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PARAGENESIS OF THE TOPAZ-BEARING PORTION OF THE BROWN DERBY NO. 1 PEGMATITE, GUNNISON COUNTY, COLORADO

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ABSTRACT

The paragenesis of the asymmetrically zoned, Li-rich, topaz-bearing portion of the Brown Derby No. 1 pegmatite, Gunnison County, Colorado, has been reconstructed on the basis of observed textural relationships in the light of the recent model for pegmatite genesis by Jahns and Burnham (1969).

The coarse-grained, K-rich "hood" formed in the presence of an aqueous fluid phase during the crystallization of the wall zones; topaz was originally abundant in the hood assemblage. The finer-grained texture of the footwall unit suggests crystallization directly from the silicate melt. Large topaz crystals concentrated at the base of the core unit imply gravitational settling of topaz in the melt. Lepidolite and cleavelandite crystallized later from the aqueous fluid phase, replacing pre-existing assemblages and forming the observed core unit. Topaz was armored and preserved by the residual melt trapped largely at the base of the core unit which crystallized to form multiple quartz pods.

INTRODUCTION

The Brown Derby pegmatites are a group of three main dike-like bodies and several minor ones which lie within the Quartz Creek Pegmatite District (Staatz and Trites, 1955) about 17 miles east of Gunnison, Colorado. The present study concerns the No. 1 dike, the largest and most complex of the group which is well exposed at the surface and in underground mine workings. Although this dike has been the subject of several previous investigations, the origin of the internal structure and mineralogy has not yet been deciphered. This paper attempts to reconstruct the paragenesis of the Li-rich, topaz-bearing portion of the dike based on textural relationships reported in the literature and observed by the author during the summers of 1966 and 1969. Paragenesis has been interpreted in the light of the recent model for pegmatite genesis by Jahns and Burnham (1969).

The extensive literature on the Brown Derby pegmatites has been ably reviewed by Heinrich (1967). Detailed discussions of the internal structure and mineralogy of Dike No. 1 have been published by Hanley *et al.* (1950, p. 70–71) and by Staatz and Trites (1955, p. 52–53). After consideration of field relations and previous theories of origin of zoned pegmatites, the latter authors conclude that the pegmatites of the Quartz Creek District were formed by fractional crystallization of a

residual magma in a closed system from the walls inward but no further details are given (*ibid.*, p. 49). Variations in the chemistry and the physical properties of tourmaline in Dikes No. 2 and 3 seem to bear out these conclusions (Staatz *et al.*, 1955). With the exception of a highly limited study by Heinrich and Levinson (1953) and a study of micas (Heinrich, 1967) in which spatial distribution is explained by an assumed paragenesis, previous investigators have not attempted to establish the sequence of crystallization of the Brown Derby pegmatites. However, generalizations on the genesis of the Brown Derby pegmatites are offered as conclusions to the study of micas by Heinrich (1967).

Internal Structure and Mineralogy

The main part of Dike No. 1 which is Li-rich and topaz-bearing contains at least six mappable pegmatite units distinguished on the basis of diagnostic minerals and differences in mineral proportions (Table 1; Staatz and Trites, 1955, p. 52–53). This part of the dike is asymmetrically zoned and has a layered appearance but boundaries between layers tend to be gradational, irregular and, in places, transgressive (Hanley *et al.*, 1950, p. 70; Heinrich, 1967). Distinct changes in the pegmatite units have been observed along the strike and some units are discordant with respect to the general attitude of the dike

TABLE I

PEGMATITE UNITS IN THE LI-RICH, TOPAZ-BEARING PORTION OF DIKE NO. 1*

Unit	Average Thickness	Principal Minerals (%)
Hangingwall Unit	4'-8'	microcline-perthite (40), albite (30), quartz (20), muscovite (10)
Hangingwall Quartz Pod	2'	quartz (70), cleavelandite (25), lepidolite (5)
Curved Lepidolite Unit	2'	cleavelandite (44), quartz (40), lepidolite (15), topaz (1)
Lepidolite-Microlite Pod	~7'	cleavelandite (43), lepidolite (40), quartz (15), topaz (2), (microlite 0.35)
Topaz Unit	2'	quartz (55), cleavelandite (25), lepidolite (10), topaz (10)
Footwall Unit	1.5'	albite (90), quartz (8), tourmaline (2)

*Modified after Staatz and Trites (1955)

(Heinrich, 1967). The units observed in this study correspond closely with those reported by other workers, although an unlocated cross section (Fig. 1, C) given by Heinrich (1967) is not familiar to this author.

