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NEPHELINE SYENITE PEGMATITES, ROCKY BOY STOCK, BEARPAW MOUNTAINS, MONTANA

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Abstract

Unusual nepheline syenite pegmatites, mineralogically resembling in part those of the Kola Peninsula, are found in a composite stock of Tertiary alkalic rocks in the Bearpaw Mountains, Montana. The pegmatites occur in the field as small segregation knots in nepheline syenite and as lens-shaped (compact or clefted) bodies, dikelets, and dikes in nepheline syenite or contiguous monzonites and shonkinites. The pegmatitic bodies are very numerous in an area of a few square miles.

Two partial chemical analyses of sanidine, and complete analyses of potash nepheline, lamprophyllite, and fibrous aegirite are presented with descriptions of the physical properties of these and associated minerals. An analysis is also included of a potash-barium rich nepheline syenite, interpreted to have given rise by fractionation to the pegmatitic magma.

The distribution and utilization of the rare constituents in the formation of the minerals in the pegmatites are discussed. The pegmatitic magma probably had a low volatile content, high concentration of rare constituents (Ti, Zr, Sr), and high initial temperature; and it probably crystallized rapidly at a shallow depth. These pegmatites are the first expression of the differentiation history of the nepheline syenites, and are followed by more volatile-rich pegmatites and complex veins.

INTRODUCTION

In the summers of 1937–39, during geological investigations of the Bearpaw Mountains of north-central Montana, the writer studied several unusual pegmatites in a stock of early Tertiary alkalic rocks. The minerals identified from these pegmatites are: sanidine, nepheline, sodalite, albite, biotite, aegirite, melanite, stilpnomelane, eudialyte, catapleiite, elpidite, lamprophyllite, sphene, brookite, zircon, smoky quartz, calcite, pyrite and galena. Of these minerals, albite, zircon, brookite, stilpnomelane, and quartz are attached to walls of small solution cavities in the pegmatites.

Some of the igneous rocks of the mountains have been described by Weed and Pirsson (1896), and a brief summary of the general petrology was prepared by the writer and incorporated in a recent paper by E. S. Larsen (1940).

ROCKY BOY STOCK

Only the largest and most complex stock in the mountains contains the pegmatites described in this paper. Because of its location in the Rocky Boy's Indian Reservation, it has been named the Rocky Boy stock, and its location is shown in Fig. 1. The stock occupies about 12 square miles, has an exposed vertical relief of about 2200 feet, and a maximum elevation of about 6430 feet.

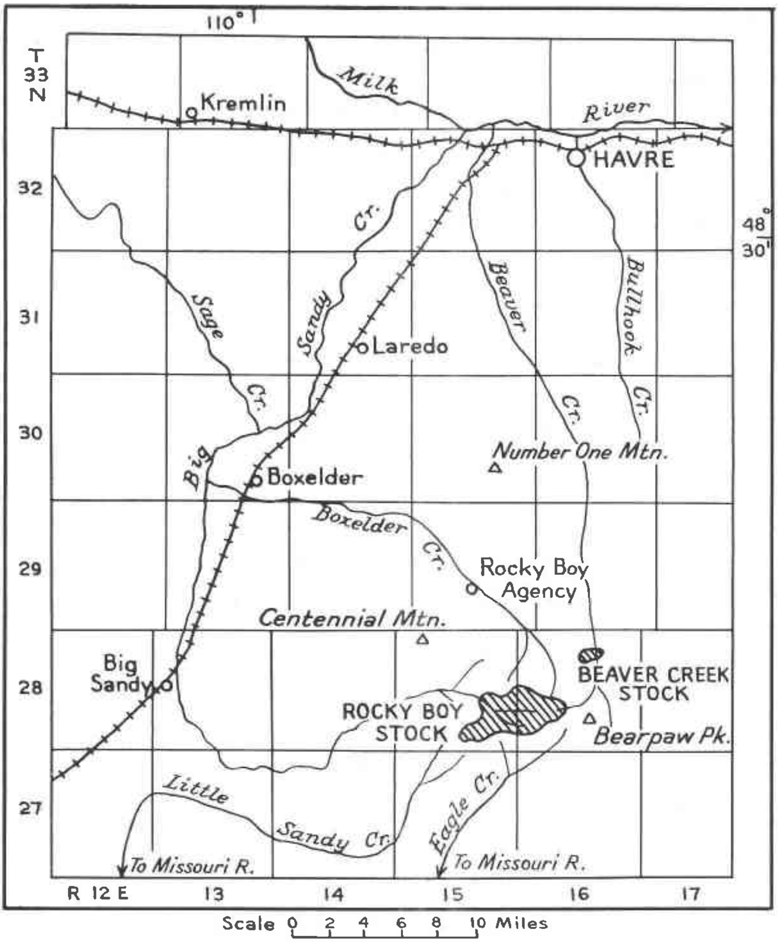

FIG. 1. Index map of a part of north-central Montana showing location of the Rocky Boy and Beaver Creek stocks.

Pyroxenites, shonkinites and syenites, nepheline or pseudoleucite shonkinites and syenites, monzonites, and pegmatite-bearing nepheline syenites make up most of the stock. The areal relations of these rocks, and the location of several pegmatite localities described in the text are shown in Fig. 2, a map of the eastern part of the stock.

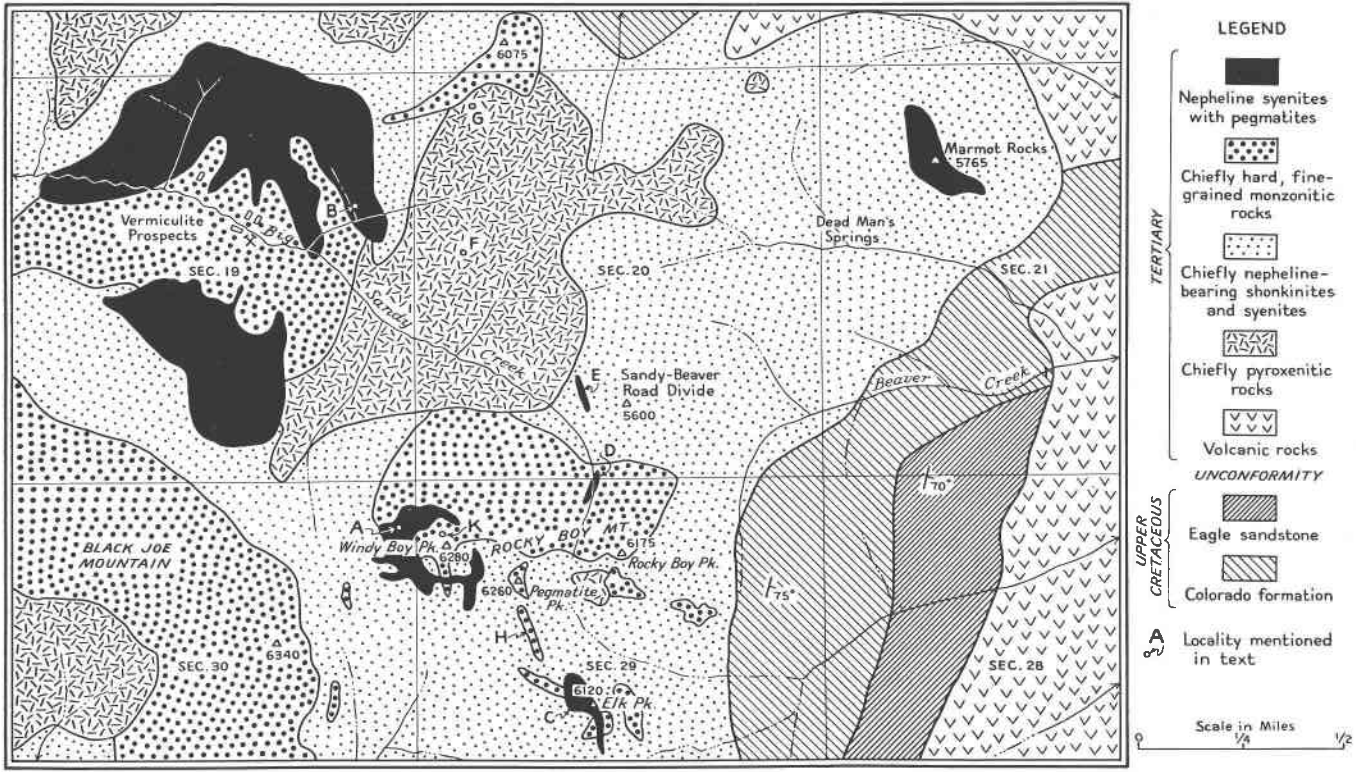

Fig. 2. General geologic map of east-central part of Rocky Boy stock showing locations of pegmatites described in text.

