# GRAPHIC GRANITE

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Contents



## Definitions and History of Term

Graphic granite is a familiar and abundant constituent of many pegmatites, and unlike most other rocks of igneous origin it possesses certain definite characteristics that permit its ready identification in the field or in hand specimen. All graphic granite, when split in certain directions, shows an interesting structure that suggests crude attempts

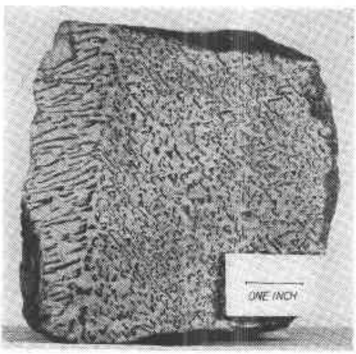



Fig. 1. Graphic granite. Topsham, Maine. The polished surface of the slab shows both transverse and longitudinal sections of the quartz rods. The cleavage of the feldspar extends without interruption through the whole piece—an indication that the feldspar is all part of a single crystal.

at writing or printing with a broad pointed pen. Commonly used terms, such as graphic granite, runite, graphic pegmatite, Hebraic pegmatite, and Schriftgranit, are all descriptive expressions designed to emphasize the importance of this most obvious property of the rock.

The graphic pattern is brought about by the growth in or with feldspar of tapering cross-striated pencils of quartz, which in transverse section generally show one or more reentrant angles and an outline that suggests anything from a stubby boomerang to an awkward attempt to construct the letter "C" with fluted angular rods of lenticular cross-section. Various writers have likened the structures to the runes of the Norsemen, to Hebraic characters, or, with less reason, to the hieroglyphs of the ancient Egyptians. From the last is derived the not uncommonly used word "hieroglyph" as applied to the quartz rods. Fersmann (1928) has coined the word "ichthyoglypts" because of the fancied resemblance of the rods to tailless fish.

Although the term "graphic granite" is well established by usage, it might be a general improvement to use the expression "graphic pegmatite," for the rock is not a true granite, and it probably has not formed by the direct, *in situ*, solidification of molten magma. Rather it has crystallized in a special environment under special conditions. Johannsen (1932) urges the usage of Pinkerton's word "runite." This term has the advantage of being descriptive, and, at the same time, it does not imply a necessary relationship to normal granite.

Graphic granite everywhere is found associated with pegmatites, and its presence serves as a well established criterion for the determination of a rock as pegmatite. As a matter of fact, Kemp (1924) points out that Haüy originally used the word "pegmatite" for a rock that today would unquestionably be called graphic granite. As the term "pegmatite" was gradually adopted, its application was extended, so that it eventually attained its present implications, and graphic granite came to be regarded merely as a variety of pegmatite.

## Texture and Composition

The two essential minerals of graphic granite, quartz and feldspar, have highly contrasting ranges in size. Inasmuch as the quartz generally appears to be embedded in feldspar, the masses of feldspar generally are larger than the quartz grains. Individual grains of feldspar in megascopic intergrowths rarely have diameters less than a centimeter and commonly are several centimeters across. In some places graphic intergrowths are present in continuous feldspar crystals that attain as much as two or three meters in width. In contrast, quartz rods show a rather limited range in size. The rods may in exceptional rocks reach a length of ten or twelve centimeters, or greater, and a diameter of two or three centimeters. Typically, however, the rods are smaller and range downward in dimensions to sizes that are almost imperceptible to the unaided eye.

In general, if the rods, or "ichthyoglypts," are not large enough to be detected in the hand specimen, the rock cannot properly be called graphic granite. For the graphic aggregates that are observed under the microscope a whole suite of terms has been devised, including such familiar words or expressions as, micropegmatite, myrmekite, micrographic intergrowth, symplektite, granophyr, etc. Although many microscopic structures are very suggestive of the megascopic features of graphic granite, there is no necessary implication that the processes of formation are the same. For example, micrographic granite or granophyr is a common but minor constituent in diabase, whereas graphic granite is ordinarily associated with more felsic rocks. However, a study of the genesis of the microscopic intergrowths probably will throw light on the perplexing queston of the origin of the large scale features seen in hand specimens.

The mineral composition of graphic granite is comparatively simple. Only two essential minerals are present, namely, quartz and feldspar. The quartz may be colorless, smoky or milky and, according to Fersmann (1928), may be of either the "high" or "low" varieties. Fersmann (p. 88) notes that an individual rod may contain both high- and low-quartz. This condition obtains in certain pegmatitic cavities where the high-quartz in the walls passes into crystallized low-quartz in the cavities. The low-quartz crystals commonly protrude from feldspar crystals, which serve as a host for the quartz. It is thought that the difference in the two varieties of quartz is proof of lowering temperatures during the period of formation of the pegmatite.

The present writer has etched half a dozen polished specimens of quartz from graphic intergrowths and has found no evidence indicating positively that the quartz in these particular specimens is either of the high or low varieties. In any event, without crystals, many of the criteria for the determination of the temperature of formation of the quartz are of very doubtful value, and a positive distinction between the two varieties is in many rocks fraught with difficulty and uncertainty.

