[AMERICAN JOURNAL OF SCIENCE, VOL. 259, MARCH 1961, P. 186-193]

ORIGIN OF ALBITE IN GRANITIC ROCKS

JOHN J. W. ROGERS

Department of Geology, The Rice Institute, Houston, Texas

ABSTRACT. Albite in granites commonly occurs adjacent to potassium feldspar, either as rims on oligoclase or as small scattered grains. The albite was not derived either from adjacent potassium feldspar or from more calcic plagioclase and appears to have formed roughly synchronously with the potassium feldspar. Consequently, the albite appears to be a product of direct crystallization during the later stages of magmatic solidification.

INTRODUCTION

The genetic significance of granitic textures has been a subject of controversy for some time. Many of the arguments concerning the "granite problem" devolve about the interpretation of porphyritic, graphic, or other textures. The classical explanation of the various features as resulting from sequential crystallization of a magma followed by minor deuteric reactions has recently been challenged by magmatists as well as granitizationists. For example, recent papers by Tuttle (1952) and Tuttle and Bowen (1958) advocate a general magmatic origin for granites but stress the importance of postsolidification recrystallization to account for many of the textures shown by the alkali feldspars.

The object of the present paper is to examine some of the properties of the minor fine-grained albite and myrmekitic albite which occurs in addition to the "normal", coarser-grained, plagioclase (generally oligoclase) in many granitic rocks. This albite generally occurs as small grains around the borders of potassium feldspar (fig. 1) or as distinct oriented rims on the more calcic plagioclase grains where they are in contact with potassium feldspar (fig. 2). The albite, whether myrmekitic or not, is generally regarded as "secondary" in the sense that it has formed by recrystallization, replacement, or some other process after the major process of formation of the solidified granite. In contrast to the concept of secondary origin, the present paper attempts to demonstrate that much of the albite in granitic rocks has formed simply as a late-stage crystallization product of a granitic melt. In order to reach this conclusion, it will be necessary to demonstrate that the albite has been derived from a fluid phase and that it has formed synchronously with the associated potassium feldspar.

The terminology used in this paper is as follows: (1) fine-grained albite refers to tiny, separate, unoriented grains; (2) rim albite refers to albitic rims on more calcic plagioclase grains; (3) the major portion of the plagioclase in granites occurs as relatively large, commonly subhedral, grains with a composition in the oligoclase range and will be referred to as normal plagioclase; (4) myrmekite signifies any intergrowth between quartz and plagioclase; and (5) graphic signifies any intergrowth between quartz and potassium feldspar. Most of the albite in granites is in the range of Ab_{100}-Ab_{95}.

A thorough review of the literature concerning myrmekite up to 1948 has been given by Drescher-Kaden (1948), and many of his citations necessarily deal with albite in general. Textural features of alkali feldspars are thoroughly

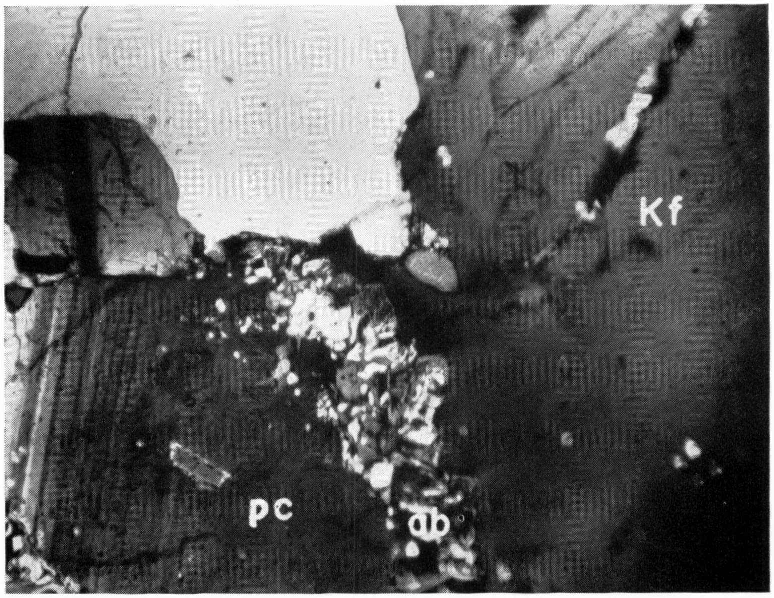

Fig. 1. Fine-grained albite (ab) along the border between plagioclase (pc) and potassium feldspar (Kf). Note the absence of albite along other borders such as plagioclase-quartz (q) and quartz-potassium feldspar. Some of the fine-grained albite is myrmekitic. The sample is from the outer facies of the Idaho batholith. Crossed polarizers, X 75.

discussed in the two papers by Tuttle and Tuttle and Bowen cited above, and in a recent paper on the Enchanted Rock batholith. Hutchinson (1956) describes a number of intricate relationships between potassium feldspar and sodic plagioclase. Robertson (1959) describes some perthitic and other feldspar textures resulting from general potash metasomatism.