NEPHELINE SYENITES

The nepheline syenites related to the pegmatites are coarse-grained, friable rocks, with a greasy luster, and are intrusive into dark, fine-grained monzonites. A large specimen from the summit of Elk Peak, composed of about 75 per cent sanidine and 13 per cent nepheline and sodalite, contains 12.0 per cent K_2O, 2.3 Na_2O, and 1.5 BaO (see Table 2). Two generations of sanidine are recognized in this rock: (1) an intratelluric, zoned, partly resorbed variety with an appreciable barium content; and (2) an unzoned variety with a much lower barium content, associated with nepheline in the groundmass. Both the nepheline and sanidine in the groundmass of the syenite are optically similar to those in the pegmatites. This relationship, and other evidence, indicates that the pegmatitic liquid fractionated from crystallizing nepheline syenite rich in potash and barium after the precipitation of the early zoned sanidine.

FIELD DESCRIPTION OF PEGMATITES

The nepheline-aegirite syenite pegmatites in the stock are present (1) as segregations in nepheline syenite, (2) as lens-shaped bodies in nephe-

TABLE 1. PRINCIPAL PHYSICAL FEATURES OF THE NEPHELINE SYENITE PEGMATITES

	Segregation Pegmatites	Lens-shaped	Dikes	Dikelets	Aplite Dikelets
Size of exposure	Small knots to few square feet	Average, 1′×10′ Largest, 2′×30′	Small, 3′× 20′ Large, 8′×200′	1″ wide, few feet long	1″ wide, several feet long
Contacts	Gradational	Well defined	Irregular but well defined	Well defined	Well defined
Host rocks	Only in nepheline syenite	In nepheline syenite or contiguous rocks	Not in nepheline syenite	Not in nepheline syenite	Only in nepheline syenite
Mineralogy	Simple* Aegirite largely prismatic Melanite and biotite common	Simple* or complex† Aegirite essentially fibrous Rare biotite near contact	Simple* Rare biotite and lamprophyllite	Simple* Biotite absent	Simple* Biotite absent
Alteration	Rare solution cavities with zircon	Aegirite locally to limonite Solution cavities with crystals of albite, zircon, etc.	Aegirite locally to limonite	Rare	None
Principal identifying features	Small size and coarse grain	Some clefted lenses Transverse aegirite and lamprophyllite	Coarse feldspar Euhedral nepheline	Small size Transverse aegirite	Small size Green color Hard, compact

* Simple: sanidine, nepheline, aegirite are essential; biotite and melanite may be present.
† Complex: above minerals and also many rare minerals described in text.

line syenite or in older rock, (3) as dikes and dikelets in rocks older than nepheline syenite, and (4) as aplitic dikelets in nepheline syenite. Of these the second type is the most complex. A great number of pegmatites are exposed within a few square miles, but they are characteristically small bodies. A summary of the principal features of these pegmatites is given in Table 1.

Segregation Pegmatites

Size and Distribution.

Pegmatitic segregations in nepheline syenite vary in size from mere shreds and knots to bodies as large as a few cubic feet. The contacts of the small pegmatites with parent rock are completely gradational.

These pegmatites are most numerous in the nepheline syenites on Rocky Boy Mountain, especially on the western side of Windy Boy Peak. In one small area (locality *A*, Fig. 2) more than 25 pegmatites were noted, with some of them so concentrated or interconnected that it is difficult to determine which is parent and which is pegmatite.

At least 10 pegmatites were observed on Elk Peak, and the largest of them, having an exposed surface area of about 1 square foot, is present at locality *C*. Small shreds and knots are numerous in the small intrusions on the saddle north of Elk Peak.

Segregation pegmatites are more numerous on the western and eastern edges of the intrusion of nepheline-sodalite syenite, north of Big Sandy Creek, than they are in the main part of the intrusion. Pegmatites are rare in the intrusion south of Big Sandy Creek and are absent in the altered intrusion at Marmot Rocks.

Composition.

In the unaltered and compact segregation pegmatites, the common minerals are glassy sanidine, nepheline, sodalite, biotite, prismatic and fibrous aegirite, and melanite. The proportion of sanidine to nepheline, which are the chief minerals, is variable, but the sanidine is more abundant, in some places making up 75 per cent of the pegmatite.

The dark minerals make up a few to 20 per cent of the pegmatites. Generally, if biotite is present in excess of a few per cent, the prismatic aegirite is more abundant than fibrous aegirite; if fibrous aegirite is very abundant in a pegmatite, prismatic aegirite is scarce. Of the two habits of aegirite, however, the prismatic is more characteristic of the segregation pegmatites.

Some pegmatites contain only one dark mineral, and in these that mineral is more abundant than in those containing more than one dark mineral. One pegmatite (locality *B*) contains prismatic aegirite, oriented as shown in Fig. 3. Many small pegmatites in the saddle north of Elk Peak contain much melanite with very sparse aegirite, and no biotite.

Solution cavities are rare in the segregation pegmatites. A few were observed at locality *C*, in the only segregation pegmatites which contain zircon.

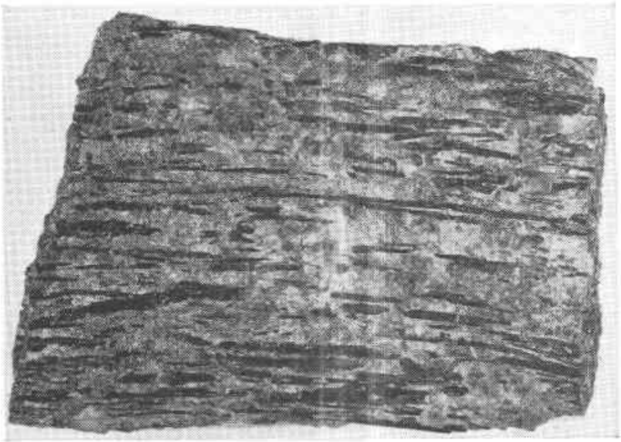

FIG. 3. Hand specimen of pegmatite showing oriented prismatic aegirite.

LENS-SHAPED PEGMATITES

General Statement.

The lens-shaped pegmatites are small but well defined, elongate bodies in nepheline syenite, or in older rocks near nepheline syenite. All of these pegmatites contain sanidine, nepheline, and aegirite as essential minerals, and a very few of them have a complex assemblage of minerals. Those pegmatites contained in nepheline syenite are commonly clefted and complex, and those not in nepheline syenite are compact and simple. There are probably all gradations between segregation and lens-shaped pegmatites in nepheline syenite.

Size, Form, and Structure.

The largest exposed pegmatite of this type is about 2 feet wide and 30 feet long. Most commonly they are less than one foot wide and less than 15 feet long. Undoubtedly their apparent size depends on the attitude of the pegmatite and the part of it which is exposed to erosion. Their complexity, however, is not dependent on their size, for some of the smallest ones are as complex in mineral composition as some of the largest.

The pegmatites are in fact individual tabular lenses. Vertical lenses are characteristic of most of the pegmatites in rocks other than nepheline syenite, whereas vertical lenses are rare in nepheline syenite at high elevations. The lenses in the small intrusions of nepheline syenite have their long dimension parallel to the borders of the intrusion which encloses them.

