shows that a pseudohexagonal symmetry exists *within the tetrahedra* in the plane of (100), the atomic structure being similar in the trace directions of (001), (031) and ($0\bar{3}1$). Alternative structures can therefore be built upon these planes which lie at an angle of 60° to each other.

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THE AMERICAN MINERALOGIST, VOL. 44, SEPTEMBER–OCTOBER, 1959

COMPROMISE GROWTH SURFACES ON PEGMATITE MINERALS

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Many crystals of pegmatite minerals display growth surfaces that form polygonal, step-sided pyramids. These are the "roots" of the crystals; the other parts display normal development, commonly with euhedral terminations. A search of available geological literature has failed to reveal a satisfactory explanation of this phenomenon.

The explanation offered here is that these anomalous pyramidal surfaces are the result of simultaneous growth of two adjacent crystals with different growth velocities. This process was described by Johnsen (1923) and is reviewed in Buckley (1951, p. 125–128).

Consider that crystal A, with growth velocities V and V', has reached the stage shown in Fig. 1*a*, and crystal B, with growth velocities v and v' first begins to develop at point x. At some time later the two crystals have reached the stage shown by the solid lines in Fig. 1*b*, in which crystallization of crystal A has continued after crystal B has ceased to grow. The angles that the sides of crystal B make with the growth directions are ϕ and ϕ', and simultaneous growth has taken place over the common distance S.

The resultant surfaces on crystal B are not in any rational way related to the axial systems of either crystal. They are called *compromise* surfaces and are the result of compromises between the relative growth velocities of the two substances.

If, for some reason, growth of crystal A ceased before crystal B ceased growing, crystal B could then terminate euhedrally outside crystal A (Fig. 1*c*). This is the situation occasionally encountered in pegmatites. In such examples the angle ϕ' cannot be measured. The only example in which ϕ' can be measured is that in which crystal B stops growing, even if only for a brief period, while growth of crystal A continues.

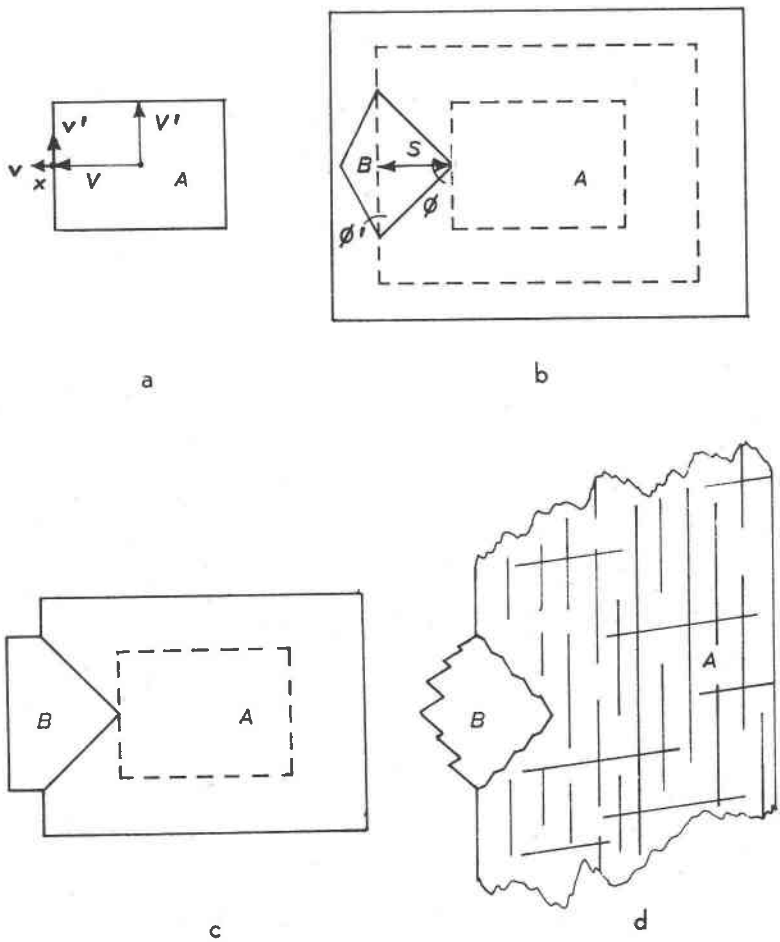


FIG. 1. Idealized representation of simultaneous growth stages.