ACKNOWLEDGMENTS

The writer expresses his thanks to Dr. Richard Pliler for his advice in the preparation of this paper. All of the samples were collected by Dr. J. M. Whitfield in the summer of 1956. This paper has resulted from work done on granitic rocks in connection with a general investigation of the geochemistry of thorium, whch is supported by Grant C-009 from the Robert A. Welch Foundation.

SOURCE OF ALBITE

If the albitic plagioclase in granites has formed by simple recrystallization and other readjustment after solidification of the rock, it has presumably been derived either from the potassium feldspar or the more calcic normal plagioclase with which it is generally associated. If the albite has not been derived from either of these two minerals, then the most readily apparent or plausible source is some fluid phase.

Two observations demonstrate that the albite has not been derived from the normal plagioclase grains. First, if derived in such manner, there is no

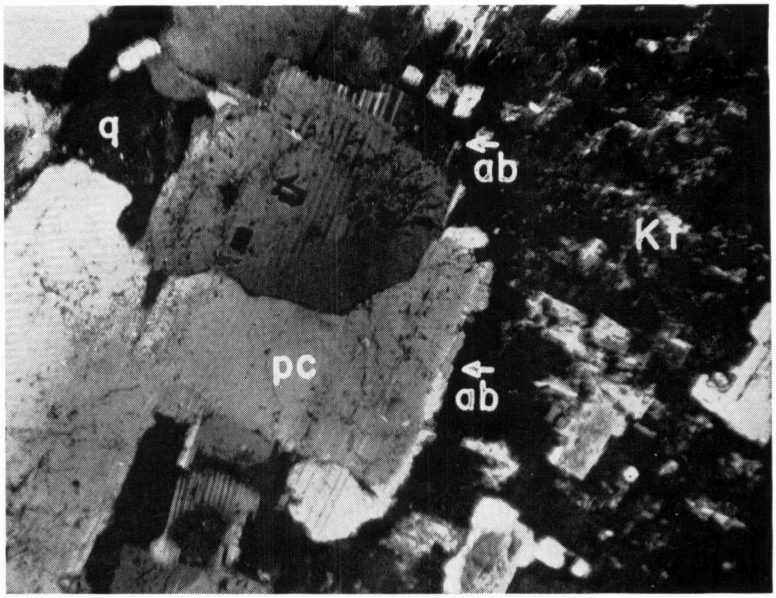

Fig. 2. Rim albite (ab) on the margins of plagioclase grains (labeled pc or showing albite twinning) adjacent to potassium feldspar (Kf). Note the absence of albite on plagioclase-quartz (q) and plagioclase-plagioclase borders. The sample is from the Taft granite of the Yosemite area. Crossed polarizers, X 75.

conceivable reason why the albite should not completely surround the plagioclase either uniformly or randomly; in actual fact, albite occurs only along those borders in contact with potassium feldspar (fig. 2), as is documented by Tuttle (1952). Second, normal plagioclase grains partially surrounded by the albite generally have a uniform composition or exhibit a symmetrical normal zoning outward from the center. Loss of albite from a grain should result either in reverse zoning or in some irregular compositional variations within the grain.

The more plausible argument that the albite is derived from potassium feldspar fails to answer two other observations. First, much of the fine-grained albite around the borders of potassium feldspar and as rims on normal plagioclase grains is myrmekitic. Albite which occurs as rod and film perthite formed by exsolution, however, is rarely, if ever, myrmekitic. It seems likely, then, that if undoubted exsolution does not produce myrmekite, the myrmekitic albite has not formed by that process. Further support for this contention is found in the fact that albitic rims around normal plagioclase inclusions in potassium feldspar (fig. 3) are rarely myrmekitic, and they have quite likely formed by exsolution from the potassium feldspar.

