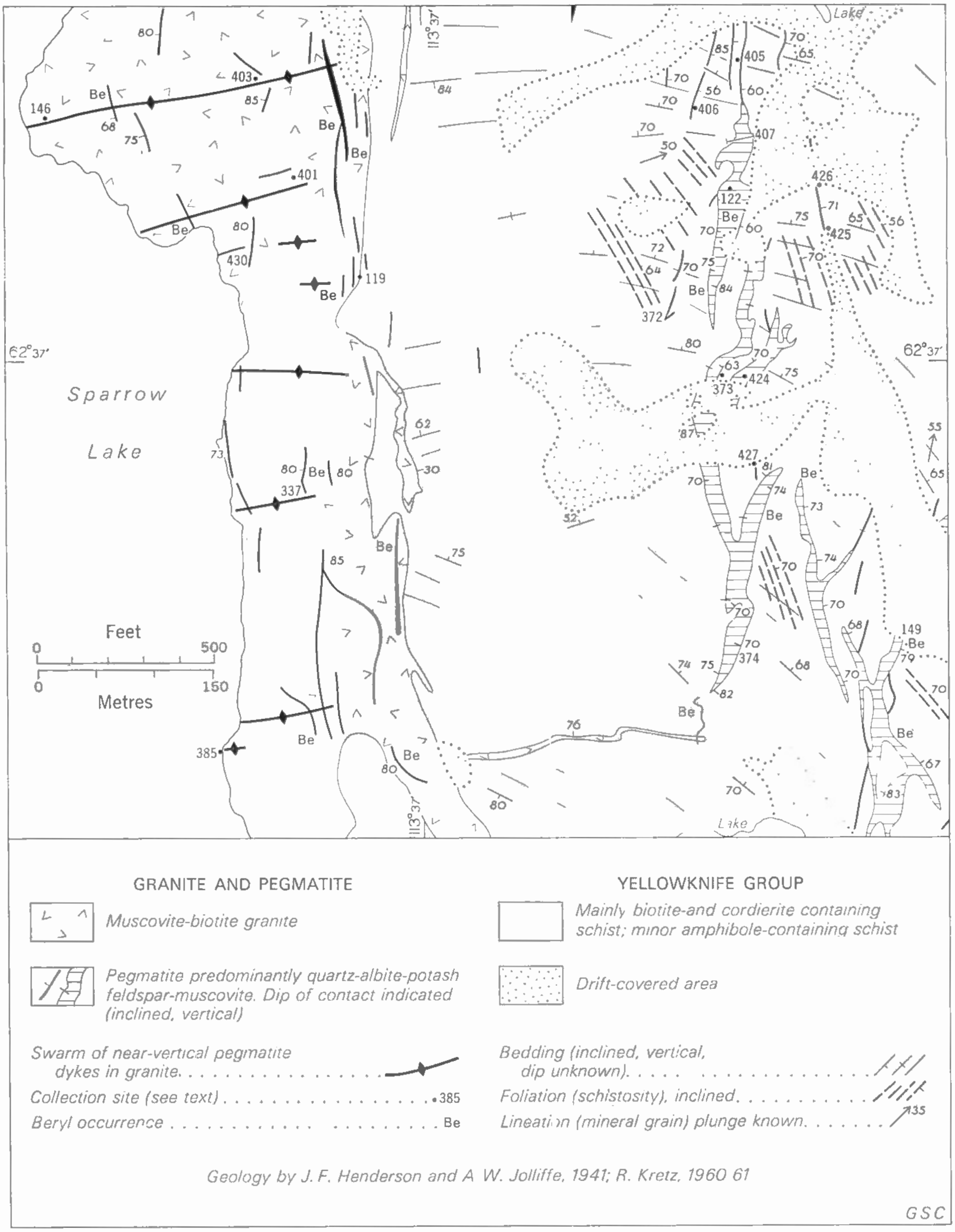


FIGURE 4. Geological and structural features of part of the Sparrow Lake – Thompson Lake area.

4. At a few places near granite plutons, metasedimentary schist was found to contain abundant muscovite, tourmaline, and apatite. These rocks are interpreted to be metasomatic rocks inasmuch as relatively large amounts of boron, potassium, and other elements were introduced into the rocks.
5. In general, the size of cordierite nodules and biotite grains increases as granite plutons are approached. Thus the largest dimension of biotite grains increases from 0.2 to 0.5 mm as the Sparrow Lake granite pluton is approached, and the diameter of cordierite nodules (composed of several cordierite grains) increases from 2 to about 20 mm.
6. A foliation, defined by parallel arrangement of biotite grains, and a lineation, defined by parallel arrangement of aggregates of biotite grains, prismatic amphibole crystals, and elongate cordierite nodules are commonly present. The foliation may or may not parallel bedding (Fig. 4).
7. Bedding may be well preserved (Pl. VI), or it may be obscure. Locally, bedding that is well preserved on the limbs of folds is obliterated in the axial regions.
8. The structure of rocks of medium as well as of low metamorphic grade is complex, and according to Fortier (1946) is the result of two episodes of

PLATE VI
Layered (bedded) schist adjacent to a pegmatite dyke; preferential development of tourmaline in biotite-rich (darker) layers. (Site 122, Fig. 4.)

Kratz, 7-5-63

folding. Beds may lie parallel with granite-schist contacts (Fig. 2) or they may terminate at these contacts (Fig. 4). The significance of foliation and lineation is not generally clear. The structural features of these rocks is considered more specifically in Chapter III.

The metasedimentary rocks of medium metamorphic grade are assigned to the hornblende hornfels facies of contact metamorphism. Evidently no representatives of the pyroxene hornfels facies occur in the Yellowknife–Beaulieu region.

Mineral-forming Reactions in the Metasedimentary Rocks

The most important mineral reaction that has taken place in the rocks of low metamorphic grade is the one that produced biotite. The required magnesium and iron were evidently obtained from chlorite, and potassium was obtained from white mica. Since a relatively small proportion of aluminum is required, the reaction has presumably left the chlorite somewhat enriched in aluminum, as follows:

$$\underset{\text{chlorite}}{9(Mg,Fe)_5Al_2Si_3O_{10}(OH)_8} + \underset{\text{white mica}}{3KAl_3Si_3O_{10}(OH)_2}$$
$$\rightarrow \underset{\text{biotite}}{3K(Mg,Fe)_3AlSi_3O_{10}(OH)_2} + \underset{\text{chlorite}}{4(Mg,Fe)_9Al_6Si_5O_{20}(OH)_{16}}$$
$$+ \underset{\text{quartz}}{7SiO_2} + 4H_2O$$

The next major change observed in the progressive metamorphism of the metasedimentary rocks was the appearance of cordierite and disappearance of chlorite. Since the Al/(Mg,Fe), ratio in cordierite is greater than that in chlorite, muscovite is considered to participate in the reaction, giving biotite as an additional reaction product. The reaction may be as follows:

$$\underset{\text{chlorite}}{4(Mg,Fe)_9Al_6Si_5O_{20}(OH)_{16}} + \underset{\text{muscovite}}{6KAl_3Si_3O_{10}(OH)_2} + \underset{\text{quartz}}{25SiO_2}$$
$$\rightarrow \underset{\text{cordierite}}{9(Mg,Fe)_2Al_4Si_5O_{18}} + \underset{\text{biotite}}{6K(Mg,Fe)_3AlSi_3O_{10}(OH)_2} + 32H_2O$$

These two reactions may acount for the two 'generations' of biotite observed in Plate IV.

The presence of garnet in rocks of medium metamorphic grade is considered to be the result of local peculiarities in bulk composition rather than peculiarities of temperature or pressure. Thus the equation

$$\underset{\text{garnet}}{4(Mg,Fe)_3Al_2Si_3O_{12}} + \underset{\text{muscovite}}{2KAl_3Si_3O_{10}(OH)_2} + \underset{\text{quartz}}{3SiO_2}$$
$$= \underset{\text{cordierite}}{3(Mg,Fe)_2Al_4Si_5O_{18}} + \underset{\text{biotite}}{2K(Mg,Fe)_3AlSi_3O_{10}(OH)_2}$$

informs us that the mineral assemblage garnet-quartz-cordierite-biotite may exist in bivariant equilibrium, provided muscovite is absent. As the right-hand side of the above equation (the high mole volume side) was more stable than the left in the Yellowknife–Beaulieu terrain, the pressure was low compared with that in the garnet-muscovite-quartz schists of regional metamorphic terrains.

The local crystallization of staurolite, andalusite, sillimanite, epidote, and cummingtonite is also attributed to local peculiarities of rock composition rather than to variations in temperature or metamorphic grade. As noted above, tourmaline and muscovite were locally produced by metasomatic reactions.

In brief, four classes of mineral-forming reactions were operative in the Yellowknife–Beaulieu terrain:

1. Regional metamorphic reactions, causing recrystallization of plagioclase, quartz, white mica, and chlorite, and neocrystallization of biotite and locally amphibole.
2. Contact metamorphic reactions, causing recrystallization of plagioclase and quartz, and neocrystallization of cordierite, biotite, and locally garnet, andalusite, sillimanite, staurolite, and cummingtonite.
3. Metasomatic reactions, causing neocrystallization of muscovite, tourmaline, and apatite.
4. Retrograde reactions, causing crystallization of chlorite from cordierite and other minerals.

Granitic Rocks

Several granitic plutons of various sizes and shapes in the Yellowknife–Beaulieu terrain (Fig. 1) were previously described by Henderson and Jolliffe (1941), Jolliffe (1942, 1946), Fortier (1947), and Boyle (1961). Although two granitic rock units are distinguishable (Fig. 1), only the muscovite-bearing granite, which bears closest relation to the pegmatite bodies, are considered here. Observations were made by the writer on the Staple Lake pluton and the adjacent western margin of the Duncan Lake pluton (Fig. 3), on the Prestige Lake pluton (Fig. 5), and on the northeastern part of the Sparrow Lake pluton and the adjacent Hidden Lake pluton (Fig. 2). Although each of these granitic masses has individual characteristics, certain features appear to be common to all. Some of the similarities and differences are outlined in the following description of two of the granite masses, namely, the Prestige Lake pluton and the Sparrow Lake pluton.

The Prestige Lake Granite Pluton

The Prestige Lake pluton, which was first outlined by Henderson and Jolliffe (1941) on a scale of 1 inch to 4 miles, was re-examined by the writer. This pluton is representative of the several relatively small granite masses of the Yellowknife–Beaulieu terrain. From surface exposure and almost vertical contacts with the enclosing metasedimentary rocks (Fig. 5), the pluton appears to possess the shape of a near-vertical cylinder, approximately $2\frac{1}{2}$ miles in diameter. The granite mass is surrounded by quartz-plagioclase-biotite-muscovite schist and a similar rock that contains, in addition, porphyroblasts of cordierite. Andalusite is locally present. At a few places near the granite contact, the schist was found to be enriched in muscovite or tourmaline.

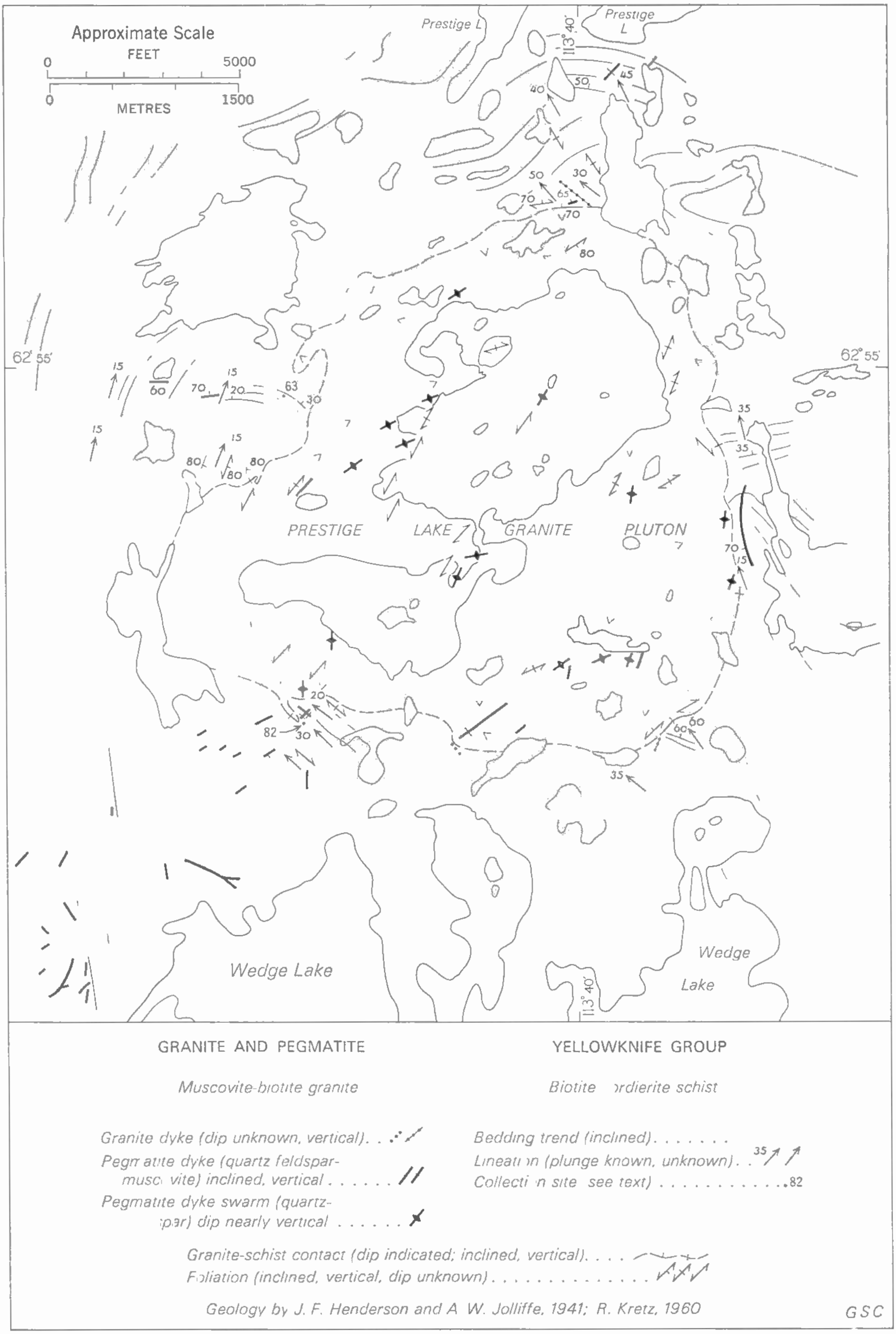


FIGURE 5. Geological and structural features of the Prestige Lake area.

Bedding is locally preserved in the schist and is marked by alternate layers of nodular (cordierite-containing) schist and even-grained biotite schist. The beds are now in irregular open and closed folds, the axes of which appear to plunge north. The beds generally terminate against the granite contact (*see* Fig. 5).

The enclosing schist possesses a distinct lineation marked by (1) a parallel arrangement of linear aggregates of biotite grains; (2) a parallel arrangement of elongate nodules of cordierite grains; and (3) fold axes and rodding structure in quartz veins that lie parallel with bedding planes. Considerable evidence exists to indicate that the lineations lie parallel with major fold axes.

The orientation of linear structures in relation to the granite pluton is of special interest. The northwesterly trend of the lineation, as found north and south of the pluton, appears to be deflected by the pluton and to wrap about it (Fig. 5). On this evidence it is postulated that the pluton was forceably emplaced, causing the schist to be pushed aside to make space for it. The pronounced development of a foliation in the schist at the contact, as observed locally, then agrees with the expectation that the contact zone was a zone of marked shear strain.

The granite is composed of an aggregate of quartz, plagioclase, potash feldspar, biotite, and muscovite grains in which relatively large (up to 2 cm) crystals of (Carlsbad) twinned potash feldspar are evenly distributed. The mineral distribution and appearance of the rock are remarkably uniform throughout the pluton. An obscure foliation is only locally detectable (Fig. 5), marked by a near-parallel arrangement of the relatively large prismatic potash feldspar crystals.

Several granite dykes or apophyses project from the granite pluton into the surrounding schist (Fig. 5) and the texture within these is more variable than that within the pluton. Some of the dykes have been broken to form boundinage structure. As the dykes become narrower at their extremities, the grain size decreases but the mineral composition does not appear to change greatly. Hence the dyke-like projections from the granite pluton are not composed of pegmatite, and no gradation from granite to pegmatite was found.

The Sparrow Lake Granite Pluton

The Sparrow Lake granite pluton has an exposed area of nearly 50 square miles (Fig. 1) and forms one of the intermediate-sized plutons of the Yellowknife–Beaulieu terrain. The pluton was first mapped by Henderson and Jolliffe (1941) on a scale of 1 inch to 4 miles and the southeastern part was examined by Fortier (1947). The position of the northeastern contact was mapped more precisely by the writer (Fig. 2). The pluton was named after Sparrow Lake, where the granite and its contact with the adjacent schist are remarkably well exposed.

The pluton is entirely surrounded by schist of the Yellowknife Group, and the granite-schist interface is locally nearly vertical. The possibility exists however that the pluton at depth joins the Hidden Lake pluton to the east and the Duncan Lake pluton to the west.

Mineral Content and Fabric

The northeastern part of the Sparrow Lake pluton is homogeneous to the extent that many specimens collected at one-half-mile intervals were indistinguishable from one another. The rock is composed of quartz, plagioclase, potash feldspar, biotite, muscovite, and apatite, with chlorite (intergrown with and replacing biotite) in variable amount. If no distinction is made between the two ferromagnesian micas, the relative proportion of the minerals does not vary greatly within the pluton, though there is locally a slight increase in the proportion of plagioclase at the expense of potash feldspar as the contact is approached (Table IV), and tourmaline may appear in granite near the contact. Also, within a few centimetres of the granite–schist contact, the rock is locally enriched in quartz and muscovite and depleted in potash feldspar (Table IV). Similar effects (described below) are found in granite near pegmatite dykes.

In contrast to the Prestige Lake granite, a foliation was detected at only one place, where it was found to parallel the granite-schist contact. According to Fortier (1947), a distinct foliation exists in the southeastern extremity of the Sparrow Lake pluton.

The rock contains plagioclase (approximately An_{10}) and potash feldspar as discrete grains. Both minerals occur as grains about 2 to 4 mm in diameter; potash feldspar also occurs as larger grains (6 to 10 mm) scattered throughout the rock. Some potash feldspar grains possess a fine perthitic texture, almost certainly the product of an exsolution reaction, and also irregularly shaped inclusions of plagioclase of less certain origin. Both feldspar minerals commonly enclose smaller grains of quartz, muscovite, biotite, and chlorite. Albite twins in plagioclase grains and 'cross-hatched' twins in potash feldspar grains are well developed. Grain boundaries involving feldspar grains are irregular. Quartz is found as grains 2 to 4 mm in diameter, which may or may not possess a mosaic structure as revealed by undulose

TABLE IV — *Mineral Proportions (volume per cent) in Specimens of the Sparrow Lake Granite and One Inclusion*

No.	Quartz	Plagioclase	Potash feldspar	Biotite[1]	Muscovite	Apatite
1	34	31	23	3.5	8.8	<½
2	34	36	18	4.3	7.5	<½
3	48	15	—	2.3	34	<½
4	37	35	7.0	1.0	20	<½
5	29	9.3	4.0	30	27	½

1. Granite, south shore of Sparrow Lake, 1.6 miles from east contact of pluton.
2. Granite, 850 feet from east contact, site 146, Fig. 4.
3. Granite, at east contact, site 120, Fig. 2.
4. Granite, from dyke in schist, site 421, Fig. 2.
5. Mica-rich inclusion in granite, site 363, Fig. 2.

[1] includes minor chlorite

extinction. Tabular grains of muscovite and biotite, 1 to 2 mm in greatest dimension, are found throughout the rock, commonly as aggregates of a few grains. Muscovite also occurs as fine-grained aggregates and as aligned inclusions in plagioclase. Apatite appears as small nearly equidimensional grains, up to one half millimetre in diameter.

Locally, near the margin of the pluton, the granite shows evidence of strain. Plagioclase and muscovite grains have been deformed, as revealed by bent albite twin planes and cleavage planes of muscovite. The mosaic structure of quartz may also be an expression of strain.

Nature of the Granite–Schist Contact

The northeastern contact of the Sparrow Lake granite pluton is consistent in trend but irregular in detail, and in general transects the bedding in the adjacent schist (Figs. 2 and 4). Although the contact is remarkably sharp, a number of parallel granite dykes are locally found in the schist near the contact, giving the impression of an interlayering of granite and schist.

Some aspects of the granite–schist interface are illustrated in Figure 6. The contact shown is between granite and a large block of schist that may or may not be attached to the wall of the pluton. Figures 6a and 6b show that the schist was deformed immediately at the contact, probably the result of the emplacement of the granite. These figures and Figure 6c show that the beds of schist have been 'cut off' at the contact. The irregularity of the contact as observed in Figure 6b is apparently the result of variation in degree of plasticity within graded beds. Figure 6c shows a mica-rich inclusion (described below) that was apparently pressed against the schist surface. Figure 6d represents the contact where it forms planar surfaces.

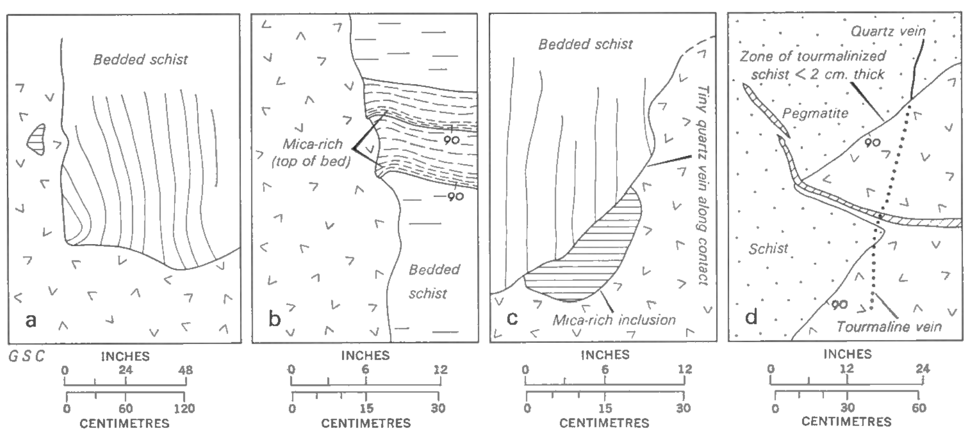


FIGURE 6. Features of the east contact of the Sparrow Lake granite pluton: a, note book sketch; b to d, tracings of photographs (site 167, Fig. 2).

Inclusions

Inclusions of schist ranging in dimension from one half foot to 500 feet are found locally as individuals or groups within 1,000 feet of the granite–schist contact. The largest of these have been mapped (Fig. 2). One exceptionally large inclusion,

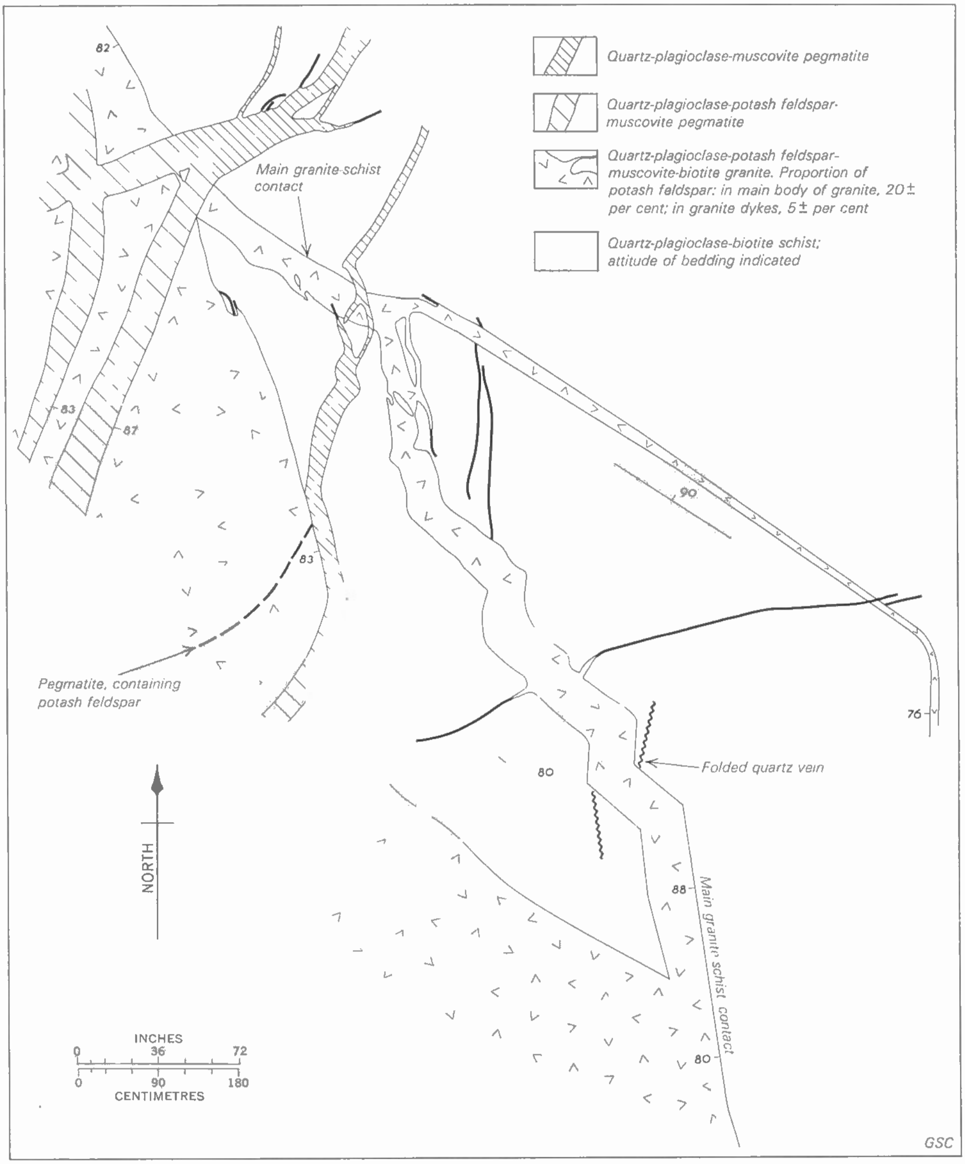


FIGURE 7. Eastern contact of the Sparrow Lake granite pluton (site 112, Fig. 2), showing projections of granite into the bordering schist and presence of pegmatite dykes intersecting the contact. Note change in mineral content of pegmatite dykes when traced from granite into schist.

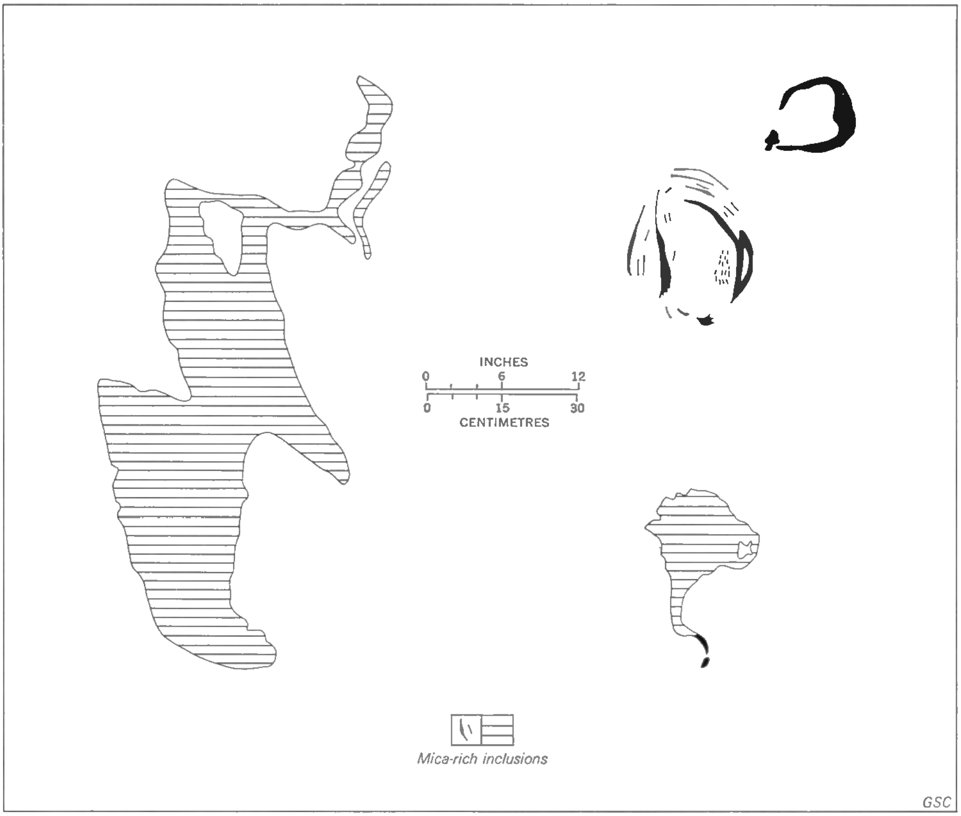


FIGURE 8. Mica-rich inclusions in the Sparrow Lake granite.

with an exposed surface area of nearly a quarter of a square mile, occurs south of Sparrow Lake and west of Hidden Lake (Fig. 2). None has been found in the central part of the pluton (west of Sparrow Lake), though small isolated inclusions may be present. The inclusions are angular blocks, practically indistinguishable from the rest of the schist. Some were evidently rotated relative to the wall-rocks, as shown in Figure 6a. Details of the granite–schist contact at one place near Sparrow Lake and a stage in the development of inclusions are given in Figure 7. Disregarding the pegmatite dykes (described below), it is evident that dyke-like projections of granite have invaded the schist, resulting in the 'isolation' of blocks of schist.

Mica-rich inclusions, distinctly separable from the schist inclusions, are found sparingly throughout the northeastern part of the Sparrow Lake pluton. Although variable in composition, the inclusions are characterized by an abundance of muscovite and biotite (Table IV). The mineral assemblage is, however, identical with that of the enclosing granite. The forms encountered are highly variable, as shown for example in the drawings of Figure 8. These inclusions have no obvious source outside the granite pluton, and their mineral content and abstruse form suggest that they may have developed by a process of mineral segregation.

Granite Dykes

Several granite dykes occur in the schist adjacent the granite pluton, and most of these lie within 1,000 feet of the contact (Fig. 2). Some are projections of granite into the adjacent schist (apophyses) as shown in Figures 2, 4, and 7, whereas others, which lie parallel with the contact, are not obviously connected to the granite.

The dykes contain more muscovite and less potash feldspar than granite within the pluton. The mineral distribution of some dykes is not uniform, but the mineral proportion listed in Table IV is perhaps representative. The texture of some dykes is also non-homogeneous to a marked degree. Grain size is finer and more variable than in the pluton. Muscovite tends to occur as aggregates of grains, forming shreds and schlieren that may bend about large (3-5 cm) crystals of feldspar or aggregates of quartz and feldspar. Quartz and tourmaline are locally abundant, occurring mainly as irregular veins in the dykes. Irregular pegmatite patches are locally present, as well as more regular pegmatite dykes. Some of the pegmatite dykes within granite dykes appear to be folded or to have developed an incipient boudinage structure. In general, the impression obtained is that the dykes have experienced a considerable strain.