Units that differ only in the presence or absence of minor constituents (*e.g.*, 0.35 percent microlite, lepidolite-microlite pod, Table 1) or in the proportion of major constituents (Table 1) are probably of second-order significance in view of the processes thought to be involved in the crystallization of pegmatites (Jahns and Burnham, 1969). Heinrich (1967) recognized two distinct types of units based on mineralogy. These types contain principally:

1. Quartz, microcline-perthite, albite, and muscovite.
2. Quartz, cleavelandite, lepidolite, topaz, and tourmaline.

Since type 1 characterizes the hangingwall and footwall units and all intermediate units are type 2 (Table 1), a simplified description of internal structure and mineralogy is possible, which will serve as a basis for discussion of genetic relationships in this paper. In this light the principal rock units are as follows:

1. Hangingwall unit—microcline-perthite, albite, quartz, muscovite pegmatite.
2. Core unit—cleavelandite, quartz, lepidolite, topaz pegmatite.
3. Footwall unit—albite, quartz pegmatite.

In accord with this classification of internal structure, both Hanley *et al.* (1950, p. 70) and Staatz and Trites (1955, p. 52) refer to a multiunit core composed of cleavelandite, lepidolite, quartz, (topaz) pegmatite.

Textural and structural relations are thought to be the best indicators of stages and processes in the formation of pegmatites (*e.g.*, Jahns and Burnham, 1969). Therefore, detailed studies of mineral relations within these units should provide important clues to the paragenesis of the pegmatite.

Textural Relations and Their Interpretation

Distribution and Orientation of Topaz

The footwall unit is distinctly finer-grained than the other units and its general grain size diminishes downward to a sharp contact with the country rock, a hornblende schist (Fig. 1). Topaz is highly concentrated at the base of the core unit at its boundary with the footwall unit (Fig. 1; Table 1) and is also present sparingly throughout the core unit (Table 1).

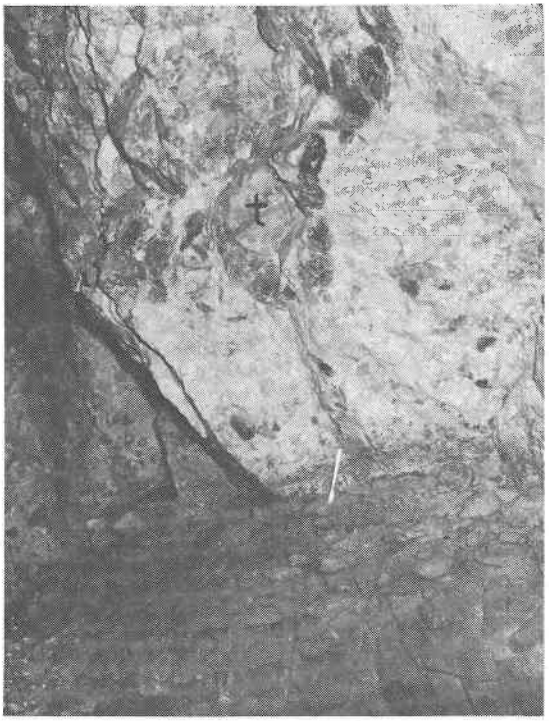


FIG. 1. Footwall unit showing sharp contact with country rock (cold chisel marks contact) and irregular contact with core unit. Topaz (t) in small quartz pod; associated dark crystals are lepidolite.

Topaz crystals are rounded to subhedral and as much as 4 feet long and 1 foot in diameter; most are at least 2 feet long and 1/2 foot in diameter. Most of these crystals (24 of 26 recorded) are also oriented with their long axes roughly parallel to the apparent layering of the pegmatite body; a few (2 of 26 recorded) are nearly perpendicular to the layering. Long axes also show strong preferred orientation in the direction of the strike (N56°E; Hanley *et al.*, 1950, p. 70) and of the dip (SE, *ibid.*).