The clefted lenses are those which have an elongate open space (cleft) parallel to the long dimension of the pegmatite. The cleft may be within the pegmatite or it may be at one wall. The rare minerals eudialyte and lamprophyllite are localized near the cleft of the deposit in which they occur. Large masses of fibrous aegirite are likewise controlled by nearness to the cleft. In all of the complex deposits, the two walls on either side of the cleft are smooth but uneven surfaces, and are up to one inch

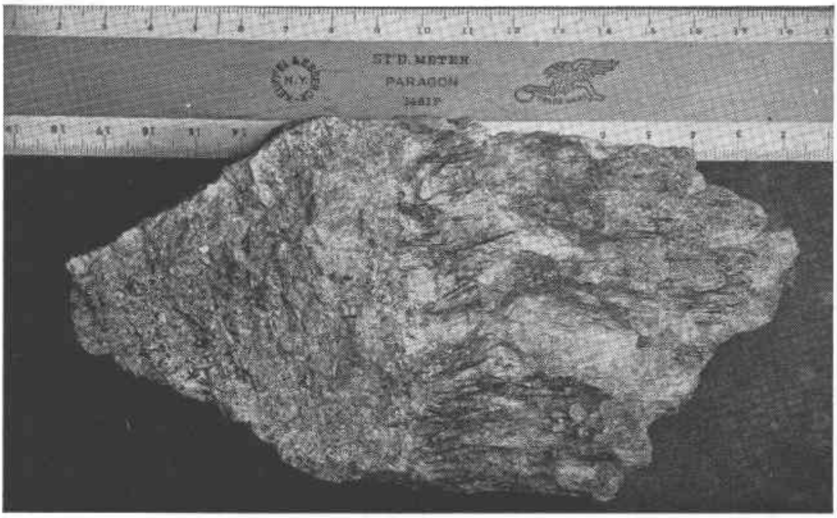

FIG. 4. Hand specimen (scale in cm.) showing well defined contact of lens-shaped pegmatite with nepheline syenite, and transverse aegirite.

apart as a maximum. The role that the cleft played during the history of the pegmatites is uncertain; but it is probable that the late residual solutions of the crystallizing pegmatite were in contact with the walls of the cleft, caused some solution, and probably soaked through the walls into the body of the pegmatite. The clefted lenses are most numerous on and near Pegmatite Peak above the elevation of 6100 feet.

The clefted and unclefted lenses have two structural features in common: (1) with one exception noted below the contacts with enclosing rock are well defined and (2) the fibers of aegirite and the cleavage fractures of sanidine are oriented in a direction normal to the contact. Both features are shown in Fig. 4. One pegmatite on the saddle southeast of the summit of Windy Boy Peak has an ill defined contact with a dike of pseudoleucite shonkinite. As shown in Fig. 5, both sanidine and aegirite have been introduced into the groundmass of the shonkinite.

A few pegmatites at the western edge of the nepheline-sodalite syenite north of Big Sandy Creek are clefted lenses exhibiting a special feature not observed elsewhere. The main mass of the pegmatite is enclosed in a shell a few inches thick of coarse-grained, tabular feldspar with a "trachytic" texture. The tablets are crowded, and are oriented parallel to the

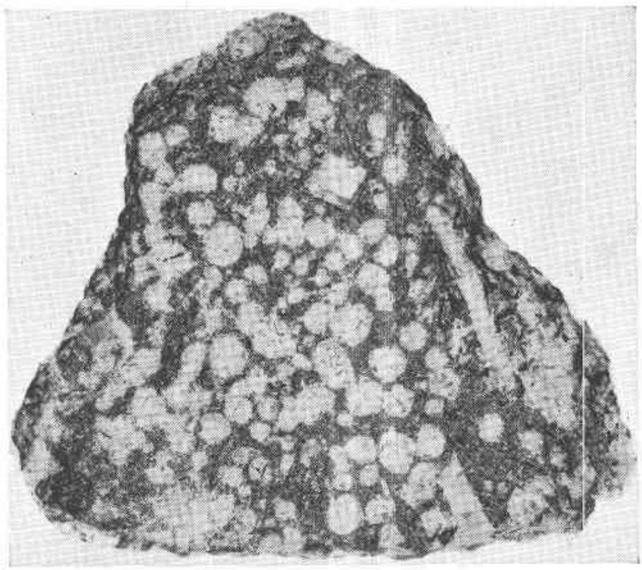

FIG. 5. Hand specimen of pseudoleucite shonkinite wall rock of a complex pegmatite showing introduced black prisms of aegirite and rectangular grains of sanidine.

well defined contact of the pegmatite. The shell is gradational into the main part of the pegmatite.

Distribution.

More than 50 lens-shaped pegmatites were noted in a few square miles of the eastern part of the Rocky Boy stock. No pegmatites have been observed in the western part of the stock, or in the country rock beyond the border of the stock. Those in nepheline syenite have their greatest concentration on the summit and upper slopes of Rocky Boy Mountain, and those not in nepheline syenite are randomly distributed in the older rocks of the stock shown in Fig. 2. Nearness to a body of nepheline syenite increases the number of pegmatites in the older rocks of the stock, and this is well illustrated at the localities of Dead Man's Springs (pegmatite lenses in pseudoleucite shonkinite), and the northern slopes of Windy Boy Peak (pegmatites in monzonite).

The lens-shaped pegmatites have been observed between elevations of 4700 feet to 6300 feet. The most complex pegmatites are on the summit of Rocky Boy Mountain between elevations of 6000 and 6200 feet. Some of these, on the summit of Pegmatite Peak, extend continuously from nepheline syenite into contiguous, hard, jointed monzonite.

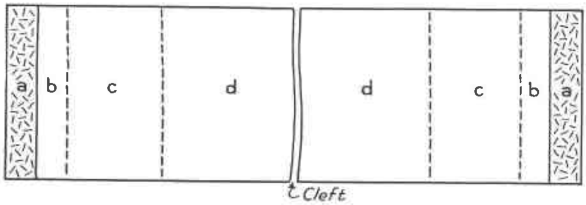

FIG. 6. Idealized, complex, clefted pegmatite (14 inches wide) showing mineral zoning: *a*, nepheline syenite; *b*, zone of biotite, sphene, and prismatic aegirite; *c*, prismatic aegirite; *d*, eudialyte, lamprophyllite and prismatic aegirite.

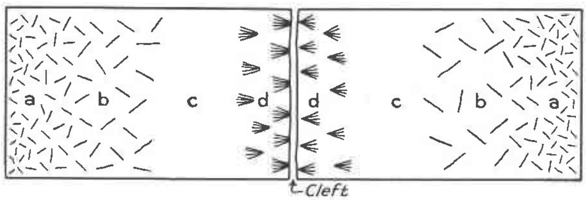

FIG. 7. Clefted pegmatite (8 inches wide) on south end of Elk Peak nepheline syenite showing zoning of biotite and sphene: *a*, nepheline syenite; *b*, biotite and prismatic aegirite; *c*, prismatic aegirite; *d*, acicular sphene replacing sanidine.

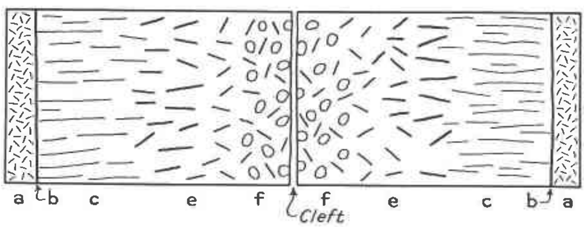

FIG. 8. Idealized, zoned, clefted pegmatite (2 feet wide) free of biotite and sphene: *a*, nepheline syenite; *b*, well defined contact; *c*, transverse aegirite fibers and lamprophyllite laths; *e* bladed lamprophyllite with fibrous and prismatic aegirite; *f*, coarse eudialyte with bladed lamprophyllite and prismatic aegirite.

Composition.