The quartz in cavities is crystallized, and where it is present with feldspar, it not uncommonly appears to lie on or protrude from crystals of the feldspar. In these crystals the quartz ordinarily extends into the feldspar as stubby cross-striated polygonal "roots," which within a few millimeters take on all of the aspects of quartz rods in ordinary graphic granite. In order to see the graphic structure in a crystal of feldspar, it is usually necessary to break the crystal open; quartz rarely appears in a graphic pattern on the surface of a feldspar crystal.

Where quartz and feldspar crystals make contact, it is generally observed that the crystal faces of the quartz lose their identity. The feldspar, however, may retain its crystal outline, and in many intergrowths the feldspar is partly or entirely euhedral. In many quartz-feldspar aggregates the contacts are striated polyhedral surfaces, the planes of which do not appear to be related to crystal directions in either of the minerals. The striations are not an expression of twinning, but, rather, are probably the result of a nearly equal struggle for space by the growing minerals.

The most abundant feldspar in graphic granite is microcline microperthite. Orthoclase is often reported in the literature, but none was observed in the specimens studied by the present writer. Some thin sections contain a feldspar that in general appearance closely resembles orthoclase; however, the optics determined with a universal stage indicate that the mineral is microcline. It is possible that most of the so-called orthoclase in graphic granites is in reality microcline.

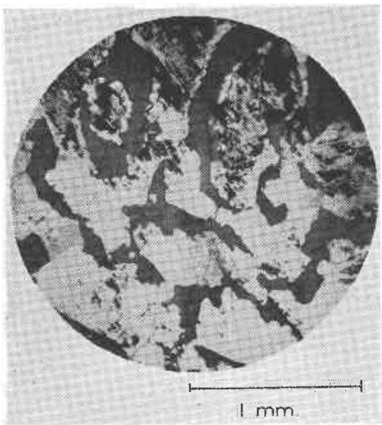



FIG. 2. Photomicrograph of albite graphic granite showing microcline being replaced by albite. Note corrosion of quartz by albite. Albite is white; quartz, medium gray; and microcline, dark gray. Redstone, N. H.

Albite, containing some calcium, is almost universally present in graphic granites. Part of the albite is believed to have formed by exsolution and is the familiar plagioclase in perthite and microperthite. However, many graphic granites contain abundant introduced albite, or albite-oligoclase, which has partly or completely replaced the microcline. Residual patches of microcline and embayed or corroded quartz rods in many graphic granites support the conclusion that the replacing plagioclase is generally later than both microcline and quartz. In some specimens all stages of replacement are visible, and, as an extreme result, all of the microcline is removed. Rocks displaying such features might properly be called "albite graphic granite." It is here suggested that most of the so-called "oligoclase graphic granites" are nothing more or less than replaced ordinary microcline graphic granites.

Many writers have stated that the ratio of quartz to feldspar is constant in graphic granite. For example, Holmes (1914) found that certain graphic granites in Mozambique showed a range of 24.2 to 27.9 per cent of quartz by weight. Vogt (1930) insists that the amount of quartz in microcline graphic granite is near 26 per cent and is definitely confined within limits ranging from 23 to 28 per cent by weight. He believes the amount of quartz in oligoclase graphic granite falls within the limits 33 to 38 per cent by weight. However, it should be stated that many workers, either by direct statement or implication, particularly in North America, do not subscribe to Vogt's ideas, and consider the quartz-feldspar ratio as variable beyond these limits. Among those who do not support the idea of a fixed ratio are Landes (1932), Hess (1933), Schaller (1933), Fenner (1926), Bastin (1911), and Bygden (1906).

## Orientation of Quartz in Graphic Granite

The question of whether or not the quartz in graphic intergrowths is definitely oriented with respect to the feldspar is of prime interest in the solution of the problem of the origin of the structure. If it is a fact that the quartz is everywhere definitely oriented, a strong point is gained in favor of a theory of simultaneous crystallization. Among the most important works on the subject of regular intergrowth of quartz and feldspar are two papers by Fersmann (1915 and 1928). The earlier paper was in Russian and, because of this, was not readily accessible to most readers of geological literature; the second paper was in German, and contained not only the substance of the first paper but, in addition, a review of progress by Fersmann and others in the period between the two papers.