Certain relatively homogeneous granite dykes are illustrated in Figure 7. Granite within these dykes is characterized by its low potash feldspar content, estimated to be 2 to 7 per cent by volume. The largest dyke illustrated is obviously a dilation dyke, whose walls became progressively more irregular and nonparallel with increasing distance from its source. The ability of granite to penetrate the schist is especially noteworthy; some of the narrow granite dykes are only 1 mm thick.

Tourmaline-containing Pods in Granite

Pods containing tourmaline were found rarely in the eastern margin of the Sparrow Lake pluton east of Sparrow Lake. One of these is circular, nearly 10 feet in diameter, and consists of three concentric zones.

The inner zone forms more than half of the pod and consists of tourmaline, 70 per cent; apatite, 1 per cent; albite, 25 per cent; and potash feldspar, 4 per cent. The intermediate zone is discontinuous, and is marked by a decrease in the proportion of tourmaline, to 10 per cent, an increase in the proportion of potash feldspar, to 40 per cent, and by the appearance of quartz (30 per cent) and a trace of muscovite. The outer zone is marked by a virtual disappearance of tourmaline, a decrease in apatite content (to ½ per cent), a further increase in the proportion of potash feldspar (to 50 per cent), and an increase in muscovite, to ½ per cent. Apart from tourmaline, which occurs as relatively large (6 mm) grains, the texture and grain size of the pods are similar to those of the enclosing granite. Boundaries between zones are gradational.

Mechanics of Emplacement of Granite Plutons

An examination of the Prestige Lake pluton has led to the conclusion that this mass was emplaced by a process that was accompanied by displacement of the pre-existing rock. The emplacement process has evidently broken beds of pre-existing metasedimentary rock and pushed them aside, accompanied no doubt by a considerable deformation of the surrounding rock. This has resulted in discordance with reference to bedding, but a rough concordance with reference to pre-existing lineation.

This model is assumed to be true for all the granite plutons examined. Depending on the structure of the country rock at the time of emplacement, beds may have been broken to produce discordant contacts, or pushed aside without notable breakage to produce concordant contacts. Thus the Staple Lake pluton (Fig. 3) is mainly concordant, the eastern contact of the Sparrow Lake pluton (Fig. 4) is mainly discordant, and the Hidden Lake pluton (Fig. 2) is mainly concordant. The model adopted is in agreement with conclusions of Henderson (1943) but in disagreement with those of Boyle (1961), who has reported evidence to suggest that the Prosperous Lake granite pluton (Fig. 1) formed largely by a process of replacement rather than displacement of the metasedimentary country rocks.

Two possibilities may be envisaged regarding the state of the granitic material during emplacement and the mechanics of flow: (1) liquid state (or liquid–solid mixture) and liquid flow, and (2) solid state and plastic flow. Although evidence may be cited in favour of either of these two hypotheses, it is not possible to be at all certain of the nature of the granite-forming matter during emplacement of the granite plutons.

Regional Distribution of Alkali Elements in Metasedimentary Rocks and Granite of the Sparrow Lake - Thompson Lake Terrain

As equations can be written to account for the observed variation in mineral assemblage of the metasedimentary rocks east of Sparrow Lake it seems that no gross variation in bulk composition of these rocks has taken place during their progressive metamorphism. These equations are not, however, a rigorous test of isochemical metamorphism, and the extent to which chemical elements have been added or subtracted from the rocks during recrystallization remains to be determined. Attention is now especially directed to the question of whether or not Na, K, and Li have been extracted from the pegmatite-enclosing schists, as an answer to this question would provide evidence regarding the source of the pegmatite-forming matter.

A preliminary investigation has been made of variation in the element content of the Sparrow Lake granite pluton and the metasedimentary rocks east of the pluton. Samples were collected at approximately one-half-mile intervals along an easterly trending line that begins near the centre-line of the Sparrow Lake pluton, passes across the metamorphic aureole, and terminates $10\frac{1}{2}$ miles to the east, in low-grade metasedimentary rock (line A-A^1, Fig. 1). Samples of granite consisted of single rock fragments, but each sample of the more heterogeneous metasedimentary rock consisted of five to ten rock fragments collected from an area 50 to 200 feet in diameter. Special care was taken to ensure that the collected material was representative, unweathered, and not found near pegmatite dykes. At the granite–

schist contact (site 120, Fig. 2), a sample of granite was collected 5 feet from the contact, thus avoiding a muscovite-rich zone immediately at the contact, and a sample of schist was collected from an area 10 to 60 feet from the contact. All samples collected were analyzed for Na, K, and Li. These data are listed in Table V, and presented in diagrammatic form in the profiles of Figure 9.

TABLE V | *Alkali Content of Granite and Schist of the Sparrow Lake – Thompson Lake Area, as a function of distance from the granite-schist interface*

Sample No.	Collecting site	Rcck	Na_2O		K_2O		Li_2O
332-61	332	granite	3.1		5.8		0.1
331-61	331	"	3.4		5.7		0.1
329-61	329	"	3.6		5.0		0.1
328-61	328	"	4.0		5.3		0.1
336-61	336	"	3.8		5.3		0.3
120-1-61	120	"	3.2		5.3		0.2
120-2-61	120	schist	2.3		2.9		0.2
343-61	343	"	3.9		2.0		0.2
345-61	345	"	4.4		1.9		0.2
453-61	453	"	4.0	4.0	2.0	2.0	0.2
452-61	452	"	3.9		2.2		0.1
445-61	445	"	3.1		2.2		0.1
444-61	444	"	3.2		2.9		0.1
456-61	456	"	3.9	3.4	2.0	2.4	0.1
457-61	457	"	3.4		2.5		0.1
458-61	458	"	3.5		2.7		0.1
461-61	461	"	3.3		2.4		0.1
462-61	462	"	2.6	3.0	2.7	2.5	0.1
463-61	463	"	2.5		2.4		0.1

W. U. Romeny, analyst

Sodium and Potassium

The Na and K profiles of Figure 9 clearly show that the granite increases in Na content and decreases in K content from centre to margin. These relationships are in agreement with the previously noted observation that sodic plagioclase increases and potash feldspar decreases in content towards the margin of the pluton.

The sample of schist nearest the granite–schist contact, when compared with the four collected samples at the next and three subsequent points eastward, is low in Na and high in K content. This is probably a reflection of the previously noted local development of muscovite in schist near granite, presumably a contact metasomatic effect. If muscovite developed at the expense of sodic plagioclase, an increase in K and decrease in Na content is to be expected. This sample is therefore disregarded in the analysis of the remaining data.

It will be noted (Fig. 9) that the trend of the Na and K profiles in the metasediments is towards a decrease in Na and an increase in K content with increasing distance from the granite pluton. This trend is more obvious if the samples are grouped into subzones A, B, and C as shown in Figure 9, and if the Na_2O and K_2O content of each subzone is averaged as shown in Table V and indicated by points a, b, and c in Figure 9.

It is not possible at present to determine whether or not the similar variations existed in the premetamorphic sedimentary terrain. Provided the variations are due to the rock metamorphism, it may be concluded that the rocks progressively nearer the granite contact and at progressively higher temperatures have experienced a proportionate addition of Na and removal of K. If the pegmatite-forming matter (notably Na and K relative to Mg and Fe) was derived from the schist, then the Na profile as well as the K profile should slope down towards the granite, i.e., in the direction of increasing pegmatite concentration. The data of Figure 9 are therefore not entirely in agreement with the postulate that all pegmatite-forming matter was derived from the enclosing rock.

Lithium

As the concentrations of Li in certain spodumene-containing pegmatite bodies of the Sparrow Lake – Thompson Lake terrain are several orders of magnitude

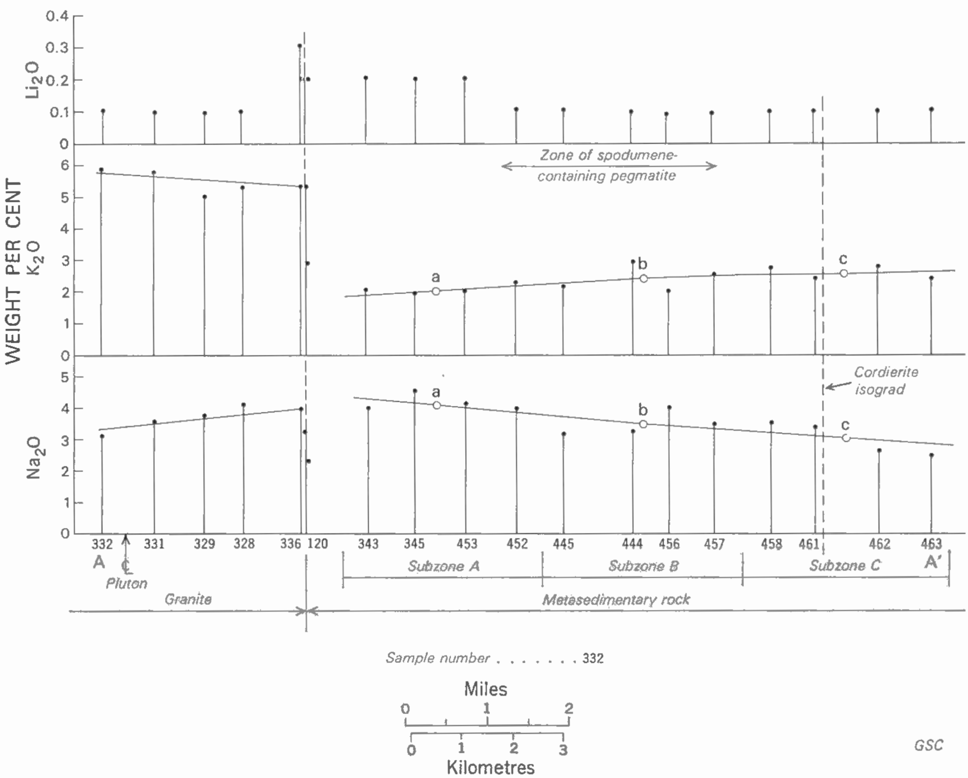


FIGURE 9. Sodium, potassium, and lithium profiles extending from the centre-line of the Sparrow Lake granite pluton to the low grade metasedimentary part of the Yellowknife Group (line A-A', Fig. 1). Data from Table V. Points a, b, and c represent average values for subzones A, B, and C.

greater than those in common metasedimentary rocks, the regional distribution of this element may provide important information regarding the source of the pegmatite-forming rare elements. Accordingly, the samples of granite and schist referred to above have been analyzed for Li. The data are listed in Table V and presented in graphic form in Figure 9.

The Li content of schist in the zone of spodumene-bearing pegmatite is not significantly more or less than that of the equivalent argillite and greywacke, beyond the metamorphic aureole (Fig. 9). Hence the source of the Li now present in the spodumene pegmatites cannot be attributed to the enclosing schist, nor was there a large-scale migration of this element from the pegmatite bodies to the enclosing rocks.

However, a relatively large concentration of Li was found in the inner zone of the metamorphic aureole and in the outer margin of the Sparrow Lake granite pluton (Fig. 9). This anomaly may possibly be attributed to an addition of Li to these rocks, presumably from a source that is closely linked to the source of the pegmatite bodies.

Conclusion

Preliminary chemical data do not support the hypothesis that the pegmatite-forming matter of the Sparrow Lake – Thompson Lake area was derived from the enclosing metasedimentary rock. They do, however, provide evidence for non-isochemical metamorphism, at least with reference to the alkali elements, provided the observed variations were not those of the original rocks. Rock metamorphism was evidently accompanied by a small magnitude increase in Na and decrease in K content on a regional scale. The Li content was evidently increased near the pluton by a factor of two.

Chapter III

SIZE, SHAPE, DISTRIBUTION, AND ORIENTATION OF PEGMATITE BODIES

A great variation exists in the size and shape of pegmatite bodies of the Yellowknife–Beaulieu terrain, but their distribution and orientation are obviously not random. The concentration of pegmatite bodies in rocks of medium metamorphic grade and their exclusion from rocks of low metamorphic grade was previously noted (Jolliffe, 1944; Fortier, 1947), and near-parallel arrangements of pegmatite dykes were found at Ross Lake (Hutchinson, 1955) and elsewhere. The following information concerning the size, shape, distribution, and orientation of pegmatite bodies was collected from the Prestige Lake area (Fig. 5), the Staple Lake area (Fig. 3), and the Sparrow Lake – Thompson Lake area (Fig. 2).

Prestige Lake Area

Two types of pegmatites were found in the rocks that underlie the Prestige Lake area:

1. Quartz-feldspar dykes that are confined to the granite pluton; that may contain tourmaline along the walls or within the dykes; that are uniformly thick (thickness ranges from ½ to 5 cm); that have diffuse contacts with the enclosing granitic rock; and that commonly occur as swarms of near-vertical, parallel dykes.
2. Quartz-feldspar-muscovite dykes that are found in both the granite and the adjacent schist; that may contain tourmaline; that tend to vary in thickness (thickness ranges from less than 2 cm to a few metres); and that commonly have sharp contacts with the enclosing rocks.

All dykes within the granite pluton tend to have a northeasterly strike and a near-vertical dip (Fig. 5). As this is also the orientation of an indistinct foliation within the granite, it may be supposed that the orientation of these dykes was governed by this foliation.

Immediately north and south of the pluton, pegmatite dykes in schist are similarly oriented (Fig. 5). This orientation cannot however be correlated with bedding or any other planar structure of the schist, and the factors governing the orientation of these dykes are unknown. Towards the southwest corner of the map-area, the dykes are not arranged in any regular pattern.

The small quartz-feldspar dykes confined to the granite may be genetically related to the granite. The larger, muscovite-bearing dykes, however, show no obvious relationship as regards orientation or distribution with the Prestige Lake granite. The frequency of these dykes appears to decrease uniformly in a north-easterly direction across the map-area despite the presence of the Prestige Lake granite pluton. It may also be recalled that the dyke-like projections from the pluton into the surrounding schist are invariably composed of granite rather than pegmatite. No evidence has thus been found to favour the hypothesis that the Prestige Lake granite pluton provided a source for the muscovite pegmatite dykes in the surrounding schist.

Staple Lake Area

The Staple Lake area (Fig. 3) displays a great abundance and variety of pegmatite bodies, as well as the small Staple Lake granite pluton and the western margin of the relatively large Duncan Lake pluton. The pegmatite units underlying this area are composed of quartz, feldspar, muscovite, and local garnet, biotite, and tourmaline. No rare element minerals were found. Information concerning the size, shape, and orientation of pegmatite bodies of the Staple Lake terrain can be best obtained by a close examination of Figure 3.

A strong tendency for pegmatite bodies to assume tabular form is immediately apparent. Many of these 'lens-out' along strike and are therefore visualized as isolated disks or lath-shaped bodies embedded in schist. Locally, and perhaps generally, beds wrap about these pegmatite bodies and are not replaced by them. Other tabular forms are joined to pods of pegmatite of apparent irregular shape. This feature is well illustrated at coordinates L-7 and O-1 (Fig. 3). Some of the bodies that are highly irregular in plan, such as those at L-7 and L-8, may be irregular, near-equidimensional isolated pods in schist. This possibility is supported at L-7 where the south contact of a pegmatite pod dips 20°N and the north contact is nearly vertical. However, at least one of these pods has near-vertical contacts on all sides (B-5, Fig. 3) and may be roughly cylindrical. The remarkable exposure of some of the pegmatite pods south of Staple Lake is shown in Plate VII.

Some deformation has evidently affected the schist subsequent to the emplacement of the pegmatite units. This is shown by the presence of folded and disjointed dykes yielding boudinage structures (Figs. 10a and b). The local distribution of these structures makes it highly unlikely that all or even most of the irregular forms shown in Figure 3 were moulded during a post-depositional deformation.

The size of the pegmatite bodies has a wide range. The upper limit is shown in Figure 3 but even larger bodies exist beyond the borders of the area covered. Many are too small to be shown in Figure 3 (*see* Fig. 10).

Numerous pegmatite bodies are also present throughout the Staple Lake pluton and in the western margin of the Duncan Lake pluton, including the adjacent granite dykes. These bodies, which have not been outlined in Figure 3, are similar in size and shape to those in the surrounding schist. At places marked 'A' (Fig. 3), pegmatite is relatively abundant.

PLATE VII
Aerial view of pegmatite pods in schist south of Staple Lake. Distance represented across photograph is about 4,600 feet. (R.C.A.F. photo.)

The orientation of pegmatite bodies in relation to the bedding of the enclosing schist and the position of the granite-schist contacts is of special interest. There is a marked tendency for tabular bodies, less than 1 foot to a few feet thick, to lie parallel with the bedding, regardless of a noticeable variation in strike of the bedding. Immediately north of the Staple Lake pluton, these bodies are absent, presumably because bedding is also absent or obscure. The bedding or the foliation (which lies parallel with the bedding planes) has obviously acted as a control in the formation of these pegmatite masses.

As for those pegmatite sheets that cross the bedding, the strike directions are not everywhere uniform. Locally, however, certain trends may be detected. This is most pronounced in the region west and northwest of the Staple Lake pluton where, in addition to the northerly striking pegmatite sheets that parallel the bedding, a distinct northwesterly trending set is present. As no northwesterly striking planar structures were observed in the schist, it is possible that these dykes were controlled by pre-existing joints.

The structures that control the emplacement of pegmatite pods present a perplexing problem. The emplacement of these bodies did not disturb the trend of

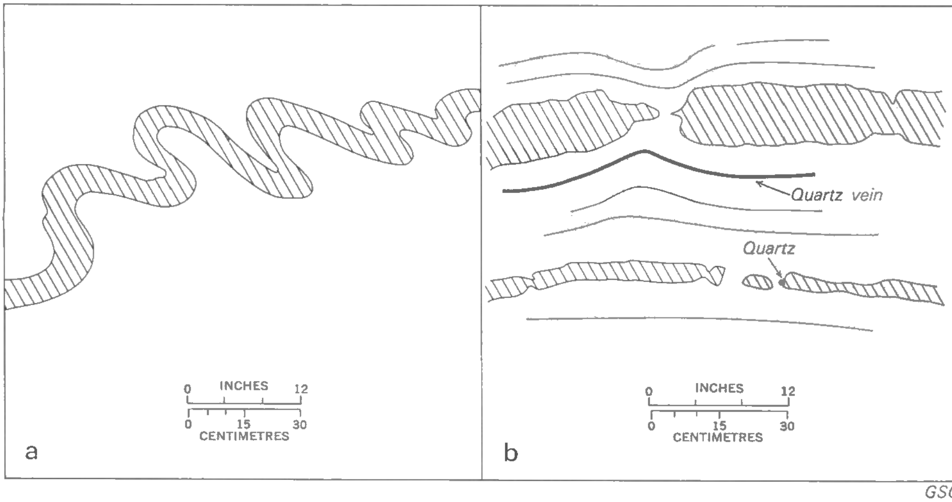


FIGURE 10. Deformed pegmatite dykes in schist, Staple Lake area. a, Section nearly perpendicular to fold axes, which parallel compositional lineation in schist. Fold overturned to west, away from Staple Lake pluton (site 297, Fig. 3). b, Disjointed pegmatite dykes forming boudinage structure. Dykes parallel to bedding and foliation (site 298, Fig. 3).

bedding or lineation in the country rock, as is clearly evident in the schist surrounding the pegmatite pod at B-7 (Fig. 3). In this respect the pegmatite pods differ from the Staple Lake granite pluton, which is mainly concordant with the bedding and lineation of the enclosing schist. It is reasonable to suggest that the 'openings' necessary for the emplacement of the pegmatite pods were formed by the opening of fractures (across the bedding) by a process of differential shear displacement along bedding planes.

No clear relationship between granite and pegmatite was determined in the Staple Lake terrain. Pegmatite bodies are evenly distributed throughout the terrain, with no apparent relationship between the size of pegmatite bodies and their distance from the Staple Lake or Duncan Lake plutons. The whole terrain, including the granite plutons, appears to have been favourable ground for the formation of pegmatite dykes and pods. Granite dykes on the other hand, are confined to a band within a few hundred feet of the granite contact.

Sparrow Lake – Thompson Lake Area

The distribution of pegmatite bodies within the Sparrow Lake granite pluton near part of its eastern margin and in the Yellowknife Group schist east of Sparrow Lake is shown in Figure 2. The pegmatite bodies in this terrain consist mainly of quartz, feldspar, and muscovite. Beryl, though not restricted to any part of the terrain, is most abundant in relatively large dykes near and to the west of the granite-schist contact at Sparrow Lake, and again in relatively large dykes near Thompson Lake, about 4 miles from the contact. Spodumene and columbite-tantalite are restricted to the region east of line S-S′. No pegmatite bodies were found east of the line C-C′, which marks the eastern limit of the cordierite-containing schist.

Pegmatite bodies, mainly tabular, are found in the northeastern part of the Sparrow Lake pluton and in the Hidden Lake pluton. The largest pegmatite bodies within granite were found immediately east of Sparrow Lake, where all dykes more than about a metre thick have been mapped (Fig. 2). The smallest dykes have a plan length of one metre and a thickness of 3 mm.

A slight increase was observed in the abundance of pegmatite dykes in the Sparrow Lake pluton from the central region to the eastern edge. Whereas dykes in the central region are apparently randomly oriented, some of the dykes in the eastern margin are in easterly trending, near vertical swarms. These dyke swarms are found at intervals along the margin (Fig. 2) and are composed of as many as twenty-seven individual dykes. Each dyke is mainly less than 15 cm thick and they may be arranged *en échelon*. These features are shown in Plate VIII and Figure 11. The eastern end of the dyke swarms is invariably within granite a few metres from the granite–schist contact. Dyke swarms of similar character and orientation were also observed in the northern margin of the pluton north of Sparrow Lake.

The orientation of seventy-eight dykes in the eastern margin of the Sparrow Lake pluton, including a few members of the easterly trending swarms, is shown in Figure 12. It is evident that although the strike of these dykes is highly variable, there is a distinct tendency for tabular sheets of pegmatite to dip west, i.e., away from the granite–schist interface. In the northern margin of the pluton, dykes of this kind appear to favour a southerly dip. Preliminary measurements of the orientation of joint sets in the Sparrow Lake granite did not reveal a coincidence of orientation between joints and dykes. The factors that determined the orientation of most of the dykes thus remain obscure. It is probable, nevertheless, in view of the regularity of the easterly trending swarms, that the position of these dykes was determined by pre-existing joint sets.

PLATE VIII
Typical easterly trending pegmatite dyke swarm in the eastern margin of the Sparrow Lake granite pluton, also a few northerly trending dykes of younger age.

Kretz, 5-2-63

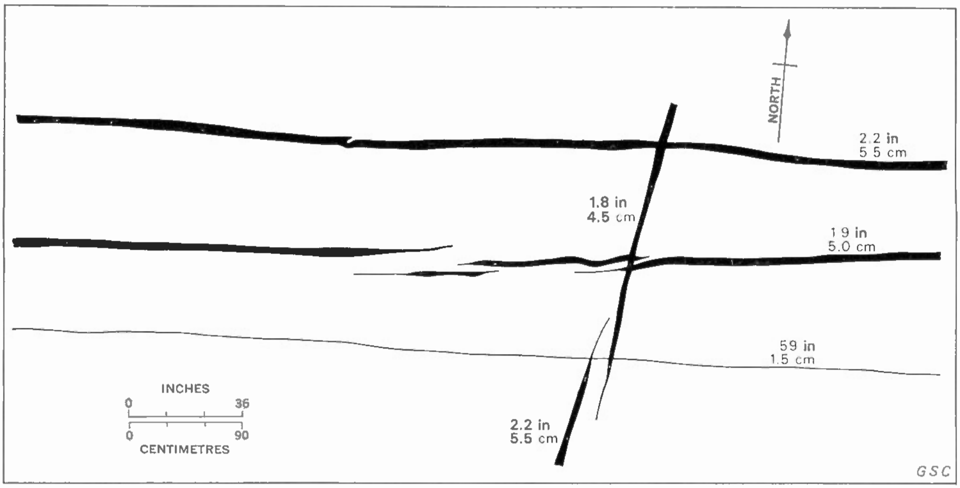


FIGURE 11. Swarm of near-vertical pegmatite dykes (thickness indicated) in eastern margin of the Sparrow Lake granite pluton (site 385, Fig. 4).

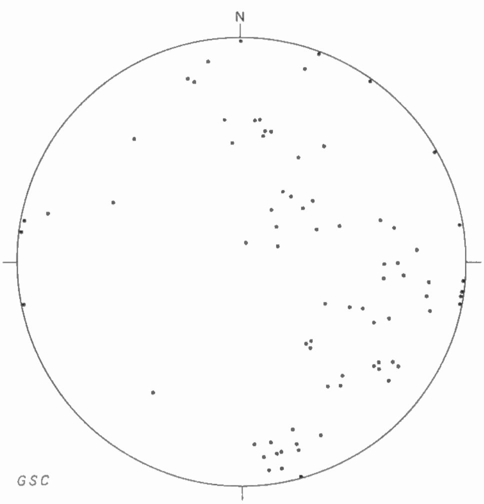


FIGURE 12
Stereographic projection of poles to 78 small pegmatite dykes in the eastern margin of the Sparrow Lake granite pluton.

Within the schist, east of the Sparrow Lake and Hidden Lake plutons, pegmatite bodies are predominantly tabular or lens-shaped. Nearly all with a thickness greater than about $\frac{1}{3}$ metre have been mapped (Fig. 2). The largest of these is about 1,000 metres long and about 40 metres thick (east of the Hidden Lake pluton, Fig. 2). The smallest pegmatite bodies in schist are narrow veins and dykes (Pl. IX), small *en échelon* veins near the termination of a dyke (Fig. 13; Pl. X), narrow filaments that join two dykes (Pl. IX), small apophyses (Pl. XI; Figs. 14 and 15) and apparently isolated pods (Pl. XII, Fig. 14) that are rarely adjacent to dykes. These data reveal

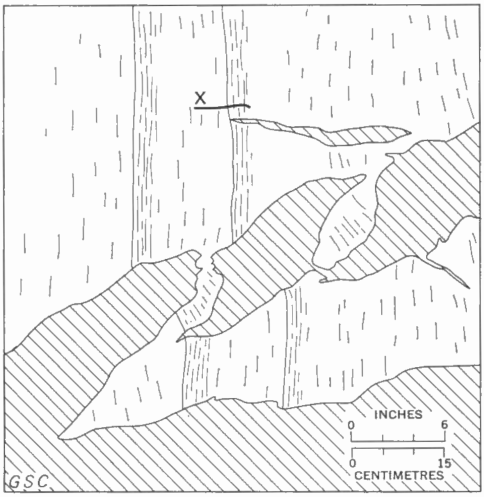


FIGURE 13
En échelon units and apparently isolated veins of pegmatite in the terminal region of a pegmatite dyke in bedded (tourmaline-containing) schist. Vein at X is 8 cm long and 3 mm thick (site 119, Fig. 4).

that the pegmatite-forming matter was capable of producing very small pegmatite bodies and of penetrating the schist.

Many of the pegmatite veins and dykes form branching structures, as shown in Figure 4. Dips are generally steep to moderate (Figs. 2 and 4), and may vary considerably on a single dyke (Figs. 4 and 14). The size of individual dykes and the frequency with which they occur in the schist terrain decrease in an easterly direction (Fig. 2), although there may be a zone immediately adjacent to the granite plutons that is devoid of pegmatite dykes (Figs. 2 and 4). Examination of Figure 2 will reveal a tendency for pegmatite dykes in schist to occur in clusters. This may indicate that the branching seen in plan (e.g., bottom right-hand corner of Fig. 4 and north of Hidden Lake pluton, Fig. 2) may also exist in vertical section, and that many of the individuals of a cluster are interconnected at depth. However, many of the dykes remote from any others, as observed in plan, are probably isolated units embedded in schist.

An examination of the orientation of pegmatite dykes and veins in the schist of the Sparrow Lake – Thompson Lake area did not reveal a relationship with the orientation of bedding. It is evident, however, that the dykes extending southeasterly from Thompson Lake are parallel with a fault (Fig. 2). The dykes and the fault, which post-dates the dykes (Fortier, 1947), may both have been controlled by pre-existing fractures. The location and orientation of certain small pegmatite veins and apophyses were evidently governed by pre-existing quartz veins (Fig. 15), or by an interface between an earlier pegmatite and schist. The latter feature is described in Chapter IV. Although the orientation of pegmatite veins and dykes is, in general, highly variable, locally certain trends are evident. This is illustrated in Figure 16, which presents a statistical treatment of the strike directions of pegmatite dykes and veins in four restricted areas. Furthermore, the trend within each group has been roughly indicated.

Kretz, 6-2-61

PLATE IX. Small pegmatite dykes in schist. Observe pegmatite filaments. (Site 406, Fig. 4.)

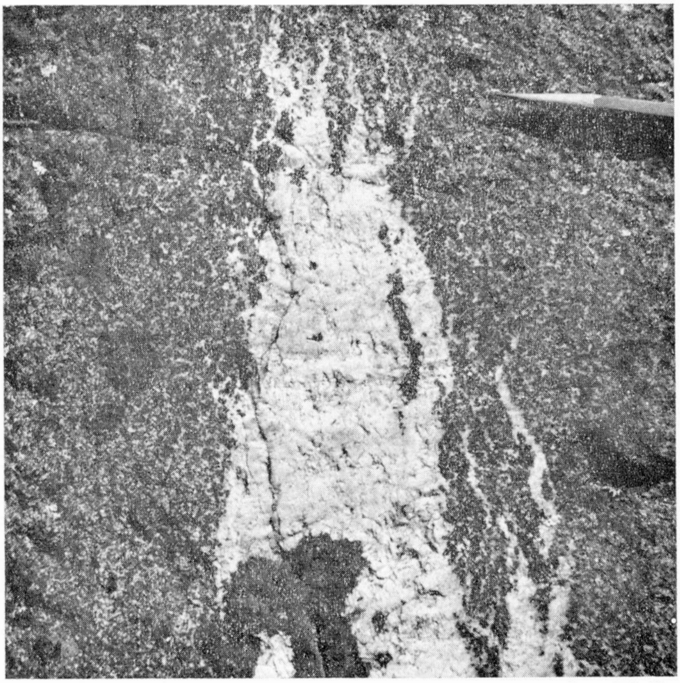


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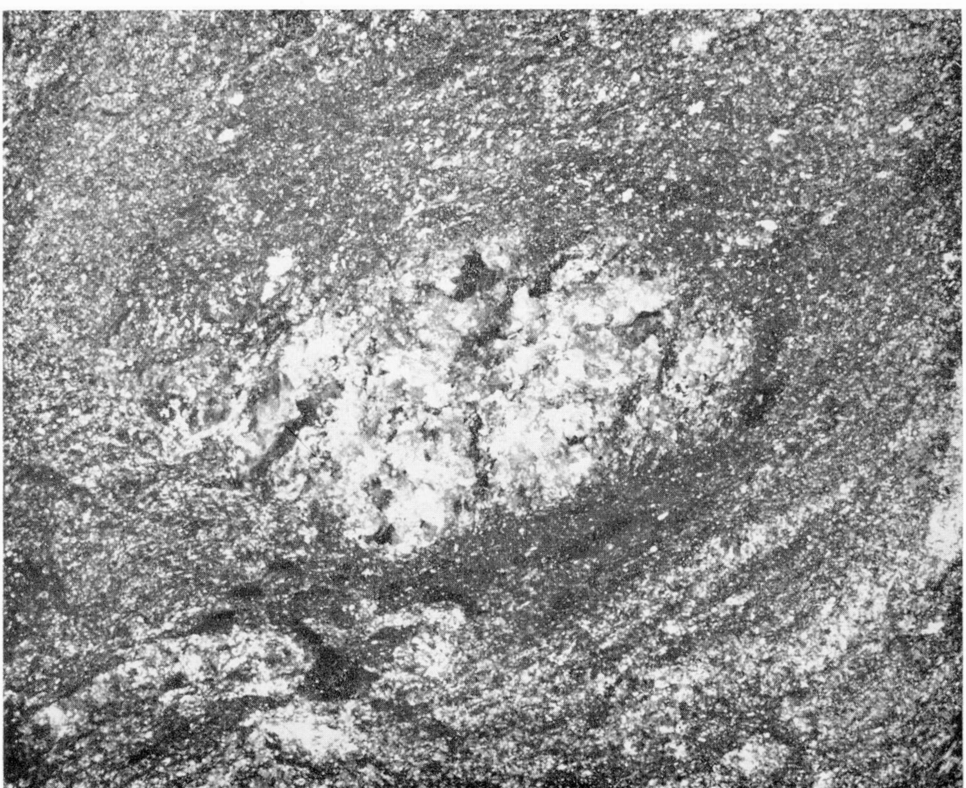
PLATE X
Termination of small pegmatite dyke, about 15 feet long. Observe filaments of pegmatite in schist. (Site 427, Fig. 4.)