Most of the pegmatites contain only sanidine, nepheline, and aegirite, and a few of the most complex ones contain all the identified minerals. Although in some pegmatites the rare minerals are abundant, they represent a small percentage of the total mineral composition. The distribution and relations of the minerals are included in a later section on descriptive mineralogy. The spatial relations of some of the unusual minerals in the complex pegmatites, in part schematically shown in Figs. 6, 7, 8 can be briefly summarized in the statements below.

1. In the observed pegmatites which contain biotite, sphene, eudialyte, and lamprophyllite, the first two minerals are restricted to the borders of the pegmatite, and the last two to the margins of the cleft.
2. In the observed pegmatite masses which contain both biotite and sphene, but in which eudialyte and lamprophyllite are absent, the biotite is restricted to the borders of the pegmatite but the sphene to the margins of the cleft.
3. In the slab-like pegmatites in monzonite at the summit of Pegmatite Peak, the sanidine, eudialyte, lamprophyllite, aegirite, and to a less extent the sphene, have been introduced into the monzonite up to 6 inches beyond the contact.
4. Melanite, which is so common in the segregation pegmatites, is a very rare constituent in the complex lens-shaped pegmatites. Melanite is common, however, in those clefted lenses which do not contain biotite, sphene, eudialyte and lamprophyllite, but which do contain an abundance of fibrous aegirite.

Alterations and Veins.

In many pegmatites, local areas are present in which all the nepheline and much of the aegirite is completely destroyed. Irregular cavities with soft limonitic dirt, and tiny crystals of albite perched on the walls now remain.

On the summit of Pegmatite Peak, a second kind of alteration has formed in a few pegmatites in addition to the one described above. Some unknown minerals, probably eudialyte and aegirite, have been destroyed, and the resulting solution cavities are coated with pyramidal crystals of zircon and compact rosettes of stilpnomelane.

In the same altered pegmatites on Pegmatite Peak, a few tiny veinlets composed essentially of albite have formed in fractures in the rock. Brookite, elpidite (?), and a few unidentified minerals are also present in these veinlets. The veinlets are insignificant, as are the alterations, in consideration of the total volume of the pegmatites; but nevertheless, they represent a recognized process of mineralization that may well have been more active if certain other conditions existed during the late history of pegmatite formation.

Sulfides and Carbonates.

A few of the complex pegmatites on Rocky Boy Mountain contain rare specks of sulfides (pyrite and galena) which are entirely enclosed in halos of altered feldspar up to ½ inch in diameter. Sulfides have not been observed in veins in these pegmatites. Microscopic quantities of calcite and ankerite have been observed on the walls of a few solution cavities.

Pegmatite Dikes

General Statement.

Four pegmatite dikes of nepheline syenite have been observed in the stock, one in monzonite, one in nepheline shonkinite, and two in biotite pyroxenite. Except for a very rare lamprophyllite, they do not contain the unusual minerals found in the lens-shaped pegmatites. Sanidine, nepheline, and fibrous aegirite are the essential minerals of the dikes, and prismatic aegirite, biotite, and melanite are locally present.

Dike in Monzonite.

A dike 8 feet thick is exposed for about 100 feet in a gully north of Pegmatite Peak (locality *D*). It strikes N.W. and dips about 25 degrees N.E. At the ill-defined footwall contact, the dike is composed of fine-grained banded nepheline syenite. Separating this from the main, feldspar-rich part of the dike is an intermediate zone about one foot thick composed of coarse-grained nepheline syenite. The upper part of the dike is not exposed. Some differences between the main and intermediate parts of the dike are listed below:

1. The sanidine of the intermediate zone is glassy, whereas that of the main part is dull, green, altered, and up to a few inches in size across cleavages.
2. The nepheline is euhedral and much more abundant in the intermediate part.
3. Biotite and aegirite are abundant in the intermediate part, and the former is absent, the latter rare, in the main part.
4. Fibrous lamprophyllite is sparse in the intermediate part, and absent in the main part.

Dike in Nepheline Shonkinite.

A pegmatite dike is exposed for a few hundred feet at locality *E*. The dike is 6 feet wide, strikes N. 30 E. and dips about 25 degrees S.E. Some cleavage faces of sanidine in this pegmatite measure up to 8 inches across.

Dikes in Pyroxenite.

Two dikes of aegirite-rich pegmatite have been observed at localities *F* and *G*. They are composed essentially of altered and glassy sanidine, altered, euhedral nepheline, and abundant fibrous aegirite.

Pegmatitic Dikelets

Individual or groups of tiny dikelets, rarely more than one inch thick, have been observed in rocks older than and contiguous with nepheline syenite. They probably represent pegmatitic liquid injected along joint cracks. At locality *H*, a large massive outcrop of poikilitic monzonite has three well defined set of joints, and most of these joints contain the dikelets of nepheline-aegirite syenite pegmatite.

Aplitic Syenite

A few thin, green dikelets in nepheline syenite, are exposed for several feet, and are hard and unaltered. In thin section, the rock of these dikelets is seen to be composed of very fine-grained sanidine, nepheline, and aegirite. The aegirite is proportionately more abundant here than in the host rock, or in pegmatites. Perhaps these green dikelets represent an aplitic phase of the pegmatites.

DESCRIPTIVE MINERALOGY

Sanidine

General Description.

Sanidine is the most abundant mineral and makes up as much as 80 per cent of some pegmatites. Large cleavage faces up to 8 inches across are present in the large dikes. Glassy, transparent sanidine is very common, especially in the segregation pegmatites; but in most of the clefted lens-shaped pegmatites it has been hydrothermally altered.

One alteration, a pale green variety, is common in lens-shaped pegmatites rich in fibrous aegirite and in the main part of the pegmatite dike in monzonite. The green color is imparted to the sanidine by a great number of tiny, included crystals of aegirite, visible only under high magnification. In some feldspar, swarms or clusters of such aegirite crystals are clearly oriented along cleavage directions. There are all gradations in the size and abundance of the included aegirite, and presumably it is of replacement origin.

A second kind of alteration, a chalky white variety, is most common in the dike in shonkinite. Powdered grains are white and "dusty" in reflected light, apparently homogeneous in plane polarized light, and have a "splotchy" texture under crossed nicols. The texture suggests an incipient form of microperthite. Integral parts of the same grain show twinning, with extinction angles differing as much as 10 degrees. This microperthite (?) is perhaps hydrothermal.

Optical Properties and Chemical Composition.

The optical properties of glassy sanidines from the pegmatites are nearly the same. Refractive indices and optic angle vary slightly, however, beyond the controlled limits of accuracy of the determinative methods. The variations for several specimens are listed below.

Refractive Indices (Na)	Monoclinic
($\pm$.001)	($-$)
$\alpha=1.521$–24	$2V=39$–$45°$
$\beta=1.526$–29	$r<v$, percep.
$\gamma=1.527$–30	

Orientation (Universal stage): $Z=b$; and on (010), $X\wedge a=9°$

The resorbed, zoned sanidine in some nepheline syenites differs distinctly optically from the unzoned sanidine of the pegmatites: β varies between 1.529–1.535 for the different zones; and 2V is nearly zero. The intermediate zones have the highest index.

In Table 2 are included partial analyses of two unzoned sanidines. One, (no. 2, Table 2) a soda-rich variety, has a β of 1.527 (Na $\pm$.001), and a 2V of 40° ($\pm$1°); the second (no. 3, Table 2) a soda-poor variety, has a β of 1.528 and a 2V of 44°.