Fersmann states that 88 per cent of all the specimens of graphic granite that he has examined are characterized by the growth of the quartz in such a manner that one of its trapezohedron zones coincides with the prism zone of the feldspar. Thus is brought about the parallelism of the prism edges of the feldspar and an edge between two adjacent rhombohedron faces of the quartz. This supposed coincidence is called the trapezohedral law (or as termed by many other writers, "Fersmann's law") and shows several modifications, all of which possess one property in common, that is, in each the *c* axis of the quartz makes an angle of 42°16′ with the *c* axis of the feldspar. The modifications of the law are graphically portrayed by the points on the small circle in Fig. 3, which shows the points of emergence of the *c* axis of quartz on a stereographic projection perpendicular to the prism zone of the feldspar. Figure 3 also shows the orientations of quartz according to other laws as described

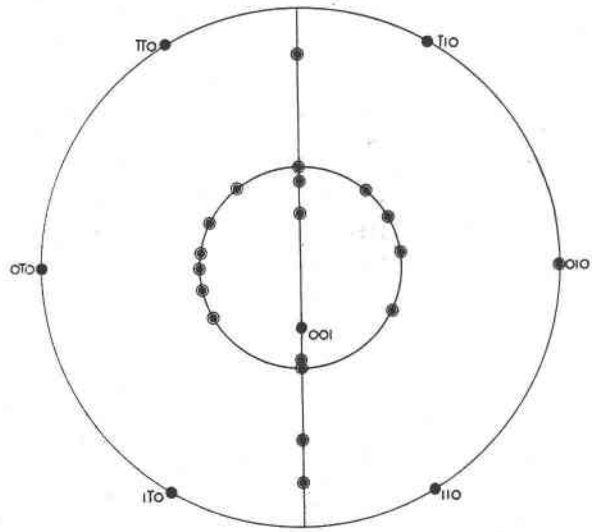



FIG. 3. Stereographic plot showing points of emergence of *c* axis of quartz. Plane of projection is perpendicular to the *c* axis of the feldspar. Modifications of the trapezohedral law are indicated by the double circles in the inner small circle of *rho* equal to 42°16′. Other laws are indicated by the points lying within or without the inner circle. After Fersmann (1928).

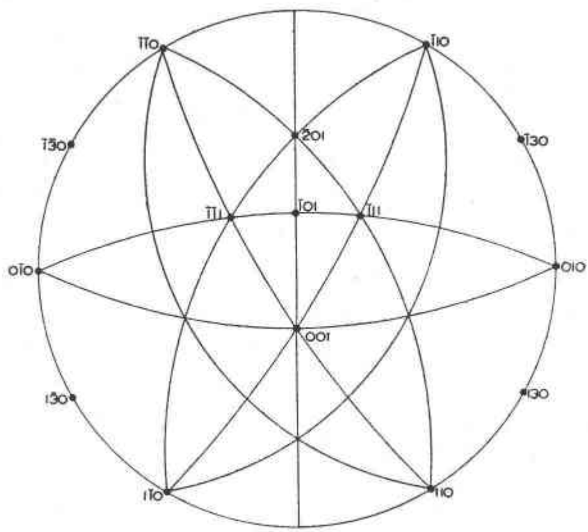



FIG. 4. Stereographic projection of orthoclase showing important faces and zones.

by various writers. Laws other than the trapezohedral law are included in 12 per cent of the specimens Fersmann examined.

Visualization of the modifications of the trapezohedral law is aided by the use of stereographic projections of quartz and feldspar in appropriate orientations. A diagram of orthoclase serves equally well for microcline, because the two minerals, although crystallizing in different systems, are very similar morphologically. Figure ~~4~~ 5 is a projection of quartz

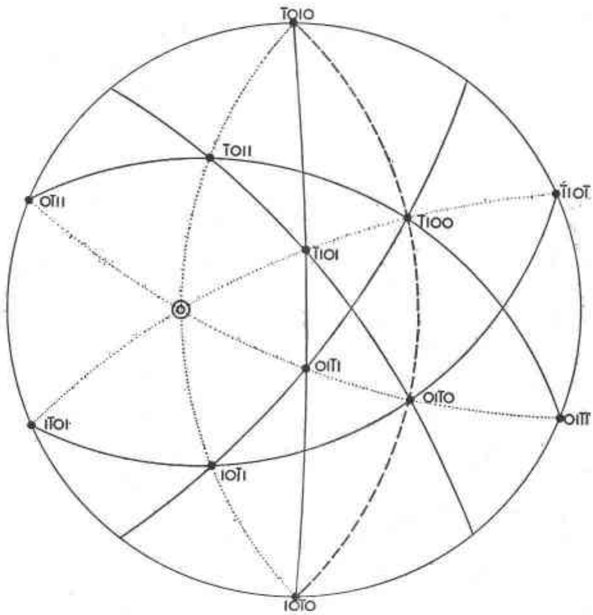


FIG. 5. Stereographic projection of quartz on its trapezohedral zone. The double circle indicates the point of emergence of the *c* axis. Solid lines are the trapezohedral zones; dashed line is the prism zone; and the dotted lines lie in the principal sections of the quartz and are zones including a rhombohedron and a prism face. After Fersmann (1928).

on its trapezohedral zone. If one of these projections is drawn on transparent paper, placed on the other, and rotated about the common center, it will be seen that at intervals certain zones of the two minerals come into approximate coincidence. Each coincidence is described by the position of the point of emergence of the *c* axis of the quartz on a small circle of *rho* 42°16′.

