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MICAS OF THE BROWN DERBY PEGMATITES, GUNNISON COUNTY, COLORADO[1]

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ABSTRACT

The Brown Derby No. 1 pegmatite, of Gunnison County, Colorado, contains a highly diversified suite of micas: biotite, muscovite, zinnwaldite, rose muscovite, sericite, and five major varieties of lepidolite. Each of the micas was formed in a unit of characteristic mineralogy and texture. Chemical analyses demonstrate that the Li micas show nonsystematic variations in both major and minor elements with respect to their positions in the pegmatite and probably with respect to relative time of formation. These data coupled with nonsystematic variations in texture and mineral composition, and cross-cutting structural relationships indicate that the albite-Li mica units are not primary zones but are replacement layers formed by reactions between zonal pegmatite rock and deuteric, residual pegmatitic fluids in a closed-system environment.

INTRODUCTION

The Brown Derby group of pegmatites, long known as one of the most celebrated of mineral occurrences in the Rocky Mountains, is in Gunnison County, Colorado. The group, which forms the most interesting and important swarm of dikes in the Quartz Creek pegmatite district, is well exposed on the upper slopes of the east side of Quartz Creek about 6 miles northeast of Parlin at the junction of Colorado State Highway 162 with U.S. Highway 50.

The first description of the Brown Derby No. 1 pegmatite by Eckel (1933) was followed shortly by two other brief notices (Landes, 1935; Eckel and Lovering, 1935). The pegmatites were mapped between 1942 and 1944 by teams of the U.S. Geological Survey (Hanley, Heinrich and Page, 1950; Hanley, 1947). From 1948 to 1949 the geology of the entire Quartz Creek district was studied by Staatz and Trites (1955). General observations on the geology of the pegmatite district have been made by: Heinrich (1953) in describing the district zoning; McLellan (1956) in discussing the economic geology; Heinrich (1957A) in defining Colorado pegmatite provinces; and by Heinrich and Vian (1965), who compared the Brown Derby mineral assemblage to those of several other Li-rich pegmatites in Colorado and northern New Mexico.

Many of the more unusual minerals of the Brown Derby pegmatites have been studied in detail (Table 1).

The chief purpose of this paper is to present a chemical and paragenetic study of the micas of the Brown Derby pegmatites and to discuss their origin.

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Geology of the Pegmatites

The Brown Derby group includes a swarm of three main dikes and several minor ones that strike generally northeast and dip 20–35° SE into the steep upper valley side. Dike No. 1 (the original discovery site) is the uppermost (and easternmost) of the three; parallel dikes 2 and 3 lie 120 and 220 feet respectively, east of No. 1, down slope (Hanley *et al*, 1950). The dikes range in thickness from a few feet to about 40 feet; dike No. 1 has a strike length of about 1000 feet. Local variations in thickness

Table 1. Minerals Studied, Brown Derby Pegmatites

Mineral	References
bismutite	Heinrich, 1947
columbite	Heinrich and Giardini, 1956, 1957; Heinrich, 1957B; Heinrich, 1962
garnet (yttrian)	Jaffe, 1951
lepidolites	Stevens, 1938; Stevens and Schaller, 1942; Winchell, 1942; Ahrens, 1951; Heinrich *et al.*, 1953
microlite	Eckel and Lovering, 1935
monazite	Heinrich, Borup and Levinson, 1960
muscovite (pink)	Heinrich and Levinson, 1953
stibiotantalite	Heinrich, 1957B; Heinrich and Giardini, 1957; Hamilton, 1957; Heinrich, 1960
tourmaline	Staatz *et al.*, 1955

are common and abrupt, commonly associated with distinct convolute changes in strike and in the angle of dip ("rolls"). Both along strike and down dip the dikes branch (Hanley *et al*, 1950; McLellan, 1956), and they are probably completely interconnected. The wall rocks are dark hornblende schists with interlayered biotite schist. Age determinations on the parent granite to the south gives a Rb/Sr age of 1310 m.y. (Tilton *et al*, 1957). K-A dates on Brown Derby muscovites and lepidolite gave 1250, 1260 and 1300 m. y. (Aldrich *et al*, 1957).