PLATE XI
Projection of pegmatite into schist. Variation in feldspar content of the pegmatite is shown in Figure 36.

Kretz, 6-8-61

PLATE XII. Cross-section of a small pegmatite pod in schist. Greatest diameter is $2\frac{1}{2}$ cm. (Site 230, Fig. 2.)



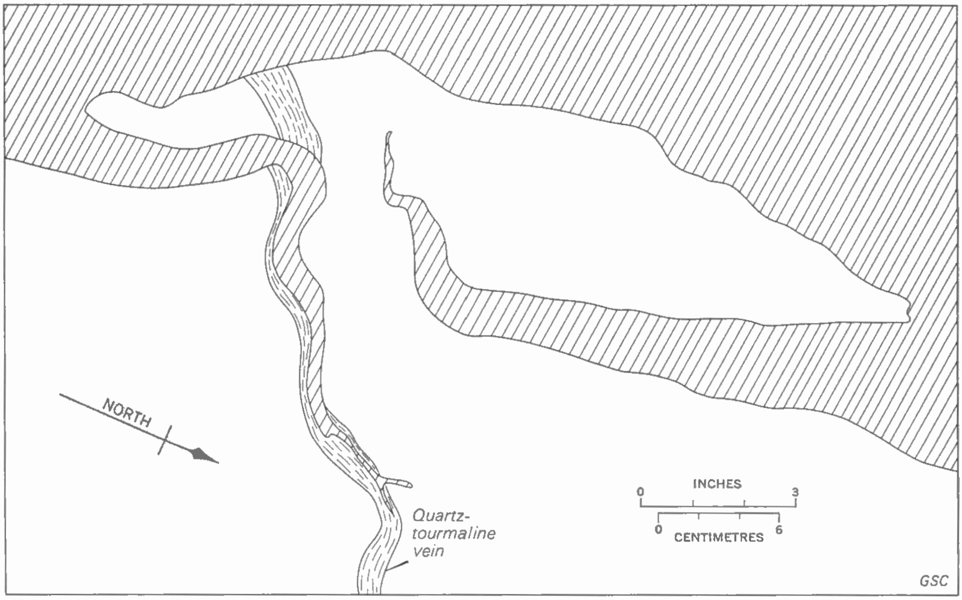


FIGURE 15. Projections of pegmatite into schist (site 406, Fig. 4).

An examination of Figure 16 will show that the trend line orientations have a definite relationship to the orientation of the nearest granite–schist interface. Thus the curvatures, in the pegmatite trend lines in areas 1, 2, and 3 are parallel, provided the areas are rotated to bring the adjacent granite–schist contacts into parallelism (Fig. 16, inset). Furthermore, the pegmatites roughly follow two sets of near-vertical intersecting planes that lie at moderate angles to the near-vertical granite–schist interface. In area 4, these angles are relatively small.

It is therefore postulated that the position of the pegmatite dykes and veins was controlled by shear fractures that resulted from emplacement of the granite plutons. It is supposed that the maximum compressive stress during granite emplacement was approximately normal to the granite–schist interface and that shear fractures developed at moderate angles to this interface.

Structural Control of Pegmatite Bodies

This problem has occupied numerous investigators of pegmatite dykes and veins, and several types of rock structure have been held responsible for the distribution and orientation of particular pegmatite masses.

A survey of the literature shows however that nearly all pegmatite masses described may be assigned to one of two categories:

1. Pegmatite masses that lie parallel with fractures in the country rock or are inferred to have developed along pre-existing fractures, either through a process of dilation or by replacement outward from the fracture. The fractures include shear and tension joints (including breaks resulting in

boudinage structures), shear zones, and faults. Pegmatite masses of this category have been described by Andersen (1931), McLaughlin (1940), Chapman (1941), Landes (1942), Cameron, *et al.* (1949), Boos (1954), Joklik (1955a, b), Ramberg (1956), Reitan (1959a), Roering (1961), and others.

2. Pegmatite masses that lie parallel with or are inferred to have developed along planar elements exclusive of fractures. These elements include bedding planes, foliation and schistosity, interfaces between contrasting rock units of major dimension (e.g., granite–schist contacts), or minor dimensions (e.g., borders of pre-existing dykes). Pegmatite masses of this

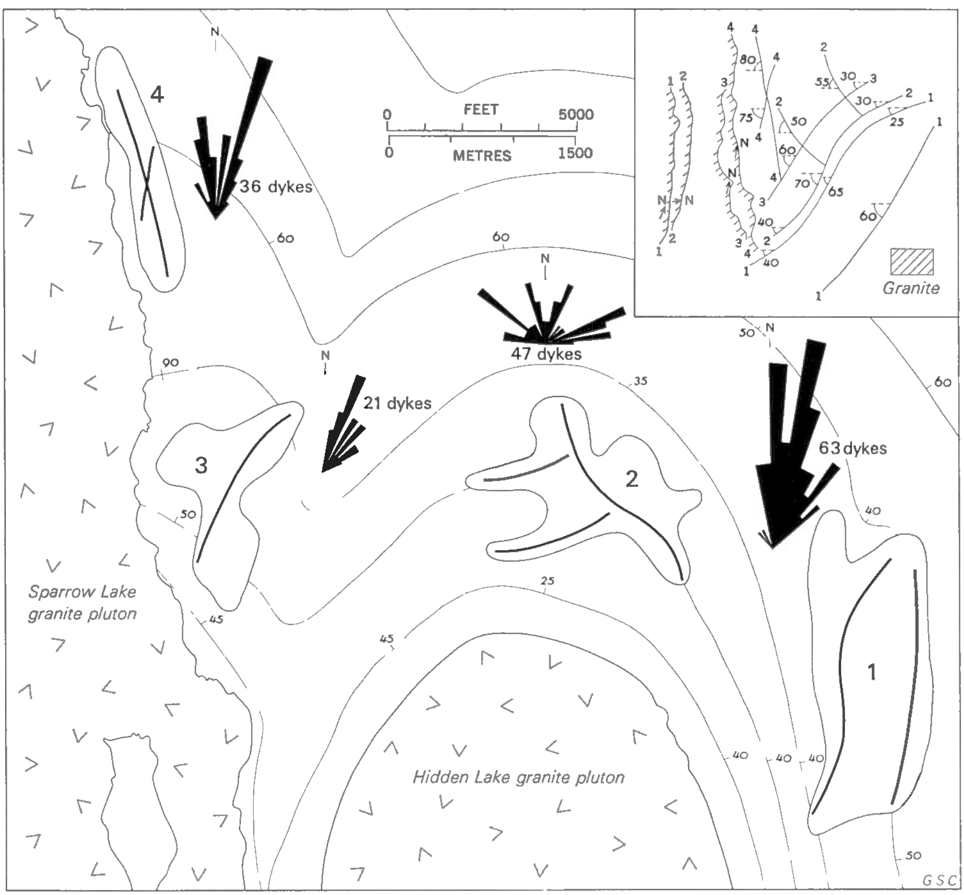


FIGURE 16. Part of the Sparrow Lake – Thompson Lake area showing: parts of the Sparrow Lake and Hidden Lake granite plutons; trend of bedding in the adjacent schist; position of four areas (numbered 1 to 4) that contain abundant pegmatite dykes; the dominant trend of pegmatite dykes, shown in heavy lines, within each of the four areas; statistical plot of the strike of pegmatite dykes in each of the four areas; position of pegmatite trend lines relative to the position of the nearest granite–schist interface for each area (inset).

category have been described by Gevers and Frommurze (1929), McLaughlin (1940), Cameron, *et al.* (1949), Boos (1954), Joklik (1955b), Ramberg (1956), Staatz and Trites (1955), and others.

With reference to the second group, in general it is difficult to prove that no fracture existed, not even an incipient fracture that might have imposed a control on the pegmatite vein during its initial stage of development. Locally, however, it is possible to demonstrate that a pegmatite vein followed a path that could not have been determined by a fracture. This is discussed in Chapter IV.

Pegmatite masses of the Yellowknife–Beaulieu terrain fall into both categories as shown by the following summary of data:

Pegmatite masses controlled by fractures:

- Southeast of Thompson Lake—dykes parallel with fault (Fig. 2), both dykes and fault possibly controlled by earlier fracture set.
- East margin of Sparrow Lake pluton—easterly trending dyke swarms (Fig. 2), possibly controlled by joint sets.
- Dykes in schist, Sparrow Lake – Thompson Lake area—orientation related to nearest granite–schist contact, and possibly controlled by shear fractures related to granite emplacement (Fig. 16).

Pegmatite masses controlled by planar elements (excluding fractures):

- Dykes in Prestige Lake pluton—lie parallel with indistinct foliation (Fig. 5).
- Near Staple Lake—dykes lie parallel with bedding and foliation (Fig. 3).
- East of Sparrow Lake—dyke follows contact of earlier quartz vein (Fig. 15) or earlier pegmatite dyke (described in Chapter IV).

Chapter IV

ROLE OF DILATION AND REPLACEMENT IN PEGMATITE EMPLACEMENT

It is now generally realized on evidence produced by numerous pegmatite studies that the emplacement of certain pegmatite bodies was accompanied by a displacement or dilation of the country rock whereas the emplacement of others was accompanied by a replacement of the country rock. The two processes must be somewhat different, and it is therefore important to determine which process was operative in the development of any pegmatite rock mass. It is also generally realized that some pegmatite mineral grains may form at the expense of pre-existing mineral grains of the same pegmatite mass, regardless of the initial process of pegmatite emplacement. Evidence for this kind of replacement is not considered at present.

A number of criteria designed to distinguish between dilation and replacement processes have been set out in Figure 17. These are now considered separately and applied to pegmatite masses of the Yellowknife–Beaulieu region, with special reference to the Sparrow Lake – Thompson Lake area.

Application of Dilation and Replacement Criteria

Criterion 1. Offset of pre-existent planar structures

If two blocks of rock forming the walls of a fracture are separated and the space thus formed is filled with pegmatite minerals, then any planar structure that initially crossed the fracture will be offset (Fig. 17a). If, on the other hand, a pegmatite mass developed by a replacement, the earlier planar structure will not be offset (Fig. 17b) (Goodspeed, 1940; King, 1948). It is possible but improbable that the offset shown in Figure 17a was caused by shear movement rather than by dilation, and that the dyke is actually a replacement dyke. It is also possible but improbable that the dyke shown in Figure 17b is a dilation dyke, in which the direction of separation of the walls was such that no noticeable offset was obtained. For these reasons the criteria offered by Figure 17a and b are not by themselves sufficient proof. However, those doubts may be eliminated if the pegmatite dyke under study intersects two nonparallel planar structures, as shown in Figure 17c and d. The criterion of offset may then be rigorously applied.

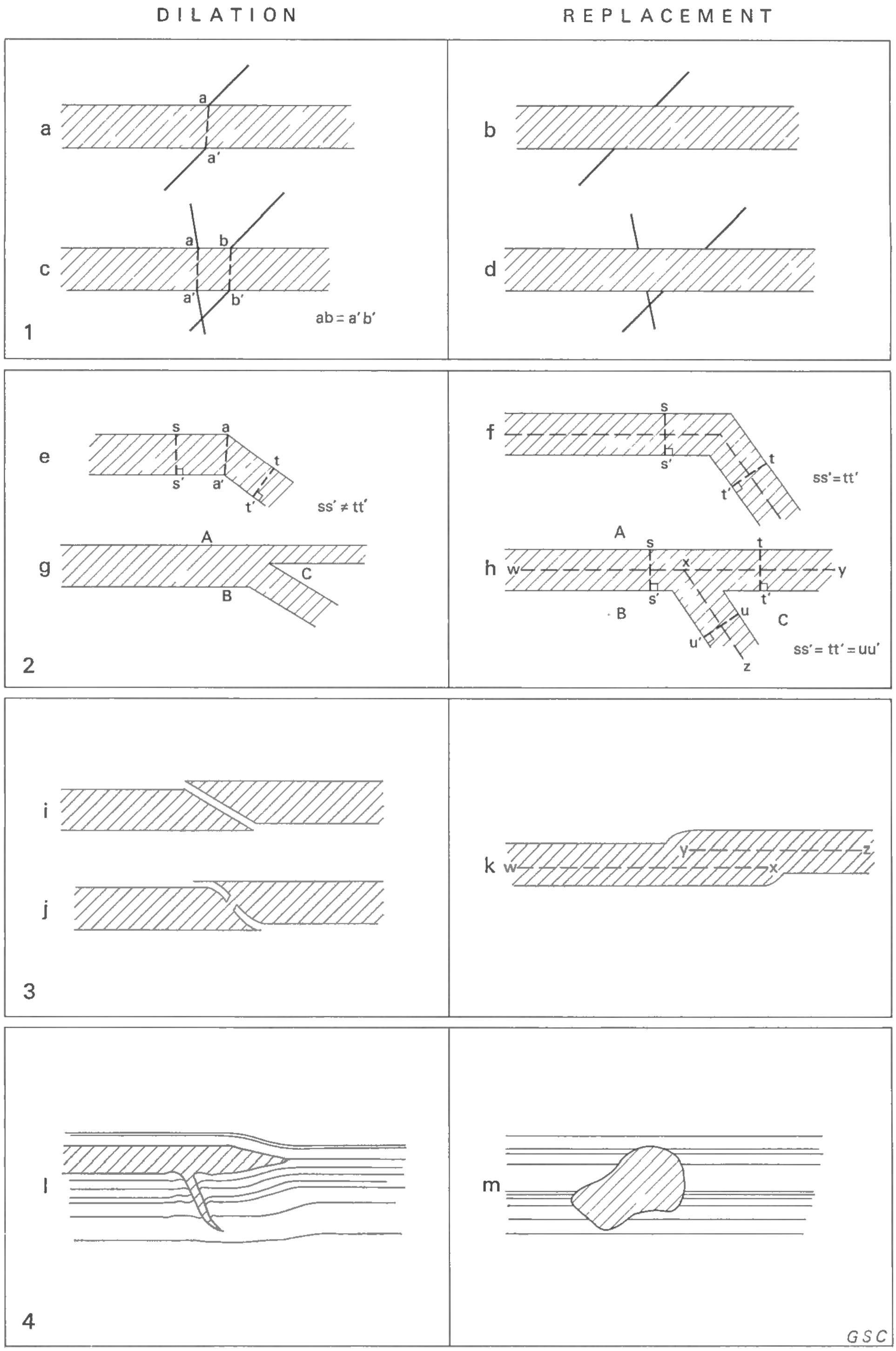


FIGURE 17. Criteria that may be applied to determine if dilation or replacement processes were operative in the development of pegmatite masses.

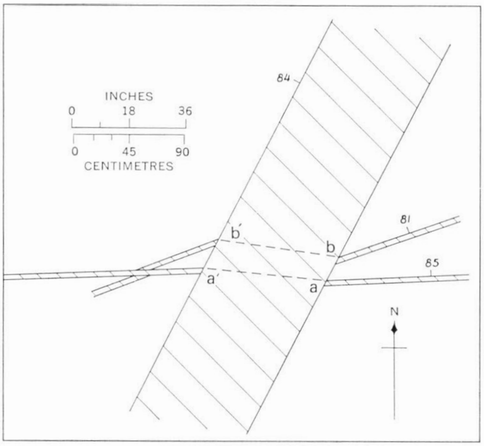


FIGURE 18
Intersecting pegmatite dykes in Sparrow Lake granite (site 401, Fig. 4). Evidence for dilation with reference to large dyke is provided by offset of two earlier non-parallel narrow dykes.

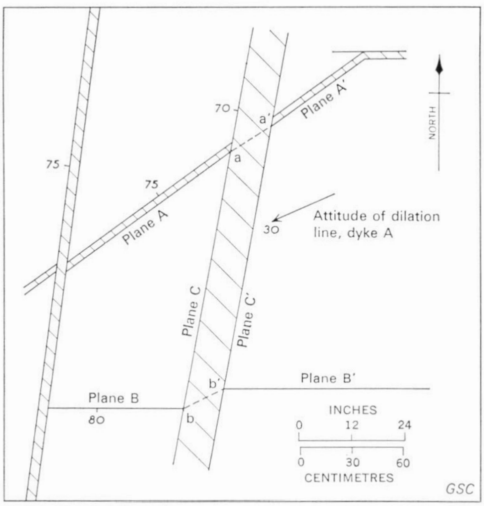


FIGURE 19
Intersecting pegmatite dykes in Sparrow Lake granite (site 167, Fig. 2).

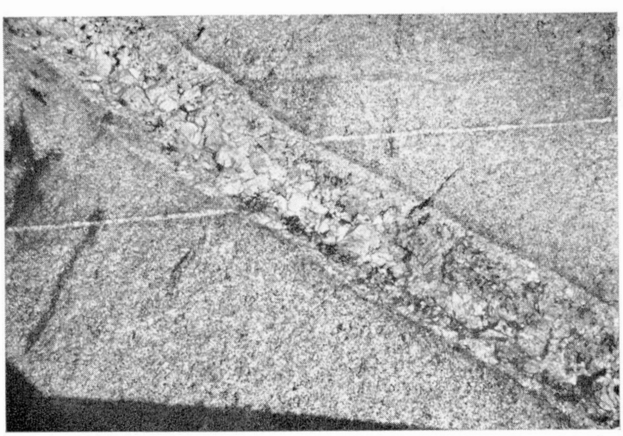


PLATE XIII
Intersecting pegmatite dykes in Sparrow Lake granite. Note evidence of dilation with reference to larger dyke, which is 28 cm (0.9 ft) thick. (Site 125 Fig. 2.)

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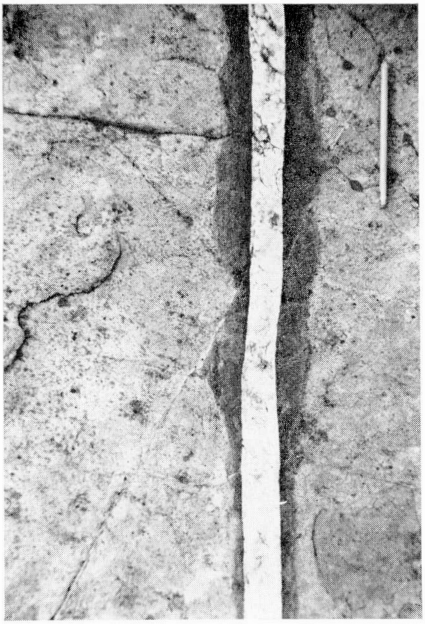


Kretz, 14-3-60

PLATE XIV
Pegmatite dyke in schist, enclosed by tourmaline-rich aureole (black). Observe offset of quartz vein (at pencil point), providing evidence for dilation in association with pegmatite emplacement. (North of Bighill Lake, lat. 63°31′N, long. 114°03′W.)

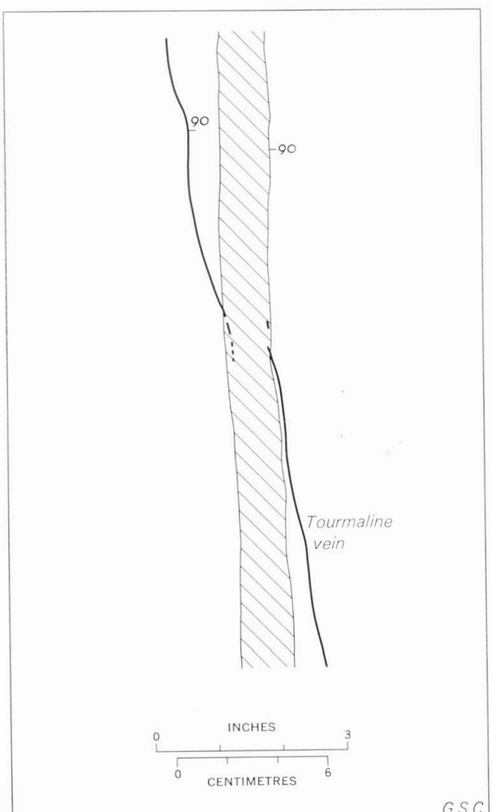


FIGURE 20
Anomalous age relationship between pegmatite dyke and tourmaline vein in Sparrow Lake granite (site 110, Fig. 2).

Numerous examples of offsets of the type shown in Figure 17a and c were found in the Yellowknife–Beaulieu terrain, and some of these are illustrated in Plates XIII and XIV and Figures 18 and 19. Dilation is also evident in the dyke shown in Figure 20. Note, however, that the tourmaline vein is offset by the pegmatite and also 'cuts' it. This may be due to the following sequence of events: (1) formation of two intersecting joints; (2) dilation with reference to one of the joints, accompanied by pegmatite emplacement, causing an offset of the second joint; (3) development of tourmaline along the second joint, also penetrating the pegmatite.

In contrast to the evidence for dilation that these criteria presented, no such evidence was found indicating replacement dykes.

There is no *a priori* indication that the walls of dilation dykes invariably separate in a direction normal to the walls, and the actual direction of movement, or rather the resultant thereof, forms a measurable property of certain dykes. The solution to this problem is possible provided the dyke intersects two nonparallel planes, and the orientation of these planes and the dyke is known. Thus in Figure 19, let the intersection point of planes A, B, and C be denoted c (above the plane of the figure) and the intersection point of planes A′, B′, and C′, c′, and let c-c′ which joins two initially coincident points on opposite walls of a dyke be referred to as the dilation line.

Provided one block has not rotated relative to the other, the orientation of the dilation line may be determined by a simple stereographic procedure. Given the orientation of planes A and C, the orientation of line a-c, the intersection of these planes is obtainable. This line together with line a-a′ (which is easily measured) determine the orientation of plane a-c-c′-a′. Similarly the orientation of plane b-c-c′-b′ is obtainable. The intersection of these two planes gives the dilation line c-c′. Note that a-a′ and b-b′ are dilation lines only if c-c′ is parallel to the plane of observation. Thus, in the dyke shown in Figure 18 the dilation line was found by the above procedure to be horizontal, and hence a-a′ is the bearing of this line. This is confirmed by the observation that a-a′ and b-b′ (Fig. 18) are nearly parallel.

If a dyke intersects only one plane the orientation of the dilation line is indeterminate, though it is possible to determine the orientation of a plane in which the line must lie. Preliminary measurements of the orientations of such planes as well as some dilation lines in the eastern margin of the Sparrow Lake pluton have not revealed a consistency in the direction of dilation in this part of the granite pluton.

Criterion 2. Variation in thickness of limbs of multi-limbed dykes

Consider a joint that changes direction abruptly, and suppose the blocks on either side of the joint separate, thereby providing space for pegmatite minerals. The resulting dyke will possess a form of the type shown in Figure 17e. The thickness of the limbs of this dyke will not be equal except when the dilation line exactly bisects the angle s-a-t. On the other hand, if replacement proceeds outward from the joint at an even rate, the resulting dyke will probably be uniformly thick, as shown in Figure 17f. Hence a variation in the thickness of the limbs of dykes possessing the general form expressed in Figure 17e and f may be accepted as a fairly reliable criterion of dilation.

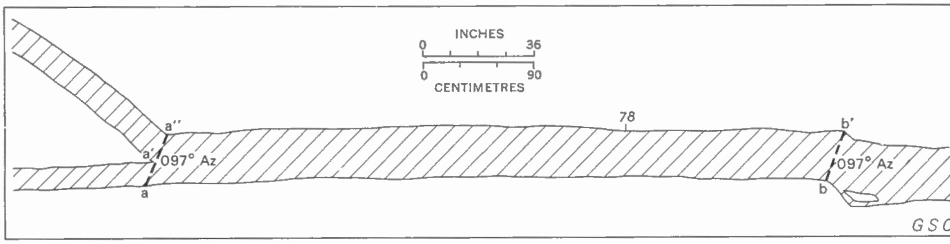


FIGURE 21. Branching pegmatite dyke in Sparrow Lake granite (site 351, Fig. 2). Thickness varies from one limb to another, providing evidence for dilation; a-a'-a'', and b-b' are horizontal traces of planes that contain dilation lines.

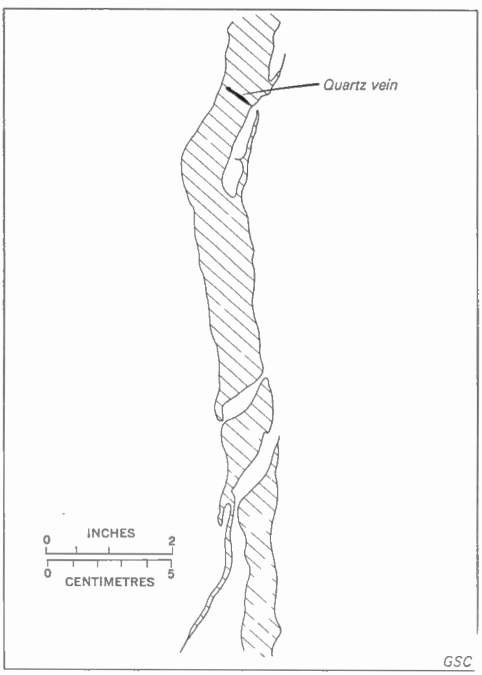


FIGURE 22. Pegmatite dyke in schist, showing presence of two schist bridges. (Location: north of Bighill Lake, lat. 62°31′N, long. 114° 03′W.)

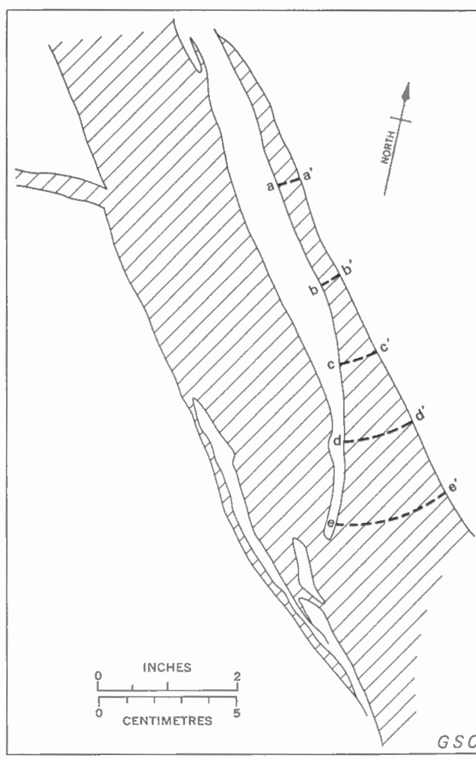


FIGURE 23. Pegmatite dyke in schist, showing narrow schist bridge, severed at one end (site 149, Fig. 4). Observe that the bridge has been bent.

Similar conclusions apply to dykes of more complex geometry. Consider for example two joints, w-x-y and x-z as shown in Figure 17h. If the direction of displacement of block B relative to A is parallel to the direction of displacement of block C relative to A (all dilation lines parallel), the resulting dyke will possess a geometry as shown in Figure 17g. Note especially that the limbs are not uniformly thick. On the other hand, if replacement proceeds outward from the specified joints, the resulting dyke will possess a geometry similar to that shown by Figure 17h. All limbs will have approximately equal thickness. Thus an examination of branching dykes may reveal whether these are dilation or replacement dykes.

Several examples of multi-limbed dykes have been examined in the Yellowknife–Beaulieu terrain, and some of these are shown in Figure 21 and Plate XV. In each example, different limbs have different thicknesses, thus providing exclusive evidence for dilation.

It may be noted that in a dyke of the type shown in Figure 17e and g, the orientation of a plane that contains the dilation line may be determined, but not the orientation of the dilation line itself.

Criterion 3. Presence of bridges or partial bridges across dykes as evidence of dilation

Consider two parallel joints in *en échelon* relationship, as shown by lines w-x and y-z in Figure 17k. A separation of the walls accompanied by the emplacement of pegmatite minerals will then produce a dyke that possesses a bridge of country rock, as shown in Figure 17i (Farmin, 1941; Ramberg, 1956), or if the bridge is broken, projections of schist into the pegmatite as shown in Figure 17j (Farmin, 1941). On the other hand, if a replacement of country rock by pegmatite proceeds outward from *en échelon* joints, the resulting dyke will possess a shape like that shown in Figure 17k, and no bridges or projections will result. Hence the presence of bridges in dykes is considered evidence of dilation as opposed to replacement (Farmin, 1941).

Several interesting examples of bridges extending completely or partly across pegmatite dykes were discovered in the Yellowknife–Beaulieu terrain, especially in relatively small dykes. Some of these are shown in Figures 22 and 23, and Plate XVI. These are considered to provide reliable evidence of dilation, and in addition provide information on the state of pegmatite-forming matter, as discussed later in this chapter.

Criterion 4. Distortion of layered structure or foliation in the country rock about pegmatite masses

Consider a volume of layered or foliated rock containing an embedded mass of pegmatite. If emplacement of the pegmatite mass was accompanied by dilation, the layered structure should be distorted. If for example a lens of pegmatite lies parallel with the layering, the layers must bend about the lens, or if it lies across the layers, they may be distorted adjacent the pegmatite lens as a result of a 'pushing aside' of the country rock by the pegmatite (Fig. 17l). On the other hand, if a pegmatite mass forms in a layered rock by replacement, some of the layered sequence will be missing, little distortion of the layers is expected, and a geometry like that shown in Figure 17m will result.

Kretz, 15-2-60

PLATE XV
Pegmatite dyke emplaced along a set of tourmaline veins in schist. Note evidence of dilation. Dyke is 6 cm thick. (North of Bighill Lake, lat. 63°31′N, long. 114°03′W.)