Schiebold (1927) has tested Fersmann's conclusions by comparing the atomic structures of quartz and feldspar. He states that the atomic groupings of the two minerals are in many respects similar, and he accepts Fersmann's conclusions as valid. In a later publication (1930)

Spangenberg and Neuhaus concur with Schiebold and Fersmann, but Schiebold's structure for feldspar was shown to be wrong by Taylor (1933).

In order to test the validity of Fersmann's law, the present writer assembled and studied a representative suite of graphic granites from the collections in the mineralogical laboratories of Harvard University. Specimens were chosen more or less at random and included samples of

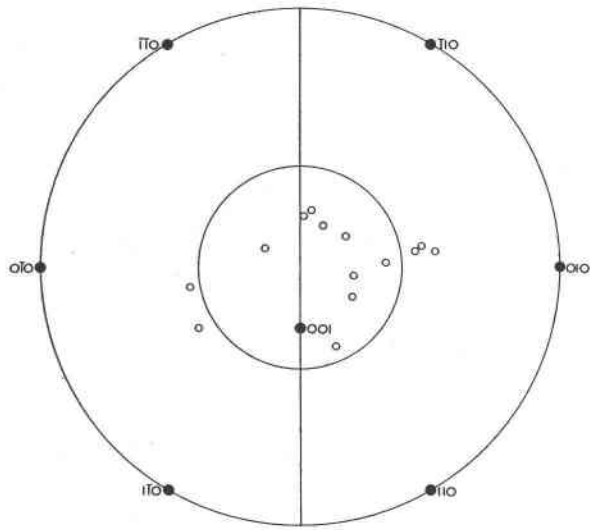



FIG. 6. Plot of graphic granite from Auburn, Maine, showing points of emergence of *c* axis of quartz (small circles) on a stereographic projection of orthoclase. All the orientations are present in a single thin section of feldspar of uniform orientation. Points determined with a universal stage.

material from several localities in Colorado, California, Connecticut, New Hampshire, Maine, Japan and Portugal. Thin sections of thirty of these specimens were examined on a universal stage, and the relative orientations of the crystallographic directions of the quartz and feldspar were determined from their optics by the usual means.

Another, more direct, method of study was the measurement with a contact goniometer of numerous well crystallized intergrowths of quartz and feldspar from the extensive Bello Portuguese collection at Harvard. Almost without exception the studied specimens from this collection show graphic intergrowths in the basal portion of the feldspar crystals, and from a study of thin sections of these crystals, it was observed that, in general, most of the quartz in the graphic intergrowths is connected

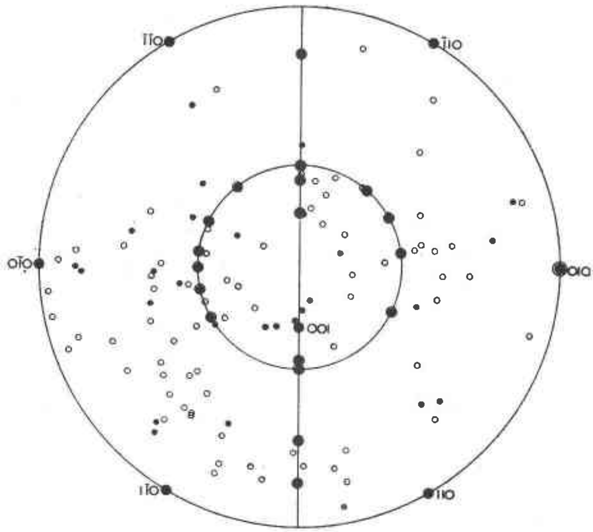



FIG. 7. Points of emergence of the *c* axis of quartz on a stereographic projection of feldspar. The solid circles represent measurements with a contact goniometer, and the hollow circles indicate the results of measurements with a universal stage. The double circles indicate the points of emergence of the *c* axis of quartz according to Fersmann and other writers.

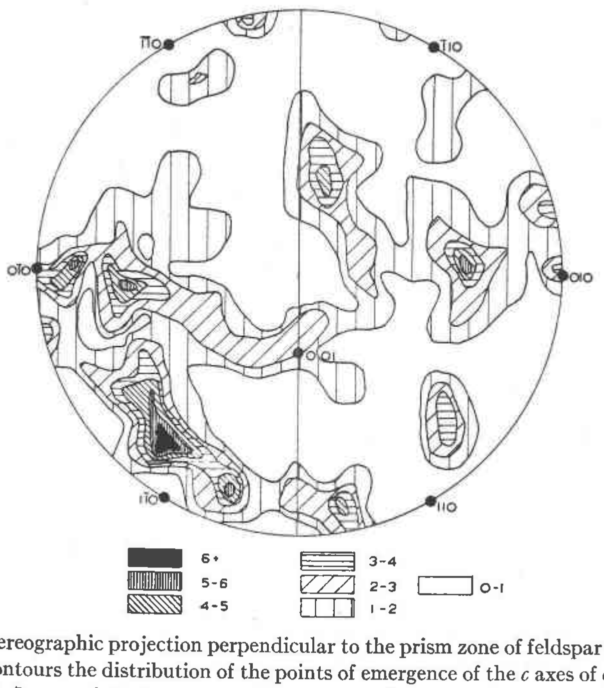



FIG. 8. Stereographic projection perpendicular to the prism zone of feldspar showing by percentage contours the distribution of the points of emergence of the *c* axes of quartz. The points in Fig. 7 were plotted on an equal-area net and contoured according to the technique suggested by Ingerson (1938).

with and has the same orientation as the crystals protruding from the sides and tops of the feldspar crystals.

