THE AMERICAN MINERALOGIST, VOL. 55, JANUARY-FEBRUARY, 1970

INTERGRANULAR ALBITE IN SOME GRANITES AND SYENITES OF HONG KONG

CHARLES C. J. PENG, *Department of Geography and Geology, University of Hong Kong, Hong Kong.*

ABSTRACT

In some granites and syenites of Hong Kong plagioclase and perthite are often overgrown coaxially by fine-grained albite where in contact with perthite. The albite always forms rims on plagioclase. Where two K-feldspars are in contact, each may be covered by a row of albite grains if their interface is anhedral; or one of them may be mantled by a rim if it is euhedral to its neighbor, which generally lacks any overgrowth. The differences are explained in terms of the structural and growth characteristics of the substrate surfaces involved.

Evidence suggests that this intergranular albite has crystallized from a residual magmatic liquid and has grown into adjacent K-feldspar by replacement, rather than by unmixing from the K-feldspar. It is most likely genetically related to a late albitic plagioclase that replaces the K-feldspar. Most of the perthitic albite is probably also of replacement origin.

INTRODUCTION

The literature contains many references to the occurrence in granites and other plutonic salic rocks of fine-grained albite along the boundary between K-feldspar and K-feldspar or between K-feldspar and more calcic plagioclase. The K-feldspar involved is usually perthitic. In most cases described, the albite occurs as rims on the borders of plagioclase against K-feldspar. Some perthite-quartz granites showing fine-grained albite between perthite grains have also been reported. But there are only a very few examples in which this kind of intergranular albite is found at both these types of grain contact in the same rock. The purpose of the present paper is to describe such an occurrence in some of the granites and associated syenites of Hong Kong. The paper, based on a petrographic study of about fifty thin sections, will describe in more detail the albite at the K-feldspar interface, for it displays some features hitherto unreported. The origin of the albite will be discussed.

GENERAL PETROGRAPHY

The granite specimens used for this study were obtained from Kowloon Hills and the nearby Chakwoling kaolin mine on the north side of Hong Kong Harbor. The syenite specimens examined also came from Chakwoling, where the rock forms small, irregular segregation masses in the granite.

The granite is a reddish to light gray, medium to coarse grained rock and consists of 23.0–45.0 K-feldspar, 17.6–38.3 plagioclase, and 30.4–43.0 percent quartz with subordinate biotite up to 6.3 percent. Accessory minerals include fluorite, zircon, allanite, sericite, and epidote.

K-feldspar, the dominant mineral, forms large grains up to 15 mm in size. It is mostly microcline, but many grains are devoid of grid twinning. All the K-feldspar is microperthitic. The albite phase of the perthite occurs mainly as large veins and patches and occasionally as fine films and stringers, and is highly variable in distribution in a given section.

Plagioclase plates up to 8 mm in length are of two generations. The early plagioclase is normally zoned with a composition ranging from An_{18} in the core to An_4 in the margin as determined from extinction angles. It is often deeply embayed by surrounding K-feldspar and commonly develops an albite rim at the contacts (Fig. 1). The rims will be described in some detail later. Sericitization is moderate to weak. The plagioclase of late crystallization has a composition in the albite range and is unzoned. It varies considerably in amount in different specimens and is about one third to one half as abundant as the early plagioclase. Many grains are heavily sericitized, especially in the crystal core, whereas others show weak or little alteration. This albitic plagioclase is commonly found as oriented plates around or within K-feldspar (Fig. 2), but may invade it irregularly. It replaces K-feldspar extensively and to various degrees. The reaction is usually crystallographically controlled, resulting in a variety of replacement textures (Fig. 2). In such cases, the replacing plagioclase joins up the perthitic lamellae within the K-feldspar and is crystallographically continuous with them, suggesting that the two types of albite may be genetically related.

Quartz is generally interstitial to feldspar and commonly penetrates and embays it (Figs. 1a, 2a, 2b, 3d). Some sections show micrographic intergrowths of quartz and K-feldspar or albite. Biotite also occurs interstitially and invades feldspar (Figs. 1b, 1c). It may be partly altered to chlorite with epidote and iron ore, or to sericite.