Kretz, 9-3-60

PLATE XVI
Illustration of a schist bridge across a pegmatite dyke. Bridge is composed of numerous thin leaves of schist. (Site 134, Fig. 2.)

The above criterion has been applied at certain places in the Yellowknife–Beaulieu terrain. Figure 24 for example shows a pegmatite mass in layered schist. If the pegmatite mass has replaced the schist, part of the layer of sillimanite-containing schist should be missing from the section to the left of the fault, i.e., at the place where the layer is penetrated by the pegmatite. Careful measurements show however, that distance a + b = c, and nothing is missing from the section. Hence the pegmatite mass is interpreted to be a dilation pegmatite.

Additional evidence for dilation was found in a projection of pegmatite into schist, as shown in Figure 25. As all the schist layers are present, the pegmatite projection is inferred to have formed by dilation rather than replacement. Note that the projection has developed preferentially along a quartz vein–schist interface, and that the adjacent layers bend about the pegmatite as shown in Figure 17l. Similar structures, developed on a larger scale were observed at Staple Lake, where some lens-shaped pegmatite masses lie parallel with the bedding and deflect the adjacent beds. Jahns (1955) has illustrated structures of this kind. Observe finally (Fig. 25) that the layers adjacent to the pegmatite have been thickened, resulting presumably from a plastic deformation (shortening) during their sideways displacement.

Distortion of layered structure in country rock adjacent to pegmatite masses has been observed by many people (*see* review by Chadwick, 1958). Two examples from the Yellowknife terrain are shown in Figure 26a and b. These, when considered in relation to the above-mentioned criterion, provide additional evidence of dilation.

A special example of deformation adjacent to a pegmatite mass is illustrated in Figure 27. In addition to distortion of the schist adjacent to the dyke, the pegmatite–schist interfaces were evidently greatly distorted and 'stretched'. Thus the corner at s′ (matching the corner at s) has been rounded, and the distance t′-u′ is greater than t-u, suggesting that the interface between t′ and u′ has been 'stretched'. Aside from the indications these structures give as to the nature of the pegmatite-forming matter, it is concluded that the dyke under discussion is a dilation dyke.

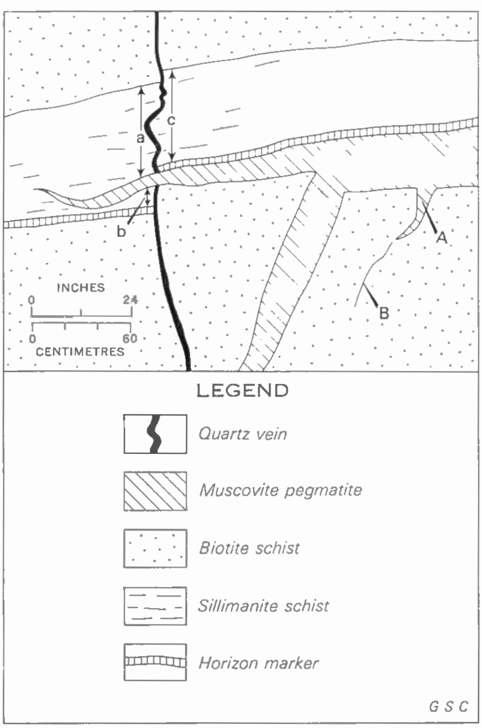


FIGURE 24
Vertical section of a pegmatite mass inferred to be a dilation pegmatite (a+b=c. (Location: 1.7 miles due west of southwest corner of Staple Lake, i.e., lat. 62°43.3′N, long. 114°06′W.)

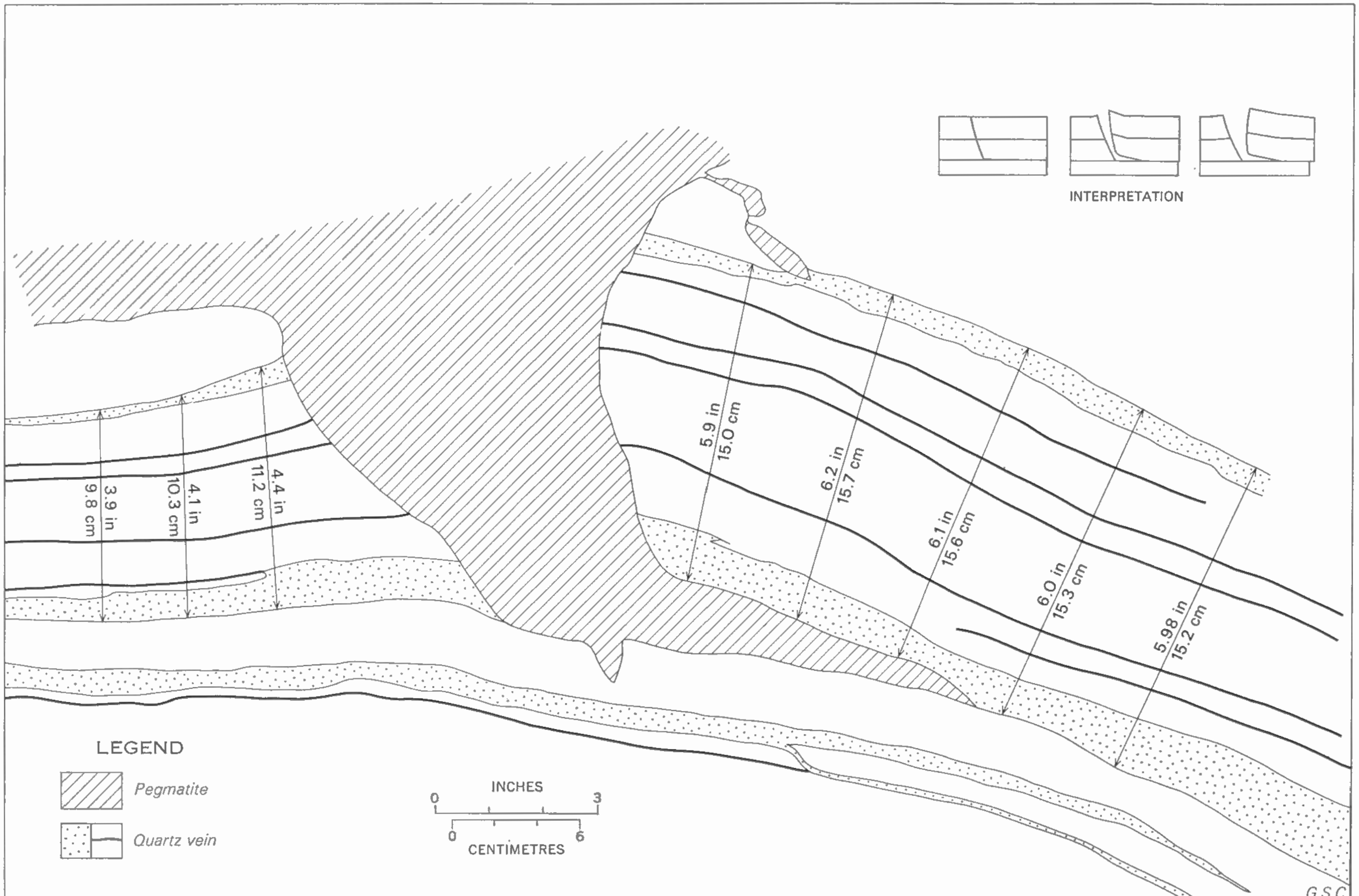


FIGURE 25. Projection of quartz–plagioclase–muscovite pegmatite into common biotite schist containing several parallel quartz veins. Note that layered structure in schist is deflected by the pegmatite, providing evidence for dilation. Thickening of the layers is attributed to plastic flow resulting from pegmatite emplacement. (Section is normal to quartz veins and inclined at about 60° to the pegmatite–schist contact) (site 373, Fig. 4).

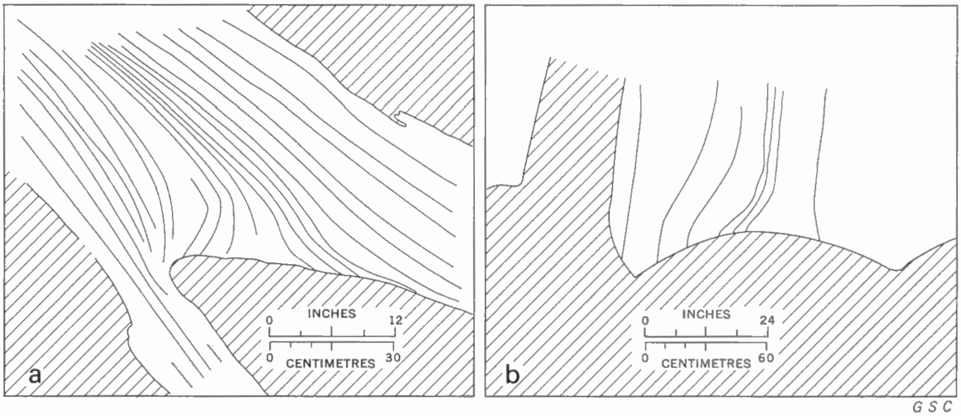


FIGURE 26. Deformed schist layers (bedding) adjacent pegmatite: (a) tracing of photograph; (b) note book sketch. Location: a, shore of Hidden Lake, lat. 62°32′N, long. 113°31′W; b, site 257, Fig. 3.

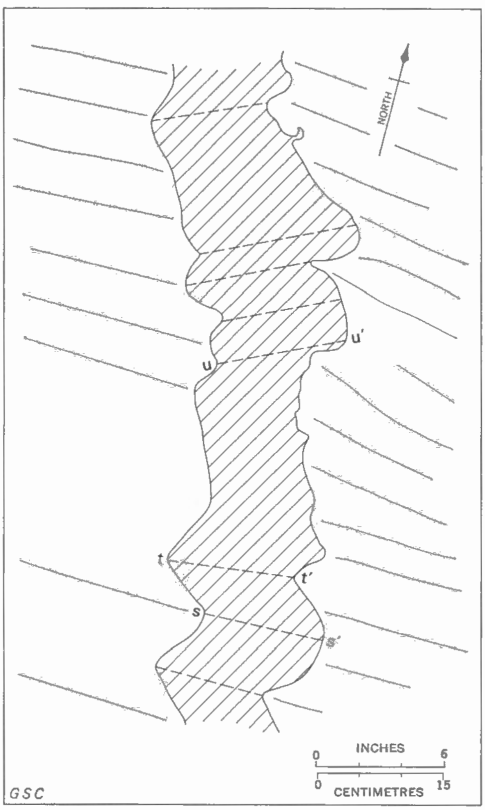


FIGURE 27. Pegmatite dyke in schist, showing distortion of foliation in the schist adjacent the dyke, and apparent deformation of the pegmatite–schist interfaces (site 471, southwest of Thompson Lake, Fig. 2).

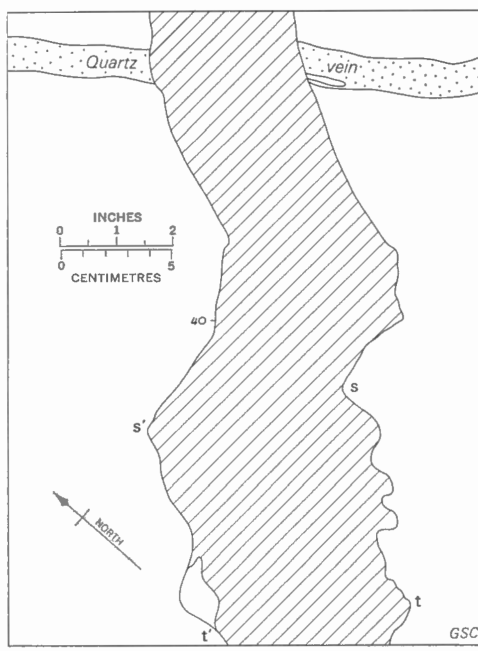


FIGURE 28. Small pegmatite dyke in schist. Observe irregular contact between s and t. Plane of observation dips about 20 degrees southeasterly. (Location: shore of Hidden Lake, lat. 62°32′N, long. 113°31′W.)

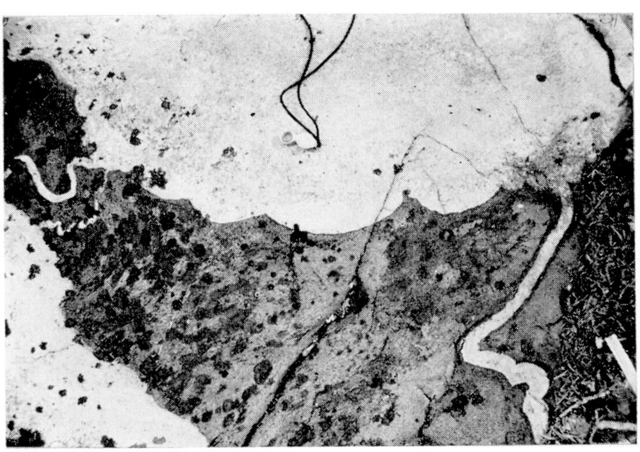
A small but clear example of replacement was found in the Sparrow Lake pluton. Pods of pegmatite have formed in a layer of mylonitic granite (a shear zone) and the layer is not deflected about the pods. It must be concluded therefore that pegmatite has replaced parts of the shear zone.

An apparent case of replacement is found in the irregular pods of pegmatite at Staple Lake (for example at coordinated B6, Fig. 3). It is however possible, as noted in Chapter III, that 'openings' were formed by slip parallel with the bedding planes, somewhat analogous to 'openings' formed between boudins, and that these pegmatite bodies formed by dilation rather than replacement.

Criterion 5. Irregular contacts

Although some irregularity in pegmatite contacts may be accounted for by plastic deformation of the adjacent country rock (Fig. 27), the highly irregular contacts may in certain places be interpreted as a replacement of country rock by pegmatite, at least along the margin of the pegmatite mass. Thus the irregular contacts illustrated in Figure 28 may be taken as evidence of at least local replacement of schist by pegmatite minerals. Irregularities appear that are not reflected in the opposite wall (compare contact between s and t with contact between s′ and t′). It is difficult to determine to what extent these irregularities represent replacement and to what extent they are products of a mechanical distortion of the pegmatite-schist interface.

Numerous observations in the Yellowknife–Beaulieu terrain have revealed that where irregularities exist in the pegmatite–schist contacts, curvatures are more commonly concave towards the pegmatite mass rather than concave towards the schist (Pl. XVII). The significance of this observation is uncertain as the curvatures may be the result of either replacement, or dilation accompanied by deformation of the adjacent schist.



Kretz, 13-3-60

PLATE XVII
Pegmatite–schist contact, showing tendency for interface to be concave towards the pegmatite. (Site 224, Fig. 2.)

Summary

It is evident that application of the criteria of Figure 17 to the pegmatite bodies of the Sparrow Lake – Thompson Lake area and to other areas of the Yellowknife–Beaulieu terrain leads to the conclusion that a large number of pegmatite dykes, mostly rather small, both in granite and schist were emplaced by a process involving dilation of the enclosing rock. Most dykes in granite and some dykes in schist have straight parallel contacts, and dilation probably resulted from a process that involved little plastic deformation of the country rock. On the other hand, certain dykes in schist are bordered by deformed schist and the pegmatite–schist interface is also deformed, indicating that some dykes were emplaced by a process that involved considerable plastic deformation of the adjacent rock.

Little evidence was found for the replacement of country rock by pegmatite, and it is inferred that this process operated on a small scale only, mainly along the margins of certain dykes in schist.

The only other investigations reported to date of dilation and replacement in the Yellowknife–Beaulieu terrain are those of Hutchinson (1955) from the Ross Lake – Redout Lake area to the east of the area covered by Figure 1. The pegmatite bodies he studied are in interlayered granodiorite and amphibolite and it is interesting to note that he (Hutchinson, 1955, pp. 10–13) found evidence to indicate that both replacement and dilation were operative on a large scale, replacement near the Redout Lake granite and dilation farther from the granite.

Inferences Concerning the Dilation Process Based on the Evidence of Intersecting Dykes and Schist Inclusions in Dykes

Now that the importance of dilation in the emplacement of the pegmatite masses of the Sparrow Lake – Thompson Lake area is established, it is desirable to inquire in greater detail into the mechanism of dilation. Did dilation accompany or precede pegmatite emplacement? Did dilation occur continuously or discontinuously? Was dilation slow or fast? A close examination of certain intersecting pegmatite dykes and inclusions in dykes has provided at least a partial answer.

Intersecting Pegmatite Dykes in Granite

Some groups of intersecting pegmatite dykes in the eastern margin of the Sparrow Lake pluton were examined in detail. Results of two of these follow:

Example 1 (Fig. 29). An examination of the dyke group shown in Figure 29 will show that dykes A and B are offset by dyke D indicating that D is younger than A and B.[1] This is confirmed at point X, where the margins of D can be traced for some distance into dyke A. Dyke D does not however continue through A, and is noticeably offset by this dyke. What then is the age of dyke D relative to A?

[1] The offset is more obvious if the page is held so that the line of sight meets Figure 29 at a low angle.

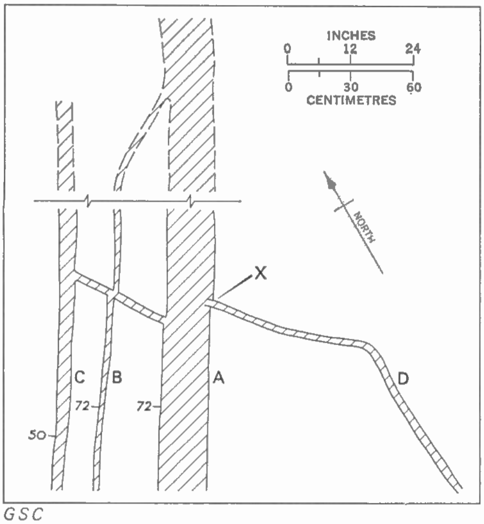


FIGURE 29. Intersecting pegmatite dykes in granite (site 125, Fig. 2). Observe mutual offset of dykes A and D.

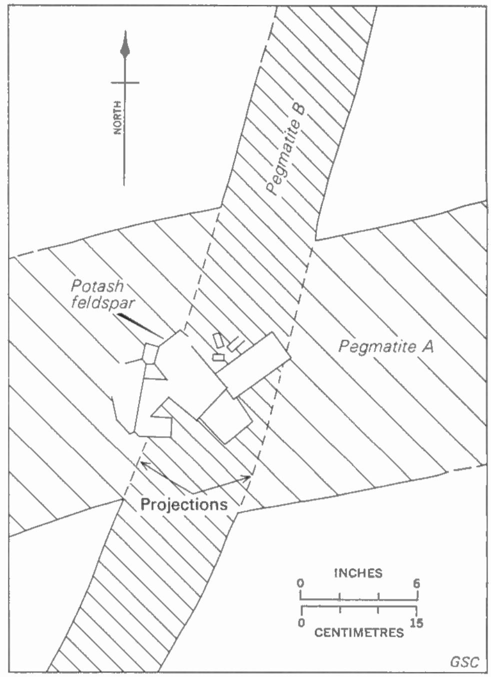


FIGURE 30. Intersecting pegmatite dykes in Sparrow Lake granite (site 403, Fig. 4). Observe that dyke A is offset by dyke B and appears to be older than B. Large potash feldspar crystals in the central part of dyke A are not however appropriately displaced.

These data are interpreted as follows. The first pegmatite rock to form is dyke B and the outer margins of A, i.e., dyke A was initially much thinner, possibly a quarter of its present thickness. Dyke D was then emplaced as a dilation dyke, possibly contemporaneously with C, causing offset of dykes A and B. Dyke A must have been a solid rock at this time, as dyke D has made sharp contacts with it at X. After or during the emplacement of D, dilation was resumed at dyke A, the east wall moving in a roughly easterly direction relative to the west wall, with consequent offset of dyke D. Hence the central, relatively coarse grained part of dyke A is considered to be significantly younger than its margins.

It is commonly difficult or impossible to detect contacts between pegmatite masses of different age. This is illustrated by the absence of contacts where dyke B (Fig. 29) intersects dyke D. It is also noteworthy that no contact can be detected between the easterly marginal pegmatite of dyke A and the later relatively coarse grained central part. Close inspection between the east wall and centre of this dyke reveals only a gradational change from a relatively fine grained to a relatively coarse grained assemblage of quartz, feldspar, and muscovite. It is suggested therefore that pegmatite material may have been deposited against solid pegmatite of an earlier generation without leaving a trace of the surface of the earlier pegmatite.

Example 2 (Fig. 30). A second example of intersecting dykes in granite is shown in Figure 30. Observe that dyke A is offset by dyke B, and although the boundaries of dyke B cannot be traced through pegmatite A (these shown as projections), dyke B is apparently younger than A. Note, however, that the projected contacts of B are obstructed by large potash feldspar crystals in the central part of dyke A. Hence the central part of dyke A must be younger than dyke B.

This apparently conflicting evidence can be resolved satisfactorily if the margins of dyke A are considered to be older than the central, relatively coarse grained part. Dilation accompanying the crystallization of the central part of dyke A must then have occurred in a direction that did not noticeably offset dyke B.

Inclusions in Pegmatite Dykes

Inclusions of schist in pegmatite masses enclosed by schist are not uncommon in the Sparrow Lake – Thompson Lake terrain, and although some of the inclusions are tourmalinized, they can be recognized as pieces of the immediately enclosing rock. Results of examination of two samples in relation to dilation and multiple stages of pegmatite development follow:

Example 1 (Fig. 31). The margin of a pegmatite dyke and the inclusions contained therein are shown in Figure 31. If no distinction is made between different types of pegmatite, all that is visible are a number of apparently isolated inclusions extending obliquely into the dyke from its contact with the enclosing schist. On closer inspection, however, three types of pegmatite are distinguishable:

C. Quartz-feldspar-muscovite pegmatite; grain size highly variable, increasing towards centre of dyke where potash feldspar crystals are ± 60 cm in diameter.

B. Quartz-feldspar-muscovite pegmatite; nearly even grained; grain size ± 3 mm.

A. Quartz-feldspar-muscovite pegmatite with minor tourmaline; grain size $\frac{1}{2}$–1 mm.

Pegmatite A forms a clearly recognizable small dyke with easily detectable contacts against pegmatites B and C.

Pegmatite B is, for the most part, clearly distinguishable from pegmatite C but as the contact between the two is traced to the south, a point is reached (X, Fig. 31) beyond which it disappears and no distinction can be made between the two pegmatite units. Pegmatite B, where it can be recognized as such, 'cuts' pegmatite A ($1\frac{1}{2}$ feet south of the northern boundary of Figure 31), and is therefore younger than A.

Pegmatite C forms the major part of the dyke, and is found both east and west of the swarm of inclusions. A contact can be detected within this unit near Y (Fig. 31), although south of there the contact disappears, and pegmatite C may have developed in two stages.

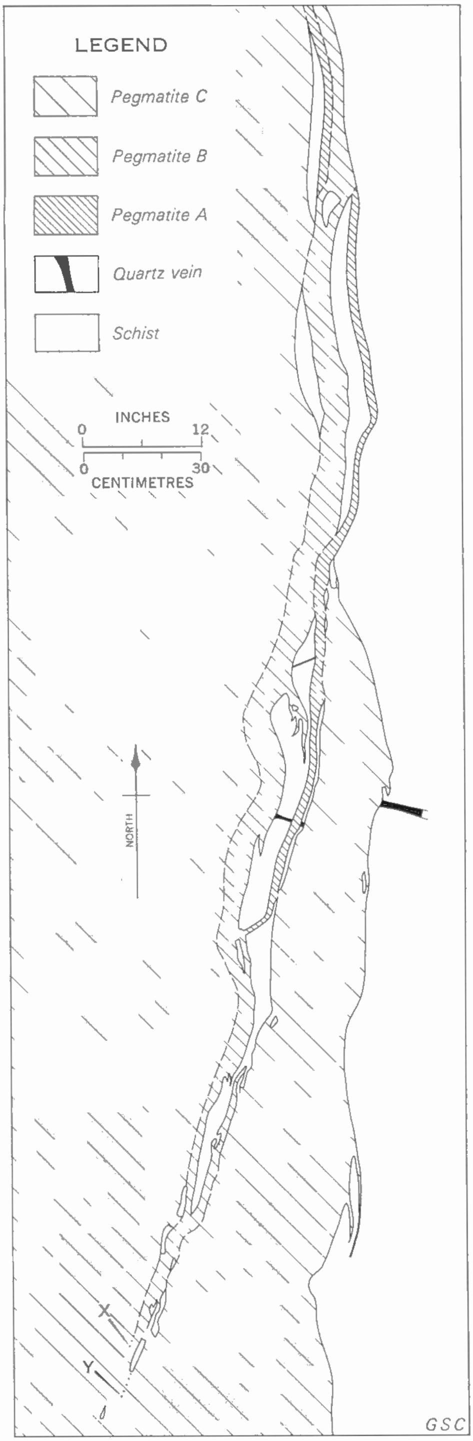


FIGURE 31. East contact of a pegmatite dyke in schist (site 426, Fig. 4). The presence of schist inclusions is accounted for by a sequential emplacement of three pegmatite units, A, B, and C. Observed disappearance of pegmatite contacts at X and Y.

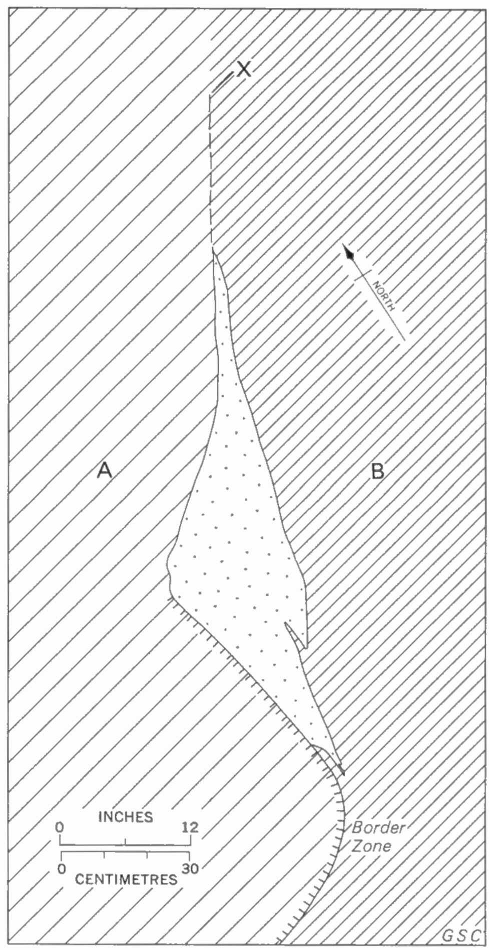


FIGURE 32. One of several schist inclusions in a pegmatite dyke enclosed by schist (site 424, Fig. 4). Observe isolated border zone, and disappearance of contact at X.

The linear disposition of the inclusions and the absence of noticeable rotation or shear displacement of one relative to the other, can be satisfactorily explained in terms of multiple stages of pegmatite emplacement. As pegmatite B 'cuts' A, A was solid when B was emplaced, and as the emplacement of pegmatite C caused a slab of rock composed of pegmatites A and B plus inclusions to be pried from the wall, pegmatite B must have been solid when pegmatite C was emplaced. Thus at least three separate stages of pegmatite emplacement are envisaged.

The 'disappearance' of contacts between pegmatite units of different age, as observed at point X (Fig. 31) presents an intriguing problem. South of X, pegmatite B appears to have been incorporated in pegmatite C, possibly by some process of replacement or recrystallization.

Example 2 (Fig. 32). At site 424 (Fig. 4) a northeasterly trending dyke about 32 feet thick contains several small inclusions of schist. The longest dimension of these inclusions, as viewed in plan, is subparallel with the strike of the dyke, and the strike of bedding within inclusions does not differ from that of the enclosing schist by more than about 15 degrees. One of the inclusions which is centrally situated in the dyke is shown in Figure 32.

Many of the pegmatite masses in the schist near Sparrow Lake contain narrow (1–5 cm) border zones that are relatively rich in quartz and muscovite. One of these zones can be seen along one side of the inclusion illustrated in Figure 32, and can be traced for some distance into the pegmatite mass. Northward from the inclusion, a boundary can be traced for a distance of about a foot (to point X), revealing two pegmatite units. Both these units (A and B, Fig. 32) are composed of quartz, feldspar, and muscovite of variable grain size, and are distinguishable from each other only by the boundary between them. North of point X the boundary disappears, and only one pegmatite unit can be recognized.

These data suggest that the development of pegmatite in the dyke at site 424 has occurred at more than one stage. Later units of pegmatite have evidently developed beside earlier units, and occasionally parts of the wall-rock have become detached and caught between the pegmatite units. If later episodes of pegmatite emplacement occurred only after the earlier units were solid rock, inclusions could be transported to the central regions of dykes without rotation. In this way relicts of border zones may also be displaced to the central region of pegmatite dykes.

Summary

An evaluation of the data presented above leads to the conclusion that certain dykes have formed by a process that entails repeated dilation, accompanied by renewed stages of pegmatite emplacement and crystallization.

With reference to pegmatite dykes in the Sparrow Lake granite, subsequent stages of pegmatite development are marked by a dilation and deposition of pegmatite minerals in the central regions of earlier dykes. It is especially noteworthy that no contacts can be detected between different pegmatite units, i.e., pegmatite minerals of a later stage were deposited against the surface of solid pegmatite of an earlier stage without leaving a trace of this surface. The formation of these dykes

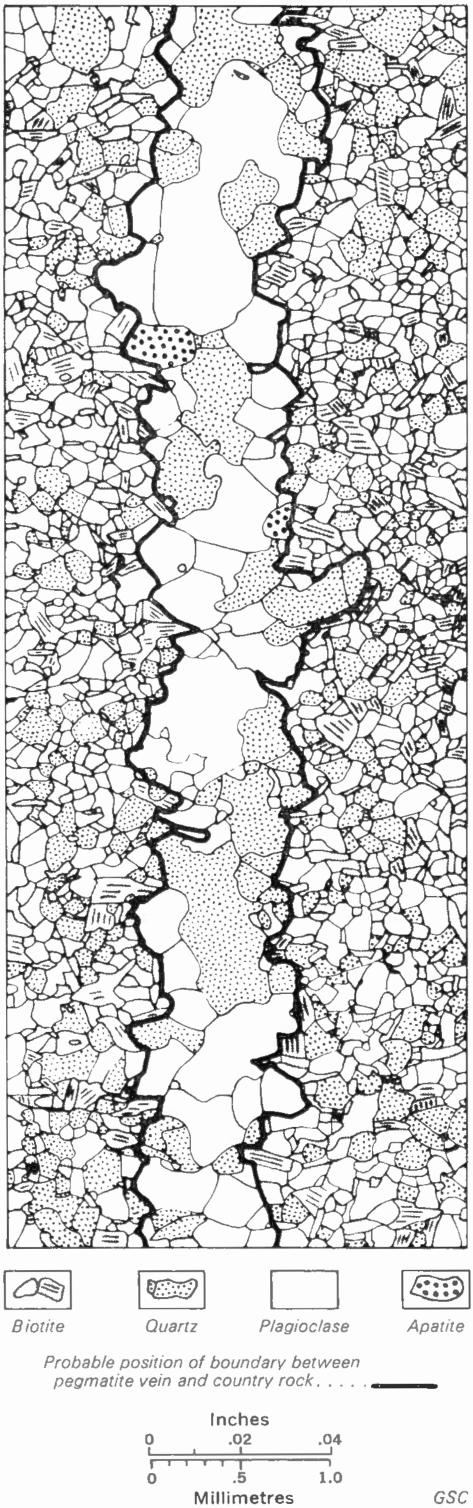


FIGURE 33. Cross-section of the small pegmatite vein at B, Figure 24.

is therefore envisaged as a slow growth (Ramberg, 1952, p. 252), the second stage taking up the process of crystallization where the first stage left off.