Like flat-lying pegmatite dikes in most other districts, the internal structure is strongly asymmetrical; similarly along the strike marked changes appear in the petrologic units. Several examples of the sequence of internal units are shown in Figure 1. Mineralogically these units fall into two distinct types:

1. Those made up chiefly of quartz, microcline, albite (not cleavelandite) biotite and muscovite, with accessory schorl or dark green tourmaline, blue beryl and columbite.

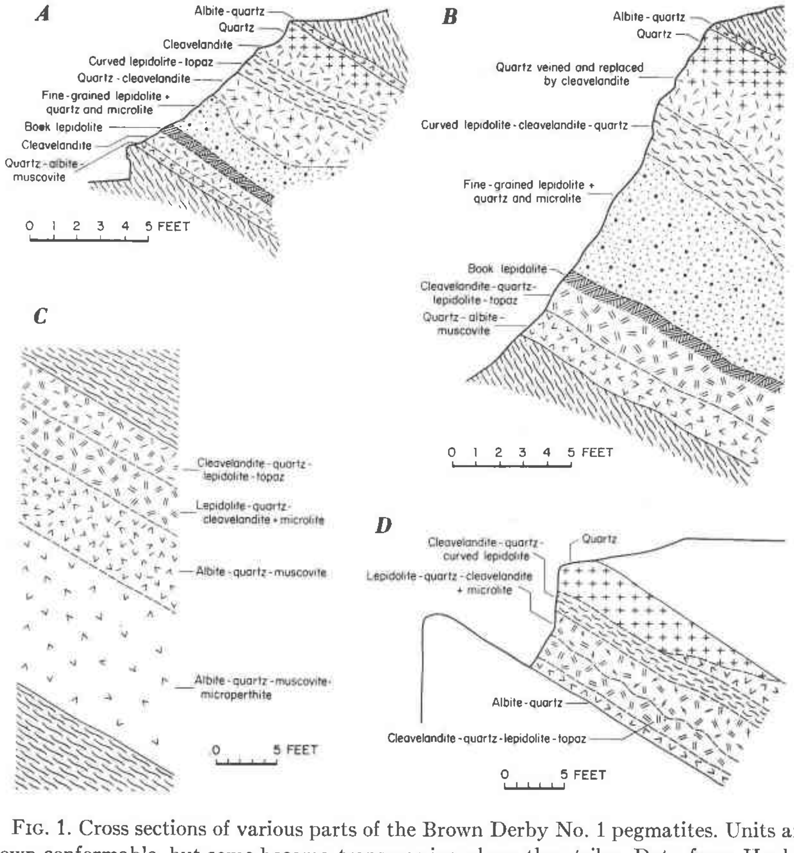

FIG. 1. Cross sections of various parts of the Brown Derby No. 1 pegmatites. Units are shown conformable, but some become transgressive along the strike. Data from Hanley *et al.* (1950), McLellan (1956) and Heinrich, personal observations.

2. Those made up mainly of quartz, cleavelanditic albite, several types of lepidolite, multicolored pink, red, light green, yellow, and lilac tourmalines plus accessory microlite, stibiotantalite, topaz, rose muscovite, fluorite and rose beryl.

Although, *in general in earlier exposures*, units characterized by abundant cleavelandite-lepidolite rock were found to be crudely conformable in strike and dip with the general over-all pegmatite structural attitude, later exposures showed them to be crosscutting in most cases. This was particularly well displayed in new exposures made in 1959 on the Brown Derby No. 1 dike just south of the main incline where exposures show:

1. A three-layer banded unit composed of cleavelandite and lepidolite that strikes at right angles to the strike of the dike, directly across the attitude of the original zonal structure (Figs. 2, 3).