The syenite, a white and coarse-textured rock, is made up essentially of microperthitic K-feldspar and plagioclase, which vary in amount from 42.5–66.5 and 31.1–55.6 percent, respectively. The feldspars are of the same types as those found in the associated granite and show similar grain-boundary relations, but the plagioclase is predominantly the unzoned, albitic variety, and textures indicative of the replacement of K-feldspar by this mineral are even more strongly developed (Figs. 2c, 2d, and 4d). Quartz is usually absent, but occurs in minor amounts up to 3.5 percent in some specimens. Little biotite is present. White mica, chiefly in the form of sericite, is abundant and, besides replacing plagioclase, exists in small cavities with one or more of such minerals as fluorite, quartz, zircon, allanite, and kaolinite, evidently representing the effect of late-stage activity.

Intergranular Albite

One of the most striking textural features of the rocks is the strong development of intergranular albite at the K-feldspar interface and the boundary between K-feldspar and the early, more calcic plagioclase. It can be found at many of the two types of grain contacts in all thin sections examined.

Albite Between K-feldspar and Early Plagioclase. Intergranular albite at contacts with early plagioclase is found mainly in the granite, which contains more of this variety of plagioclase than the syenite. The albite generally forms a sharply defined, continuous rim around the plagioclase and projects into the adjacent K-feldspar (Fig. 1); but in a few cases, it occurs as a row of oriented discrete grains. The rims range in width from less than 0.1 to about 0.3 mm; even the rim on a given plagioclase usually

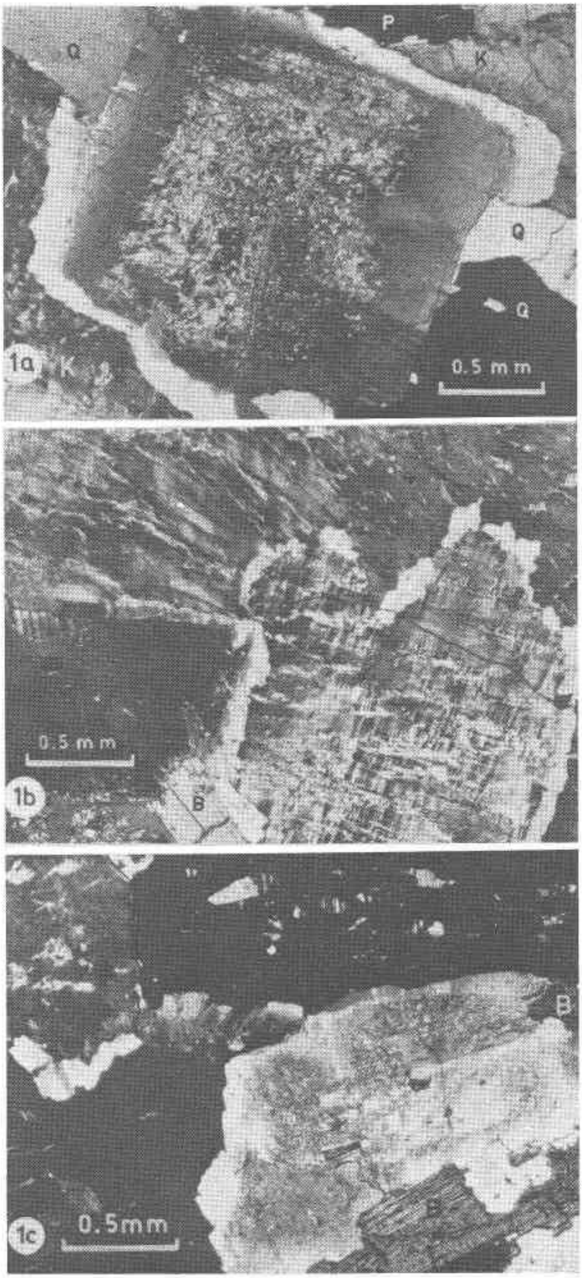

FIG. 1. (a): Albite rim on early plagioclase adjacent to perthitic K-feldspar (K). (b) and (c): Its relation to intergranular albite along K-feldspar interface. P, late albitic plagioclase; Q, quartz; B, biotite. Granite. Crossed polars.