As for the pegmatite dykes in schist, contacts between successively formed pegmatite units can more commonly be detected. Although it is not known why sharp contacts should be locally created, the absence of contacts as observed for example at X (Fig. 32), may be accounted for by the method suggested above.

It is possible that multiple stages in the formation of pegmatite dykes have occurred more commonly than is realized. It is only when successive stages are crossed by a dyke or contacts between successive pegmatite units are visible that this phenomenon becomes detectable.

Inferences from Deformed Schist Bridges Regarding the State of Pegmatite-forming Matter During Dilation

One of the pegmatite dykes that contains schist bridges is of special interest (Fig. 23). As already stated, the dyke is a dilation dyke, and hence line a-b-c-d-e- must have initially coincided approximately with line a'-b'-c'-d'-e'-. It is evident therefore that the bridge of schist has been bent during pegmatite emplacement.

A similar feature was described by Ramberg (1956) who, realizing that the bending of solid rock must be a slow process involving an application of non-hydrostatic stress throughout, inferred that the space now occupied by the pegmatite could not have been filled with a fluid. He concluded, on the basis of this and other evidence, that the pegmatite mass was emplaced by a slow accumulation of matter, the pegmatite body being in a solid state during its growth. This interpretation may also be applied to the dyke shown in Figure 23.

Inferences Regarding the Path of Penetration of Pegmatite-forming Matter Based on an Examination of a Small Vein in Schist

The pegmatite mass shown in Figure 24 was classified earlier in this report as a dilation dyke. The small pegmatite vein at B is now examined in detail. This vein, which in vertical section is apparently isolated from the larger pegmatite mass, forms an *en échelon* continuation of one of the apophyses. The vein is 30 cm (1 foot) long as viewed in vertical section. At the upper end the thickness is about 5 mm and towards the bottom it tapers to one-half millimetre. A specimen was collected 10 cm from its lower end and a cross-section of the vein at this place is shown in Figure 33.

It is immediately apparent that no clearly defined boundaries exist between pegmatite and schist. An attempt was made to locate these boundaries by drawing lines that excluded all biotite from the vein, and included all quartz and feldspar grains apparently too large to be indigenous to the schist. The boundaries so defined are not parallel. If this pegmatite vein developed along a fracture (Chapter III) that passed either through grains or along grain boundaries, the vein boundaries should be nearly parallel. As they are not, and furthermore, as they are apparently too irregular to represent a fracture path, it is inferred that the vein was not emplaced along a pre-existing fracture.

It is postulated therefore that the vein was emplaced by a 'filling of space' created by dilation along a plane that followed grain boundaries in the schist but was highly irregular in detail. The observation that the walls of the vein do not match may be accounted for by the deposition of pegmatite-forming quartz and plagioclase on pre-existing quartz and plagioclase respectively, new material being deposited in crystallographic continuity. Thus the vein borders as shown in Figure 33 are considered to be approximate only, as parts of certain grains included with the pegmatite belong to the schist and certain embayments into the schist were 'filled' with pegmatite minerals.

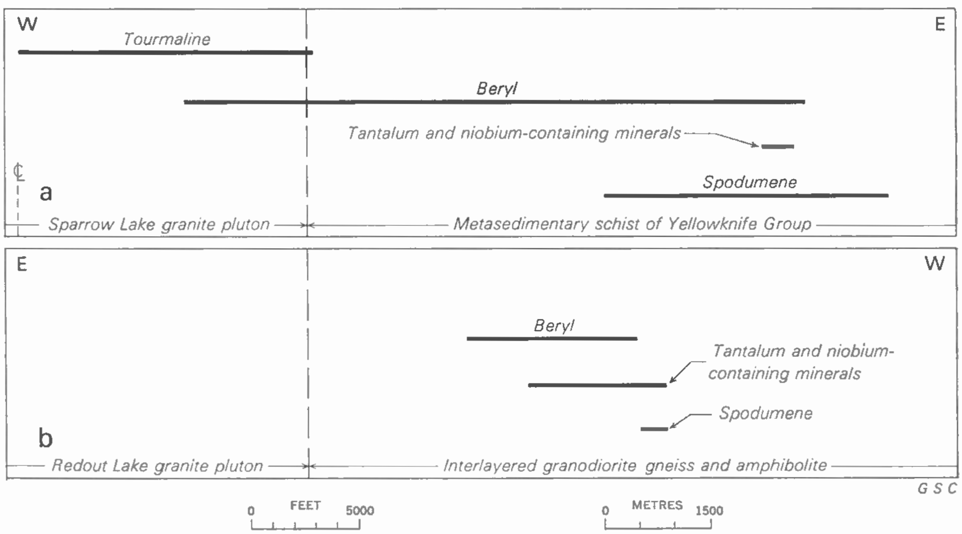


FIGURE 34. Regional distribution of certain pegmatite minerals in relation to the position of the nearby granite contact. The Sparrow Lake – Thompson Lake area (a) is compared to the Ross Lake – Redout Lake area (b) (Hutchinson, 1955), both within the Yellowknife–Beaulieu region.

Chapter V

THE PEGMATITE MINERALS

The purpose of this chapter is six-fold: (1) to place on record a list of all of the pegmatite minerals of the Yellowknife–Beaulieu region found to date; (2) to examine the regional distribution of pegmatite minerals in the Sparrow Lake – Thompson Lake terrain; (3) to examine briefly the distribution of pegmatite minerals within individual pegmatite bodies; (4) to describe some of the textures found in pegmatite; (5) to report certain mineralogical relationships between pegmatite bodies and the enclosing rocks; and (6) to examine the distribution of sodium and potassium among albite, potash, feldspar, and muscovite. From these data inferences are drawn regarding crystallization temperatures and equilibrium relation in the pegmatite mineral assemblages.

List of Pegmatite Minerals

The most abundant minerals in the pegmatites of the Yellowknife–Beaulieu region are plagioclase, potash feldspar, quartz, and muscovite. Beryl, spodumene, and tantalite–columbite are present in some dykes in notable concentrations, and numerous additional minerals have been found infrequently or in very small amounts.

All the pegmatite minerals identified to date are listed in Table VI. The list includes minerals initially reported by Jolliffe (1944), and additional finds by Rowe (1952), Hutchinson (1955), Boyle (1961), and the writer. The minerals reported here by the writer for the first time were identified or their identity was confirmed in the X-ray laboratory of the Geological Survey of Canada. The collecting sites of these minerals are also given in Table VI.

Rare element minerals are found only within some pegmatite dykes confined to specific parts of the Yellowknife–Beaulieu terrain. Thus beryl, spodumene, and tantalite–columbite are found in pegmatite masses underlying the Ross Lake – Redout Lake area (Hutchinson, 1955), the Sparrow Lake – Thompson Lake area (Fig. 2), and several other areas within the region. On the other hand, they are absent from pegmatite masses underlying the Staple Lake area (Fig. 3) and others.

TABLE VI | *Pegmatite Minerals of the Yellowknife – Beaulieu Region*

alluadite (1)	ilmenite
amblygonite	lazulite
andalusite (2)	lepidolite
apatite	lithiophyllite
arsenopyrite	magnetite
beryl	molybdenite
biotite (3)	muscovite
bismuth	petalite
carbonate (4)	plagioclase
cassiterite	potash feldspar
chlorite (5)	pyrite
cordierite	quartz
epidote? (6)	scheelite
fluorite	sillimanite (8)
gahnite	spodumene
garnet	tantalite–columbite
graphite	tapiolite
heterosite (7)	tourmaline
hornblende	uraninite? (9)
hydromica[1]	unknown mineral[2] (10)
	zircon

Collecting sites of pegmatite minerals reported here for the first time:
(1), site 146, Figure 4 and site 325, Figure 2; (2), sites 63 and 82, Figure 5; (3), sites 4 and 20, Figure 3; (4), site 407, Figure 4; (5), *see* Figure 24; (6), site 407, Figure 4; (7), sites 227 and 325, Figure 21; (8), site 291, Figure 3; (9), site 344, Figure 2; (10), site 407, Figure 4.

[1] Reported by W. R. A. Baragar, pers. com.

[2] Minute amounts of a black mineral giving the following d spacings:

I	d(Å)
100	3.1486
25	2.9931
35	2.8386
80	2.7443
15	2.6307
20	2.2860
<5	2.1825
<5	2.0613
50	1.9372
5	1.9008
10	1.7596
5	1.7035
50	1.6491

Regional Distribution of Pegmatite Minerals in the Sparrow Lake – Thompson Lake Terrain

All pegmatite dykes within the northeastern part of the Sparrow Lake granite pluton contain quartz, plagioclase, and potash feldspar. Muscovite is present in all but some of the smallest dykes. Tourmaline is commonly present, especially as scattered grains along the borders. All pegmatite masses in schist beyond the granite pluton contain plagioclase. Quartz and muscovite are generally present, and with the exception of some small dykes, potash feldspar. Tourmaline is rare.

Beryl was found in many dykes along the east margin of the Sparrow Lake pluton, including members of the easterly trending swarms, but evidently none of the dykes in the central region of the pluton contains this mineral. In dykes immediately east of the granite–schist contact, beryl is extremely rare. Towards the east, with increasing distance from the granite, beryl crystals again appear more commonly, and reach a second culmination in certain dykes near Thompson Lake where crystals reach a maximum length of 30 cm (e.g., at site 433, Fig. 2).

Spodumene and tantalite–columbite were found only in pegmatite masses situated at a considerable distance from the granite pluton, and are not found in any of the pegmatite masses west of the lines S-S′ (Fig. 2).

Hence there is a definite zonal distribution of certain pegmatite minerals, notably tourmaline, beryl, spodumene, and tantalite–columbite. Distributions of this kind are not uncommon, and exist elsewhere in the Yellowknife–Beaulieu region, as noted by Rowe (1954) and described in detail by Hutchinson (1955). Moreover, regional zoning of this kind has been reported from other pegmatite-containing terrains, as summarized by Heinrich (1953), although details of the zonal distribution evidently vary from one area to another (Fig. 34).

The common interpretation of this phenomenon, as offered by Heinrich (1953) and Hutchinson (1955), is that different elements for certain reasons were able to migrate different distances from their source, which is generally assumed to be a nearby granite mass.

Distribution and Orientation of Minerals in Pegmatite Dykes

The early work of Brögger (1890) and others, followed by the detailed investigations of Cameron, *et al.* (1949), and several recent investigations, for example by Sheridan, *et al.* (1957), Brotzen (1959), Norton, *et al.* (1962), Sundelius (1963), and Wright (1963) have provided an abundance of information on the distribution of minerals in pegmatite masses. Investigations by Rowe (1952) and Hutchinson (1955) showed that the zonal distribution of minerals described by Cameron, *et al.* (1949) is also present in the Yellowknife–Beaulieu terrain. It should be noted however that, in addition to the zoned dykes reported by Rowe and Hutchinson, this terrain contains a large number of dykes with an irregular mineral distribution (Pl. XVIII).

Feldspar

All pegmatite masses in the eastern margin of the Sparrow Lake pluton contain both plagioclase and potash feldspar, either as discrete grains or as intergrowths. The ratio between the two ranges from approximately 1:5 to 5:1. Pegmatite masses in the schist east of Sparrow Lake commonly contain both feldspars, but in many small veins (Fig. 14), apophyses (Fig. 35) and pods (Pl. XII), potash feldspar is absent. In general, the ratio of the feldspars in dykes within schist also varies, but no attempt was made to estimate the maximum proportion of potash feldspar.

The distribution of the feldspars within each pegmatite mass is characteristically irregular (Fig. 14), but there is a tendency for potash feldspar to be concentrated near the centre of dykes and plagioclase near the margin (Fig. 36). On the other

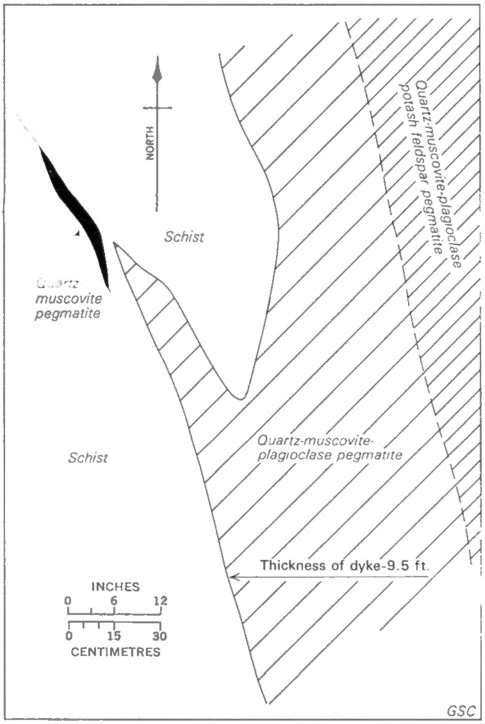


FIGURE 35. Distribution of minerals in the marginal region of a pegmatite dyke in schist (site 425, Fig. 4).

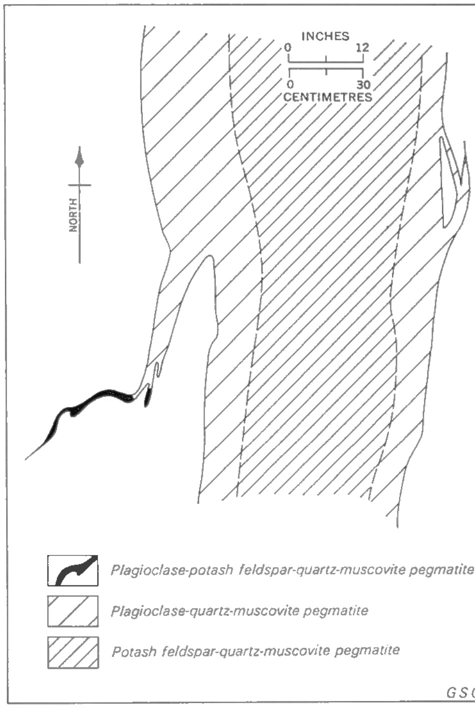


FIGURE 36. Part of pegmatite dyke in schist, showing distribution of feldspar minerals (site 406, Fig. 4). Details of pegmatite projection into schist are shown in Plate XI.

hand, in certain dykes potash feldspar is concentrated near the margin and is absent from the central part (Fig. 37).

The size of feldspar grains, as for other pegmatite minerals, is highly variable. The largest crystals found were about a metre long, and there is a distinct tendency for the size of grains to increase towards the centre of pegmatite dykes. Indeed, single crystals of potash feldspar were observed to extend from the marginal to the central zone, becoming progressively larger inwards. Generally the feldspar grains appear to be randomly oriented.

Quartz

Although quartz generally occupies about a tenth of the pegmatite rock by volume, locally the proportion increases until in parts of certain dykes pure quartz extends from wall to wall. In the common pegmatite dykes, both in granite and schist, quartz either is irregularly distributed or is concentrated in the central, relatively coarse grained zone (core), where it is associated with plagioclase or potash feldspar. Narrow marginal zones composed of quartz (Fig. 14) or quartz and muscovite are moderately common. Grain size is highly variable, and a preliminary examination showed little tendency for preferred orientation.

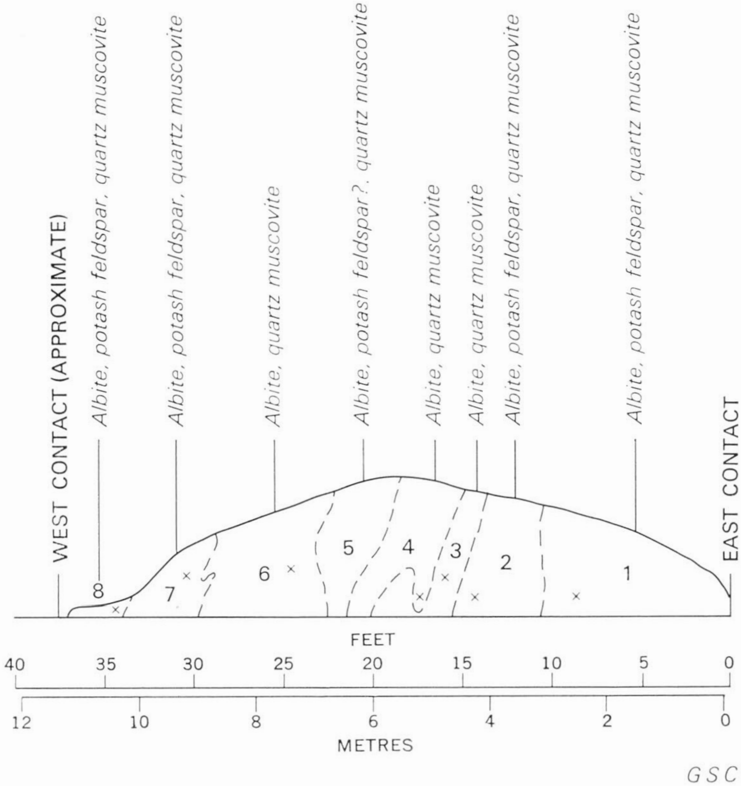


FIGURE 37
Vertical cross-section of a pegmatite dyke, showing position of zones 1 to 8, defined by mineral assemblage and texture (Table VIII). Specimens for mineral analysis collected at places indicated by an X (Site 407, Fig. 4.)

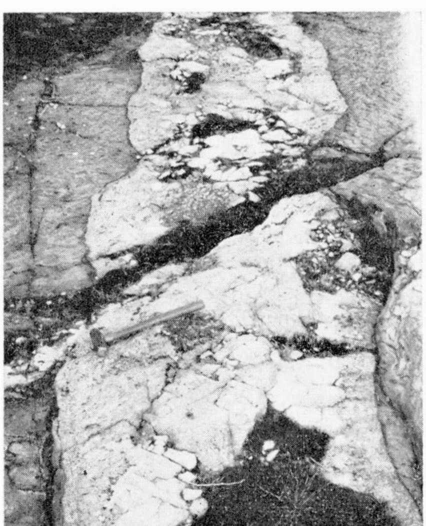


PLATE XVIII
Pegmatite dyke in schist, showing erratic mineral distribution. White = quartz, grey = feldspar, dark grey pods (e.g., at hammer handle) = aggregates of nearly pure muscovite; relatively fine grained margins are composed of quartz, feldspar, and muscovite. (North of Bighill Lake, lat. 63°31′N, long. 114°03′W.)

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Muscovite

Muscovite occurs as distinct tabular grains or aggregates of grains. It may be evenly distributed, irregularly distributed, or concentrated in the marginal zones of pegmatite masses. Quartz–muscovite margins, less than 3 cm thick are common in dykes enclosed by schist. In general, grain size ranges from minute to about 5 cm.

In many dykes enclosed by schist, muscovite grains tend to be oriented perpendicular to the walls, a common feature of pegmatite dykes in general (Megathlin, 1929; Jacobson and Webb, 1946; Cameron, *et al.*, 1949; Carl, 1962). The muscovite grains thus define a lineation but apparently not a foliation.

Beryl

Beryl crystals have been found in all parts of a pegmatite mass, from immediately adjacent the wall to the central region, although the latter position appears to be favoured. It is found as isolated crystals, as groups of a few crystals, or as bundles of crystals. The largest crystal found at Sparrow Lake was 9 cm long, and at Thompson Lake, 30 cm (1 foot) long. Beryl is commonly associated with quartz.

Examination of the orientation of fifty-six beryl crystals in the central zone of a pegmatite dyke revealed that the favoured orientation is with the c axes nearly perpendicular to the walls.

Spodumene

Locally spodumene may comprise up to 30 per cent by volume of a pegmatite dyke, but the general average content is estimated to be about 2 or 3 per cent. This mineral tends to be concentrated in tabular zones that lie parallel with the dyke walls but which may be situated anywhere except immediately adjacent the walls. Grain size is highly variable, ranging to a maximum length of about 30 cm (1 foot).

Spodumene grains are commonly elongate, the long axes may be randomly oriented or nearly perpendicular to the walls. The latter orientation has been observed by Derry (1931), Tremblay (1950), Rowe (1954), and others, and is evidently a common feature of spodumene pegmatite dykes in general.

Tourmaline

In some dykes in granite, tourmaline grains are evenly distributed, in others they are concentrated in the marginal zones, and in yet others in the central zones. One of the highest concentrations found was in a dyke 1 metre (3.7 feet) thick where twenty crystals ranging in size from very small to 6 cm are exposed in an area of 9 square feet. In some dykes the c axes of tourmaline crystals are randomly oriented whereas in others there is a distinct tendency for these to be oriented perpendicular to the walls.

Garnet

At site 146 (Fig. 4), a pegmatite dyke 3 cm thick in granite contains approximately 3 per cent garnet. The mineral occurs as irregularly shaped masses ranging from 1 to 6 mm in diameter, evidently concentrated to some extent in the two marginal zones that form about one half of the total dyke. At site 206 (Fig. 2) a large pegmatite dyke in schist contains a minute amount of garnet, confined to places less than 1 metre from the walls. The garnet occurs as nearly euhedral grains, ½ mm in diameter, irregularly distributed in the marginal zones. No garnet was found in the adjacent schist.

Apatite

Apatite is a common minor constituent of pegmatite dykes. The mineral occurs as subhedral grains, irregularly distributed and not confined to particular zones.

Further information on mineral distribution, grain size, and orientation appears in Tables VII and VIII and the interpretation of these features is discussed in Chapter VII.

TABLE VII | *Description of Rock Units in a Pegmatite Dyke (see Fig. 14)*

Unit	Minerals	Description
A	plagioclase quartz muscovite	Grain size variable (minute to 3 cm). Quartz forms pods in central zone, and narrow (3 mm) veins along walls. Muscovite grains are oriented perpendicular to walls in the marginal zones, and are randomly oriented in the central zone. A sharp contact separates unit A from unit B.
B	plagioclase quartz (±3%) muscovite	Grain size variable (minute to 3 cm). Muscovite is nearly evenly distributed, and quartz is concentrated in a narrow central zone. Plagioclase occurs as prismatic grains, slightly elongate or tabular, oriented perpendicular to the walls; muscovite grains appear randomly oriented. A few grains of a phosphate mineral present. An increase in quartz content marks the boundary between units B and C.
C	plagioclase quartz (10–15%) muscovite	Grain size variable, reaching a maximum of 1½ cm for muscovite and 3 cm for plagioclase. Muscovite (increasing in concentration towards the north) occurs as clusters, about 15 cm in diameter. Quartz locally is somewhat concentrated in a zone near the centre-line of the dyke; otherwise minerals are evenly distributed. All mineral grains (including muscovite grains in clusters) appear randomly oriented. Appearance of potash feldspar marks the gradational boundary between units C and D.
D	plagioclase potash feldspar quartz muscovite	Grain size variable, reaching a maximum of 6 cm for muscovite; potash feldspar grains mainly between 3 and 12 cm. Plagioclase and potash feldspar are distributed throughout the unit, but locally potash feldspar is confined to the central zone and plagioclase to the marginal zones. Potash feldspar may occur as relatively small grains at the pegmatite–schist contact. The total content of potash feldspar increases towards the north end of the dyke. Quartz is unevenly distributed, locally forms pods, and tends to be concentrated in the central zone. Muscovite grains tend to form clusters as in unit C, but in the marginal zones tend to be oriented nearly perpendicular to the walls. A few grains of phosphate mineral and arsenopyrite are present.

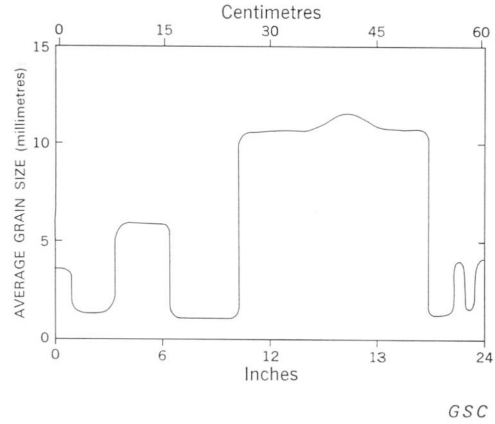

FIGURE 38. Variation in grain size across a pegmatite dyke (site 284, Fig. 3).

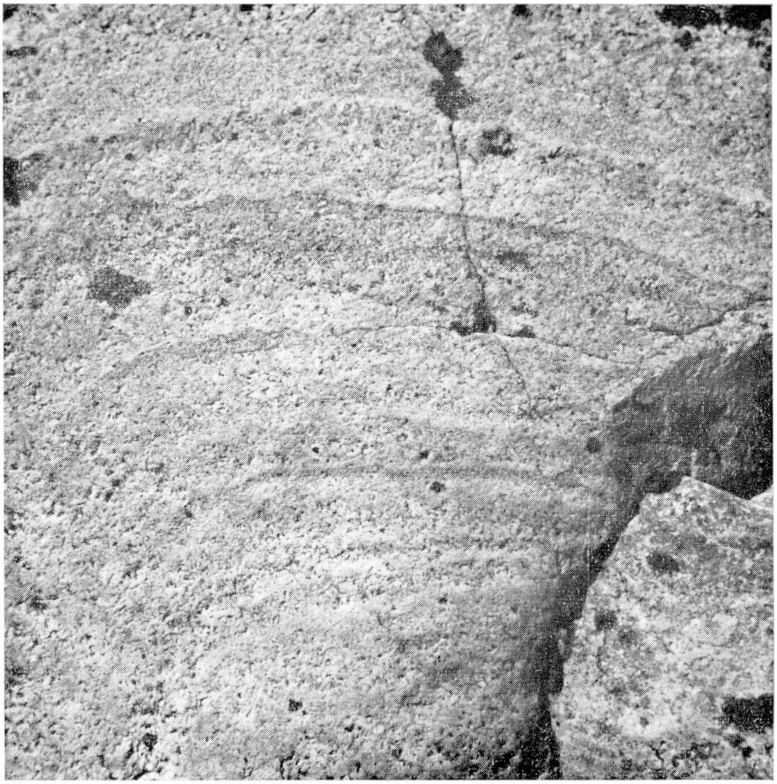

PLATE XIX
Laminar structure in pegmatite. (Site 374, Fig. 4.)

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Pegmatite Textures

No other group of rocks displays the variety and complexity of texture as is found in pegmatites. In this aspect pegmatite rocks differ from common metamorphic rocks and from rocks known to have crystallized from silicate melt (basalt, diabase dykes, etc.), and are more like certain metasomatic rocks of great heterogeneity (e.g., skarns). It seems desirable therefore, despite difficulties of interpretation, to collect detailed information on pegmatite textures. Recently, this has to some extent been done by the valuable study of Norton and others (1962).

Certain textural features of the Yellowknife–Beaulieu pegmatite rocks are briefly considered in the following. This part of the study is far from comprehensive, and is intended only to focus attention on the problem of pegmatite textures, and to emphasize the remarkable peculiarities of these textures compared with those found in rocks of known igneous origin.

Grain Size

Some information on variation in grain size of specific minerals in pegmatite dykes was given above, and the tendency for minerals to be coarser in the central zones and finer in the marginal zones was noted. However, rarely if ever is there a systematic relationship between grain size and distance from a wall, as is found in diabase dykes (Fig. 38). In general, variations are so great that if a curve like that of Figure 38 were drawn for each mineral, the curves would all be quite different. In the extreme case, where large and small grains of a mineral are found helter-skelter throughout the dyke, no curve of this kind could be constructed.

Locally, in the large dykes east of Sparrow Lake, a faint laminar structure was observed (Pl. XIX). These structures are confined to certain parts of the pegmatite dykes, and are oriented so that the convexity faces the nearest wall. They appear to reflect variation in the size of quartz and feldspar grains.

On the microscopic scale, variation in grain size is especially apparent. Small grains of muscovite or quartz are commonly aggregated along grain boundaries, and aggregates of fine muscovite grains are found within albite grains, locally concentrated along certain crystallographic planes.

Mineral Intergrowths

Mineral intergrowths form one of the most controversial aspects of pegmatite texture. In addition to the puzzling quartz-feldspar intergrowths that have been discussed by Bastin (1910), Schaller (1925), Wahlstrom (1939), Gurieva (1957), Nikitin (1958), Simpson (1962), and others, there are the common feldspar-feldspar intergrowths as described by Andersen (1928), Adamson (1942), Higazy (1953), and many others, and the less common quartz-muscovite, quartz-tourmaline, and quartz-garnet intergrowths as noted by Bastin (1910) and others.

Mineral intergrowths are not so common in those parts of the Yellowknife–Beaulieu terrain examined by the writer as in other pegmatite terrains. Nevertheless, all the above-mentioned intergrowths have been found locally, especially in pegma-

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PLATE XX
Quartz–spodumene intergrowth in pegmatite. White = spodumene, grey = quartz. (Site 467, Fig. 2.)

tite masses underlying the Staple Lake area. In addition to these, plagioclase-muscovite intergrowths are rather common and quartz-spodumene intergrowths were found near Thompson Lake (Pl. XX).

Since different kinds of mineral intergrowths are found in a single pegmatite body, it is obvious that all the intergrowths cannot be products of eutectic crystallization (Bastin, 1910).

Deformed Mineral Grains

It is well known that pegmatite mineral grains commonly show signs of deformation or strain, sometimes more pronounced than those found in metamorphic tectonites. Thus broken tourmaline crystals with the fractures healed by quartz, feldspar, or additional tourmaline have been described by Mäkinen (1913), Anderson (1933), Brotzen (1959), and others. Similarly, beryl crystals may be broken, as described by Megathlin (1929), Anderson (1933), and others. In the Yellowknife–Beaulieu terrain, these textures have been found at several places.

It is noteworthy that some of the tourmaline and beryl crystals of the Yellowknife–Beaulieu terrain are not only fractured, but the fractures have 'opened', i.e., the broken pieces have been displaced one relative to another. These crystals are found in pegmatite dykes that do not display evidence of gross deformation (folding, pinch-and-swell, or boudinage structures), and hence the breaking cannot be attributed to large-scale deformation. It appears more likely that the fractures occurred during pegmatite emplacement.

If the above interpretation is correct, the process of pegmatite emplacement must have been unique inasmuch as directional stresses were applied to break the crystals, and the broken fragments were only slightly displaced. The crystals must therefore have been surrounded by solid rather than fluid matter.

Additional evidence of strain is found in bent albite twin planes in plagioclase grains, as shown in Plate XXI and reported from other terrains by Megathlin (1929), Carl (1962), and others. Mosaic structure in quartz grains is present and may also be evidence of strain. This structure has been observed in other pegmatite bodies by Quensel (1942) and Ramberg (1956). Mosaic structures are also apparently present in plagioclase (Pl. XXI).