2. Six-inch composite veins of lepidolite bands and cleavelandite bands in comb structure cutting across large microcline masses. Similarly, in

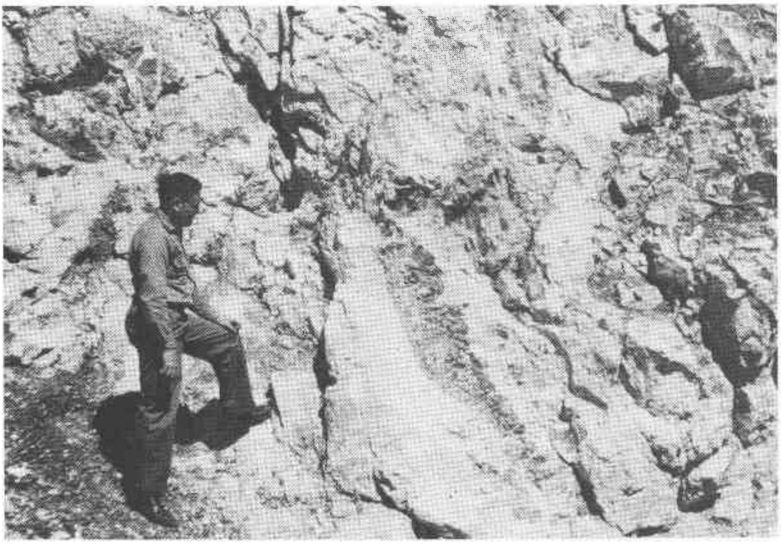

FIG. 2. Lenticular bodies of cleavelandite-lepidolite pegmatite (just east of lower center and behind man's shoulder) and cleavelandite pegmatite (in NE quarter), cutting quartz-microcline pegmatite of Brown Derby No. 2 dike. Note corroded microcline relicts (above man's knee). Cleavelanditic units lie at nearly right angles to strike of dike (essentially east–west of photograph).

the deeper parts of the workings of dike No. 1, contacts of Li-rich units are discordant with respect to the general attitude of the dike. In addition, in dike No. 1 the footwall side of the quartz-core pod has been strongly albitized and large blue beryl crystals have been partly replaced by albite.

THE MICAS

Micas are unusually well developed in these pegmatites: muscovite, biotite, zinnwaldite and lepidolites are represented, the last occurring in a variety of grain sizes, forms and associations. Indeed it is probably for its extraordinary, large books of lepidolite that the Brown Derby is mineralogically most famous; some of these have been found measuring 10 inches across. New analyses of the micas are given in Tables 2; formulae in Table 3.

Biotite. Biotite is common locally in outer zones. In dike No. 2 the border zone is an albite-quartz-biotite rock with accessory garnet and tour-

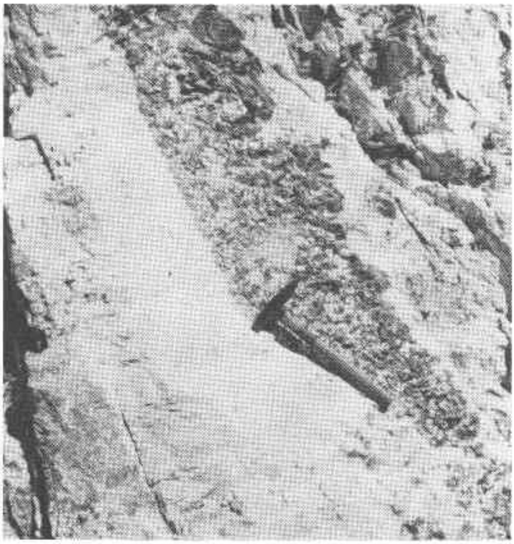

FIG. 3. Close-up view of central cleavelandite-lepidolite-pod of Fig. 2. The sequence from SW to NE across photograph is: quartz-microcline, marginally albitized; cleavelandite with comb-structure; fine-grained lepidolite-cleavelandite (at hammer); coarse books of lepidolite; thin cleavelandite band; microcline.

maline. Biotite occurs locally in the wall zone of dike No. 1 in quartz-plagioclase-microcline pegmatite with accessory magnetite.