The relationships illustrated are for the ideal situation in which the directions of growth in both crystallizing substances are tautozonal. The situation is far more complex when growth directions are askew, which is most commonly the situation. It should be mentioned here that adjacent materials of the same mineral can develop compromise faces if their growth directions are inclined to each other. This could account for the so-called "feather structure" observed on some columbites.

From the foregoing it is apparent that the anomalous pyramidal forms observed on some pegmatite minerals are compromise surfaces. The steps observed on many of these forms have yet to be explained.

Buckley (1951, p. 127) points out that the growth velocities of crystallization are dependent upon the temperature and concentration of the mother liquid. In the foregoing illustrations the constancy of the growth velocities was assumed and implies that the temperature and concentration remained constant. If either or both were to fluctuate, there would be a corresponding change in the growth velocities V, V', v, and v'. The resulting changes in ϕ and ϕ' on the compromise surfaces would appear as steps if abrupt changes took place (Fig. 1*d*) and as curved surfaces if gradual changes took place. Both types are observed on some pegmatite minerals. It is suggested that the presence of steps on compromise faces is evidence that fluctuating conditions of temperature, and possibly concentration, existed in the immediate vicinity of the minerals displaying these features. It is further suggested that these fluctuations are the result of thermal convection within the pegmatite chamber during crystallization. Thus a crystal growing on the wall of the chamber would be subjected to fluctuating temperatures as the pegmatitic fluids circulated about the chamber. If the concentration of the fluids varied, then the crystal would grow more rapidly as the more concentrated portions passed by. For illustrative purposes the more concentrated portions might be termed concentration clouds. These hypotheses are illustrated in Fig. 2. The number of narrow planes forming steps on the compromise surfaces indicates the number of changes that have taken place during the period of simultaneous growth. The mean angles of the compromise planes forming the steps are represented by the general overall angles of the sides of the stepped pyramid (Fig. 1*d*).

These compromise growth shapes have been observed on several pegmatite minerals including cyrtolite, thorite, fluorite, gadolinite, monazite, multiple oxides, and quartz in simultaneous growth with microcline, mica, and clevelandite.

Cyrtolite

In Colorado numerous pegmatites contain cyrtolite displaying compromise growth surfaces. The South Platte area in particular has produced many excellent specimens. In these pegmatites crystal aggregates of cyrtolite 10 pounds or more in weight occur partially embedded in very large crystals of biotite that measure as much as 3 feet on an edge. The cyrtolite aggregates have euhedral terminations outside the biotite. These terminations display the curved tetragonal pyramids so typical of cyrtolite. Within the biotite, however, the cyrtolite "roots" are finely stepped polygonal compound pyramids. Generally the cyrtolite *c* axes are oriented approximately normal to the basal cleavage of the biotite. An approximation of the average ϕ is 60°, indicating that cyrtolite grew

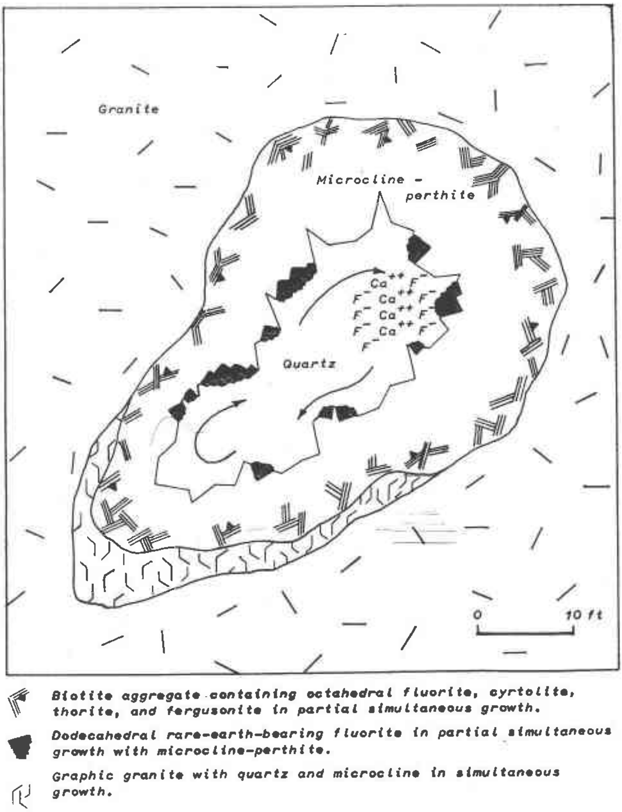


FIG. 2. Diagrammatic cross section of a South Platte area, Colorado, pegmatite showing hypothetical thermal convection currents and concentration cloud.

laterally at a greater rate than biotite grew vertically with respect to its basal cleavage plane. The fine steps, some of which are superimposed upon larger steps, indicate that temperature, and possibly concentration, fluctuated relatively rapidly though irregularly. Many of the steps are less than 0.1 mm. high. In general outline the basal cross section of the pyramidal "roots" is irregular or somewhat rounded due, in part, to individual crystals in the aggregate being askew with respect to each other.