Bent twin planes and mosaic structures do not represent a great deal of strain, and generally it is not possible to determine if the implied strain occurred during pegmatite emplacement or during a later tectonic disturbance. Thus the feldspar shown in Plate XXI was taken from a dyke that contains some flexures, which may have formed during a post-pegmatite regional deformation (coordinates B-19, Fig. 14), albeit from a part of the dyke that is apparently undeformed.

PLATE XXI
Bent twin lamellae and mosaic structure in a plagioclase grain within pegmatite. (Site 372, Fig. 4.)

Detailed Texture of a Small Pegmatite Vein

The texture of a small vein-like projection from a larger pegmatite mass has been examined in detail. The pegmatite body is shown in Figure 24, and a cross-section of the vein at A is shown in Figure 39. The vein at this place contains quartz, albite, muscovite, tourmaline, and intergrowths of biotite and chlorite; the adjacent schist contains quartz, plagioclase, biotite, and minor muscovite. The following points of interest have appeared:

1. The contact of the vein with the enclosing schist may be either sharp and clearly definable, or gradational and difficult to define exactly.

2. Grains of biotite presumably derived from the wall-rock are present locally in the margin of the vein. Relatively large grains of a biotite–chlorite mixture, of less certain derivation, are found in the central region of the vein. If these grains were derived from the wall-rock, recrystallization has caused grain enlargement.

3. Variation in the size of muscovite, quartz, and albite grains is obviously very great. In certain places the average grain size of these minerals is relatively small (e.g., at coordinates G-20), and their average in the vein margins is less than the average for the whole vein, but greater than the average for the fine-grained patches.

4. Within the space examined, tourmaline grains are confined to one of these fine-grained patches.

5. Although the distribution of muscovite grains generally appears to be nearly random, here and there (e.g., at G-15 and B-12) it is clearly in clusters.

6. A slight tendency exists for muscovite grains to be arranged with (001) planes perpendicular to the vein walls. This is especially apparent in the vicinity of D-5. In the central region of the vein the tendency disappears, indeed, a cluster of grains was found there in which all grains are arranged parallel with one another but not perpendicular to the walls (B-11). Some of the grains in this cluster are very small and are apparently isolated inclusions in albite grains.

7. There is a slight tendency for quartz grains to be oriented with crystallographic c axes perpendicular to the vein walls. This is evident in the vicinity of C-18 and elsewhere.

These observations show clearly that the texture of pegmatite veins differs greatly from that of dykes known to have crystallized from a melt, and suggest that the processes of crystallization were different and more complex than those that take place in silicate melts.

Mineralogic Relationships Between Pegmatite and Enclosing Rocks

Relationships Observed

It is now well known that, at least in some crystalline terrains, relationships exist between minerals of pegmatite masses and minerals of the enclosing rocks. These relationships must be a product of the pegmatite-forming process and as such deserve careful consideration. The following relationships were observed in the Yellowknife–Beaulieu terrain.

1. Within the boundaries of the Sparrow Lake – Thompson Lake area and elsewhere, at least as regards the numerous pegmatite masses examined in sufficient detail to identify the contained feldspars, pegmatite masses that contain albite as the only feldspar were common in schist but absent in granite.
2. Dykes that cross a granite–schist contact were particularly interesting. They are not uncommon; two relatively large dykes (Fig. 2) and several smaller ones (Fig. 7) observed to intersect the same granite–schist contact were studied in detail.

The mineral assemblages in the parts of the larger dykes in granite were not noticeably different from those in the parts in schist. In the small dykes (Fig. 7), however, those parts of the dykes in the granite containing potash feldspar also contain potash feldspar, whereas those parts of the same dykes in granite or schist without potash feldspar do not contain potash feldspar.

3. A few pegmatite dykes were found to contain andalusite, sillimanite, or cordierite (Table VI, Chapter V), minerals characteristic of metasedimentary rocks. These dykes were found only in metasedimentary rock, never in granite.
4. In the eastern margin of the Sparrow Lake granite pluton, mica-rich inclusions (described in Chapter II) were found locally to be intersected by small pegmatite dykes. Where the pegmatite dyke is against the muscovite-rich inclusion, the muscovite content of the dykes is noticeably greater than where it is against granite.
5. Although different layers of the schist east of Sparrow Lake are composed of different mineral assemblages and proportions (Chapter II), no conspicuous analogous differences were observed in any of the enclosed pegmatite dykes. The schist also contains numerous quartz veins, commonly lying parallel with the layered structure, and small pegmatite dykes were observed to intersect these veins without noticeable change in mineral content. An important exception to this is illustrated in Figure 40. A small quartz-feldspar pegmatite vein or dyke cuts across a quartz-tourmaline layer in schist, and where it crosses this layer it changes to a pure quartz vein. Figure 40 however also shows another pegmatite vein that intersects the same quartz-tourmaline layer without noticeable change in mineral content.

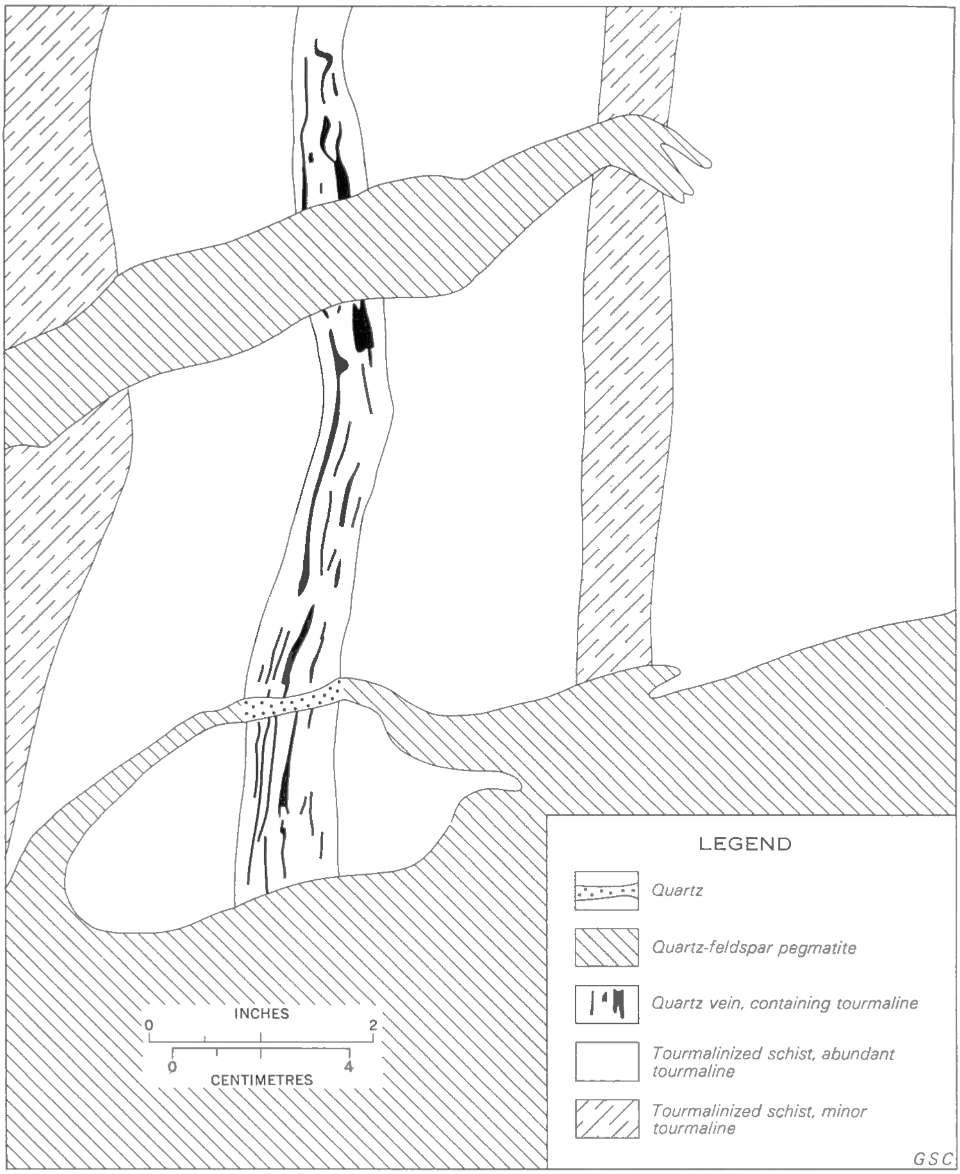

FIGURE 40. Pegmatite veins in schist (site 122, Fig. 4). Where the small vein intersects a quartz–tourmaline layer, the vein is composed of pure quartz.

Interpretation

Relationships between the mineral content of pegmatite masses and that of the enclosing rocks have been recorded and discussed for many years, for example, Roy and others (1939), Bouladon and others (1950), Joklik (1955a), Ramberg (1956), and Hitchon (1960). As noted by A. M. Smith in 1899 (reported by Roy, *et al.*, 1939), observations of this kind were probably responsible for the hypothesis that attributes the source of the pegmatite-forming matter to the enclosing rocks. This hypothesis, though rarely adopted, has gained great strength as a result of extensive detailed observations by Ramberg (1949, 1952, 1956), and also by Higazy (1953), Reitan (1956, 1959a), Heier and Taylor (1959), Ryabchikov and Solov'yeva (1961), and others.

The data obtained from the Yellowknife–Beaulieu terrain are too meagre to contribute much to this discussion. Indeed, the exceptions found to the 2nd, 4th, and 5th observations enumerated above prohibit the formulation of any general statement. The only conclusion that can be reached from these data is that, in certain cases, some of the pegmatite-forming matter was derived from the enclosing rocks.

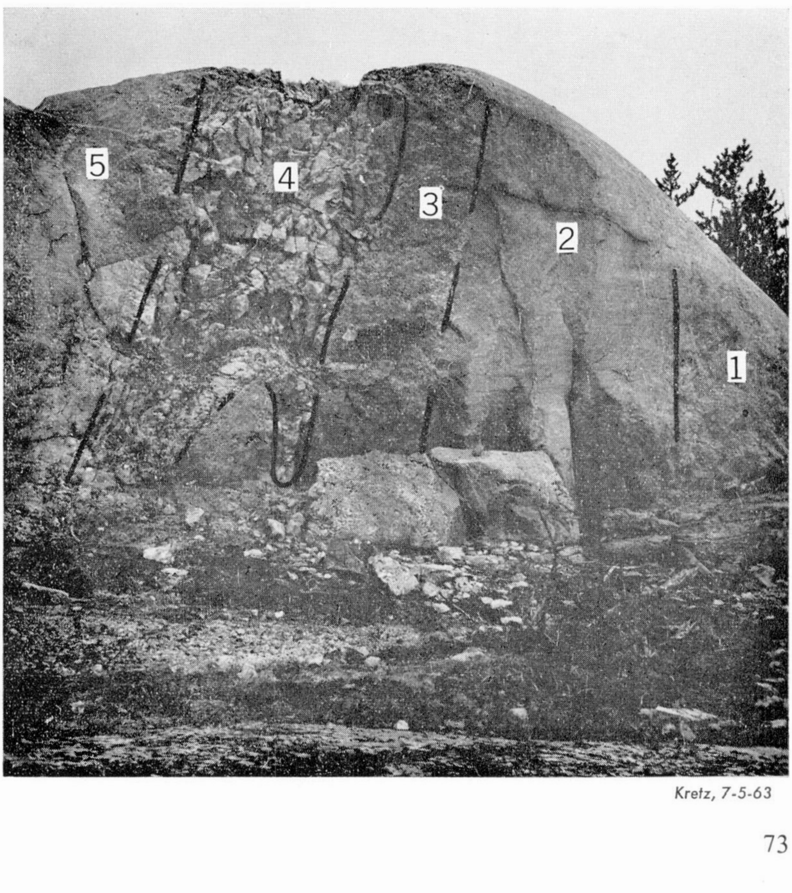

PLATE XXII
Zones 1 to 5 of the pegmatite dyke of Figure 37.

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TABLE VIII *Description of Zones in a Pegmatite Dyke (refer to Figure 37)*

Zone	Minerals	Description
1	albite potash feldspar quartz muscovite apatite garnet	Grain size highly variable, reaching a maximum of about 1 cm for albite, quartz, and muscovite, and about 30 cm for potash feldspar. The relatively large crystals of potash feldspar, containing inclusions of quartz, are scattered in the matrix of predominantly albite, potash feldspar, quartz, and muscovite.
2	albite potash feldspar quartz muscovite apatite ilmenite?	Nearly even grained, grain size about 1 mm. Zone contains some quartz-feldspar veins in which feldspar crystals reach a diameter of 3 cm. These veins dip steeply west. Potash feldspar to albite ratio in this zone is approximately 1:1.
3	albite quartz muscovite apatite garnet magnetite	Grain size variable, reaching a maximum of about 2 cm for each of albite, quartz, and muscovite. Minerals are evenly distributed and randomly oriented.
4	albite quartz muscovite cordierite	Largest grains of albite, quartz, and muscovite are 50 cm, 20 cm, and 4 cm respectively. One grain of cordierite (about ½ cm in diameter) was observed. Albite grains show mosaic structure and contain tiny inclusions of muscovite.
5	albite potash feldspar? quartz muscovite	Similar to zone 2
6	albite quartz muscovite apatite unknown	Irregular mixture of masses of pegmatite of grain size about ½ cm and masses of pegmatite of grain size up to 10 cm.
7	albite potash feldspar quartz muscovite epidote? unknown	Grain size ranges from about ½ cm in margin of zone to about 30 cm for feldspar, and 15 cm for quartz in the centre of this zone. Muscovite occurs in aggregates, together with quartz, of grain size ½ cm.
8	albite potash feldspar quartz muscovite magnetite or ilmenite carbonate apatite?	Grain size highly variable, ranging from 1 mm to 15 cm. Average grain size decreases slightly towards pegmatite–schist contact. In specimen collected, maximum grain diameters of albite, potash feldspar, quartz, and muscovite are 3 mm, 20 mm, 3 mm, and 10 mm respectively. Potash feldspar: plagioclase ratio is approximately 1:3. Small amount of albite lamellae in potash feldspar.

Distribution of Sodium and Potassium Among Albite, Potash Feldspar, and Muscovite

Data on Equilibrium Relations and Their Interpretation[1]

A study was made of the sodium and potassium content of albite, potash feldspar, and muscovite from a relatively large pegmatite dyke enclosed by schist. A vertical cross-section of this dyke was examined in detail, leading to a subdivision into eight zones, based on mineral assemblage and texture (Fig. 37, Table VIII, and Pl. XXII).

Specimens were collected from the zones, at places indicated in Figure 37. Those measuring approximately 8x4x3 cm were selected for mineral separation and analysis, and with the exception of some large potash feldspar crystals, the minerals of each specimen are considered to comprise a coexisting assemblage. The sodium and potassium content of the minerals, the index of refraction of albite, and the atomic ratios calculated are listed in Table IX.

[1]Subsequent experimental data (Eugster, pers. com.), have demonstrated the existence of an albite–muscovite field and have shown that the muscovite–paragonite solvus lies at a slightly lower temperature than first reported. Consequently a slight modification of the above discussion is necessary. The temperatures listed in the second-last column of Table X must be decreased by about 25 degrees. Point b in Figure 43 must be shifted to the right to 0.12. Temperatures of crystallization of specimens 3, 4, and 6, based on the composition of muscovite and Figure 43, are estimated to be equal to or slightly less than 450 degrees (Table X, last column).

TABLE IX — *Sodium and Potassium Content of Albite, Muscovite,[1] and Potash Feldspar from a pegmatite dyke (refer to Figure 37 for relative position of samples)*

Zone No.	Mineral	Na_2O	K_2O	$\frac{Na}{Na+K}$	Index of refraction X	Index of refraction Z	Anorthite[2] (mol. fraction)
3	albite	10.2	0.54	0.97	1.528	1.539	<0.03
4	albite	10.4	0.75	0.96	1.528	1.539	<0.03
6	albite	7.5	4.8	0.70	1.529	1.540	<0.03
7	albite	9.9	0.58	0.96	1.528	1.539	<0.03
8	albite	9.5	0.78	0.95	1.529	1.540	<0.03
1	muscovite	0.64	10.5	0.085			
2	muscovite	0.64	10.3	0.086			
3	muscovite	0.72	9.7	0.101			
4	muscovite	0.76	10.1	0.102			
6	muscovite	0.74	10.1	0.100			
7	muscovite	0.65	10.3	0.088			
8	muscovite	0.68	10.2	0.092			
1	K feldspar[3]	2.3	12.8	0.214			
7	K feldspar	2.8	12.4	0.255			
8	K feldspar	1.7	13.3	0.163			

R. K. analyst

[1] X-ray powder photographs reveal that all muscovites are common 2M polymorphs (Yoder and Eugster, 1955).

[2] Based on index of refraction measurements compared with the data of Smith (1960).

[3] Large crystals, may not be 'coexisting' with associated muscovite and albite.

The index of refractions indicates that the albite specimens contain a very small calcium content. These minerals are therefore regarded as essentially binary solid solutions of $NaAlSi_3O_8$(Ab) and $KAlSi_3O_8$(Or). As potash feldspar generally contains only very small amounts of calcium, this mineral is also regarded as a binary solid solution of Ab and Or. Similarly, muscovite is regarded as a solid solution of $KAl_3Si_3O_{10}(OH)_2$ (Mu) and $NaAl_3Si_3O_{10}(OH)_2$ (Pg).

In only one of the specimens from which potash feldspar was analyzed (No. 8) are the feldspar phases so closely associated that they may be reasonably inferred to represent an equilibrium association. According to the solvus of Barth (1959), this mineral pair was equilibrated at approximately 450°C (Fig. 41). According to this solvus and the solvus in the system Mu-Pg (Eugster and Yoder, 1955), other minerals of the pegmatite mass provide the lower limits of temperature listed in Table X.

TABLE X — *Deductions Regarding Temperature of Pegmatite Crystallization (in °C)*

No.	Based on Na content of potash feldspar (Barth, 1959)	Based on K content of albite (Barth, 1959)	Based on Na content of muscovite: (Eugster and Yoder, 1955)	Based on Na content of muscovite: Proposed equilibrium diagram, Figure 43
1	⩾500	—	⩾410	<450
2	—	—	⩾410	<450
3	—	—	⩾450	⩾450
4	—	—	⩾450	⩾450
6	—	⩾700	⩾450	—
7	⩾550	—	⩾425	<450
8	≃450	≃450	⩾425	450

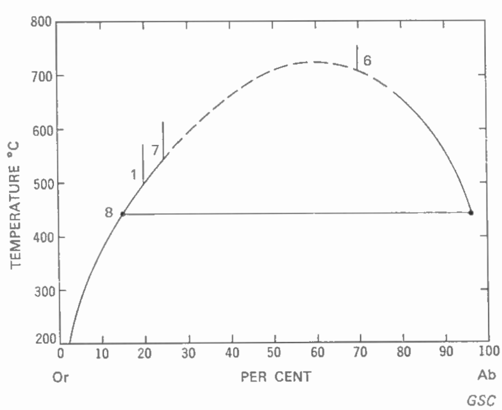


FIGURE 41
The alkali feldspar solvus, according to Barth (1959). The composition of certain feldspars of Table IX in relation to the solvus is indicated.

The compositional data for specimen 8 together with the solvus of Barth (1959) and Eugster and Yoder (1955) may be used to construct an equilibrium diagram for the system $KAlSi_3O_8$ – $NaAlSi_3O_8$ – $Al_2O_3.H_2O$ at about 450°C (Fig. 42). This diagram differs slightly from that constructed by Eugster and Yoder, as the solvus of Barth was used in place of the solvus of Tuttle and Bowen (1958). The main difference however is that from the present study, a two-phase field (muscovite+albite) is inferred to exist in this system.

In relation to pegmatite, the assemblage potash feldspar+albite+muscovite is of greatest interest. According to the phase rule, the Na:K ratio of each of these phases becomes invariant, provided temperature and pressure are fixed. Hence the sodium content of muscovite is temperature dependent, provided it coexists with potash feldspar and albite. This is expressed by a movement of point a to the right,

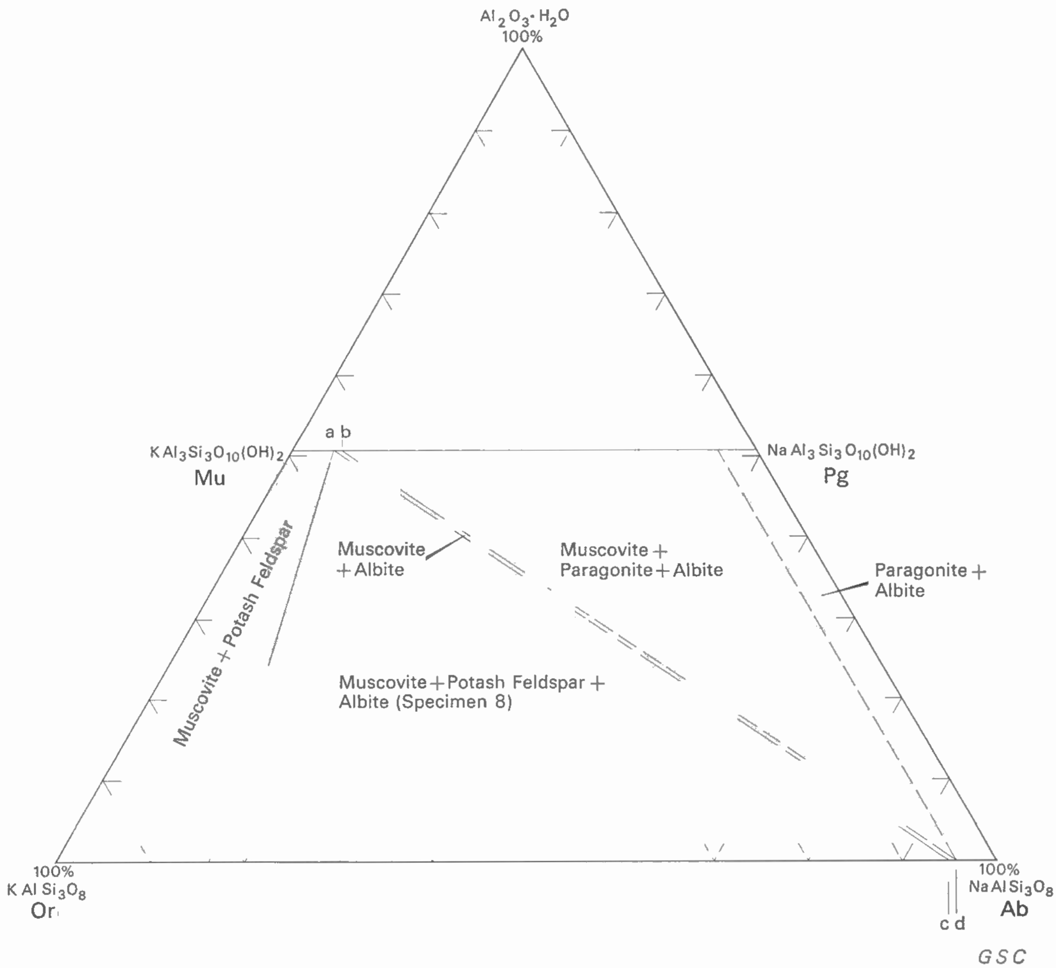


FIGURE 42. Suggested equilibrium relations in a part of the system $KAlSi_3O_8$–$NaAlSi_3O_8$–Al_2O_3. H_2O at about 450°C based on the muscovite-paragonite solvus of Eugster and Yoder (1955), the alkali feldspar solvus of Barth (1959), and pegmatite specimen 8 (Table IX).

along the line Mu-Pg, as temperature rises. The point cannot of course move beyond point b, which represents the maximum sodium content possible in muscovite at the specified temperature.

The position of the boundaries in the right-hand side of the diagram is less certain. The position of point d, as marked, is hypothetical, but it may be noted that this point must lie to the right of point c, or it may coincide with c.

Muscovite 1 and 2 coexist with two feldspar phases, and hence its sodium content should provide an indication of the temperature of crystallization. As these contain smaller concentrations of sodium than found in muscovite 8 (Fig. 43), they have presumably crystallized at a temperature lower than about 450°C. Muscovite 3 and 4 coexist with albite but not with potash feldspar, and consequently, at about 450°C their sodium content should lie between points a and b (Fig. 43). As the points lie to the right of b, specimens 3 and 4 are inferred to have crystallized at temperatures greater than about 450°C. Specimen 7, which also is not associated

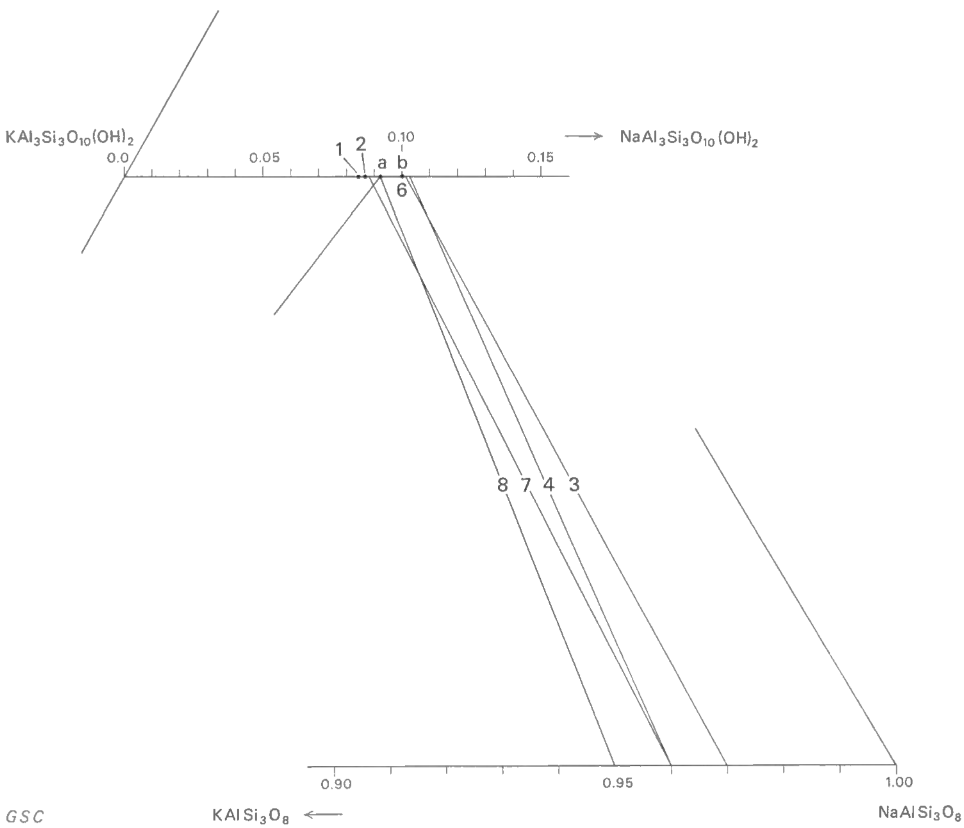


FIGURE 43. Distorted phase diagram, showing position of the tie lines joining muscovite and albite for different specimens from a pegmatite dyke. Numbers correspond to those of Figure 37 and Table X. The invariant muscovite composition indicated by assemblage 8 is marked (a), and the maximum permissible sodium content of muscovite at 450°C is marked (b).

with potash feldspar, lies to the left of point a, and is therefore inferred to have crystallized at a temperature lower than about 450°C. Finally, muscovite 6 coincides with point b, and therefore represents a temperature greater than about 450°C. Note that the associated albite contains an unusually high potassium content, reflecting a temperature greater than about 700°C (Fig. 41). Since this albite is anomalous in the pegmatite mass under study, it is questionable if it represents equilibrium conditions. The muscovite–albite tie-line is therefore omitted from Figure 43.

Specimens 3, 4, and 7 do not contain potash feldspar, and if these specimens crystallized at a uniform temperature they would provide information regarding the position of the tie-lines in the two-phase region muscovite+albite. Since the position of the field shifts as a function of temperature and pressure, the tie-lines experience both a shift and rotation with change in temperature and pressure. However, tie-lines 3, 4, and 7 are not even approximately parallel, which indicates that the three mineral pairs did not crystallize at a uniform temperature and pressure, assuming equilibrium prevailed.

Although the data of Table X are somewhat contradictory, they suggest that the central zones of the dyke crystallized at a higher temperature than the marginal zones.

Variations in Composition of Albite and Muscovite

Numerous investigations have been reported recently on variations in the chemical composition (both major and trace elements) of minerals within single pegmatite bodies. These studies have dealt with a large number of minerals and elements. The work of Staatz, *et al.* (1955), Oftedal (1959), Solodov (1960), and Hitchon (1960) is especially noteworthy. Numerous trends have been established of a progressive increase or decrease in the concentration of certain elements from the margin to the central region of pegmatite masses.

The data of Table IX show that in a dyke near Sparrow Lake the Na content of muscovite increases from margin to centre. Such is not so however for dykes in other terrains. Grootemat and Holland (1955), Solodov (1960), and Norton and others (1962) all report a decrease in the sodium content of muscovite from margin to core. The cause of this disagreement is not known.

The data of Table IX also show that the potassium content of albite in one of the intermediate zones is much higher than in the marginal zones. Otherwise, the Na:K ratio in albite is remarkably uniform all across the dyke. These findings are in general agreement with those of Solodov (1960) who reported an enrichment of potassium in albite within the central region relative to albite in the marginal zones.

Although a systematic variation in mineral composition from margin to centre may be expected from the crystallization of a silicate melt under certain conditions, similar variations may conceivably also result from other processes, and the data discussed here do not immediately lead to a conclusion concerning pegmatite crystallization.