These observations suggest the gravitational settling of topaz in the silicate melt after the crystallization of the footwall layer. An experimental determination of the viscosity of a water-rich but undersaturated, pegmatitic melt gave a value of 10^6 poises at 700°C (Burnham, 1964). Although pegmatitic melts are extremely viscous, the density of topaz is relatively high (~3.5 gr./cc). Correlations of settling velocity with the size and density of crystals and the viscosity of the medium (Shaw, 1965) suggest that an average sized topaz crystal

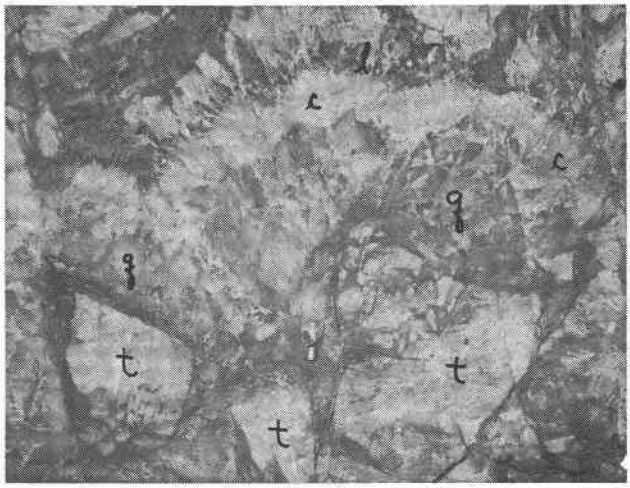
could have settled to the top of the footwall unit in less than a week. On the basis of this estimate, gravitational settling of topaz appears to be a feasible hypothesis. Shaw (1965) regards crystal settling as a factor of possible importance in the crystallization of granitic magmas.

Textural Relations of Topaz

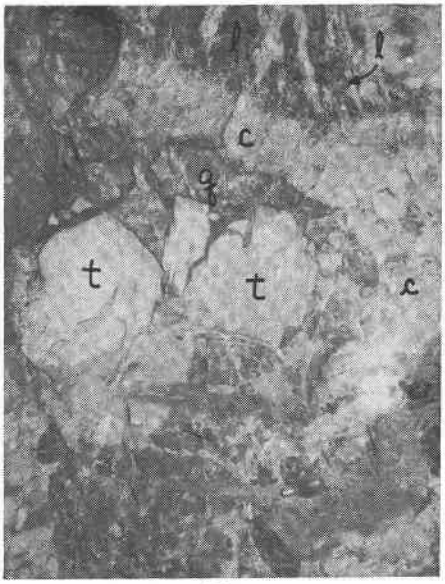
At the base of the core unit, topaz is closely associated with lepidolite bands, radial cleavelandite, and small quartz pods (Figs. 2a and 2b). Lepidolite and quartz occur in arcuate bands spanning several feet and as much as 8 to 10 inches in width (Fig. 2b). These bands are composed of aggregates of varying crystal size which are oriented radially with respect to the arc. Below the bands and within the arc, a zone of radial cleavelandite is present, below which, toward the center of the arc, quartz or, in a few places, quartz and minor albite form a pod. Within these pods are topaz and rose muscovite. Rose muscovite (± quartz) rims, corrodes, and forms veinlets extending into and through topaz crystals, indicating late-stage replacement of topaz (Heinrich and Levinson, 1953).

The arcuate structures commonly coalesce to form a series with continuous or discrete quartz pods. A single pod may contain one or several topaz crystals. Although topaz is invariably enclosed in quartz pods, the arcuate structures may be absent in the vicinity of a particular topaz crystal. In places, the pods consist of no more than a thin rim of quartz surrounding a large topaz crystal (Fig. 3), whereas other pods are several feet in diameter. At higher levels in the core unit textural relations are more chaotic but similar structures have been observed mostly without topaz. Where topaz does occur textural relations are similar to those at the base of the core unit. Hanley *et al.* (1950, p. 70) briefly mention lepidolite bands and radial cleavelandite associated with topaz near the base of the core unit but relationships are neither described nor discussed.