TABLE 2. CHEMICAL ANALYSES

	1	2	3	4	5	6	7	8	9
SiO_2	54.32			41.52	41.87	51.72	30.92	30.80	28.90
TiO_2	0.51			none		1.32	31.73	31.26	27.70
Al_2O_3	18.26			34.09	33.94	1.56	0.32	—	3.75
Fe_2O_3	3.76			0.79	0.70	26.14	0.97	0.37	0.95
FeO	2.36					2.38	2.90	3.16	2.07
MnO	0.03					0.21	2.01	3.21	2.72
MgO	0.98					1.41	0.31	0.53	2.38
CaO	1.68			0.06	0.47	2.56	1.68	1.20	1.9
Na_2O	2.36	3.82	0.95	15.76	15.03	11.28	10.64	12.70	10.30
K_2O	12.04	11.82	14.83	6.85	6.68	0.34	0.99	—	0.60
BaO	1.46	0.26		0.03			1.12	1.09	1.8
SrO	n.d.			none			14.66	14.49	14.4
ZrO_2	n.d.					0.24	—	—	—
P_2O_5	0.22						—	—	—
F	n.d.						1.71	1.65	—
H_2O+	0.94			0.55		0.50	1.07	0.39	1.00
Total	98.92			99.65		99.66	101.03	100.85	99.47
$O=F_2$							−.86	−.83	
							100.17	100.02	

1. Nepheline syenite ($Q0_4$), Elk Peak, Rocky Boy stock.
2. Sanidine, segregation pegmatite, Pegmatite Peak.
3. Sanidine (potash-rich), pegmatite dike in shonkinite.
4. Nepheline, complex pegmatite, Pegmatite Peak.

F. A. Gonyer, *analyst.*

5. Nepheline, Greenland (Bøggild, 1905).
6. Fibrous aegirite, pegmatite dike in shonkinite. F. A. Gonyer, *analyst.*
7. Lamprophyllite, complex pegmatite, Pegmatite Peak. F. A. Gonyer, *analyst.*
8. Lamprophyllite, Kola Peninsula, Russia (Fersman, 1928, p. 121).
9. Molengraaffite, Transvaal, S. Africa (Brouwer, 1910). CaO, BaO, and SrO by H. C. G. Vincent (Tilley, 1938).

The variation of refractive index is probably a reflection of the barium content of the sanidine; whereas the 2V may be largely controlled by the physical conditions of crystallization.

Nepheline

General Description.

Nepheline is common, but makes up less than 30 per cent of any pegmatite. Euhedral outlines of hexagonal crystals are generally well preserved in the dikes, and the largest crystal observed is about 2 inches across the base. The largest single mass of nepheline observed in a complex pegmatite is about 4 inches in diameter.

Contact surfaces between nepheline and sanidine are most favorable for early replacement minerals, and, with few exceptions, the sanidine tends to be selectively replaced. Rarely, the replacement has been so complete that grains of slightly altered nepheline are imbedded in a mass of the replacing mineral (Figs. 9, 10).

The principal unidentified alteration product is a substance flesh-pink to red in color which encloses irregular cores of unaltered nepheline. Under high magnification it is sub-fibrous, and contains small unidentified inclusions of a metallic mineral and a reddish, translucent mineral. The composite refractive index of the alteration product is about 1.55, and its optical character indeterminate. Some grains appear to be biaxial (+) with a 2V of about 55°.

Yellowish, powdery halloysite is another alteration product and is most abundant in the syenite on Elk Peak.

Optical Properties and Chemical Composition.

The refractive indices of several samples of nepheline are variable: $\omega = 1.544$–51; $\epsilon = 1.539$–45. No systematic variation was observed in the pegmatites. The mineral is uniaxial (−).

In Table 2 is included an analysis (no. 4) of nepheline from a complex pegmatite. The sample was free of aegirite and lamprophyllite, and contained a fraction of one per cent of sodalite. The refractive indices, higher than those for common nepheline, are: $\omega_{Na} = 1.543$; $\epsilon_{Na} = 1.539$ ($\pm .001$).

The high content of K_2O, Fe_2O_3, and the low CaO are unusual for nepheline and are comparable to an analysis of nepheline from Greenland (no. 5, Table 2). The analyzed nepheline from the Bearpaw Mountains has a soda-potash ratio of 2.5:1, whereas most analyses of nepheline have a soda-potash ratio of from 4:1 to 5:1.

Bowen (1936) has described a nepheline containing about 11 per cent K_2O and has demonstrated that potash-rich nephelines are associated only with potash-rich rocks. Bannister's (1931) experimental data suggest that an increase in K_2O in nepheline commonly increases both the refringence and cell volume. The low percentage of BaO excludes the possibility of a control of refractive index by barium content, as is the suggestion for sanidine.

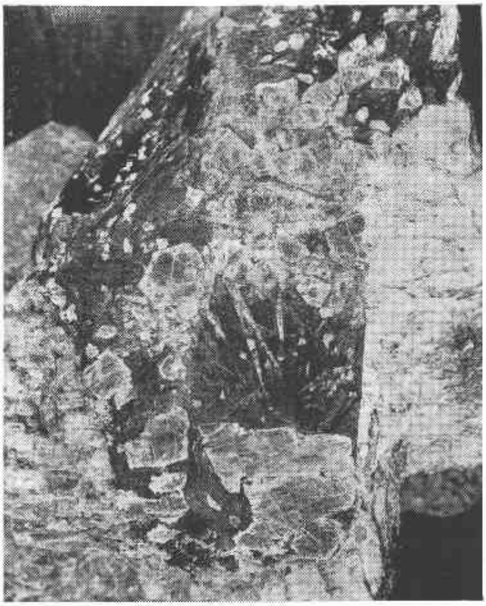

FIG. 9. Hand specimen from pegmatite dike in shonkinite showing fibrous aegirite (black), euhedral nepheline (gray), and sanidine (light).

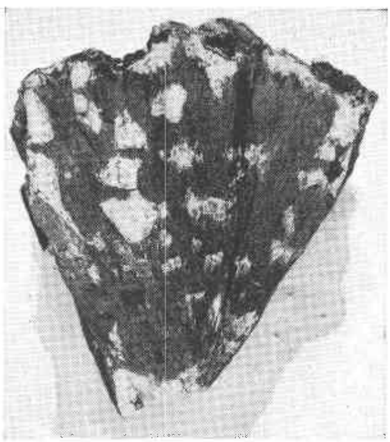

FIG. 10. Hand specimen of botryoidal mass of fibrous aegirite including grains of altered nepheline.

Sodalite

Sodalite is a common associate of fresh nepheline, and in some specimens is in graphic intergrowth with it. Sodalite is more abundant in the segregation pegmatites than in the host nepheline syenite. The mineral is isotropic and weathers to a bluish-white, amorphous substance having n near 1.427.

Biotite

Black biotite is an essential, though not abundant, mineral in the nepheline syenites and segregations and is present in the marginal parts of some lens-shaped pegmatites. The mineral makes up less than 5 per cent of any rock. It is coarser in the pegmatites, where it also has a higher refractive index. At locality *A*, some biotite books measure one inch across the base and two inches along the prism edge.

The mean refractive index on the cleavage flakes varies from 1.67 to 1.73; the highest values being restricted to long, thin, laths of biotite intimately associated with fibrous aegirite and lamprophyllite in the dike in monzonite. The biotite with lower refractive index is uniaxial (−); and some with high refractive index is biaxial (−), with 2V up to 25°. The biotite may be the variety lepidomelane.

Fersman (1937) has shown that an increase in the state of oxidation of iron is probably responsible for the increase in refractive index of lepidomelane from the Kola Peninsula. This oxidation, for the biotite in the pegmatite dike, could have been effected during the hydrothermal formation of fibrous aegirite

Garnet (Melanite)

Garnet is most abundant in those segregation pegmatites which contain coarse biotite, but in which prismatic aegirite is scarce. None has been observed in the complex lens-shaped bodies which contain eudialyte, lamprophyllite, and prismatic aegirite. Many pegmatites on Rocky Boy Mountain contain abundant garnet, and in some of them fibrous aegirite is also abundant.

The garnet commonly is interstitial between sanidine and nepheline, molding around the grains of sanidine. In some places it is present along cracks in the feldspar and appears to replace it.