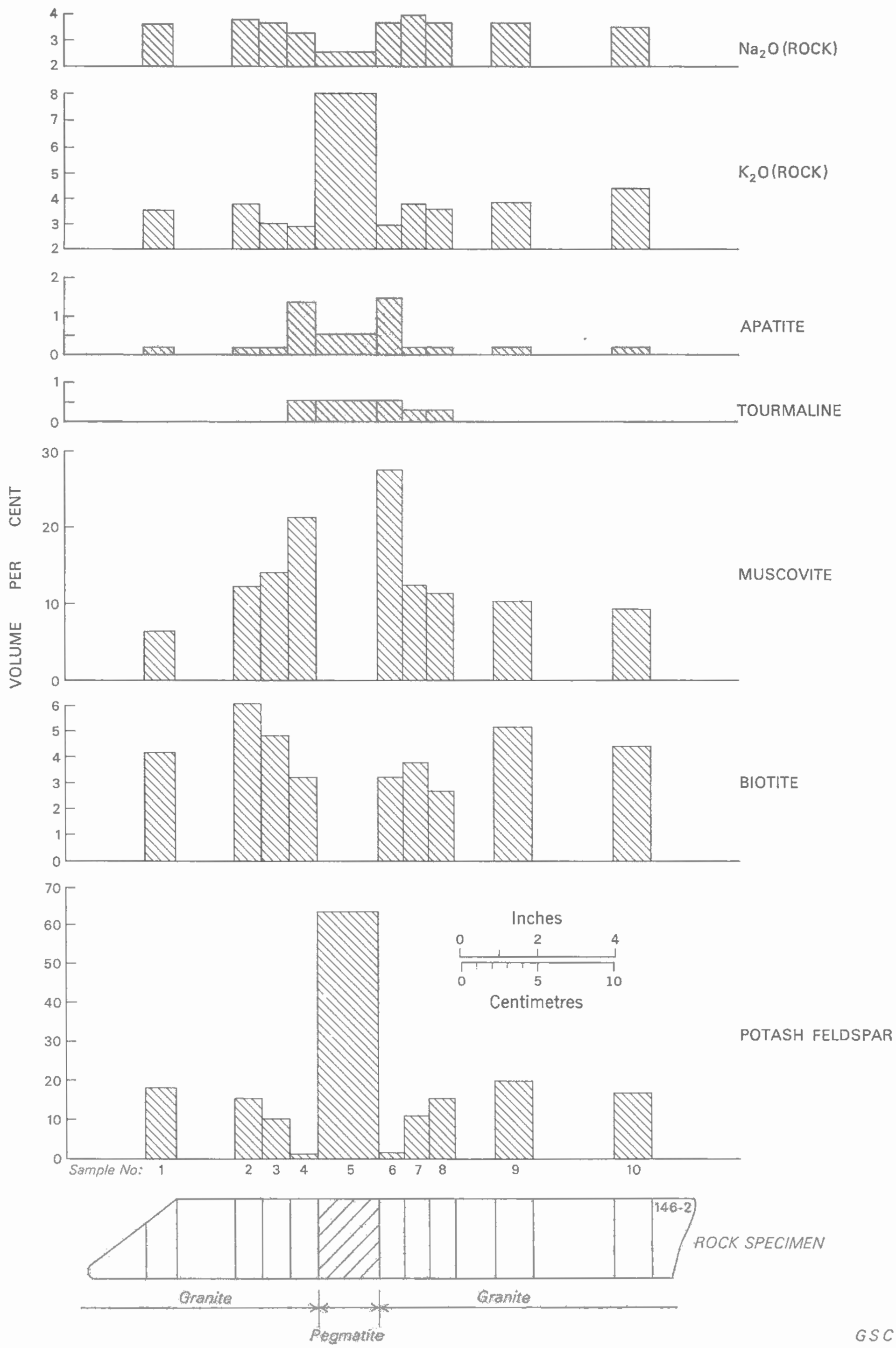


FIGURE 44. Profiles across a pegmatite dyke in granite (Pl. XXV) with reference to sodium and potassium content and volume per cent of apatite, tourmaline, muscovite, biotite, and potash feldspar.

Chapter VI

WALL-ROCK ALTERATION

Some of the pegmatite dykes in the eastern margin of the Sparrow Lake pluton are surrounded by aureoles of rock enriched in muscovite and depleted in potash feldspar. The aureoles are commonly 1 to 3 cm thick and are slightly darker than the normal Sparrow Lake granite (Pl. XXIII). Similarly some of the pegmatite bodies in schist of the Yellowknife–Beaulieu region are surrounded by aureoles of variable thickness, characterized by abundant tourmaline (Pl. XXIV). An understanding of these wall-rock alterations may be of considerable intrinsic value, and may, in addition, throw some light on the closely associated pegmatite-forming process.

Muscovite-rich Aureoles about Pegmatite Dykes in Granite

Muscovite-rich aureoles are associated with various pegmatite dykes in the eastern margin of the Sparrow Lake granite pluton, but most commonly with dykes of the easterly trending swarms, as found for example at site 146 (Fig. 4). No apparent relationship exists between the thickness of dykes and the thickness of the associated aureoles. The aureole about the pegmatite dyke shown in Plate XXV was examined in detail. This is an easterly trending vertical dyke with a maximum thickness of 6 cm and a plan length of more than 24 metres. The nearest dyke to the north is 25 cm, and to the south, 90 cm.

Units studied (1 to 10) were at intervals across the dyke, extending well into the country rock beyond the aureole but not into the aureoles of the adjacent dykes (Fig. 44). Mineral assemblages, mineral proportions, estimates of plagioclase composition, and the sodium and potassium content of each unit were determined and are listed in Table XI. Some of these data are presented graphically in Figure 44, which expresses the observed variation in volume per cent of potash feldspar, biotite, muscovite, tourmaline, and apatite, and the sodium and potassium content of the wall-rock as a function of distance from the pegmatite dyke.

In Chapter II a remarkable homogeneity in the northeastern part of the Sparrow Lake pluton is noted, and in Table IV mineral proportions of a typical specimen (No. 1) are presented. A comparison of this specimen with the granite on either side of the aureole under study reveals that the proportions of all the samples of granite are nearly identical. It is assumed therefore that the muscovite-rich aureole about the pegmatite dyke initially possessed a mineral assemblage and mineral proportion similar to that of the granite beyond the aureole.

It is immediately apparent (Fig. 44) that the transformation of granite adjacent the pegmatite dyke involved an increase in the content of muscovite, tourmaline, and apatite, and a decrease in the content of potash feldspar and possibly biotite. The proportions of quartz and plagioclase have not noticeably changed, but the chemical composition of the plagioclase is estimated to have changed slightly (Table XI). The estimated slight increase in the sodium content of plagioclase is not however reflected in the sodium profile (Fig. 44).

TABLE XI — *Variation in mineral assemblage, mineral proportion (volume per cent), estimated plagioclase composition, and sodium and potassium content in a zone extending across a pegmatite dyke, its aureole, and the adjacent normal granite (refer to Fig. 44 for relative positions of units 1 to 10)*

Units	1	2	3	4	5[1]	6	7	8	9	10
quartz	36	29	38	42	27	34	34	29	40	32
plagioclase	35	38	33	31	11	34	39	43	25	37
potash feldspar	18	15	10	½	62	1	11	15	20	17
biotite[2]	4.2	6.0	4.8	3.2	0	3.2	3.8	2.7	5.1	4.4
muscovite	6.6	12	14	21	<½	27	12	11	10	8.7
tourmaline	0	0	0	½	½	½	<½	<½	0	0
apatite	<½	<½	<½	1.3	½	1.4	<½	<½	<½	<½
beryl	0	0	0	0	<½	0	0	0	0	0
[3]Na_2O	3.6	3.8	3.6	3.3	2.5	3.6	3.9	3.6	3.6	3.4
[3]K_2O	3.6	3.7	3.0	2.9	≃ 8.0	2.9	3.7	3.5	3.7	4.2
plagioclase										
Max. extinction angle	11	12	13	15	17	14	13½	13	12	11
An estimated composition	10	9	7	6	0	6	7	7	9	10

[1] pegmatite   [2] includes minor chlorite   [3] R. K. analyst

The inverse relationship between the muscovite and potash feldspar content within the aureole is expressed graphically in Figure 45. This relationship, as seen especially in the left wall (i.e., the left side of Figure 44) suggests the possibility that muscovite crystallized at the expense of potash feldspar.

It is possible to write several potential reactions to produce muscovite from potash feldspar. The most simple of these does not require an addition or removal of potassium and silicon:

$$\underset{\substack{\text{potash feldspar} \\ 109\text{ cc}}}{KAlSi_3O_8} + Al_2O_3 + H_2O \rightarrow \underset{\substack{\text{muscovite} \\ 140\text{ cc}}}{KAl_3Si_3O_{10}(OH)_2} \qquad (a)$$

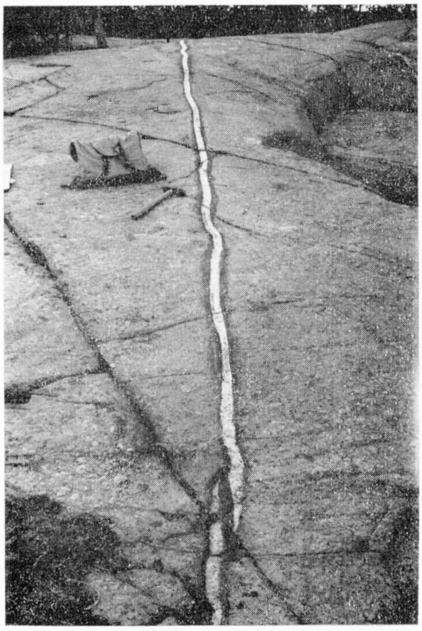
According to this reaction each cc of potash feldspar will form approximately 1.3 cc of muscovite. Another possible reaction is one in which there is no effective addition or removal of oxygen ions:

$$\underset{\substack{\text{potash feldspar} \\ 109\text{ cc}}}{KAlSi_3O_8} + Al + 4/3\ H \rightarrow 2/3\ \underset{\substack{\text{muscovite} \\ 93\text{ cc}}}{KAl_3Si_3O_{10}(OH)_2} + 1/3\ K + Si \quad \ldots \quad (b)$$

According to this reaction each cc of potash feldspar yields approximately 0.85 cc of muscovite.

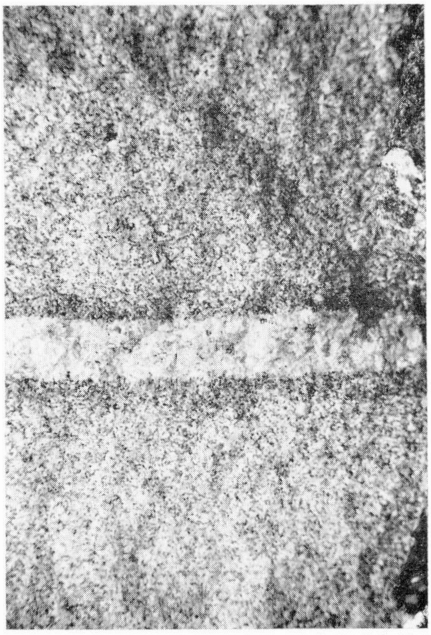
PLATE XXIII
Branching pegmatite dykes in the eastern margin of the Sparrow Lake granite pluton. Observe dark muscovite-rich aureoles. (Site 123, Fig. 2.)

Kretz, 8-8-60



Kretz, 13-7-60

PLATE XXIV Pegmatite dykes in nodular (cordierite-containing) schist of the Yellowknife Group. Observe dark, tourmaline-rich aureole. (North of Bighill Lake, lat. 63°31′N, long. 114°03′W.)



Kretz, 9-5-60

PLATE XXV Pegmatite dykes in Sparrow Lake granite. Observe dark, muscovite-rich aureole. This dyke, which is 4 cm thick, was selected for detailed study. (Site 145, Fig. 4.)

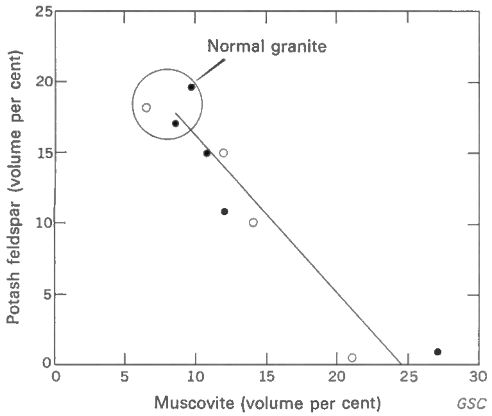


FIGURE 45
Reciprocal relationship between volume per cent of potash feldspar and muscovite in a contact aureole adjacent a pegmatite dyke in granite. Open circles refer to the left wall and closed circles to the right wall, as shown in Figure 44.

The calculations of Table XII show that in the aureole examined the disappearance of each cc of potash feldspar is accompanied by the appearance of approximately 0.83 cc of muscovite. This figure is nearly identical to that predicted by equation (b). Note also that equation (b) demands a removal of potassium which agrees with the observation that the muscovite-rich aureole has been depleted in potassium (Fig. 44). A reaction similar to (b) is therefore considered plausible.

Although the decrease in potash feldspar and the increase in muscovite are quantitatively the most important alterations imposed on the granite adjacent the

TABLE XII — *Calculation of mineral volume changes in an aureole about a pegmatite dyke in granite (data from Table XI; refer to Fig. 44 for relative positions of rock units 1 to 10)*

Mineral	Rock Unit	Volume (per cent)	Change in volume (cc of mineral per cc of rock)	Width of zone (cm)	Change in volume of mineral (in cc): in prism of rock 1 cm x 1 cm x width of zone		Change in volume of mineral (in cc): total
potash	1, 9, 10	0.18(av.)					
feldspar	2	0.15	—0.03	1.9	—0.057		
	3	0.10	—0.08	1.7	—0.136	—0.525	
	4	0.005	—0.175	1.9	—0.332		—1.00
	6	0.01	—0.17	1.7	—0.289		
	7	0.11	—0.07	1.8	—0.126	—0.469	
	8	0.15	—0.03	1.8	—0.054		
muscovite	1, 9, 10	0.084(av.)					
	2	0.12	+0.036	1.9	+0.068		
	3	0.14	+0.056	1.7	+0.095	+0.403	
	4	0.21	+0.126	1.9	+0.240		+0.83
	6	0.27	+0.186	1.7	+0.316		
	7	0.12	+0.036	1.8	+0.065	+0.428	
	8	0.11	+0.026	1.8	+0.047		

pegmatite dyke, the appearance of tourmaline and the increase in apatite in the aureole are definitely established (Fig. 44). A possible decrease in the amount of biotite within the aureole is suggested by the data of Figure 44, and it is possible that the iron and magnesium necessary to produce tourmaline there were derived from biotite. No information is available concerning the reaction that has produced a notable concentration of apatite in the aureole near the dyke. Perhaps the required calcium was derived from plagioclase. It is certain however, that some phosphorus was introduced, and, as most apatite crystals contain appreciable fluorine (Vasileva, 1957), some of this element was also probably introduced.

Another interpretation of the data of Figure 44 may be offered. Note that the profiles for potash feldspar and muscovite are the type to be expected if potash feldspar moved from the aureole to the dyke, while muscovite moved from the site now occupied by the pegmatite to the aureole. A calculation will show, however, that whereas a volume of 1.0 cc of potash feldspar is available (Table XII), a volume of 1.76 cc is required by the pegmatite dyke, and whereas a volume of 0.34 cc of muscovite would be made available from the volume of granite now represented by the dyke, a volume of 0.83 cc is required by the aureole (Table XII). The agreement between these pairs of figures is poor, and no positive evidence was found in the available data to support an hypothesis of mineral segregation for pegmatite formation. It may be noted in this connection that some dykes approximately a metre thick are surrounded by aureoles no larger than the one about the small dyke under study.

It is possible, however, that some of the pegmatite material was derived from the enclosing rock. As the wall-rock reactions have released potassium and as the pegmatite represents a concentration of potassium, some or all of the liberated potassium may have been used to produce pegmatite-forming minerals.

Variation in the Sodium and Potassium Content of Granite as a Function of Distance from a Beryl-containing Pegmatite Dyke

A particular beryl-containing dyke in the eastern margin of the Sparrow Lake granite pluton was examined from the viewpoint of variation in the sodium and potassium content of the surrounding granite as a function of distance from the dyke. The examination was extended well beyond a narrow but conspicuous muscovite-rich aureole about the dyke.

The dyke under study is at site 337 (Fig. 4). It strikes north, dips 75°W, and has a horizontal thickness of 1.8 feet (54 cm). It is composed of quartz, plagioclase, potash feldspar, muscovite, and beryl. An estimate of the beryl content, based on an intersection of five crystals in the area of 15 square feet, is 0.14 per cent. The muscovite-rich aureole is about 3 cm thick. Samples of granite were collected along lines nearly at right angles to the pegmatite-granite contact, and extend a distance of 12.6 feet west and 6.5 feet east of the dyke. The sodium and potassium analyses of the samples and of a channel sample of the dyke are listed in Table XIII and presented in graphic form in Figure 46.

TABLE XIII	*Sodium and potassium content of pegmatite and surrounding granite* *(refer to Figure 46 for relative positions of samples 1 to 10)*	
No.	Na_2O	K_2O
1	3.0	5.1
2	2.6	4.9
3	2.8	5.3
4	3.6	4.3
5	4.2	2.0
6	3.2	5.7
7	4.9	2.0
8	3.2	5.5
9	3.2	5.3
10	3.2	5.3

W. U. Romeny, analyst

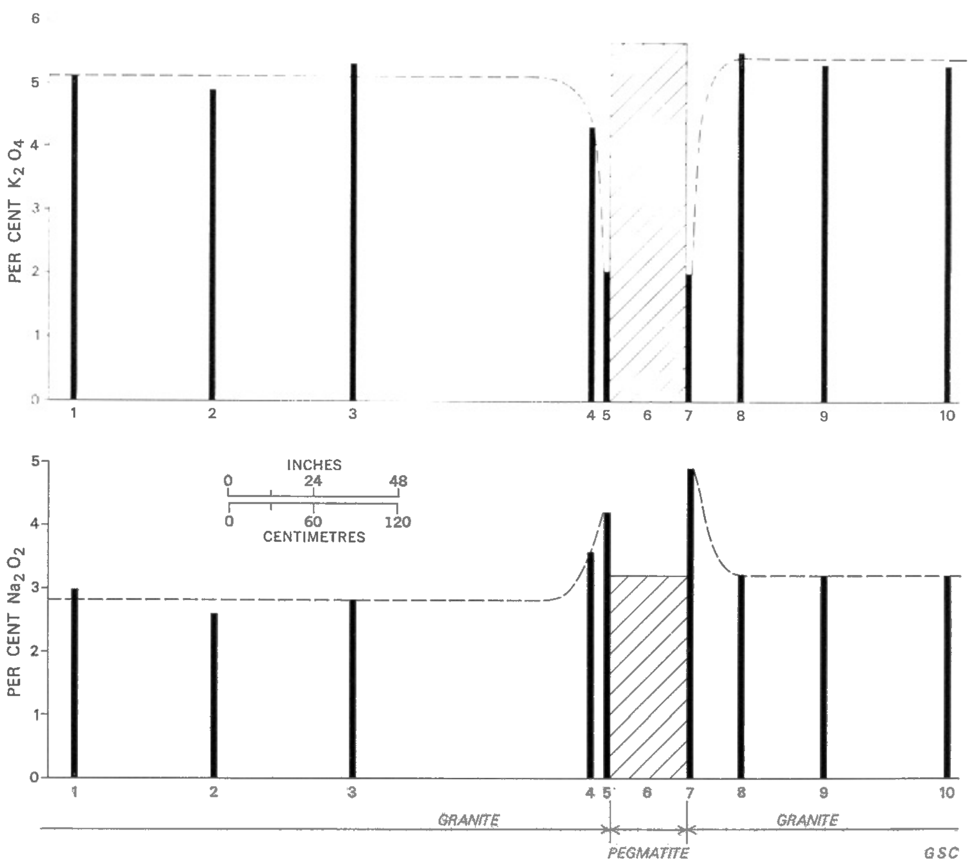


FIGURE 46. Sodium and potassium profiles across a pegmatite dyke in granite (site 337, Fig. 4). Numbers correspond with those of Table XIII.

The data obtained show that the muscovite-rich aureole is conspicuously depleted in potassium relative to the granite beyond the aureole, as expected from the preceding investigation. However, the observed enrichment of sodium in the aureole was not found previously.

Observe that specimen 4, collected about 0.4 foot west of the pegmatite contact, and beyond the aureole as defined by macroscopic inspection, is also enriched in sodium and depleted in potassium. Hence the muscovite-rich aureole is somewhat thicker than estimated, but since specimen 8 contains 'normal' amounts of alkali elements, the aureole does not extend as far as 1.3 feet from the pegmatite. No significant variations in sodium and potassium content were found in the granite beyond the narrow muscovite-rich aureole.

Tourmaline-rich Aureoles about Pegmatite Dykes in Schist

A distinct aureole of tourmaline-rich rock of variable properties and thickness was observed about many of the pegmatite bodies in Yellowknife Group schist. Different aspects of these aureoles are shown in Plates XIV, XXVI–XXX and Figure 14. In the terrain east of Sparrow Lake (Fig. 2), tourmaline-rich aureoles are more commonly found about pegmatite dykes near the Sparrow Lake granite pluton than about similar dykes farther from the granite, i.e., near Thompson Lake.

No relationship exists between thickness of dyke and thickness of the associated aureole. Thus the thickness of aureoles was found to range from a small fraction of a centimetre (Pl. XXX) to several centimetres (Pl. XXVII), regardless of the thickness of the associated pegmatite dyke. Also, the thickness of an aureole commonly varies about any particular pegmatite mass, as is clearly shown in Figure 14. This variability cannot be related to the mineralogy of the pegmatite.

The following observations reveal certain factors that appear to be instrumental in governing the extent of development of tourmaline-rich aureoles.

1. An increase in the thickness of an aureole is commonly found where a discontinuity is encountered in the associated pegmatite dyke. These discontinuities may take several forms, for example a narrowing of the dyke (Pl. XXVI), termination of a dyke with *en échelon* continuation (Pl. XXVII), and a branching or direction change (Pl. XXIX).

2. The thickness of an aureole is locally governed by the composition of the schist in which it develops. Biotite-rich schist appears to be the most favourable rock for tourmaline growth, as shown for example by Plate VI.

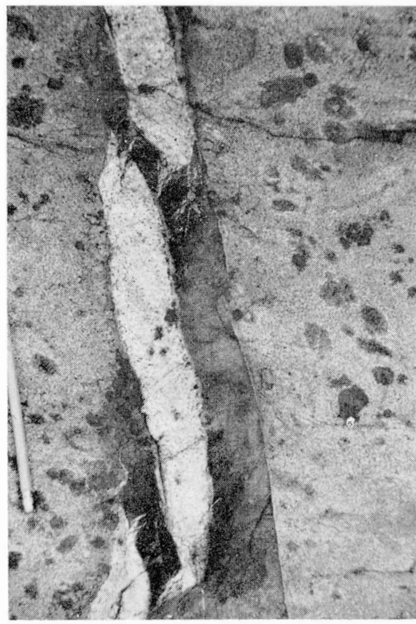
3. Where a pegmatite dyke intersects schist at one place and an earlier pegmatite dyke at another, a tourmaline-rich zone may form in the schist but not in the earlier pegmatite.

4. Tourmaline-rich aureoles were commonly observed to terminate abruptly against a pre-pegmatite quartz vein. This is illustrated in Plates XXVI, XXVII, and XXVIII, and in Figure 14. Quartz veins appear to have formed barriers to a supposed advancing front of wall-rock alteration.

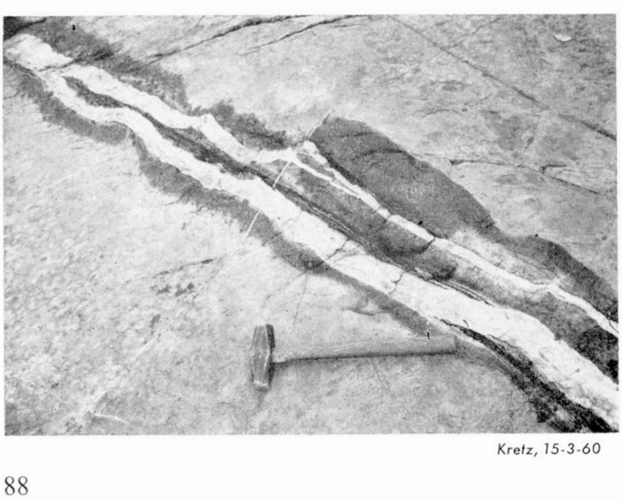
Kretz, 14-2-60

PLATE XXVI
Part of the pegmatite dyke shown in Plate XXIV. Observe offset of quartz vein, and variation in thickness of dyke and aureole; also, abrupt termination of aureole against quartz vein near top of photograph.

PLATE XXVII
Part of the pegmatite dyke shown in Plate XXIV. Most of the filaments between the *en échelon* units are composed of pegmatite but some are quartz. Observe abrupt termination of tourmaline-rich aureole against quartz vein.



Kretz, 13-8-60

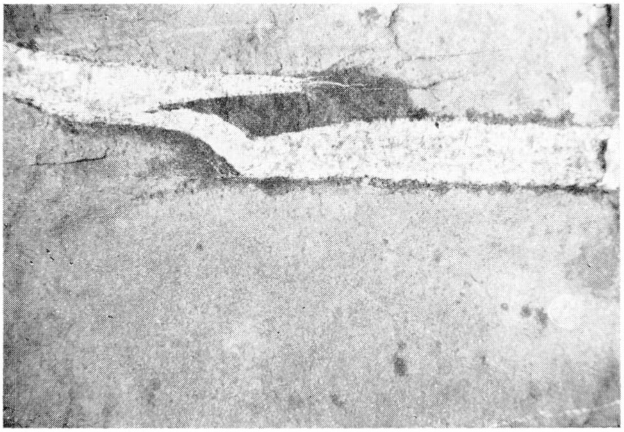


Kretz, 15-3-60

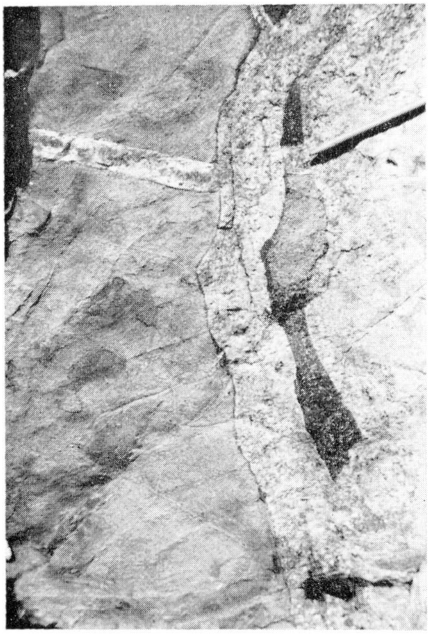
PLATE XXVIII
Pegmatite dyke emplaced along an earlier tourmaline vein set. Observe offset of vein set (at hammer handle), suggesting dilational emplacement. Observe properties of the (dark) tourmaline-rich aureole, especially the preferential development of tourmaline in cordierite nodules, and the abrupt termination of the aureole against a quartz vein. (North of Bighill Lake, lat. 63°31′N, long. 114°03′W.)

PLATE XXIX

Pegmatite dyke in schist, showing concentration of tourmaline-rich aureole (dark) at a discontinuity in the pegmatite dyke. Thickness of dyke, 5 cm. (Shore of Hidden Lake, lat. 62°32′N, long. 113°32′W.)



Kretz, 13-1-60



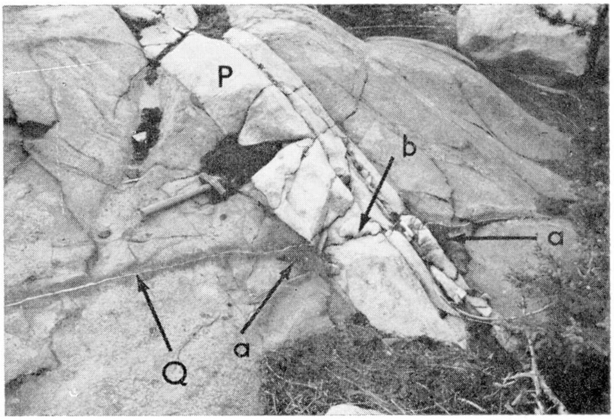
Kretz, 12-8-60

PLATE XXX

Marginal area of a pegmatite dyke, $3\frac{1}{2}$ metres thick, showing very narrow tourmaline-rich aureole, and abundant development of tourmaline within inclusion. Note offset of quartz vein in inclusion (at pencil point) relative to quartz vein in schist wall-rock. (Shore of Hidden Lake, lat. 62°32′N, long. 113°32′W.)

PLATE XXXI

Schist of the Yellowknife Group enclosing a pegmatite dyke (P) which is cut by a quartz vein (Q). A tourmaline-rich aureole is associated with the quartz vein but not with the pegmatite dyke. Note enlargement of tourmaline-rich zone as pegmatite is approached (at a), and absence of this zone where the quartz vein traverses the pegmatite dyke (at b). (North of Bighill Lake, lat. 63°31′N, long. 114°03′W.)



Kretz, 15-5-60

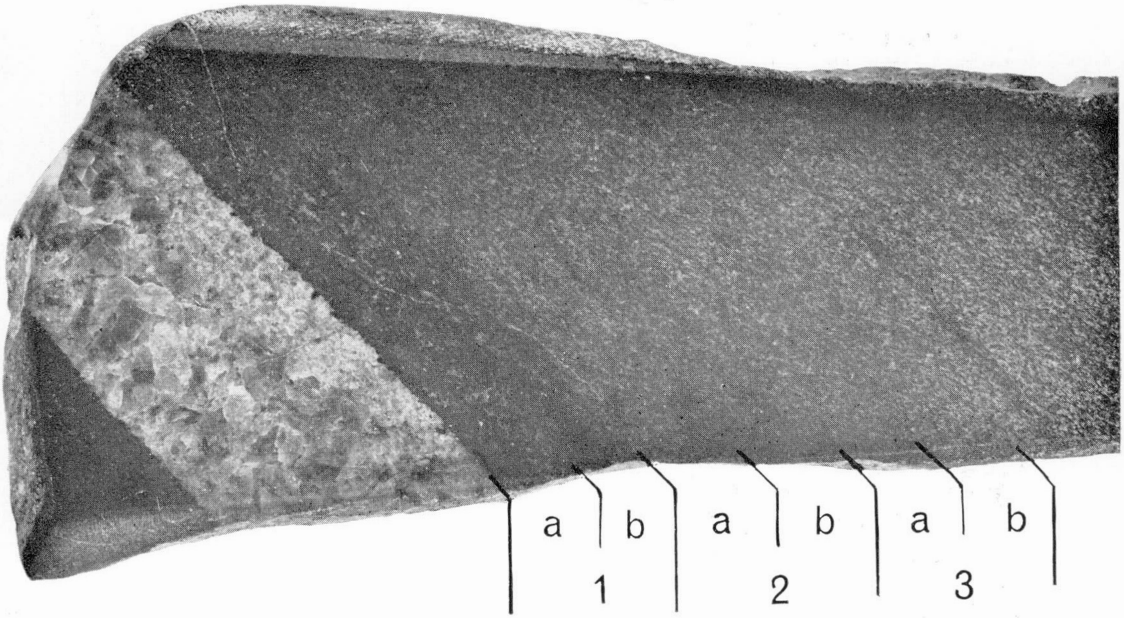


PLATE XXXII. Specimen of pegmatite dyke (1.6 cm thick), its tourmaline-rich aureole, and adjacent unaltered schist, selected for detailed study. Zones 1 to 3 are referred to in text. (Site 210, Fig. 2.)

5. Inclusions of schist in pegmatite may be more extensively altered than the wall of the dyke (Pl. XXX). This is not, however, common.
6. Tourmaline-rich aureoles are also associated with some quartz veins. This is shown for example in Plate XXXI which also illustrates the fact that some pegmatite dykes are entirely free of such aureoles.

Microscopic Examination of a Tourmaline-rich Zone Adjacent a Small Pegmatite Dyke

Numerous specimens of tourmaline-rich aureoles were collected and examined microscopically. These examinations revealed that the aureoles are characterized by the presence of apatite, decrease in the amount of biotite, and the presence of abundant tourmaline.

One of the specimens (Pl. XXXII) was selected for detailed study. The pegmatite is composed predominantly of albite and quartz. Minor apatite, traces of ilmenite (?), and grains of tourmaline are also present. The dyke lies parallel with a pronounced foliation in the enclosing schist.