A second argument against the derivation of the albite from potassium feldspar is that in such a process the albite should be distributed uniformly or randomly around the margins of the potassium feldspar. The albite, however, is almost invariably concentrated along potassium feldspar-oligoclase borders, rather than along potassium feldspar-quartz, etc., borders (fig. 1). The only

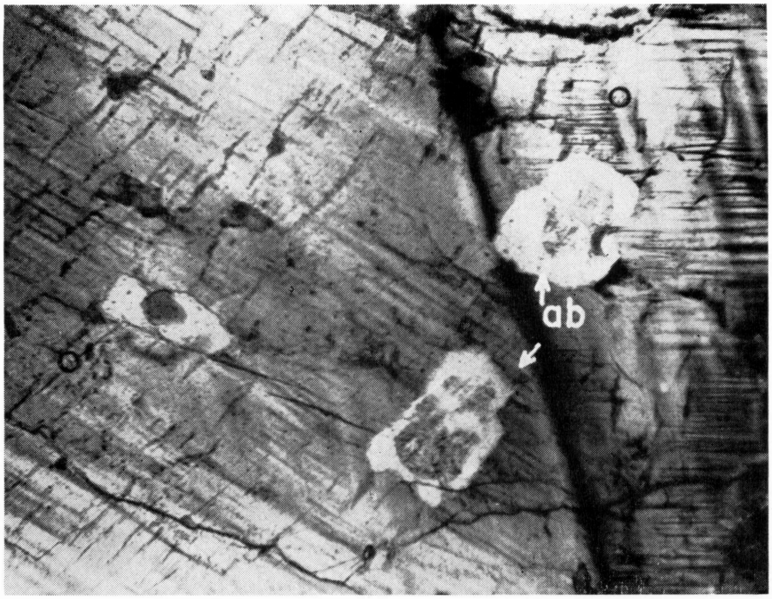

Fig. 3. Albite (ab) around inclusions of plagioclase in potassium feldspar. This type of albite is very rarely myrmekitic, as opposed to albite on the external borders of potassium feldspar. The sample is from the Doublehead pluton in the Front Range, Colorado. Crossed polarizers, X 75.

explanation for this concentration during exsolution is that the similarity of the lattices of albite and the more calcic plagioclase would result in a minimum interfacial free energy between the grains and thus a lower total free energy for the rock. This explanation assumes that such an extremely close approach to ultimate equilibrium (minimum free energy) exists in the granite that the free energy differences between albite-oligoclase and albite-quartz borders would be significant. It seems likely that granites do not approach ultimate equilibrium this closely, as shown by the presence of zoned plagioclase, albite, and oligoclase together, erratic distribution of deuteric alteration products, and the simple fact that no granite consists merely of one giant grain of each mineral (which would yield the absolute minimum total surface area and the minimum interfacial free energy).

In some rocks fine-grained albite occurs along the borders between two adjacent potassium feldspar grains, but such occurrences are uncommon.

If the albite, therefore, has not been derived either from normal plagioclase grains or from potassium feldspar, it must have another source. The most likely source is a fluid, possibly the magma from which the remainder of the granite crystallized, or possibly a deuteric or hydrothermal fluid permeating the solid rock. In order to determine the nature of this fluid, it is necessary to find the time of formation of the albite relative to the formation of the associated potassium feldspar.