Muscovite. The main wall zone rock in dike No. 1 is a quartz-plagioclase-microcline-muscovite aggregate. The muscovite occurs in flakes as much as several inches across. The composition of the associated plagioclase is Ab_{87-90}. For the chemical composition see No. 224, Table 2.

TABLE 2. CHEMICAL ANALYSES OF MICAS FROM THE BROWN DERBY NO. 1 PEGMATITE

No.	224	1341	499	503	504	508	511
SiO_2	45.15	45.31	50.33	52.38	50.28	55.17	50.92
Al_2O_3	32.91	32.88	27.87	24.34	24.62	24.06	26.92
TiO_2	0.13	0.27	0.01	0.02	0.08	0.01	0.02
FeO	3.34	3.53	0.02	0.02	0.00	0.07	0.01
Fe_2O_3	1.87	1.36	0.02	0.02	0.14	0.07	0.02
MnO	0.35	0.17	0.22	0.44	2.21	0.04	0.04
Li_2O	0.55	0.82	4.26	5.46	5.26	4.61	4.71
Na_2O	0.60	0.70	0.64	0.51	0.49	0.35	0.33
$(K, Cs)_2O$	9.93	10.06	10.06	9.81	10.20	9.17	10.04
Rb_2O	0.62	0.62	1.20	1.44	1.34	1.44	1.53
H_2O^-	0.42	0.46	0.32	0.36	0.39	0.28	0.31
H_2O^+	3.17	3.68	1.54	0.62	0.77	1.00	1.59
F	2.26	1.48	6.24	7.82	7.97	6.47	6.71
O=F	0.95	0.62	2.63	3.29	3.36	2.72	2.82
MgO	0.01	0.01	0.01	0.015	0.03	0.01	0.01
CaO	0.005	0.01	0.005	0.002	0.004	0.002	0.003
SrO			0.006	0.006	0.005	0.006	0.006
BaO		0.002	0.0004	0.0003	0.0004	0.0003	0.0004
SnO		0.078	0.019	0.024	0.021	0.026	0.023
Ga_2O_3		0.047	0.026	0.021	0.017	0.031	0.035
V_2O_5		0.0005					

Total

224—Muscovite
1341—Zinnwaldite
499—Fine-grained lepidolite in albite
503—Coarse, thin platelets of lepidolite
504—Fine-grained lepidolite in masses with microlite
508—Curved lepidolite
511—Book lepidolite

Elements through CaO determined by R. L. Craig; others by C. E. Harvey; Co_2O_3, Sc_2O_3 and Cr_2O_3 absent.