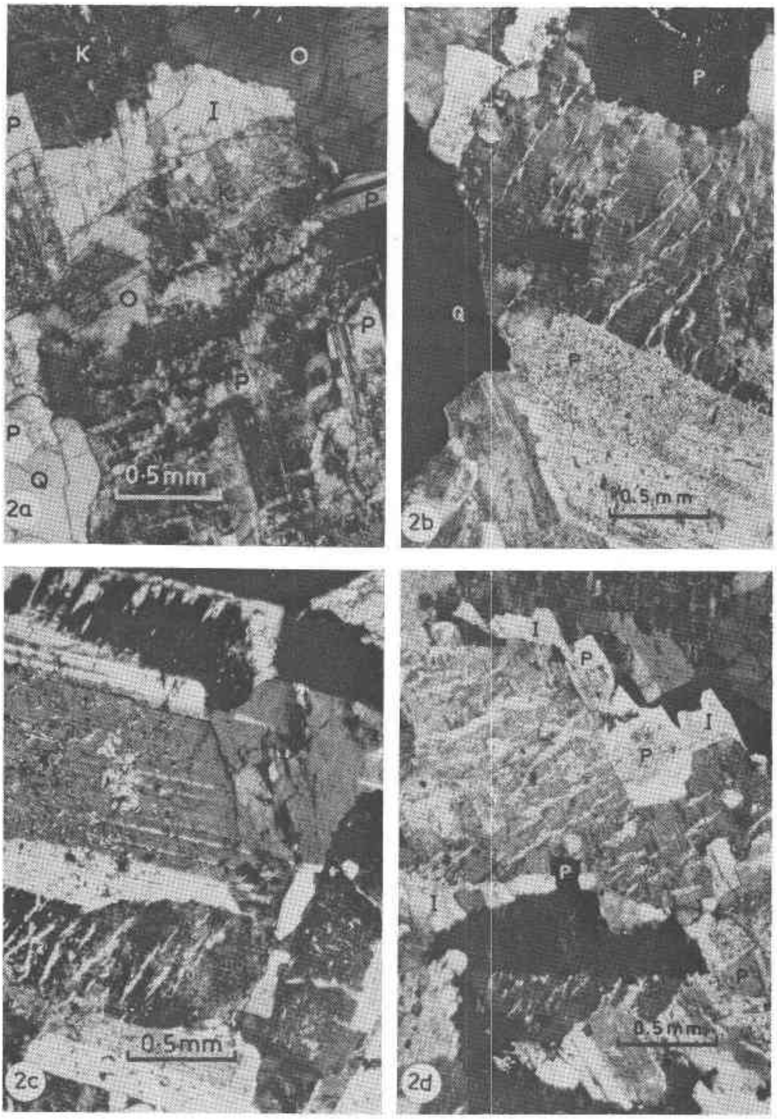

Fig. 2. Late albitic plagioclase (P) replacing K-feldspar (K) and its relations to intergranular albite (I) at K-feldspar interface and to perthitic lamellae. O, early plagioclase; Q, quartz. Granite (a, b) and syenite (c, d). Crossed polars.

varies in width along the length of the border, but it tends to be uniform if the border is geometric in outline. The rim albite invariably has the crystallographic and optical orientation of the core plagioclase and continues the twin lamellae if the core is twinned, but it shows no fixed orien-