The garnet is rarely altered, is black, has a pitchy luster, breaks with conchoidal fracture, and has a brownish-red translucent color in strong light. Its specific gravity is 3.88 (Berman balance), and its n is about 1.95. A complex of interference faces characterizes its development, with striated contact surfaces intersecting in sharp ridges and valleys. The faces are possibly close to the dodecahedron, although that form cannot definitely be determined in any of the masses studied.

A qualitative test for titanium proved positive. The mineral may possibly be classified as a melanite, or titano-melanite, in accord with Mackowsky (1939), or may be related to schorlomite.

Sphene

Sphene is not an abundant mineral in these pegmatites and has been observed in four relationships. One is typified by a segregation pegmatite at locality *C*. In this deposit, the sphene has a pseudo-prismatic habit, is restricted to grain boundaries of, or fractures in, sanidine. A second is typified by a small, clefted pegmatite at the south end of the Elk Peak intrusion, and is sketched ideally in Fig. 7. Sphene is confined to that part of the pegmatite on either side of the cleft as coarsely acicular masses replacing sanidine.

In a third association, in some slab-like complex pegmatites on Pegmatite Peak, sphene is confined to the border zone with biotite and prismatic aegirite (Fig. 6). In a fourth association at the same locality sphene has been introduced into monzonite for a few inches.

The sphene is honey-yellow, biaxial (+), has a small 2V, and $\beta = 1.94$.

Aegirite

Prismatic Aegirite.

Thin, black, non-terminated prisms of aegirite commonly up to one inch long, and rarely up to 4 inches in length, have been observed in many complex pegmatites. They are present in sanidine as randomly oriented, and in places, bent, curved, or broken prisms. The prismatic habit of aegirite is most conspicuous where the fibrous habit is scarce. Although there are all gradations in size of prisms, there appears to be a well defined break between the two habits in the same deposit, and commonly masses of the green, fibrous variety includes black prisms. Prismatic aegirite has a wide association of minerals in the pegmatites as shown in Figs. 6, 7, and 8.

Fibrous Aegirite.

In some deposits compact masses of green, fibrous aegirite include earlier formed minerals (Figs. 12, 13). Commonly the aegirite is developed between grain boundaries, or along cracks and cleavage faces of sanidine. Locally the aegirite is altered to limonite.

In small lens-shaped pegmatites the mineral is oriented with its long dimension normal to the wall of the deposit (Figs. 5, 8). Long laths of lamprophyllite are not uncommonly associated with fibrous aegirite in the pegmatite dikes and in the complex pegmatites.

Fibrous aegirite has been reported from Libby, Montana (Larsen and Pardee, 1913; and Goranson, 1927) and from Iron Hill, Colorado (Larsen, report in press). Washington (1927) has made a survey of acmitic pyroxenes.

Optical Properties and Chemical Composition.

An analysis of fibrous aegirite from the dike in shonkinite is given in Table 2, no. 6. The material has 80 per cent of the acmite molecule, 10.3 per cent diopside, 4.7 per cent hedenbergite, and 5 per cent unassigned, composed principally of SiO_2 and Fe_2O_3. The calculated chemical formula, in agreement with Berman's classification (1938) is expressed: $(Na, Ca)_{.94}(Fe''', Mg, Mn, Fe'', Al)_{1.05}Si_{1.98}O_6$; where Na:Ca=8:1, and Fe''':(Mg, Mn, Fe'', Al)=8:3.

Many specimens of fibrous and prismatic aegirite have similar optical properties. Data for the analyzed material is given below:

Refractive indices (Na ±.001)	Monoclinic
X (near c) = 1.757	Biaxial (−), $r>v$
Y(= b) = 1.786	2V = 62°
Z = 1.797	Neg. elongation
Cleavage, (110) perfect	
Parting (?), (001)	

Small crystals studied in immersion liquids under high magnification afforded some opportunity for the determination of crystallographic data. By measuring the angles between prism edge and the traces of inclined terminal faces, the following crystal (or parting?) forms are indicated: $c\{001\}$; $u\{111\}$; $s\{\bar{1}11\}$; and $S\{\bar{3}11\}$.

Eudialyte

This complex sodium-zirconium silicate is present in a few of the complex and clefted pegmatites, and in them is coarse-grained and limited to the portions near the cleft (Fig. 8). It is intimately associated with bladed lamprophyllite. On Pegmatite Peak, eudialyte has been introduced into monzonite for about 6 inches. Within the pegmatites, eudialyte selectively replaces feldspar. Where the replacement has been complete, the mineral has a rose-red color, and where the replacement is incipient the mineral has a pink to flesh-pink color. In the few deposits in which it has formed it is an abundant mineral. The largest grains seen are about an inch in diameter.

No crystals of the mineral have been observed. The rose-red material is uniaxial (+), with $\epsilon = 1.606$, and $\omega = 1.600$. Grains in immersion media are pale yellow in transmitted light, and have a poorly developed basal cleavage.

A buff colored alteration product of eudialyte is, as seen in immersion media, deeper yellow in transmitted light, sensibly isotropic, and has a slightly higher refractive index than the unaltered mineral.

Lamprophyllite

General Description.

This complex sodium-strontium titanosilicate has hitherto been reported only from the Kola Peninsula, Russia; although molengraaffite from the Transvaal, South Africa, is probably closely related to it. Coarse, platy books are associated with coarse eudialyte and prismatic aegirite, and long, thin laths are associated with fibrous aegirite. The largest plates are $2\times\frac{1}{2}$ inches, and the longest laths are 4 inches. The mineral selectively replaces sanidine. No terminated crystals have been observed.

History.

Lamprophyllite is the name assigned by Hackman (1894) to the unidentified, brown, platy, astrophyllite-like mineral described by Ramsay (1890) from the Khibina Tundra of the Kola Peninsula. The present writer first discovered lamprophyllite in the Bearpaw pegmatites in 1937 and recognized its remarkable similarity to the Kola mineral. For comparison, lamprophyllite from Kola, molengraaffite from the Transvaal, and astrophyllite from southern Norway—all specimens from the Holden Collection at Harvard University—were studied microscopically. The Bearpaw and Kola lamprophyllite are almost identical in refringence, habit, and orientation. Molengraaffite has the same orientation and habit but lower refringence. Astrophyllite differs markedly in cleavage, orientaion, and refringence (see Table 3).

Bohnstedt (1931) and Berman (1937) have suggested that molengraaffite is not a distinct species, as originally proposed by Brouwer (1911), but that it belongs in a series with lamprophyllite. Tilley (1938) has shown that the two minerals are chemically and optically related.

Gossner and Drexler (1935) concluded that x-ray studies on the Kola specimens indicate an orthorhombic symmetry. Their conclusions are not in accord with optical data obtained by the present writer and others on either Bearpaw or Kola specimens. Lamprophyllite has a fine, polysynthetic twinning parallel to the dominant (platy) cleavage; a fact which may have caused Gossner's erroneous conclusions. Laue photographs made by Professor C. S. Hurlbut, Jr., indicate either a monoclinic or triclinic symmetry.

Optical Properties and Chemical Composition.

An analysis of lamprophyllite from Pegmatite Peak is given in no. 7, Table 2, with a typical analysis of the Kola material (no. 8), and a partial analysis of molengraaffite from the Transvaal (no. 9). The optical data are listed in Table 3, and orientation indicated in Fig. 11.