TABLE 3. FORMULAS OF THE BROWN DERBY MICAS CALCULATED FROM ANALYSES IN TABLE 2

No.	Name	Formula
224	muscovite	$(K_{1.67}, Na_{0.23}, Ca, Rb_{0.09}, Cs)(Fe^{2+}_{0.38}, Mn_{0.04}, Mg)$ $(Al_{3.41}, Li_{0.30}, Fe^{3+}_{0.19}, Ti_{0.02})(Si_{6.12}, Al_{1.88})O_{20.14}(OH_{2.89}, F_{0.97})$
1341	Zinnwaldite	$(K_{1.69}, Na_{0.26}, Ca, Rb_{0.09}, Cs)(Fe^{2+}_{0.40}, Mn_{0.02}, Mg)$ $(Al_{3.36}, Li_{0.41}, Fe^{3+}_{0.14}, Ti_{0.03})(Si_{6.13}, Al_{1.87})O_{20.03}(OH_{3.33}, F_{0.64})$
499	lepidolite	$(K_{1.54}, Na_{0.23}, Ca, Rb_{0.23}, Cs_{0.02})(Fe^{2+}, Mn_{0.03}, Mg)$ $(Al_{2.98}, Li_{2.33}, Fe^{3+}, Ti)(Si_{6.66}, Al_{1.34})O_{20.01}(OH_{1.37}, F_{2.62})$
503	lepidolite	$(K_{1.54}, Na_{0.42}, Ca, Rb_{0.22}, Cs_{0.01})(Fe^{2+}, Mn_{0.05}, Mg)$ $(Al_{2.68}, Li_{2.85}, Fe^{3+}, Ti)(Si_{6.96}, Al_{1.04})O_{20.15}(OH_{0.55}, F_{3.30})$
504	lepidolite	$(K_{1.61}, Na_{0.29}, Ca, Rb_{0.22}Cs)(Mn_{0.25}, Mg_{0.01})$ $(Al_{2.55}, Li_{2.84}Fe^{3+}_{0.01}, Ti_{0.01})(Si_{6.73}, Al_{1.27})O_{19.92}(OH_{0.69}, F_{3.39})$
3[1]	lepidolite	$(K_{1.75}, Na_{0.15}, Rb_{0.14}, Cs)(Fe^{2+}_{0.02}, Mn_{0.32})$ $(Al_{2.50}, Li_{2.74}, Fe^{3+}, Ti_{0.01})(Si_{6.70}, Al_{1.30})O_{19.70}(OH_{1.10}, F_{3.20})$
4[2]	lepidolite	$(K_{1.77}, Na_{0.14}, Ca, Rb_{0.15}, Cs_{0.01})(Fe^{2+}_{0.02}, Mn_{0.29}, Mg_{0.01})$ $(Al_{2.60}, Li_{2.77}, Fe^{3+}, Ti_{0.01})(Si_{6.65}, Al_{1.35})O_{19.97}(OH_{1.09}, F_{2.94})$
508	lepidolite	$(K_{1.43}, Na_{0.11}, Ca, Rb_{0.21}, Cs_{0.01})(Fe^{2+}_{0.01}, Mn, Mg)$ $(Al_{2.94}, Li_{2.55}, Fe^{3+}_{0.01}, Ti)(Si_{7.24}, Al_{0.76})O_{20.43}(OH_{0.88}, F_{2.69})$
511	lepidolite	$(K_{1.53}, Na_{0.13}, Ca, Rb_{0.25}, Cs_{0.01})(Fe^{2+}, Mg, Mn_{0.01})$ $(Al_{2.85}, Li_{2.58}, Fe^{3+}, Ti)(Si_{6.70}, Al_{1.30})O_{19.78}(OH_{1.41}, F_{2.81})$

[1] Stevens (1938, p. 615).
[2] Winchell (1942, no. 10, p. 115).

Rose Muscovites. The rose muscovites have been studied in detail by Heinrich and Levinson (1953) including two chemical analyses. In the Brown Derby No. 1 dike, rose muscovite occurs chiefly in the curved lepidolite-topaz unit (Fig. 1A), closely associated with the topaz which some of it replaces. In the White Spar No. 1 dike, about 0.8 mile northeast of the Brown Derby group, rose muscovite is abundant, also as a replacement of topaz and as veinlets across cleavelandite. This mica is post-lepidolite in age and the youngest of all the micas (Heinrich and Levinson, 1953) except for sericite.

Lepidolites. At least five distinct types of lepidolite, based on flake size, association and form, occur in the Brown Derby dikes: (1) uniformly fine-grained flakes disseminated in albite, (2) coarse platelets scattered through cleavelandite-quartz aggregate, (3) fine-grained masses of almost pure lepidolite with disseminated grains of microlite, (4) curved bowl-shaped masses, and (5) large thick books.

1. Fine-grained lepidolite flakes in albite. The color is reddish lilac; flakes are 1/16–1/8 inch across. The analyzed material contained both the 1M and 6M lepidolite structure from single crystal studies; from the powder diffraction study only the 6M lepidolite structure was determined. Chief associates are albite (Ab_{95}), gray quartz, blue-gray apatite, and a rare grain of microlite. It occurs locally in the lepidolite-quartz-microlite unit (Fig. 1A). The chemical analyses are in Table 2, No. 499.