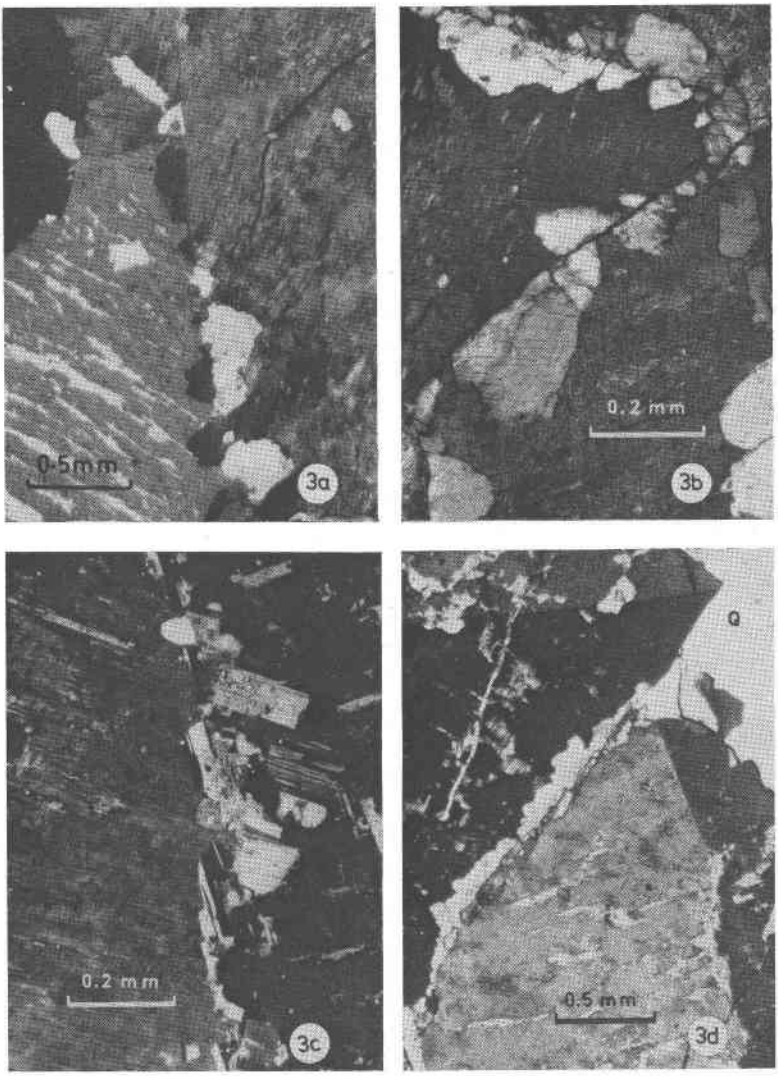

FIG. 3. Double row of albite grains along anhedral K-feldspar interface. Albite warts in granite (a) and syenite (b); albite laths in granite (c, d). Q, quartz. Crossed polars.

tation relative to the neighboring K-feldspar. It is free of sericite; and whereas the rim albite in the granite is nearly always myrmekitic, that in the syenite is usually non-myrmekitic. The writer concurs with Ramberg (1962) and Hall (1966) that such rims are overgrowths on plagioclase and have grown into the associated K-feldspar by replacement.

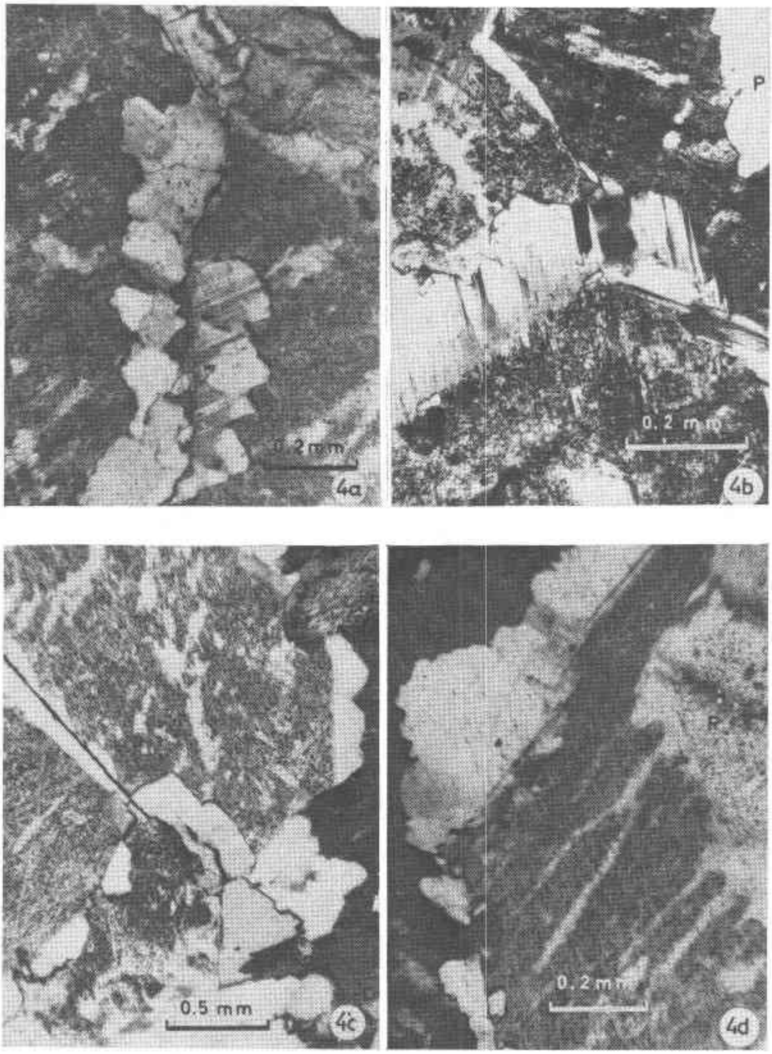

FIG. 4. (a) Albite warts on one side of anhedral K-feldspar interface and albite laths on the opposite side. Granite. (b) and (c): Albite rim on euhedral K-feldspar surfaces. Syenite. (d): A double row of albite warts at the anhedral border of K-feldspar and an albite rim along its euhedral border. P, late albitic plagioclase. Syenite. All crossed polars.