The combined results of a hundred measurements with the universal stage and contact goniometer are shown in Figs. 7 and 8. Figure 8 is a variation of the plot in Fig. 7 and is designed to show by contours the nature of the distribution of the *c* axes of quartz on an equal-area stereographic projection in the prism zone of the feldspar. An examination of either Fig. 7 or 8 shows that there is no consistent orientation of the quartz in the feldspar. This is in direct contradiction of the views expressed by Fersmann and others as outlined in preceding paragraphs. It should be especially noted that what minor concentrations are present are not on or near the small circle that marks the positions of emergence of the *c* axis of the quartz as demanded by the "trapezohedral law."

Because of certain errors inherent in the technique of universal stage measurement, the results as shown in the stereographic plots cannot be regarded as exceedingly accurate. However, an allowance of plus or minus three degrees in any direction should take care of all errors of observation. But even with such an allowance there is no basis for an assertion that the quartz is consistently oriented with respect to the feldspar.

In crystallographic usage the term "law," as applied to twins and other variations of crystal growth, generally signifies a definite geometrical relationship between different portions of a crystalline substance. The exact nature of the growth depends on several factors such as the environment during and subsequent to the formation, composition, etc. However, when twins or other crystal variations develop in accordance with one law or another, certain space relations must obtain. If these conditions are not rigidly fulfilled, the substance in question cannot be said to have grown in accordance with a specific law.

A statistical study of hundreds of graphic intergrowths of quartz and feldspar might show a tendency for the quartz rods to repeatedly favor certain directions in the feldspar, but unless the crystallographic directions are sharply defined by specific mutual angular relations, the intergrowths cannot be regarded as conforming to specific laws. The present investigation is not comprehensive enough to determine whether or not quartz statistically favors any particular direction or directions in the feldspar, but it does indicate that the relations probably do not conform to the requirements of a definite set of crystallographic laws.

One of the strongest arguments in favor of crystallographic control of the quartz by the feldspar is the common observation that adjacent quartz grains show simultaneous extinctions over broad areas in thin sections. This argument is particularly compelling when it is demon-

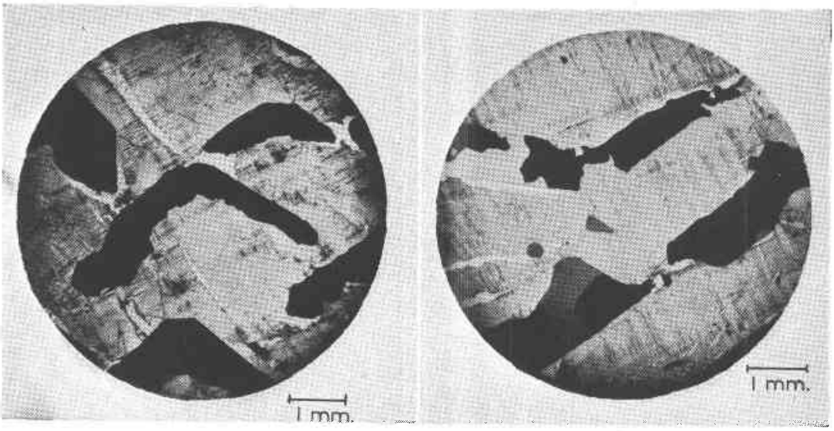



FIG. 9. Photomicrograph of graphic granite showing uniform orientation of quartz rods. Crossed nicols. Auburn, Maine.

FIG. 10. Photomicrograph of graphic granite showing non-uniform orientation of quartz within individual rods. Crossed nicols. Auburn, Maine.

strated that the quartz is present in a series of separate rods that do not interconnect. The idea that the simultaneously extinguishing patches are of necessity parts of a single branching or anastamosing crystal has been shown repeatedly to be erroneous.

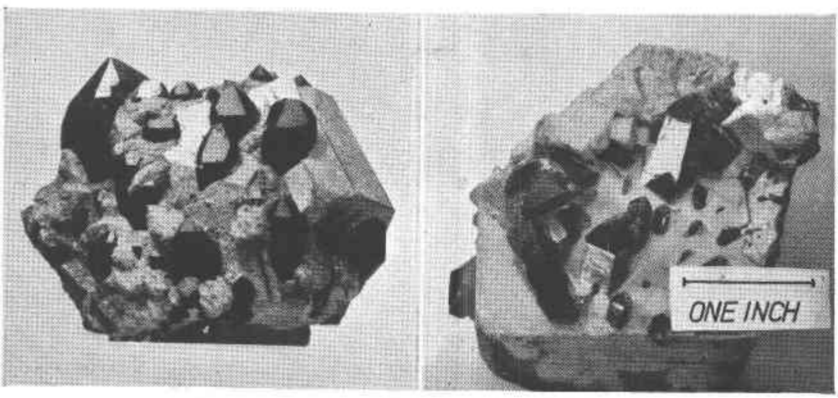



FIG. 11. Parallel growth of smoky quartz crystals in an aggregate of non-uniformly oriented feldspar crystals. The quartz forms graphic pencils within the feldspar crystals. $\frac{2}{3}$ natural size. Laboreiro, Portugal.