The arcuate structures are interpreted as replacement features. Similar composite bands of lepidolite and cleavelandite with "comb structure" clearly replace microcline near the base of the hangingwall unit (Heinrich, 1967; see also Fig. 5). Replacement is believed to have taken place during the resurgent boiling of pockets of residual silicate melt trapped at the base of the core unit and at higher levels in the core. Lithium-bearing minerals are thought to crystallize mainly from the aqueous phase in Li-rich pegmatites (Jahns and Burnham, 1969). Transfer of alkalis through the aqueous phase, released during the crystallization of quartz from the silicate melt, probably caused replacement of pre-existing mineral assemblages producing the lepidolite



(a)



(b)

FIG. 2. Arcuate structures at the base of core unit. Radial lepidolite bands (dark grey) and cleavelandite (light grey to white) partially surround quartz pods (intermediate grey) containing large blocky topaz crystals (light grey to white). t, topaz; q, quartz; c, cleavelandite; l, lepidolite. Note comb structure of lepidolite band in Fig. 2b.

bands and radial cleavelandite which form the arcuate structures. Na and Li appear to have entered the aqueous phase in waves or pulses in which one predominated over the other giving rise to the alternating bands of lepidolite and radial cleavelandite observed at the base of the core unit and at higher levels in the core. Following the crystallization of quartz (± minor albite), rose muscovite and late quartz formed from the last fluids producing the observed pods.

Textural Relations in the Hangingwall Unit

The hangingwall unit represents a K-rich "hood" similar to those reported from many other localities (*e.g.*, Jahns and Wright, 1951; Orville, 1960). Microcline-perthite is locally abundant in this unit occurring in giant crystals which have been partially replaced by muscovite (Fig. 4) and at a later stage, by lepidolite and cleavelandite (Fig. 5). Replacement of microcline and muscovite by the

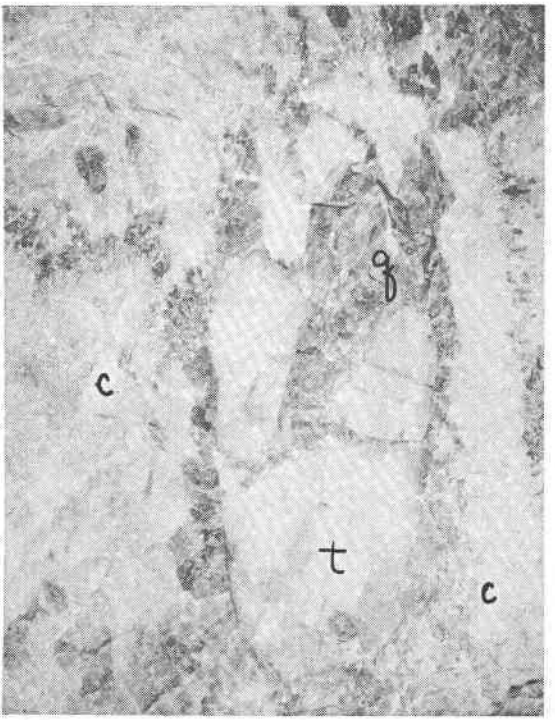


FIG. 3. Topaz crystal enclosed in small quartz pod; arcuate structure (lepidolite and cleavelandite bands) absent here. Upper central portion of topaz crystal removed revealing quartz lying behind it. t, topaz; q, quartz; c, cleavelandite.

FIG. 4. Microcline crystal partially replaced by muscovite (and quartz) in the hangingwall unit.

latter assemblage (see also Heinrich, 1967) is extensive at the base of the hangingwall unit but it diminishes upward. Microcline decreases in abundance downward in the hangingwall unit and is absent at its base. Over most of the length of the dike microcline has been almost completely replaced, muscovite being concentrated in the upper part of the unit just below the hanging wall (Hanley *et al.*, 1950, p. 70).