Thorite

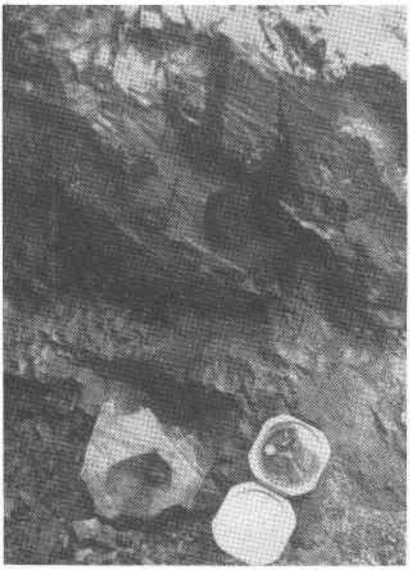
In addition to cyrtolite, there is also thorite in some of the South Platte pegmatites. It is less abundant than cyrtolite with which it usually occurs in subparallel growth. In some examples the boundary surface between cyrtolite and thorite displays compromise stepped growth surfaces. The thorite crystals commonly have their "roots" in biotite as does cyrtolite; however, the average angle ϕ is somewhat smaller than that of cyrtolite. This indicates that the lateral growth velocity of cyrtolite exceeded that of thorite and that both of these exceeded the vertical velocity of biotite with respect to the biotite cleavage plane.

Fluorite

The White Cloud pegmatite near South Platte, Colorado contains rare-earth-bearing fluorite which occurs in several zones. In the outer intermediate zone octahedral fluorite occurs with "roots" showing stepped compromise surfaces in biotite. The "roots" on individual fluorite octahedra are flat, stepped, four-sided pyramids. The average ϕ of the fluorite is approximately 80°. Cyrtolite, associated with the fluorite has a smaller ϕ and fergusonite, associated with cyrtolite has ϕ less than that of cyrtolite. Thus the lateral growth velocity of fluorite exceeds that of cyrtolite, which, in turn, exceeds that of fergusonite.

Fluorite with stepped surfaces occurs in the inner intermediate zone with "roots" in perthitic microcline and euhedral terminations in quartz of the core. These fluorite crystal aggregates display distorted dodecahedral forms and the "roots" are stepped pyramids with six or more sides. Some masses weigh upwards of 10 pounds. In one area of approximately 1 square yard (Fig. 3) there are at least 17 "roots" exposed in quartz by the removal of feldspar. Individual steps can be correlated from crystal to crystal. Corresponding steps have the same height irrespective of the size of the crystal. These relationships are to be expected if the steps are caused by convection. They help support the hypotheses proposed in this paper. At a particular time during crystallization all of the fluorite crystals in a localized area are subjected to the same conditions of temperature and concentration, so compromise surfaces are all developing simultaneously at the same rate and with the same angle ϕ. When, because of thermal convection, the temperature, and possibly the concentration, changes, the growth velocities change simultaneously on all fluorite crystals within the localized environment. Thus during any given period nearly identical steps are formed on compromise surfaces of crystals within the same local environment of temperature and concentration. This process is represented diagrammatically in Fig. 2.

In a pegmatite $1\frac{1}{2}$ miles northeast of Foxton, Colorado, some fluorite crystals have been completely included by microcline during simultaneous growth. Some of these fluorite crystals are doubly terminated with six-sided pyramids displaying stepped surfaces (Fig. 4).



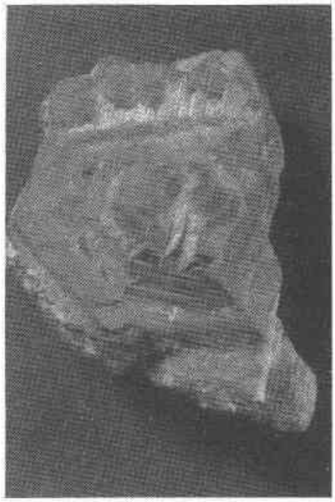


FIG. 3. (Left) Mining of feldspar at the White Cloud mine has exposed several "roots" of rare-earth bearing fluorite that grew simultaneously with microcline-perthite, and that terminates dodecahedrally in quartz. The mass of microcline-perthite to the left of the Brunton compass has been removed from the fluorite "root" above and slightly to the right.