TABLE 3. COMPARISON OF OPTICAL DATA (SEVERAL SOURCES) OF TYPICAL LAMPROPHYLLITE WITH MOLENGRAAFFITE AND ASTROPHYLLITE

	Lamprophyllite, Bearpaw Mts. (Sp. gr.=3.46)	Lamprophyllite, Kola (Sp. gr.=3.5)	Molengraaffite (Sp. gr.=3.54)	Astrophyllite (Sp. gr.=3.4)
α	1.746	1.747	1.735	1.691
β	1.754	n.d.	1.747	1.705
γ	1.778	1.779	1.770	1.735
2V	40° (ca.)	23°–41°	28°	70° (ca.)
Character	(+)	(+)	(+)	(+)
Dispersion	$r>v$, str.	$r>v$, str.	$r>v$, str.	$r>v$, str.
Absorption	Z>X	Z>X	Z>X	Z>X
Pleochroism	deep to honey-yellow	deep to honey-yellow	brownish-yellow	deep orange to lemon-yellow
Cleavage*	(100)? platy, dom. (011)? good (010)? poor	(100) platy, dom. (011) good	(100) perf. (011) good	(010) perf. (001) imperf.
Orientation*	Y=or near a X=or near b $Z\wedge c=5°$	Y=or near a X=or near b $Z\wedge c=7°$	Y=or near a X=or near b $Z\wedge c$=small	Y near b Z near a
Symmetry	mon. or tric.?	mon. or tric.?	mon. or tric.?	mon. or tric.?

* See Fig. 11.

Conclusions.

Molengraaffite is probably structurally identical with lamprophyllite, and despite slight differences in chemical composition and optical properties may be considered a member of the lamprophyllite series. Lamprophyllite itself may be monoclinic, or possibly triclinic.

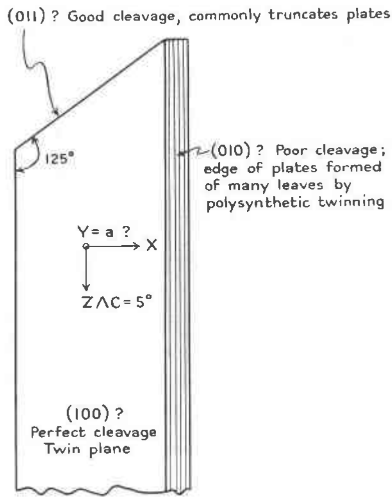

FIG. 11. Sketch showing relation of cleavages to optical orientation of lamprophyllite.

CATAPLEIITE

In a small part of some altered complex pegmatites on the summit of Pegmatite Peak, the writer observed a few granular aggregates of altered material in association with relatively fresh feldspar, nepheline, lamprophyllite, and prismatic aegirite. The alteration, probably derived from eudialyte, is composed of compact grains of glassy, twinned and untwinned catapleiite, mixed in a matrix of brown colored carbonate. The optical data of the catapleiite are listed below:

Refractive Indices ($\pm$.002)	Twinned, both uniaxial (+) and biaxial (+) with very small 2V.
$\alpha = 1.590$	
$\beta = 1.592$	Gelatinizes in HCl
$\gamma = 1.623$	

Cleavage: poorly developed pyramidal. The twin law is not known. It is likely that this mineral is a hydrous alteration product of eudialyte.

ALBITE

Albite is commonly present as well formed tablets attached to the walls of solution cavities in altered pegmatites. The largest crystals are less than one inch long, and are best developed in the altered pegmatites on the summit of Pegmatite Peak.

BROOKITE

In one place tiny crystals of brookite are imbedded in a thin veinlet of albite, but these crystals are not observed in the cavities. The crystals have the apparent shape of hexagonal bipyramids but are actually a combination of the forms $m\{110\}$ and $e\{122\}$ of the orthorhombic system.

Zircon

Zircon has been observed in two localities. In one locality it is intimately associated with stilpnomelane and smoky quartz. In a second, a large segregation pegmatite on Elk Peak (locality *C*), small solution cavities are coated with tiny pyramidal crystals of green zircon, with $\omega = 1.94$.

Stilpnomelane

In an altered pegmatite on the summit of Pegmatite Peak, larger cavities are coated with rust-covered pyramidal crystals of zircon, and these are coated with compact rosettes of stilpnomelane. Tiny prisms of smoky quartz are attached to surfaces of the rosettes. Small flakes of stilpnomelane have also been observed to replace or to be attached to prisms of aegirite. In these altered areas, which are adjacent or contiguous to cavities containing albite, the eudialyte, some aegirite and some lamprophyllite have been destroyed.

In habit, the stilpnomelane resembles chlorite. The mineral is yellowish-brown to red, has a very high birefringence, is uniaxial (−) with ω about 1.78. The mineral has a strong absorption with $\omega > \epsilon$.

Elpidite (?)

A few silky tufts of a white, prismatic mineral of uncertain identification replace the albite of one veinlet on Pegmatite Peak. The optical properties of the mineral are listed below. The properties resemble those of elpidite, and the habit of the mineral resembles a fibrous zeolite.

Refractive Indices ($\pm .002$)	Orthorhombic
$X = 1.563 =$ elongation	$2V = 90° \pm 5°$ (est.)
$Y = 1.568$	One perfect cleavage in zone of elongation.
$Z = 1.573 = \perp$ to cleavage	

PARAGENESIS AND GEOCHEMISTRY

Mineral Associations

The precise order of formation of every mineral in the pegmatites cannot be determined with certainty; but, as shown in the paragenetic chart (Fig. 12) and in Table 4, age relations of group associations are more reliable.

TABLE 4. GROUP MINERAL ASSOCIATIONS AND THEIR RELATIVE AGES

Age groups	Minerals	Origin
1	Sanidine, nepheline, biotite	Magmatic
2	Biotite, prismatic aegirite, melanite, sphene	Transitional
3	Prismatic aegirite, eudialyte, lamprophyllite	Replacement
4	Lamprophyllite, fibrous aegirite	
5	Fibrous aegirite	Hydrothermal
6	Catapleiite	
7	Zircon, stilpnomelane, smoky quartz	
8	Albite, elpidite, brookite	
9	Pyrite, galena	

Where no alterations have occurred the minerals precipitated in the magmatic stage now form a solid, and compact rock. The compactness of the rock was maintained during the replacement stage of mineralization although some movement of materials was effected. In the hydrothermal stage, however, compactness was destroyed through solution of nepheline, eudialyte, and aegirite.

TEMPERATURE AND DEPTH OF FORMATION

The experimental data available in the literature concerning the behavior of twinned catapleiite, smoky quartz, and brookite may serve to indicate that the hydrothermal stage of mineralization existed at a temperature over 200° C. These minerals are confined to those deposits at the highest elevation (about 6300 feet). From a knowledge of the petrological relations in the Bearpaw Mountains, the depth of sedimentary and volcanic cover existing at the time of intrusion of these alkalic syenites is interpreted to have been at least 3000 feet, and may have been as much as 7000 feet.

At shallow depth, the rate of fall in temperature of the implaced magma may have been rapid, although the initial temperature was high. The writer believes that the coarseness of grain for these syenitic rocks is an inherent character, and that crystallization as well as eruption were rapid phenomena.

Rare Constituents

As noted earlier in this paper, a potash and barium-rich (but soda-poor) syenitic magma gave rise, by fractionation, to a later (pegmatitic) syenitic magma not so rich in potash and barium, but much richer in soda. More barium was contained in the early magma than in the later one, whereas strontium, titanium, and zirconium became progressively more concentrated in the later magma. The affinity of these four rare elements for alkalic rocks has been widely recognized in the geological literature, and the close affinity of potash and barium is well supported in these studies.

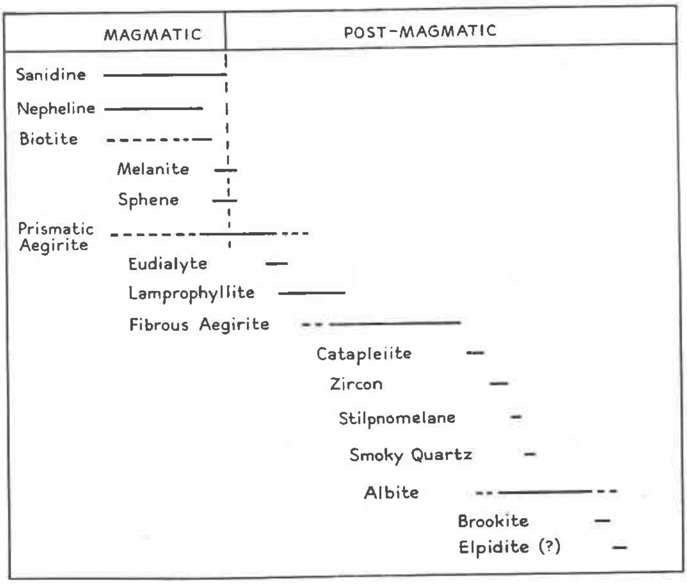

Fig. 12. Paragenetic chart of nepheline-aegirite syenite pegmatites.