FIG. 12. Microcline crystal showing several differently oriented smoky quartz crystal groups. The quartz forms graphic pencils within the feldspar. None of the quartz crystals are oriented according to the requirements of the trapezohedral law. Serra Castro, Laboreiro, Portugal.

Most thin sections of graphic granite actually do show simultaneous extinction of quartz grains over the whole field of view under the microscope. However, some sections contain several rods of different orientation, and it is not unusual to observe several grains of decidedly different orientation within a single rod of quartz; parts of adjacent single rods may extinguish simultaneously over a section. The simultaneously extinguishing rods commonly are present in single crystals of feldspar, and, in general, the complexity of orientation of the quartz increases with a decrease in the size of the feldspar grains. But some complex aggregates of feldspar crystals are cut cleanly across by a group of parallel quartz individuals. In other words, parallelism of the quartz rods is not dependent on the relation to the feldspar host.

Despite the complexities of orientation as outlined above it is probable that in certain localities graphic quartz does show a fairly constant orientation in some particular direction or directions in the feldspar. As a matter of fact, it would be strange if this were not so because of the laws of chance; but the data at hand seem to indicate that intergrowths of quartz and feldspar according to a geometric law are the exception rather than the rule.

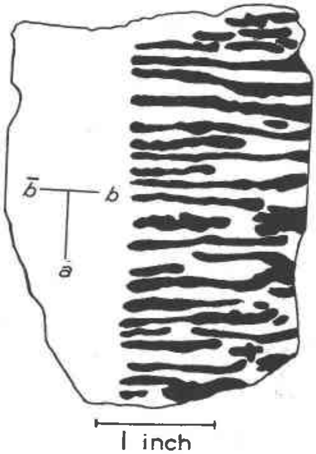
## Origin of Graphic Granite

Fersmann states that the regular intergrowth of quartz and feldspar proves the theory of simultaneous growth of these minerals. Schaller (1926) suggests that the quartz rods have formed by replacement and tend to follow zones of weakness, such as cleavage planes and twinning planes. However, many investigators have shown that the quartz rods do not necessarily follow such planes, but develop with no regard for these structures. Landes (1933) offers the theory that replacement may be controlled by the lattice structures of the host and guest minerals so as to give graphic structures.

Vogt (1930 and 1931) vigorously supports Fersmann's contentions and offers what he regards as additional proof of simultaneous crystallization. He examined suites of feldspar specimens showing "oriented" graphic granite and observed many feldspar individuals containing a core of feldspar sharply separated from wholly or partly enclosing layers of graphic granite. The feldspar in the core has the same orientation as that in the graphic intergrowth and is commonly separated from it by a sharp boundary plane, which parallels a possible crystal face. In general, the quartz rods are nearly, or quite perpendicular to the plane of contact. The most important bounding planes are (010), (001), (110), and ($\bar{2}01$), although other planes are locally important. These observations by Vogt appear at first glance to substantiate the conclusions drawn by

Fersmann as to the manner of development of the quartz rods or "ichthyoglypts" in graphic growths. Fersmann believes that the quartz rods grow at right angles to "induction faces" (important crystal faces) in the feldspar. The same phenomenon has been described by other writers, as for example, by Brögger (1881) and Mäkinen (1913).

Figures 13 and 14 are based on two of Vogt's photographs of "oriented graphic granite" (1930 and 1931). The original specimens came from



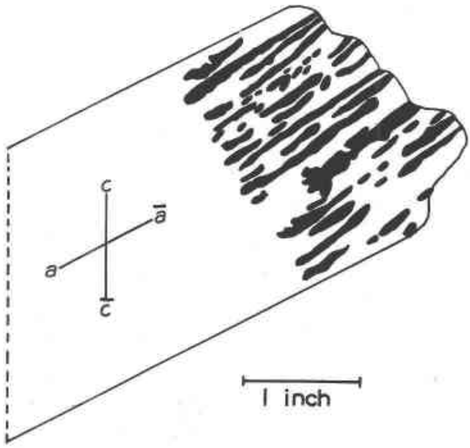




FIG. 13. Sketch to show nature of quartz-feldspar intergrowths in "oriented graphic granite." Rods of quartz (black) are approximately perpendicular to 010 plane of feldspar. Section cut parallel to 001. Based on a photograph by Vogt (1931, p. 200) of a specimen from near Norestø, Norway.