FIG. 4. (Right) Detailed view of stepped compromise surfaces on rare-earth bearing fluorite from the South Platte area, Colorado. Maximum dimension is about 5 cm.

Gadolinite

Compromise surfaces have been observed on gadolinite from Benton's prospect near Cotopaxi, Colorado. Some of these crystals occur in primary microcline, which indicates that gadolinite also is a product of primary crystallization, having grown simultaneously with microcline. Thus, some gadolinites are not necessarily a product of a replacement stage of crystallization. At Roscoe Dike, on Clear Creek west of Golden, Colorado, some gadolinite crystals are included in albite. It is suggested that the albite selectively replaced primary microcline and left the gadolinite unaffected, except perhaps for superficial alteration.

Some gadolinite crystals with compromise surfaces in contact with biotite occur at Roscoe Dike and in the South Platte area. The stepped pyramids on these gadolinites are extremely flat with ϕ near 90°. This indicates that biotite crystallization had practically ceased when the gadolinite started to crystallize.

Monazite and Xenotime

An aggregate of two monazite crystals from the Bucky mine, Quartz Creek district, Colorado (Staatz and Trites, 1955, p. 61) occurs in simultaneous growth with clevelandite. The compromise surfaces are not stepped which indicates crystallization under constant conditions of concentration and temperature. Stepped compromise surfaces have been noted on xenotime from Benton's prospect near Cotopaxi, Colorado.

Multiple Oxides

Compromise surfaces have been observed on samarskite, fergusonite, betafite, and several unidentified multiple oxides. Most of these forms have been the result of simultaneous growth with biotite. Most of the betafites from Madagascar illustrated by Lacroix (1922) display compromise surfaces on "roots" in biotite.

Quartz

Compromise surfaces between quartz and microcline are common features in many pegmatites, and the cuneiform-like intergrowths in graphic granite display compromise surfaces, some of which are minutely stepped. Such examples are given as evidence in support of simultaneous growth of microcline and quartz in some graphic granite.

Conclusion

The recognition of compromise growth surfaces between two minerals is evidence for simultaneous growth. Only in ideal examples can the growth velocities be determined by the relationships stated by Johnsen (1923). Some examples, however, are suitable for an approximation of relative velocities in two directions normal to each other.

It is suggested that steps on compromise surfaces may be evidence for thermal convection within the system, whereby two mineral phases in simultaneous growth are subjected to cyclic changes in temperature and possibly concentration. Those changes alter the relative growth velocities periodically, produce successive planes with different values of ϕ and ϕ' and thus give rise to steps.

Correct interpretation of compromise surfaces aids in determining the paragenetic sequence in pegmatites.

Acknowledgments

Funds for this investigation were provided by the American Institute of Research. Dr. Robert H. Carpenter, Hans Heinicke and Donald H. Johnson reviewed the manuscript; their suggestions are appreciated.

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THE AMERICAN MINERALOGIST, VOL. 44, SEPTEMBER–OCTOBER, 1959

UNUSUAL GALENA FROM THE BOULDER BATHOLITH, MONTANA[1]

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During studies of some uranium-bearing veins in the Boulder batholith, Montana, a mineral of unusual appearance was encountered in polished sections of ore from the Lone Eagle mine. This mineral was ultimately proven to be galena, and it was called galena "B" (Wright and Shulhof, 1957) to distinguish it from the associated ordinary galena "A." In polished section the unusual galena resembled uraninite, so much so that it proved impossible to identify the two by simple observation. Because of the importance of uraninite in these studies the impostor had to be carefully worked out. Further, a comparison of the isotopic composition of a possibly radiogenic galena with that of associated common galena could have important bearing on the interpretation of age and origin of the "siliceous reef" and the "base metal" uraniferous deposits of the batholith (Wright, 1956).

Galena "B" is in formless, somewhat rounded blebs ranging from a few microns to 0.5 mm. in length. In polished sections it appears as a soft (hardness B), seemingly sectile, opaque mineral having a tan to gray color and low but variable reflectivity resulting in a faintly mottled appearance. Some of the galena "B" is intergrown with other ore minerals, especially uraninite, although most is in isolated blebs in the microcystalline quartz gangue. Etch tests with the usual reagents suggested galena, and microchemical tests confirmed lead and silver. The lack of the characteristic cleavage pits, high polish and white color of galena masked its identity for some time.

[1] Contribution No. 58-119 from the College of Mineral Industries, The Pennsylvania State University, University Park, Pa.