2. Coarse thin platelets in cleavelandite-quartz aggregate. The color is dark reddish purple; flakes measure about 1/4 inch across. The structure is 1M lepidolite; the powder data show predominantly the 1M type with a small amount of 6M. Chief associates are cleavelandite (Ab_{98}) and light gray quartz. This lepidolite occurs mainly in the cleavelandite-quartz-lepidolite-topaz rock (Fig. 1B). The chemical analyses are presented in Table 2, No. 503.

3. Fine-grained masses of lepidolite. The color is pale gray-lilac; flakes are 1/16 inch or less in diameter. The structure is 6M lepidolite by the powder method. Chief associates are microlite and very minor amounts of interstitial albite. It is confined to the fine-grained lepidolite-quartz-microlite unit (Fig. 1, A,B). The chemical analyses are given in Table 2, No. 508.

4. Curved lepidolite. This variety is pale silvery lilac in color. It occurs in thick curved shells, some of which are 4–5 inches across and almost an inch thick. The structure is 6M lepidolite by the powder method. Chief associates are quartz and cleavelandite (Ab_{97}). It is confined to parts of the curved lepidolite topaz unit (Fig. 1, A) and the curved lepidolite-cleavelandite-quartz layer (Fig. 1, B). The chemical analyses are given in Table 2, No. 511.

5. Book lepidolite. The books, which are as much as 10 inches across and 2 inches thick, are a medium bronze-lilac in color. The structure is 6M lepidolite by the powder method. Chief associates are quartz, albite (Ab_{95}), topaz and pink and green tourmalines. It appears primarily in the book lepidolite band (Fig. 1, A, B). New chemical analyses are given in Table 2, No. 504; see also Stevens (1938, p. 615) and Winchell (1942, No. 10, p. 115).

Zinnwaldite. Zinnwaldite was found chiefly in but a single prospect pit—pit No. 11, in a pegmatite "arm" that appears to connect dikes 2 and 3 near their southern ends (Hanley *et al*, 1950, Pl. 9). Here it occurs in a pod of very limited size of relatively fine-grained albite (Ab_{94})-quartz-

TABLE 4. GENERALIZED SEQUENCES OF THE MICAS

		Anal. No.
	Spatial distribution	
Hanging wall	biotite	
	muscovite	224
	curved lepidolite	511
	fine-grained lepidolite, with microlite	508
	large book lepidolite	504
	coarse, thin lepidolite platelets	503
	fine-grained disseminated lepidolite	499
	zinnwaldite	1341
	muscovite	
Footwall		
	Temporal distribution	
Oldest		
Group I	1. biotite	
	2. muscovite	224
Group II	3. curved and fine grained microlite-bearing lepidolites	511, 508
	4. large book lepidolite	504
	5. coarse lepidolite platelets	503
	6. fine-grained disseminated lepidolite	499
	7. zinnwaldite	1341
Group III	8. rose muscovite	
	9. sericites	
Youngest		

zinnwaldite rock. Accessories in this unit include monazite euhedra (as long as 2 in.), columbite (72% Nb_2O_5), euxenite, spessartite, gahnite and schorl. The color is a deep bronze-black. The structure is 3H. The chemical analyses are in Table 2, No. 1341.

Sericite. Very fine-grained sericitic muscovite occurs as replacements of the following minerals: 1. microcline, along with small amounts of purple fluorite in vuggy aggregates and, 2. tourmalines.

PARAGENESIS

If it can be assumed that the layered units composed of various albite-lepidolite rocks were developed, *in time*, successively, downward from the bottom of the quartz core,[1] then the paragenetic sequence of the micas approximates the spatial sequence (Table 5). A similar relationship was postulated by Staatz *et al* (1955) who related variation in tourmaline

[1] Which, as mentioned earlier, is asymmetrically situated near the top of the pegmatite.

composition with distance from the contact between albite-quartz pegmatite (their "core") and cleavelandite-quartz-lepidolite pegmatite (their "wall zone"). Their thesis is that the more distant the tourmaline is from this contact the older it is; the older tourmalines being thus in the outer parts of the pegmatite, the younger in the interior parts. The results of their studies are summarized in their abstract (Staatz *et al*, 1955, p. 789):