FIG. 14. Sketch to indicate nature of quartz-feldspar intergrowths in "oriented graphic granite." Rods are nearly perpendicular to $\bar{2}01$ plane in feldspar. Based on a photograph by Vogt (1930, p. 109) of a specimen from near Hitterø, Norway.

Hitterø and Norestø in Norway and were chosen for illustration because Vogt regarded them as proof of this theory of the cotectic crystallization of the quartz and feldspar in graphic granite. But such specimens are probably exceptional, and it is a simple matter to find specimens that do not conform to Vogt's ideas. For example, Fig. 15 is a photograph of a polished section of the interior of a feldspar crystal from Nuevo, California. The crystal consists of a core of microcline surrounded in turn by a layer of graphic granite and an outer layer of microcline. The side pinacoidal cleavage extends without interruption through the entire crystal. The described features may be explained as the result of replacement of a favorable layer in a zoned crystal, or as alternate deposition of feldspar and graphic granite. Neither of these explanations supports Vogt's assertions, and merely serve to show that conditions are not as simple as Vogt supposed.

Vogt's views (1930) may be expressed tersely in his own summary, which follows:

"1. Fersmann's crystallographical investigations decisively prove the simultaneous primary crystallization.

"2. The investigations concerning the oriented graphic" (Vogt's investigations) "demonstrate the same conclusion. By two different working methods, quite independent of each other the simultaneous crystallization is thus now established.

"3. Further, we point out that the quantitative proportion between quartz and feldspar (microcline) varies only within narrow limits."

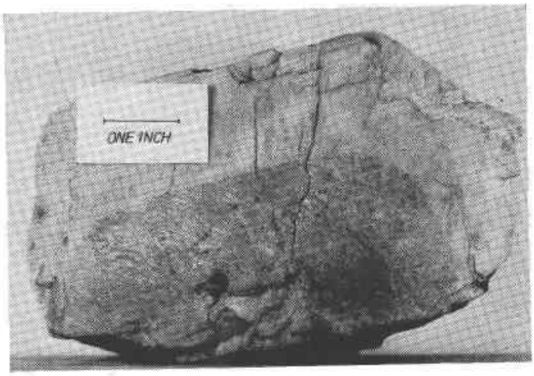



FIG. 15. Polished section through a microcline crystal from Nuevo, California. The crystal has a core of pure feldspar surrounded by a layer of graphic granite, which, in turn, is surrounded by a layer of feldspar. The section is cut parallel to the side pinacoid of the feldspar. The feldspar forms a single crystal as shown by the fact that the 010 cleavage extends without a break through the whole mass.

Vogt rejects as erroneous any theories involving the concept of replacement and, in particular, attacks the views held by Schaller and by later workers stimulated by Schaller's observations.

The idea that quartz and feldspar are precipitated simultaneously suggests the action in artificial binary or ternary systems where, under certain conditions, eutectic and cotectic conditions prevail. Vogt regards graphic granite as a result of precipitation along a cotectic curve in an essentially ternary system consisting largely of quartz, potash feldspar with some albite (and a little anorthite), and containing small amounts of $Fe_3O_4$, mica components, water, etc.; he regards as a probable constituent of the system a compound represented by the formula $SiO_2 \cdot nH_2O$. Vogt finds it necessary to postulate the last named component in order to explain the fact that again and again large amounts of massive quartz are present in the central portions of pegmatite dikes—an observation which would tend to nullify the conclusion that graphic granite forms as a cotectic mixture, if it could be proved that the late quartz existed in solution as such. It is assumed that the component $SiO_2 \cdot nH_2O$ breaks down upon cooling and gives "free quartz" and water. In other words, in considering the origin of graphic granites, Vogt places much significance on the presence of a hypothetical compound in the pegmatitic solutions.

As has been demonstrated in the present paper, quartz in graphic growths is not ordinarily consistently oriented with respect to feldspar. However, this conclusion does not necessarily disprove the theory of simultaneous crystallization, but, rather, it calls for a revaluation of the data used to support this theory. At the same time necessity arises for a consideration of the theory of the replacement origin of graphic granites, so that the opposing theories may be balanced against each other in the light of the new data.

The writer feels that it is very difficult to distinguish positively between structures produced by simultaneous growth and replacement. Without doubt replacement is entirely capable of producing the same features as simultaneous growth, for crystal forces will be similar in either process. There seems to be no obvious reason for stating that the forces interplaying between quartz and feldspar during contemporaneous concomitant growth are not almost, if not exactly, the same as those active during replacement of the feldspar by quartz. The final explanation of the origin of a specific deposit must accordingly, be based on all available evidence and must include a careful consideration of both field and laboratory evidence. Accumulated observations will probably demonstrate that graphic granite can form as a result of either simultaneous crystallization or replacement.

Fairly positive evidence that the quartz has been introduced is found in graphic granite masses closely associated with cross cutting veins or lenses of massive quartz. However, as pointed out above, Vogt (1930) regards the massive quartz as residual from the breakdown of hydrated silica. In such examples conclusions based on field evidence probably are valid and are more trustworthy than data gathered from hand specimens or thin sections.