The presence of a K-rich hood is consistent with formation of the hangingwall unit by transfer of alkalis at high temperatures through an aqueous fluid phase. More extensive transfer of K relative to Na (and Li) in response to a temperature gradient (Orville, 1963; Jahns and Burnham, 1969) accounts for the segregation of microcline and muscovite in the outer parts of the pegmatite bodies. The asymmetrical distribution of K-rich minerals in the upper parts of pegmatite bodies has been explained by the gravitational rise of the aqueous fluid phase (Jahns and Burnham, 1969). In the later stages when K was no longer the most abundant alkali in the aqueous phase, Na and Li replaced

K-rich minerals in the lower portion of the hangingwall unit and probably in what is now the core unit.

A quartz pod takes the place of the K-rich hood for 84 feet along the length of the dike (Table 1; Staatz and Trites, 1955, p. 53). Its location in the dike, the absence of evidence of replacement of the "normal" hangingwall assemblage and the introduction of cleavelandite and lepidolite at the base of both units suggests simultaneous crystallization of the quartz pod and the K-rich hood. This interpretation is in accord with the suggestion by Jahns and Burnham (1969) that quartz segregations completely separate from adjacent feldspar segregations may form by transfer through the aqueous phase.

Discussion of Paragenesis

The presence of an aqueous fluid phase generated by resurgent boiling at the time of emplacement of the magma or shortly thereafter can account for the observed relationships in the hangingwall and footwall units. According to the model of pegmatite genesis proposed by Jahns and Burnham (1969) generation of an aqueous fluid phase is essential to the formation of igneous pegmatites. The crystallization of some pegmatites is thought to begin at this stage (*ibid.*).

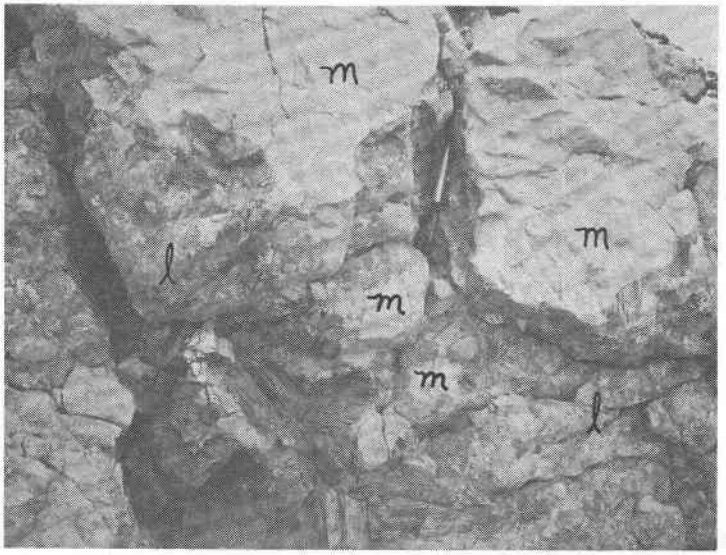


Fig. 5. Giant microcline crystal partially replaced by lepidolite (and quartz) in the lower portion of the hangingwall unit. m, microcline; l, lepidolite. Note microcline relicts within lepidolite below corroded microcline crystal.

During the crystallization of the wall zones, selective transfer of K through the aqueous phase as it was gravitationally rising enriched the hangingwall unit in K at the expense of the footwall unit and produced the sequence of crystallization observed in the hangingwall unit (*i.e.*, microcline followed and replaced by muscovite). A quartz segregation formed simultaneously at the hanging wall. Crystallization in the presence of an aqueous fluid phase resulted in a much larger grain size in the hangingwall unit than in the footwall unit; the "normal" phaneritic texture of the footwall unit suggests crystallization directly from the silicate melt (Jahns and Burnham, 1969).

The distribution and orientation of topaz suggests formation at an early stage perhaps during or immediately after the crystallization of the wall zones. It seems probable that topaz formed as part of the K-rich hood. Topaz has been reported as an accessory mineral in the hangingwall unit (Hanley *et al.*, 1950, p. 70) and the assemblage quartz, muscovite, topaz is well known from greisen associated with granitic intrusives. Due to their high density, topaz crystals settled in the melt to the top of the footwall unit; rounded crystal outlines suggest that topaz was partially resorbed by the melt.