> "Tourmaline crystals of the bizonal, lepidolite-bearing Brown Derby pegmatites no. 2 and no. 3 of Gunnison County, Colo., show a consistent variation in color, refractive index, and composition with position in the pegmatite. Starting with the outer wall of the pegmatite and going inward toward the core, the colors of the tourmaline crystals are black, dark green, blue, light green, and pink. The omega index decreases from 1.655 to 1.635 in the same direction.
>
> The concentration of K, Rb, Cs, Pb, Be, and Li in tourmaline increases toward the pegmatite core. Fe, Mg, Ti, Na, Co, Ni, Cr, and V decrease in concentration toward the core; the last four are restricted to the crystals of the outermost part of the pegmatite. The main variation in tourmaline composition is a substitution of lithium for iron. Elements that remain more or less constant are Ga, Sr, Sc, Zr, Nb, Sn, Cu, Bi, and Zn. The concentrations of Mn, Y, and La show an interesting maximum at an intermediate position between the pegmatite wall and core."

Staatz *et al* (1955) make no mention of the fact that many tourmalines in the Brown Derby pegmatites are zoned; thus relationship of color and composition to position within the pegmatite is not usually as simple and straightforward as they describe.

A number of attempts were made to relate certain compositional variations in the micas (particularly the Li micas) to their "stratigraphic" positions within the pegmatite. An exact distance from a contact could not be used inasmuch as the various albite-cleavelandite layers are of variable thickness. Nor, as can be seen from Figure 1, is the sequence of layers in all parts of the dike the same. Plots that were tried included: (1) Position *vs* "volatile index" = F/O+OH+F (1) Position *vs* *Mn*/Fe^{2+}+Mn+Mg (3) Position *vs* Rb/K+Na+Ca+Rb+Cs (4) Position *vs* Sr, Ba, Sn, Ga. None of these plots showed any systematic variations.

Thus we are confronted with a series of micas (particularly the lepidolites) that show, both with respect to their position within the pegmatite and probably also with respect to their relative ages, nonsystematic variations in: (1) texture and grain size (2) associated minerals (3) structure (4) general composition (5) minor elements.

Conclusions

One of the major differences between pegmatite zones and replacement units is that in the former, textural, modal and mineral-compositional variations are systematic, whereas in the latter these characteristics vary erratically (Heinrich, 1948, 1953; Cameron *et al*, 1949).

A common misapplication of terminology among students of pegmatite origin concerns the use of the term "hydrothermal replacement units." Staatz *et al* (1955, p. 803–804) conclude:

> "The change noted in the Brown Derby no. 2 and no. 3 pegmatites is a gradual one that is most simply explained by means of a single process in which the pegmatite fluid changes in composition during crystallization. In other words the tourmaline was formed from one fluid whose chief method of change was of decreasing some elements by crystallizing out minerals rich in these elements and increasing the elements left in solution. Hydrothermal replacement, *with its influx of new fluids* (italics-EWH), would produce erratic variations in the concentration of such elements as lithium and iron from the outside wall to the core. This is not what is found, and it is believed that the two pegmatites were formed in a closed system by gradual crystallization from the wall inward."

Both the new geological and mineralogical data presented here require modification of this theory. The writer believes that:

1. The pegmatites formed under closed-system conditions.
2. The process was a gradual, continuous, but, nevertheless, two-stage affair in which an early magmatic stage (direct crystallization from a fluid inward) was succeeded by a hydrothermal stage (reaction of newly crystallized zonal pegmatite with residual hydrous pegmatitic fluid) in which the asymetric layered replacement units were formed.
3. The hydrothermal fluid was not introduced from an external source but was derived by fractionation from the pegmatite magma analogous to the way in which the pegmatite magma was descended from its parent granitic magma.
4. Characteristic and diagnostic of the hydrothermal stage are nonsystematic variations in the composition of some multigenerational species (at least with respect to position within the pegmatite), particularly lepidolites,[1] owing to the achievement of only local equilibrium conditions.

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