The proponents of the theory that all graphic granites form by replacement must answer the question as to what does actually happen when quartz and feldspar do develop simultaneously. Significant information bearing on this question may be found in cavities in pegmatite where individual crystals of quartz and feldspar come into contact with each other. The surface of contact duplicates the contact of graphic pencils with the surrounding feldspar. The surface of contact, then, is identical whether the quartz develops entirely within a crystal of feldspar or whether single adjacent crystals of the two minerals interfere during growth. Crystals of quartz resting on feldspar almost invariably extend into the feldspar as irregular roots, which give rise to a typical graphic structure within the crystal. It is more logical to assume that the quartz and feldspar grew simultaneously than to assume that late quartz developed crystals on the surface of the feldspar crystal and at the same time, sent a long pencil-like root into it by replacement. However, crystal lined cavities are special features of pegmatites and occupy only a fraction of a per cent of the bulk of most pegmatites.

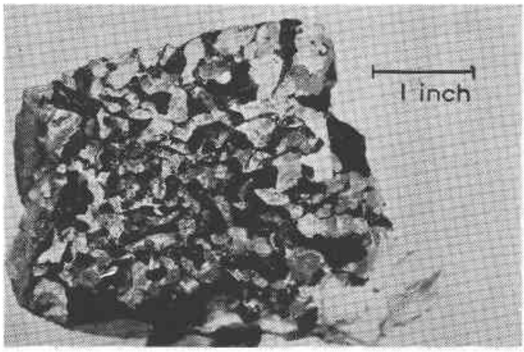



FIG. 16. Graphic intergrowth of quartz and back tourmaline. Portland, Connecticut.

Megascopic graphic intergrowths of quartz with minerals such as tourmaline, garnet, hornblende and muscovite are present in some pegmatites and possess many of the properties of ordinary graphic granite. As in graphic granite, there is no evidence of a fixed proportion of one mineral to another, and it is very unlikely that pairs of minerals were precipitated simultaneously along a cotectic curve. Quartz-tourmaline intergrowths from Portland, Connecticut, and Auburn, Maine, probably formed by tourmaline replacement of quartz (Fig. 16). However, a thin section of quartz and hornblende in graphic intergrowth provides evidence indicating that the quartz is younger than the hornblende. These examples suffice to demonstrate that quartz, either by replacing or by being replaced, can form graphic textures, and provide an excellent argument for the replacement origin of graphic granite.

Selective replacement of the feldspar in graphic granite by late pegmatitic minerals produces interesting features. For example, graphic intergrowths of quartz and muscovite from Auburn, Maine, and Amelia Court House, Virginia, are reasonably interpreted as selective replacements of microcline in ordinary graphic granite by later muscovite.

The writer has examined many pegmatites in the broad pre-Cambrian terranes in the Front Range of Colorado and believes that most of the widespread and abundant graphic granites he has examined there have formed by replacement of massive microcline by quartz, which gained access through fractures or complex zones of weakness. But it is quite possible that many of the graphic structures in the walls of cavities in the well known pegmatites in the Pikes Peak and other regions in Colorado represent simultaneous intergrowths.

Inasmuch as graphic granites are very similar the world over, it is reasonable to assume that the processes active in one place are active in another. But too strong adherence to a single theory of formation may lead to broad generalizations that do not conform to all the facts for a given deposit. The writer believes that quartz replacement in feldspar is the dominant process in graphic granite formation, but at the same time, believes that simultaneous growth is locally important.

## Summary and Conclusions

A study of megascopic graphic intergrowths of quartz and feldspar from many localities indicates that, in general, the geometric relations between the two minerals do not conform to the requirements of any crystallographic law or laws of growth; that is, the quartz in graphic granites does not show any constant orientation with respect to the feldspar. Most quartz crystals resting on microcline are connected with and have the same orientation as graphic quartz rods within the feldspar. Quartz in graphic granite commonly is present in groups of separate parallel rods; however, adjacent rods may or may not have the same optical orientation, or individual rods may contain several grains of random orientation. Groups of parallel rods generally are confined to single crystals of feldspar, but in some specimens the rods cross the boundaries between adjacent feldspar grains. The *c* axis of the quartz may or may not be parallel to the long direction of a rod.

Selective replacement of the microcline in graphic granite results in the formation of graphic intergrowths of such pairs of minerals as quartz and albite, quartz and muscovite, etc. However, graphic intergrowths of quartz with such minerals as tourmaline, hornblende and garnet probably are produced either by partial replacement of the quartz or by the action of silica-rich solutions on older minerals.

Graphic granite probably forms either by the partial replacement of feldspar or by the simultaneous growth of quartz and feldspar. Most graphic granite appears to have formed by partial replacement of massive microcline by quartz from silica-rich solutions which were guided by fractures or complex zones of weakness in the feldspar. Too strict adherence to one or the other of the opposing theories of origin may lead to erroneous interpretations of field and laboratory data.

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