Crystallization continued simultaneously from the melt and the coexisting aqueous fluid phase. Partition of constituents between these two phases, diffusion through the aqueous phase and gravitational rising of the aqueous fluid produced pods and zones of unusual composition in the core unit (Jahns and Burnham, 1969) (*e.g.*, lepidolite pod, now mined out; Staatz and Trites, 1955, p. 52). Na and Li entered the aqueous phase selectively in waves or pulses producing the lepidolite bands, radial cleavelandite, and other minerals which replaced pre-existing assemblages as evidenced by textural relations in the lower portion of the hangingwall unit.

Eventually pockets of residual melt were trapped at the base of the core unit and at higher levels in the core. Topaz that was not completely enveloped within these melts was replaced by reaction with the aqueous fluid phase whereas topaz that was enclosed in pockets of residual melt was armored and preserved. Late waves of alkali-bearing aqueous fluids are thought to have produced the arcuate structures by localized replacement of pre-existing minerals. The crystallization of quartz (± minor albite) from the remaining silicate melt forming multiple quartz pods was accompanied by continued transfer of alkalis through the aqueous fluid phase. Finally, where the system remained locally closed the last fluids which corroded topaz yielded rose muscovite and late quartz.

The system probably remained closed throughout the crystalliza-

tion of the pegmatite as the surrounding rocks appear to be unaffected except for a very narrow recrystallized zone. Previous investigators have also concluded that these pegmatites crystallized under closed system conditions (Staatz *et al.*, 1955; Heinrich, 1967). The proposed paragenesis of Dike No. 1 is in accord with this conclusion and with other recent generalizations on the crystallization of the Brown Derby pegmatites (Heinrich, 1967).

Crystallization Temperature of Topaz

If it can be assumed that the Brown Derby No. 1 pegmatite crystallized in a closed system and that topaz formed in the presence of an assemblage which provided internal buffering of HF and H_2O fugacities, it should be possible to estimate the crystallization temperature of topaz on the basis of its F-content. Crystallization in a closed system seems probable in the light of this study and those of previous investigators. If topaz crystallized as part of the K-rich hood, it may well have been in equilibrium with an assemblage that would serve to buffer f_{HF} and f_{H_2O}.

A univariant curve relating temperature and the F/OH ratios of topaz in assemblages with quartz, mullite, and aqueous fluid has been determined by Rosenberg (1972). Preliminary studies (Rosenberg, 1969, and unpublished data) suggest that the position of this equilibrium is not affected by the addition of small amounts of K_2O ($\sim$5 wt. percent) and that the above mentioned curve is unchanged for topaz in assemblages with quartz, muscovite, K–feldspar, and aqueous fluid. X-ray ($d_{(021)}$) and optical ($2V_\gamma$) measurements of topaz from Dike No. 1 indicate a F-content of 18.8 weight percent (No. 9, Ribbe and Rosenberg, 1971) which corresponds to a crystallization temperature of about 750°C at 2000 bars (Rosenberg, 1972). Furthermore, total pressure probably may be neglected to a first approximation (Rosenberg, 1972).

Although this temperature must be considered approximate at best, it is a reasonable estimate for early-stage crystallization in the presence of a silicate melt and a coexisting aqueous fluid phase in the light of the model proposed by Jahns and Burnham (1969).

Summary and Conclusions

The proposed paragenesis of the Li-rich, topaz-bearing portion of the Brown Derby No. 1 pegmatite may be summarized as follows:

1. Emplacement of a water-saturated (or nearly saturated) magma.
2. Onset of crystallization followed by resurgent boiling. Simultaneous crystallization of footwall unit from melt and K-rich

hangingwall unit from aqueous fluid phase. Topaz formed as part of the hood assemblage at about 750°C.

3. Gravitational settling of topaz in the melt to the top of the footwall unit.
4. Selective transfer of alkalis through the aqueous fluid phase produced cleavelandite, lepidolite, and other minerals which replaced pre-existing assemblages and produced pods and zones of unusual composition in the core unit.
5. Preservation of topaz only within pockets of residual silicate melt trapped at the base of the core unit and at higher levels in the core.
6. Crystallization of residual melt to form multiple quartz pods.

The validity of the proposed paragenesis, which accounts for many of the observed features of the Brown Derby No. 1 pegmatite, remains to be tested by more detailed field and laboratory studies of stages and processes in the formation of pegmatites.

Acknowledgments

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