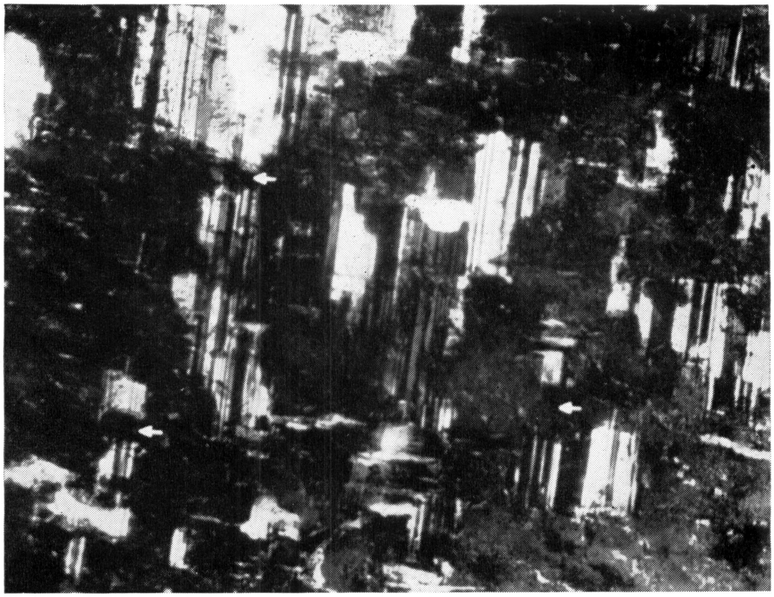

Fig. 4. Sodic plagioclase in oriented intergrowth in potassium feldspar (dark background). The discontinuity in albite (and other) twins between separate plagioclase grains indicates that this texture has not formed by replacement of plagioclase by potassium feldspar. Places where the discontinuity is particularly marked are shown by arrows. The sample is from the Conway granite of New Hampshire. Crossed polarizers, X 75.

TIME OF FORMATION OF ALBITE

Three possibilities exist for the time of formation of albite relative to the formation of associated potassium feldspar: (1) prior to the potassium feldspar; (2) after the potassium feldspar (presumably by replacement); and (3) synchronously. The first possibility, albite preceding potassium feldspar, is disproven by the geometrical arrangement of the two minerals; it is doubtful that the small albite grains would arrange themselves in some geometrical pattern which would later be filled in by a potassium feldspar grain.

The argument that the albite does not form after the potassium feldspar by replacement is based on the following facts. First, both the oriented albite rims on the normal plagioclase grains and the unoriented, fine-grained albite are generally restricted to portions of the potassium feldspar border adjacent to the oligoclase (fig. 2). If the unoriented albite grains had formed by replacement of the potassium feldspar, it seems likely that they would be randomly distributed around the potassium feldspar margins and that the adjacent plagioclase, quartz, or other grains would have no effect on the location of the albite. A second argument against a replacement origin for the albite is that albite very rarely, if ever, occurs in rocks in which the normal plagioclase is more calcic than about An_{25} or An_{30}, even if potassium feldspar is present. Deuteric activity is certainly not absent from comparatively basic rocks, and if albite is a deuteric replacement product, even fairly basic rocks should exhibit some replacement of their potassium feldspar by sodic plagioclase (not necessarily pure albite).

If the albite, therefore, is neither pre- nor postpotassium feldspar, it is synchronous. In this connection it is interesting that the plagioclase equilibrium diagram (Bowen, 1913) shows that oligoclase of the general composition (An_{20-25}) found in granitic rocks should be in equilibrium with a melt of nearly pure albite. Thus, at the time of formation of potassium feldspar the Na/Ca ratio in the magma should be extremely high, and any plagioclase precipitated should be almost pure albite. The next section describes the plausibility that both albite and potassium feldspar crystallize together in the later stages of the solidification of granitic magmas and that this simultaneous crystallization yields the textures under discussion.

SIMULTANEOUS CRYSTALLIZATION OF ALBITE AND POTASSIUM FELDSPAR

The possibility of simultaneous crystallization of sodic plagioclase and potassium feldspar has been described in previous works. Sederholm (1928) found such a rapid and complex alternation of sodic plagioclase and potassium feldspar growth in some of the rapakivi granites of Finland as to indicate effective synchrony. A texture very similar to rapakivi has been described in the White Tank quartz monzonite (Rogers, 1958) and explained on the basis of simultaneous crystallization. In portions of the White Tank quartz monzonite, the potassium feldspar formed large crystals partly intergrown with, and mantled by, oriented sodic plagioclase; proof that the texture had not formed by replacement of plagioclase by potassium feldspar was shown by the fact that twin lamellae in plagioclase intergrowths were not continuous for distances over which they were continuous in the adjacent mantles, and this feature has been found in intergrown plagioclase and potassium feldspar in other granites (fig. 4). Additional evidence of simultaneous crystallization of the two alkali feldspars is found in adjacent large albite and microcline grains in pegmatites.

The examples cited above certainly do not refer to the fine-grained or rim albite discussed in the present paper. They are mentioned only to demonstrate that the concept of simultaneous growth of the two feldspars in granites is well established. The conclusion that the fine-grained and rim albite crystallized from a magma simultaneously with the potassium feldspar is based on the evidence in the preceding two sections, namely: (1) the albite formed from a fluid; and (2) the albite formed essentially synchronously with the potassium feldspar.