Chemical analyses and optical data strongly suggest that most of the barium in the nepheline syenites and pegmatites mentioned in this paper is in the sanidine, and that more barium can be taken into solid solution with potash at the higher temperatures of crystallization. In the discontinuously zoned sanidine, refractive indices indicate that the intermediate zones of that mineral, not the cores, are richest in barium. Since the peripheral zones have about the same refractive indices as does unzoned, pegmatitic, soda-rich sanidine, perhaps 0.26 BaO (Table 2) may be considered as near the low limit of the barium content of the sanidine in these syenites. No data are available as a control of the upper limit, but at least a few per cent BaO is an acceptable value.

Strontium, titanium, and zirconium have an unequal distribution in minerals of the pegmatites, as shown in Table 5.

TABLE 5. DISTRIBUTION OF STRONTIUM, TITANIUM, AND ZIRCONIUM IN SIMPLE AND COMPLEX PEGMATITES

	Simple Pegmatites	Complex Pegmatites
Strontium	Aegirite	Lamprophyllite
Titanium	Melanite, aegirite	Sphene, lamprophyllite, and brookite
Zirconium	Aegirite	Eudialyte, catapleiite, zircon, and elpidite

The amount of titanium and zirconium shown in the analyzed fibrous aegirite from the pegmatitic dike is not necessarily a measure of the amounts of those elements in fibrous or prismatic aegirite from the simple or complex pegmatites. There are, however, no remarkable differences in composition of the aegirites for their optical properties are similar. No data are available as to the relative amounts of the rare constituents in the aegirite of the simple pegmatites, in contrast to that of the complex pegmatites, which represent a magma rich in those constituents. The MnO content of lamprophyllite and aegirite is noteworthy.

Two kinds of utilization of the rare constituents have been recognized in these pegmatites, and they are here named (1) distributive utilization, and (2) repetitive utilization.

DISTRIBUTIVE UTILIZATION

Distributive utilization is defined as the precipitation of a given constituent in more than one mineral of the same pegmatite, although the minerals containing that constituent are not necessarily contemporaneous in origin. The concept is well illustrated by those complex pegmatites on the summit of Pegmatite Peak in which titanium is contained in the minerals sphene, lamprophyllite, brookite, and aegirite; and zirconium in the minerals eudialyte, catapleiite, zircon, etc.

REPETITIVE UTILIZATION

The concept of repetitive utilization is suggested by those deposits in which some minerals (nepheline, eudialyte, aegirite) are chemically attacked or destroyed, and their constituents made available for the precipitation of stable, secondary minerals, either in place, or by transportation to another site. The reconstituted minerals may themselves be attacked under still later conditions, and robbed of certain constituents so that still younger minerals may be formed. The writer is of the opinion that the formation of catapleiite, zircon, stilpnomelane, elpidite, brookite, albite, and smoky quartz are clear examples of repetitive utilization.

The insignificant volume of the secondary minerals resulting from this process, with respect to the volume of the unaltered pegmatites, is some indication of the scarcity of a fluid volatile in these syenitic magmas. A greater array of hydrothermal minerals would have been present in these pegmatites had there been a greater quantity of the same dissolving agent. Perhaps in the now-eroded rocks of a higher elevation in the stock, veins of reconstituted minerals were more common than they are in the now-exposed rocks on Pegmatite Peak. The process of repetitive utilization is well supported, and can well be applied to the great array of hydrothermal minerals associated with a younger set of pegmatites mentioned below.

Other Deposits

In the area around the Vermiculite Prospects on Big Sandy Creek (Fig. 2) are exposed numerous pegmatites and veins which will be subjects of a forthcoming paper. For the purposes of general comparison, however, a brief list of them is here presented:

1. Biotite-acmite syenite pegmatites.
2. Biotite syenite pegmatites, with younger complex veins composed of a great array of silicates, oxides, sulfides, carbonates, and other compounds.
3. One vein composed essentially of calcite and apatite, graphically intergrown, and containing fluorite and pyrite.
4. Veins composed essentially of albite and brookite.
5. Veins composed essentially of smoky quartz, with sulfides and carbonates.

The deposits listed above are all related to the igneous activity in the Rocky Boy stock; and there is positive evidence that two deposits (1 and 2, above) are both younger than the pegmatites described in this paper.

CONCLUSIONS

The nepheline-aegirite syenite pegmatites in the Rocky Boy stock of the Bearpaw Mountains more nearly resemble the unusual pegmatites of the Kola Peninsula in northern Russia than those of any other described region. Some resemblance is noted, in part, to classic localities such as southern Greenland, southern Norway, Magnet Cove, Arkansas, and others. It is likely that the origin of the pegmatitic and parental alkalic magmas of these different regions is similar. In the Bearpaw deposits the mineralization has occurred on a less grandiose scale, but the same processes of mineralization are noted here. Initial compositions of the pegmatitic magma, rate of fall in temperature after its implacement, and amount of active volatile residue are all variable factors governing the complexity of the mineral assemblage in these pegmatites.

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REFERENCES

BANNISTER, F. A., and HEY, M. A., A chemical, optical, and *x*-ray study of nepheline and kaliophilite, *Mineral Mag.*, **22,** 569–608 (1931).

BERMAN, HARRY, Constitution and classification of the natural silicates: *Am. Mineral.*, **22,** No. 5, 342–408 (1937).

BØGGILD, O. B., Mineralogia groenlandica: *Medd. om Grøn.* **33,** 625 pages (1905).

BOHNSTEDT, E., Lamprophyllit der Chibina-Tundren: *N. Jahr. Min.*, **1,** 354 (1931).

BOWEN, N. L. and ELLESTAD, R. B., Nepheline contrasts: *Am. Mineral.* **21,** 363–368 (1936).

BROUWER, H. A., Oorsprong en samenstelling der Transvaalsche nepheliensyenieten, *Haag*, pp. 143, 179 (1910).

———, Molengraaffite, ein neues Mineral in Lujauriten aus Transvaal. *Cent. Min.*, 129 (1911).

FERSMAN, A. E., Minerals of the Khibina and Lovozero Tundras: *Acad. of Sci. Press*, Moscow, 152 pages (1937).

GORANSON, R. W., Aegirite from Libby Montana: *Am. Mineral.* **12,** 37–39 (1927).

GOSSNER, B., and DREXLER K., Über kristallform von lamprophyllit: *Zeits. Krist.*, **91,** 494–500 (1935).

HACKMAN, V., Der nephelinsyenit des Umptek: *Fennia*, **11,** No. 2, 119–120 (1894).

LARSEN, E. S., Petrographic province of central Montana: *Bull. Geol. Soc. Am.*, **51,** No. 6, 887–948 (1940).

——— and HUNT, W. F., Two vanadiferous aegirites from Libby, Montana: *Am. Jour. Sci.*, **36,** 289–296 (1913).

MACKOWSKY, M. T., Melanite and titan-melanite: *Chem. der Erde*, **12,** 123–157 (1939).

RAMSAY, W., Halbinsel Kola, *Fennia*, **3,** 45 (1890).

TILLEY, C. E., Identity of molengraaffite with lamprophyllite: *Trans. Geol. Soc. S. A.*, 109–113 (1938).

WASHINGTON, H. S., and MERWIN, H. E., The acmitic pyroxenes: *Am. Mineral.*, **12,** No. 6, 233–252 (1927).

WEED, W. H., and Pirsson, L. V., Igneous rocks of the Bearpaw Mountains, Montana: *Am. Jour. Sci.*, **1,** 283–301; 351–362; **2,** 136–148, 188–199 (1896).