A preliminary examination of the aureole showed that it can be divided into three zones of contrasting tourmaline content, as shown in Plate XXXII. These have been further divided into subzones. The mineral assemblages and mineral proportions of each of the subzones are listed in Table XIV.

TABLE XIV *Variation in mineral assemblage and mineral proportion across a tourmaline-rich aureole, extending from pegmatite contact to unaltered schist (refer to Pl. XXXII for relative position of zones 1 to 3)*

Zone:	1		2		3	
	1a	*1b*	*2a*	*2b*	*3a*	*3b*
quartz	33	39	27	27	23	27
plagioclase	≃1	≃1	37	37	44	43
biotite	0	1	23	30	32	30
muscovite	0	0	0	tr	tr	tr
tourmaline	56	54	12	5	<½	<½
apatite	9	4	0.7	<½	<½	<½
ilmenite[1]	1	½	0	tr[2]	tr[2]	tr

[1] opaque mineral, not definitely identified as ilmenite — tr trace
[2] inclusions in tourmaline — < less than

If it is assumed that the schist was initially homogeneous within the rock unit under study, i.e., the mineral assemblage and proportion of zones 1 and 2 were initially nearly identical to those of zone 3, then the results of Table XIV show that common quartz–plagioclase–biotite schist of the Yellowknife Group has been altered through an increase in tourmaline, apatite, and quartz and a decrease in biotite and plagioclase.

Variations in mineral proportions as a function of distance from the pegmatite contact are best examined in graphical form, as shown in Figure 47. Observe that there is a reciprocal relationship between the biotite and the tourmaline content of the wall-rock (Fig. 48). This observation, together with the observed increase in apatite and quartz and decrease in plagioclase, suggests that the following skeletal reaction has taken place:

$$\text{biotite}+\text{plagioclase} + \ldots \rightarrow \text{tourmaline}+\text{apatite}+\text{quartz}+$$

More detailed information regarding this reaction may be obtained by transforming the volume percentages of zones 1 and 3 (Table XIV) to number of moles per 1,000 cc of rock (Table XV). This calculation required an estimate of the Fe:Mg ratio of biotite and tourmaline, as shown in Table XVI. It also requires certain simplifications in mineral formulae as indicated in the equation to follow, and the assumption that changes in rock volume resulting from wall-rock alteration were negligibly small. The information of Table XV can then be expressed as a chemical reaction, as follows:

$$\begin{aligned}
&\underset{\text{quartz}}{11\ SiO_2}+\underset{\text{plagioclase}}{1.8\ [(NaAlSi_3O_8)_{0.85}(CaAl_2Si_2O_8)_{0.15}]}\\
&+\underset{\text{biotite}}{2K(Mg,Fe)_3AlSi_3O_{10}(OH)_2}+0.5\ Na+7.9\ Al+5.9\ Si\\
&+4.4(OH,F)+1.3\ P+6\ B+34.7\ O\\
&\rightarrow \underset{\text{quartz}}{16\ SiO_2}+\underset{\text{tourmaline}}{2Na\ (Mg,Fe)_3Al_6B_3Si_6O_{27}(OH)_4}\\
&+\underset{\text{apatite}}{0.43\ Ca_5(PO_4)_3(OH,F)}+0.05\ Ca+2K \qquad \text{(c)}
\end{aligned}$$

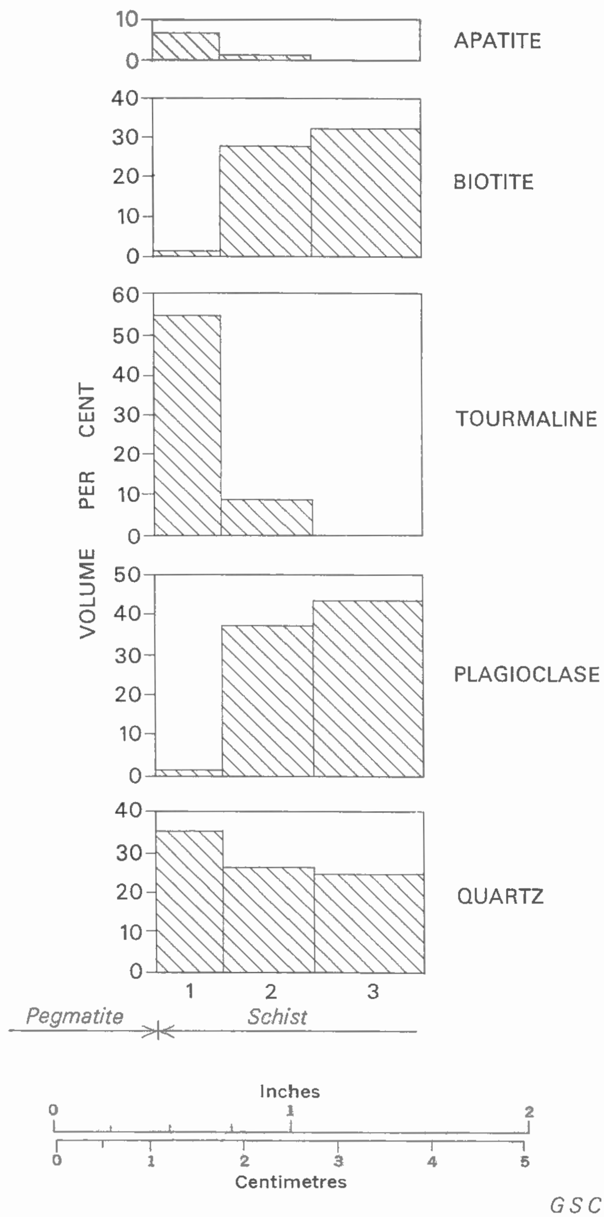


FIGURE 47. Profiles across a contact aureole (Pl. XXXII) with reference to volume per cent of quartz, plagioclase, tourmaline, biotite, and apatite.

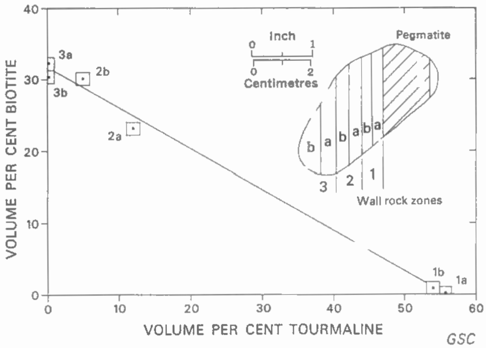


FIGURE 48
Reciprocal relation between the volume per cent of biotite and tourmaline in a zone of wall-rock alteration adjacent a pegmatite dyke in schist. Numbers correspond to those of Plate XXXII and Figure 47.

TABLE XV *Conversion of volume per cent of minerals (Table XIV) to number of moles per 1,000 cc of rock*

Rock	Mineral[1]	Volume (cc)	Density	Weight (gms)	Mol. Wt.	No. Moles
Zone 3, schist	quartz	250	2.65	662	60.09	11.0
	plagioclase	430	2.63	1130	640.0	1.8
	biotite	310	2.98	923	464.6	2.0
Zone 1, aureole	quartz	360	2.65	953	60.09	15.9
	tourmaline	550	3.17	1740	892	2.0
	apatite	70	3.07	215	502	0.43

[1] For formulae used *see* equation (c)

The above calculations have shown that the reaction does not require an addition or removal of (magnesium+iron). All of the (Mg,Fe) released by the dissolution of biotite has evidently entered tourmaline. Also, it may be noted that all the calcium needed for the crystallization of apatite may have come from plagioclase. Potassium released from biotite has certainly escaped from the rock, and since the amount of sodium made available from plagioclase is apparently insufficient to satisfy the requirements of tourmaline, an introduction of sodium is postulated. In addition, phosphorus and boron were certainly introduced, and the calculations suggest that aluminum, silicon, hydroxyl, and fluorine were also introduced.

TABLE XVI *Estimated Fe/Fe+Mg ratio in biotite (unaltered schist) and tourmaline (tourmaline-rich aureole) in specimen illustrated in Plate XXXII*

	Measurements	Estimated composition	Reference
biotite	$d_{(060)} = 1.542$Å	Fe/Fe+Mg$\simeq$0.3	Eugster and Wones (1958)
tourmaline	a = 15.97Å	schorl-dravite	
	b = 7.18Å	Fe/Fe+Mg$\simeq$0.5	Epprecht (1953)

Development of Muscovite Adjacent to Pegmatite Dykes in Schist

Several microscopic examinations have revealed that muscovite is present about some pegmatite masses in schist, regardless of the presence or absence of tourmaline. This mineral is found as tabular grains 'cutting' biotite grains, and forms only about 1 to 3 per cent of the rock by volume. The absence of muscovite from apparently unaltered schist farther from the pegmatite dykes indicates that the mineral is a product of wall-rock alteration.

An example of this type of alteration is found adjacent to the pegmatite body shown in Figure 24. At A, where muscovite is found in the pegmatite, it is also present in the wall-rock, as shown in Figure 39, but at B, where pegmatite is devoid of muscovite, no muscovite was found in the wall-rock (Fig. 33).

It is not known to what extent muscovite has formed from biotite, quartz, and feldspar initially present in the wall-rock, and to what extent its component elements have been introduced. In certain places the potassium liberated by the biotite → tourmaline reaction may have entered muscovite. However, where tourmaline is not present, and the wall-rock is enriched in potassium (as described in the following section), it appears likely that some or all of the muscovite-forming elements were introduced.

Variation in Sodium, Potassium, and Lithium Content of Schist as a Function of Distance from Pegmatite Dyke

A pegmatite dyke and the adjacent wall-rock were examined to detect variations in the sodium, potassium, and lithium content of the surrounding schist as a function of distance from the pegmatite. No macroscopically visible tourmaline was found in the walls of this dyke, and the present investigation is concerned with a possible wall-rock alteration other than the common tourmalinization.

The pegmatite mass under study is at site 433 (Fig. 2, north of Thompson Lake); it strikes northwest, dips nearly vertical, and is 31 feet thick. It consists of quartz, plagioclase, potash feldspar, muscovite, hydromica, spodumene, beryl, and tantalite–columbite. The last three minerals form roughly 3, 1, and 0.1 per cent respectively.

The surrounding rock is an interlayered sequence of nodular schist (quartz–feldspar–biotite–cordierite) and non-nodular schist (quartz–feldspar–biotite) of the Yellowknife Group. The strike of these layers is nearly parallel with that of the pegmatite dyke, and the dip is 40 to 50°NE. Samples were collected along lines bearing N75°E, i.e., along lines that lie about 55 degrees from the strike of the pegmatite dyke. Some of the samples of schist near the dyke consist of one rock fragment only, others farther from the contact consist of eight or nine fragments collected along a horizontal distance of about 20 feet. The sample of pegmatite consists of thirty fragments collected at intervals across the entire width of the dyke.

The analyses of these samples are listed in Table XVII and presented graphically in Figure 49.

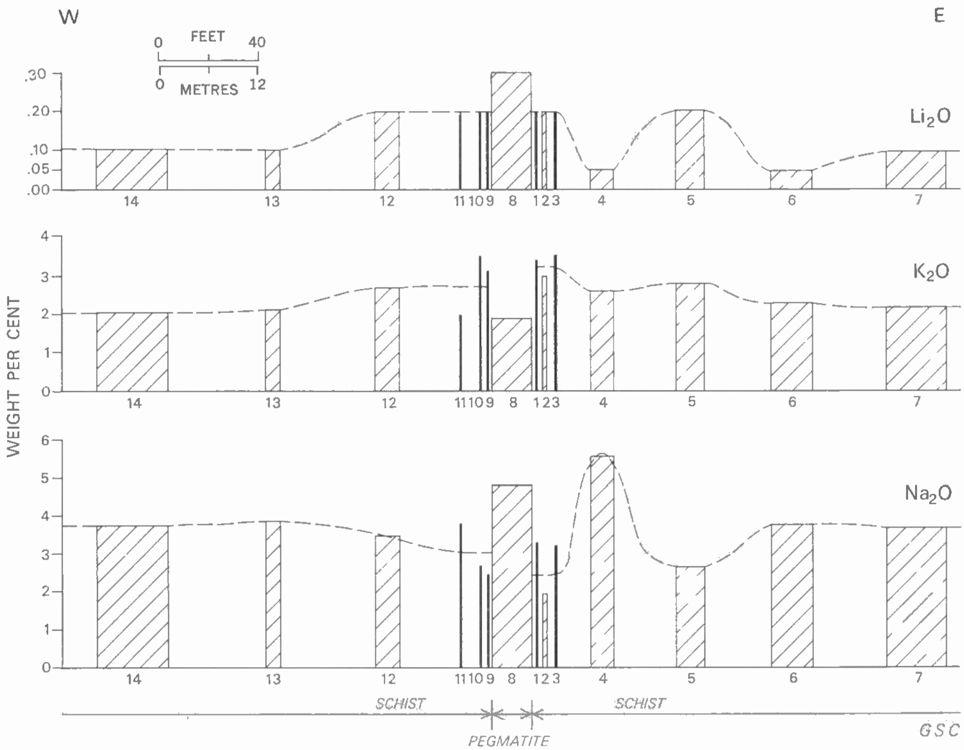


FIGURE 49. Sodium, potassium, and lithium profiles across a pegmatite dyke in schist (site 433, Fig. 2). Numbers correspond with those of Table XVII.

TABLE XVII *Sodium, potassium, and lithium content of pegmatite and the surrounding schist*
(refer to Figure 49 for relative position of samples 1 to 14)

Sample No.	Horizontal distance (ft) from pegmatite contact measured in direction 55° with strike of dyke	Na_2O	K_2O	Li_2O
7	137.5 – 160.3	3.6	2.2	0.1
6	92.5 – 108.8	3.7	2.3	<0.1
5	55.9 – 66.5	2.6	2.8	0.2
4	22.5 – 31.0	5.4	2.6	<0.1
3	8.3 – 8.9	3.1	3.5	0.2
2	3.7 – 5.0	1.9	3.0	0.2
1	1.1 – 1.3	3.2	3.4	0.2
8	pegmatite dyke	4.7	1.9	0.3
9	0.7 – 1.0	2.4	3.1	0.2
10	4.2 – 4.4	2.6	3.5	0.2
11	12.1 – 12.5	3.7	2.0	0.2
12	36.0 – 45.8	3.4	2.7	0.2
13	82.5 – 88.7	3.8	2.1	0.1
14	127.0 – 155.0	3.7	2.0	0.1

W. U. Romeny, analyst

The data have established that the schist adjacent to the pegmatite for distances of 50 feet or so has been enriched in potassium and lithium, and possibly depleted in sodium. On the basis of previous discussion, it is suspected but not confirmed that the increase in potassium may be attributed to the formation of muscovite.

Discussion of Wall-Rock Alteration

The presence of tourmaline in wall-rocks of granitic pegmatite masses has been known for many years and has been reported frequently. Thus Patton (1899) reported the development of tourmaline, quartz, and minor apatite at the expense of biotite and plagioclase adjacent to certain pegmatite masses in Colorado, alteration zones apparently identical to those of the Yellowknife–Beaulieu region. Similar reports have appeared from time to time; those by Carl (1962) and Sundelius (1963) provide examples of relatively recent studies.

The presence of muscovite in contact aureoles was reported by Chapman (1941) with reference to certain pegmatite masses in New Hampshire. Muscovite grains were found to intersect a foliation defined by biotite grains, also as found in the Yellowknife–Beaulieu terrain.

Although the development of alteration zones about pegmatite bodies is a common phenomenon, some inconsistency exists regarding the appearance and disappearance of minerals in these zones. Thus muscovite may appear (Anderson, 1933; Chapman, 1941; Hutchinson, 1955) or disappear (Schwartz and Leonard, 1927), and potash feldspar may appear (Hutchinson, 1955; Schwartz and Leonard, 1927; Reitan, 1959b) or disappear (Kretz, 1967).

Recent studies have shown that trace elements are also involved in wall-rock alteration processes. Thus Kalita (1959), Stavrov and Bykova (1961), and Ryabchikov and Solov'yeva (1961) all report an increase in lithium and rubidium in contact aureoles relative to unaltered country rock. Kalita (1959) also reported an increase in beryllium content.

The various mineralogical and chemical alterations of wall-rock adjacent pegmatite masses are normally considered to be the result of the migration of matter from the pegmatite to the wall-rock. Data obtained from the Yellowknife–Beaulieu terrain are in agreement with this interpretation.

The data collected regarding the development of muscovite in granite and tourmaline in schist are considered to be sufficiently complete to base upon them a preliminary interpretation of the kinetics of the reactions involved. The reactions, though complex in detail, may be considered to consist of three separate processes or groups of processes:

1. migration of elements to reaction site,
2. nucleation, chemical reaction, and crystallization, and
3. migration of elements away from reaction site.

Any particular reaction is considered to take place along a front that slowly advances into the country rock from the pegmatite–country rock interface. Hence it is necessary to postulate a migration of elements from a source, considered to be the pegmatite mass, to the front. Two types of movement processes may be envisaged:

1. mechanical flow of a fluid that carries the required elements to the front in solution, and
2. chemical flow, i.e., diffusion resulting from a chemical potential gradient.

Within small volumes of rock (as shown for example in Pls. XXV and XXXII) the front appears to have advanced uniformly. This implies migration through solid rock rather than along channels or fractures. The movement is therefore considered to have taken place along grain boundaries. Although little is known regarding the composition and structure of grain boundary regions in crystalline rocks, microscopic examinations have shown that no significant open spaces exist. Hence a mechanical flow of matter along these boundaries is unlikely, and a chemical migration is considered a more feasible method of transport. Certain substances that normally behave as a fluid (e.g., H_2O) will necessarily be present, and presumably will also move by a diffusion mechanism.

Different chemical species are expected to move at different rates, and the reaction rate, and hence the rate of movement of the reaction front, was probably determined by the reactant that moved most slowly to the reaction site, this being either an introduced species or a component of a mineral that is undergoing dissolution.

The general variability in the shape and thickness of reaction zones, especially of the tourmaline-rich type, may be the result of variations from place to place in the duration of time in which the chemical potentials of the various reactants were sufficiently high to allow the reaction to proceed. For example, advancing fronts were evidently stopped locally by quartz veins, presumably because the veins provided diffusion barriers to certain reactants, thus causing a decrease in their chemical potentials on the opposite side of the veins.

The fate of potassium and other products that escaped from the reaction front is not known. They may have moved in a direction away from the pegmatite, or towards the pegmatite, or more likely, in both directions. If some of this matter moved towards the pegmatite, different elements must have moved in opposite directions at the same time, a common feature of diffusion processes in general.

Chapter VII

INFERENCES REGARDING THE PEGMATITE-FORMING PROCESS, BASED ON DATA COLLECTED FROM THE YELLOWKNIFE–BEAULIEU TERRAIN

Many opinions have been expressed regarding the origin and emplacement of pegmatite rocks since these were first studied more than a century ago. The reviews of Fersman (1931), Johannsen (1932), Jahns (1955), and Chadwick (1958) reveal that no generally acceptable hypothesis has yet been formulated.

For the pegmatite bodies of the Yellowknife–Beaulieu region, hypotheses of pegmatite emplacement were previously proposed by Hutchinson (1955) and Boyle (1961).

The pegmatite bodies examined by Hutchinson are near the Redout Lake granite pluton, in a country rock of granodiorite and amphibolite. Hutchinson's hypothesis for the formation of these bodies may be summarized as follows:

1. pegmatite was derived largely or wholly from the Redout Lake granite pluton,
2. relatively near the granite pluton, the pegmatite-forming matter moved through the country rock by a process referred to as "ionic transfer"; farther from the granite it moved, at least in part, through open fractures,
3. near the granite pluton, pegmatite crystallized from a "pegmatite fluid", by replacement of the country rock, whereas farther from the granite the pegmatite minerals crystallized from a "magma".

This hypothesis cannot be accepted as it stands, mainly because of inconsistency in defining the pegmatite-forming agent, which is variously referred to as "pegmatitic fluid", "aqueous solution", "pegmatitic emanation", migrating ions ("ionic transfer"), and "pegmatite magma" or "liquid".

Boyle's investigations were confined to pegmatite bodies near the Prosperous Lake granite pluton. Boyle's hypothesis may be summarized as follows:

1. pegmatite was derived from metasedimentary rocks of medium metamorphic grade in the aureoles about granite plutons, or from solid granite;
2. the pegmatite-forming matter migrated by diffusion from solid granite to pegmatite veins in granite, and from metasedimentary rocks to pegmatite veins in these rocks, the latter migration taking place during rock metamorphism.

The data of Chapters II and V do not indicate that pegmatite bodies were largely or wholly derived from the surrounding country rock, and Boyle's hypothesis is therefore not applicable to the pegmatite bodies investigated by the writer.

As the hypotheses of Hutchinson and Boyle cannot, without modification, be applied to the pegmatite bodies of the present study, a brief reflection and discussion of pegmatite development, based on the data of this report, is presented below. It will be noticed that many of the inferences drawn are in partial agreement with the hypotheses of Hutchinson and Boyle.

The problem of pegmatite petrogenesis may be conveniently divided into three parts: (1) source of pegmatite, (2) transport of pegmatite-forming matter, and (3) crystallization of pegmatite minerals.

Source

The common association of pegmatite masses with granite plutons, as emphasized by Bastin (1910), has led to the interpretation that pegmatite and granite have a common ancestry. Usually it is assumed or inferred that the granite existed in a liquid state and the pegmatite matter was separated from the liquid (Fersman, 1931; Heinrich, 1953; Hutchinson, 1955; Joklik, 1955a; Nikitin, 1958; Tatekawa, 1959; and many others). On the other hand, the impoverished zones about pegmatite bodies (Greenly, 1923; Reitan, 1959a) as well as recent chemical evidence (Heier and Taylor, 1959; Ryabchikov and Solov'yeva, 1961) support the hypothesis that pegmatite matter was derived from the enclosing solid rock.

With reference to the Yellowknife–Beaulieu terrain, at least two potential sources for the pegmatite-forming matter may be postulated; a hypothetical pre-existing granitic liquid, and the existing solid granite and schist. The following evidence is pertinent:

1. Recent (post-1960) radioactive age determinations (Table I) have given ages for pegmatite and granite that are, within the limits of experimental error, identical. This observation links the event of pegmatite emplacement with the event of granite emplacement and contact metamorphism. Field evidence in the form of pegmatite dykes 'cutting' granite dykes and granite–schist contacts indicates however that pegmatite bodies are younger than granite masses, though the difference in age may be small in relation to the geological time scale. It is also noteworthy, as discussed in Chapter IV, that pegmatite bodies of the Sparrow Lake – Thompson Lake area are not only different in age relative to each other, but pegmatite minerals in the central part of certain dykes are significantly younger than pegmatite minerals along the margins of the same dykes. It is evident therefore that pegmatite-forming material was made available during a significant span of time.

These considerations are compatible with an hypothesis that relates granite and pegmatite to a common source as long as provision is made for the specified age relationships. A plausible sequence of events is as follows:

(i) existence of large volume of granite material

(ii) separation and crystallization of pegmatite-forming matter
(iii) emplacement of granite plutons and dykes
(iv) remobilization of pegmatite-forming matter, transport, and emplacement of pegmatite bodies.

The hypothesis as worded does not specify the state of the granite and pegmatite during emplacement.

2. A zonal arrangement of pegmatite minerals was observed in the Sparrow Lake – Thompson Lake terrain. A distribution of this kind may result if pegmatite-forming elements of different degree of mobility have a common source in the vicinity of the Sparrow Lake pluton, and have moved outward from that source.
3. It may be possible to determine whether or not the pegmatite-forming matter was derived from the Yellowknife Group schists by observing whether or not the schists near the pegmatite bodies are depleted in pegmatite-forming elements. The regional distribution of alkali elements does not support the lateral secretion hypothesis. Furthermore, in the Staple Lake terrain a relatively high proportion of which is composed of pegmatite, the enclosing schists are not obviously abnormal in composition, as might be expected if the pegmatite-forming matter was derived from these rocks.
4. Study of the wall-rock alteration revealed no depleted zones about pegmatite bodies. It is however established that potassium has been liberated from the common muscovite-rich aureoles in granite and the tourmaline-rich aureoles in schist, and it is conceivable that this element was consumed by the potassium-containing pegmatite minerals. If so, at least some of the pegmatite-forming matter was derived from solid schist and granite.
5. Certain mineralogical relationships between pegmatite bodies and the enclosing rocks were reported earlier. The most important of these is that pegmatite dykes that do not contain potash feldspar are confined to schist. Also, cordierite, sillimanite, and andalusite were found within some pegmatite masses, not necessarily in their margins. Furthermore, biotite–chlorite intergrowths, possibly derived from the wall-rock, were reported. These data suggest that, at least locally, some of the pegmatite-forming matter (minerals or elements) was derived from the enclosing rock.

From the above information it is concluded that most of the pegmatite-forming matter has a source that is closely linked with the source of the granite plutons. For the Sparrow Lake – Thompson Lake terrain, the source may lie at some depth below the central area of the Sparrow Lake pluton as now exposed. However, a small proportion of the total pegmatite-forming matter was evidently derived from the solid schist and granite country rocks.

Transportation

Field observations of pegmatite bodies have led to the general conclusion that pegmatite-forming matter can be transported over considerable distances through the earth's crust, sometimes for several miles. Moreover, pegmatite bodies, unlike basaltic dykes, characteristically possess the shape of discontinuous pods, veins, or lenses, with few visible interconnecting 'channels' to facilitate movement of the pegmatite-forming matter. This observation was emphasized by Andersen (1931) and has led Ramberg (1952), Hutchinson (1955), Micheelsen (1960) and others to postulate the migration of pegmatite-forming matter through solid rock, and to envisage a dispersed phase capable of migration along grain boundaries in common crystalline rocks.

For the Yellowknife–Beaulieu terrain, the following data bear on the problem of pegmatite transport:

1. Provided the above-mentioned interpretation regarding the source of the pegmatite bodies is correct, pegmatite-forming matter has in some terrains migrated a distance of several miles. In contrast, granite dykes have not penetrated the country rock schists for more than a few hundred feet. This suggests a greater mobility for pegmatite-forming matter relative to granite-forming matter.
2. The outline of pegmatite bodies as viewed in plan suggests that in three dimensions the bodies are pods, veins, and lenses. Even those pegmatite bodies that appear to be tabular, 'pinch-out' when followed along strike and therefore appear to be isolated narrow lenses. The sharp contrast between discontinuous pegmatite dykes and continuous diabase dykes is clearly shown in Figure 3.

Small, apparently isolated lens-shaped, masses of pegmatite are common near dyke terminations, and certain small pods of pegmatite are definitely isolated in schist. It appears therefore that at least some and possibly many of the pegmatite bodies investigated are entirely enclosed in schist or granite. Consequently, if the pegmatite-forming matter is to arrive at the site of crystallization, it must have migrated through solid crystalline rock.

3. A study of wall-rock alteration has shown that boron and other elements have permeated solid schist for distances of several centimetres or more, while potassium and other elements have migrated out of contact aureoles in both granite and schist. Hence at least some pegmatite-forming elements are capable of permeating solid crystalline rock.

It is concluded then that at least some pegmatite-forming matter has migrated through schist and granite. As macroscopic and microscopic examinations of these rocks have shown them to be generally devoid of 'openings' it is thought that the migration is most likely by diffusion. The migration is considered to have taken place along grain boundaries and minute fractures.

Crystallization

Numerous inferences have been drawn in the past regarding the process of deposition or crystallization of pegmatite minerals. Because of the general lack of agreement, at least three premises regarding the state of the pegmatite-forming matter have been suggested, i.e., liquid state (silicate melt), water-rich solution, and dispersed state (Jahns, 1955).

It is commonly realized that the texture and structure of pegmatite dykes are highly variable and are therefore not comparable to those of basalt, porphyry, or other dykes known or reasonably inferred to have crystallized from silicate melt (Andersen, 1931). Thus Brögger (1890) considered the crystallization of pegmatite to be a multi-stage process, and Hess (1925), Landes (1925), and Schaller (1925) a process involving replacement of pre-existing pegmatite minerals.

In the Yellowknife–Beaulieu region, the properties of pegmatite bodies that are unique when compared with common basalt and porphyry dykes are briefly listed below.

1. Grain size is highly variable within individual pegmatite bodies, and relatively coarse- and fine-grained masses are found side by side.

2. Crystals of feldspar, spodumene, muscovite, and beryl are locally oriented nearly perpendicular to dyke walls.

3. Minerals are rarely distributed evenly within pegmatite bodies; commonly the distribution is irregular or zonal. The quartz content for instance may vary from 10 per cent to 100 per cent along the length of certain dykes.

4. In many dykes albite and potash feldspar are found as discrete grains. Moreover, albite may be confined to the marginal regions and potash feldspar to the central regions of certain dykes, thus eliminating the possibility of a separation of these phases by an exsolution reaction. Nearly all the compositional data obtained for feldspars and muscovite indicate a crystallization temperature of 400–500°C.

5. Various types of mineral intergrowths are found locally.

6. Bent and broken mineral grains are common.

7. Schist adjacent to certain dykes has been plastically deformed, presumably during the crystallization process. Certain projections of schist into pegmatite were also deformed, necessarily through an application by the pegmatite of non-hydrostatic stress.

8. An examination of intersecting dykes and of schist inclusions in pegmatite dykes has led to the conclusion that certain dykes developed by repeated dilation and introduction of pegmatite-forming matter. In contrast to typical multiple dykes, contacts between different ages of pegmatite are rarely detectable.

9. Some pegmatite–schist contacts are highly irregular, suggesting a finite replacement of schist by pegmatite minerals. Pegmatite crystallization has locally proceeded through a replacement of pre-existing granite.

In view of these data, the hypothesis that pegmatite crystallized from a stagnant or slowly moving silicate melt is unacceptable. Pegmatites are more like certain metasomatic rocks (skarns) and quartz veins that crystallized at low temperature.

The crystallization hypothesis of Ramberg (1952) which maintains that pegmatite bodies developed by a relatively slow growth accompanied by dilation or replacement of the enclosing rock is in closer harmony with the observed data. According to this hypothesis, the pegmatite minerals represent the fixation of a mobile dispersed phase consisting of ions and atoms, including H_2O.

Résumé

The pegmatite bodies and the granite plutons are inferred to have a common source. Pegmatite-forming matter was presumably separated from granite before emplacement of the granite plutons, and was subsequently remobilized. A small proportion of the pegmatite material was derived from the country rock.

Pegmatite-forming matter is inferred to have migrated through granite and schist country rock, partly along grain boundaries and partly along minute fractures. The migration is therefore considered to have taken place by diffusion rather than by the mechanical flow of a fluid.

The sites of pegmatite crystallization were presumably determined by structures in the country rocks, particularly fractures. As the pegmatite-forming matter arrived at the crystallization sites, crystallization of pegmatite minerals and dilation of the country rock proceeded simultaneously and locally, repeatedly. Meanwhile some matter diffused into the wall-rock, forming aureoles of wall-rock alteration.

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133 Upper Devonian stromatoporoids from the Redwater Reef Complex, Alberta, *by* J. E. Klovan; Upper Devonian stromatoporoids from southern Northwest Territories and northern Alberta, *by* C. W. Stearn, 1966, $4.50 (M42–133)
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