Previous work (Rogers and Bogy, 1958) has shown that a crystallizing potassium feldspar grain exerts a major influence on nucleation and growth of grains in its immediate neighborhood. For example, a growing potassium feldspar grain tends to prevent the formation of other potassium feldspar grains adjacent to it, possibly by causing abundant nucleation and incorporation of the nuclei in the already-growing grain. The effect of crystals during growth on their immediately adjacent environments is well established. Most hypotheses to explain crystal growth postulate the formation of a seedling of material in the fluid adjacent to the crystal, rapid attachment of this seedling to the crystal surface, and spread of the seedling across the face. The seedling may be essentially "two-dimensional" or may have detectable three-dimensional thickness. Buckley (1951, p. 169-224) discusses various theories regarding the possibility of crystal growth by this type of promotion and incorporation of nuclei in the fluid adjacent to the crystal. The effectiveness of growing crystals in promoting nucleation around their margins is also demonstrated by the instantaneous "shower" of tiny crystals that results from dropping a seed into a supersaturated solution.

If, then, a growing potassium feldspar grain is an effective promoter for additional potassium feldspar nuclei, it may act in the same manner for other minerals with a similar lattice structure, such as albite. If crystallization occurs below the albite-potassium feldspar miscibility solvus, separate grains of albite should form adjacent to the potassium feldspar and may form inclusions. The restriction of the albite to the borders between potassium feldspar and normal plagioclase may indicate that the combined effects of nuclei promotion by both feldspars are necessary for the rapid precipitation of the small albite grains. Whatever the mechanism, it is apparent that equilibrium is not established between the albite and the adjacent more calcic plagioclase, even in those cases where rim albite forms by epitaxial orientation of the albite on the surface of the normal plagioclase grain.

The preceding discussion has not mentioned the formation of myrmekite, which is here considered to be a product of primary crystallization. Presumably, if quartz is crystallizing in the magma at the same time as the potassium feldspar and albite, the quartz and the feldspars may form intergrowths, especially where nucleation and growth are rapid. It is interesting that, although graphic intergrowths of quartz and microcline are widely considered to represent cotectic crystallization, the closely related myrmekite is generally considered to be a product of reaction in the solid state. There is no a priori reason, however, why the comparatively "regular" graphic texture should be more indicative of simultaneous crystallization than the "wormy" myrmekitic texture. Indeed, intergrowths between quartz and microcline are invariably regularly graphic regardless of whether they have formed by replacement or cotectic crystallization. Similarly, quartz-albite intergrowths are invariably wormy, and these facts suggest that the difference between the intergrowths is determined by the slight differences between the albite and microcline lattices and is not related to mode of formation.

Obviously not all of the albite and myrmekite in granitic rocks have the textural properties described here and on which the conclusion of primary precipitation has been based. To the extent that the textural features of the albite in any particular rock differ from these properties, then to that same extent its mode of formation may also differ from the origin proposed in this paper.

REFERENCES

Bowen, N. L., 1913, Melting phenomena of the plagioclase feldspars: Am. Jour. Sci., 4th ser., v. 35, p. 577-599.

Buckley, H. E., 1951, Crystal growth: New York, John Wiley and Sons, 571 p.

Drescher-Kaden, F. K., 1948, Die Feldspat-Quartz-Reaktionsgefüge der Granite und Gneise und Ihre Genetische Bedeutung: Berlin, Springer-Verlag, 259 p.

Hutchinson, R. M., 1956, Structure and petrology of Enchanted Rock batholith, Llano and Gillespie Counties, Texas: Geol. Soc. America Bull., v. 67, p. 763-806.

Robertson, F., 1959, Perthite formed by reorganization of albite from plagioclase during potash feldspar metasomatism: Am. Mineralogist, v. 44, p. 603-619.

Rogers, J. J. W., 1958, Textural and spectrochemical studies of the White Tank quartz monzonite, California: Geol. Soc. America Bull., v. 69, p. 449-464.

Rogers, J. J. W., and Bogy, D. B., 1958, A study of grain contacts in granitic rocks: Science, v. 127, p. 470-471.

Sederholm, J. J., 1928, On orbicular granites, spotted and nodular granites, etc., and on the rapakivi texture: Comm. géol. Finlande Bull., no. 83, 105 p.

Tuttle, O. F., 1952, Origin of the contrasting mineralogy of extrusive and plutonic salic rocks: Jour. Geology, v. 60, p. 107-124.

Tuttle, O. F., and Bowen, N. L., 1958, Origin of granite in the light of experimental studies in the system $NaAlSi_3O_8$–$KAlSi_3O_8$–SiO_2–H_2O: Geol. Soc. America Mem. 74, 153 p.