Albite at K-feldspar Interfaces. The intergranular albite along these contacts is in many respects similar to the albite rims on plagioclase, and the two often lie side by side or blend together where found around a common grain of K-feldspar (Figs. 1b, 1c). That this albite is also an oriented overgrowth is indicated by the following facts: (a) it surrounds one of two adjacent K-feldspars along their interface and protrudes into the other, (b) it is in crystallographic and optical agreement with the core crystal, but shows no regular orientation with respect to the crystal that encloses it, and (c) the cleavages are continuous through the albite and the K-feldspar core; and the albite twin lamellae in the two feldspars, if developed, are in parallel orientation. Clearly, the K-feldspar core served as a substrate from the surface of which the albite grew by replacing the adjacent crystal. Commonly, each of two neighboring K-feldspars is overgrown by albite. Like the albite rims on plagioclase, the albite overgrowths range in size up to 0.4 mm and show no sericitization. They are also generally myrmekitic if found in the granite, but are rarely so if found in the syenite. Similar textures have been described by Ramberg (1962) and Carstens (1967).

This albite varies in form with the configuration and orientation of the interface, or rather the substrate surface, upon which it has grown. Its various morphological developments observed may be classified into two main types as follows.

(1) Discrete grains. This type is characteristically found on anhedral K-feldspar surfaces. It may consist of a row of wart-like albite grains without polysynthetic twinning if the core K-feldspar displays no cross-hatching and contains untwinned perthitic lamellae. The irregular-looking warts on a given K-feldspar are of different sizes and lie discontinuously along the interface with their relatively flat sides molded upon the substrate and their convex sides projecting into the neighboring K-feldspar. The warts have a single orientation and extinguish together with the perthitic albite within the substrate. Where two untwinned, anhedral K-feldspars meet, they are usually each overgrown by a row of albite warts along their interface (Figs. 2b, 3a, 3b, 4d). The two contiguous rows of grains have different orientations and tend to be arranged alternately along the irregular interface in an interlocking fashion. But they often overlap each other because of their different shapes and sizes, so that some grains of one row may be in direct contact with their core while others may be partially or completely separated from it by the grains of the opposite row. Nevertheless, the grains on one side of the interface and their core on the other side, even not physically connected, always maintain their parallel orientation. When several anhedral K-feldspar crystals come in contact, each may be covered by overgrowths with a common orientation on more than one border and at the same time may enclose differently oriented albite grains grown separately on some or all of its neighbors (Fig. 3b).

If the core K-feldspar exhibits grill twinning, its albite overgrowth typically takes on the form of a row of lath-shaped grains elongated along the *c*-axis; and if its neighbor is also cross-twinned, it is usually mantled by a similar type of overgrowth (Figs. 3c, 3d). The laths of each row are crystallographically and optically parallel to each other, but are oblique to those of the opposite row. They show albite twinning with the twin lamellae parallel to those of the perthitic albite within the core crystal.

Many cases can be found in which a twinned and a contiguous untwinned anhedral K-feldspar crystal are each surrounded by a row of albite grains along their boundary. As would be expected, the overgrowth on the first crystal is lath-shaped with twinning whereas the overgrowth on the second one is wart-shaped and untwinned (Figs. 1c, 4a).

(2) Rims. Sometimes the borders of K-feldspar against its neighbor are low-index crystal faces such as (010), (110), (001), (101), or a combination of some of them. The albite grown on these euhedral surfaces generally assumes the form of a more or less continuous rim with the appearance of a regular zone (Figs. 2c, 2d, 4b, 4c). This type of intergranular albite is not as common as the granular type and is found mainly in the syenite, in which K-feldspar more commonly exists as subhedral or euhedral crystals than in the granite. The rims closely follow the geometric outlines of the core crystals, but their borders with neighboring K-feldspar may be straight or irregular. They may or may not develop twinning, depending upon whether or not the substrate K-feldspar is twinned.

When a K-feldspar has a nearly geometric border with its neighbor, its overgrowth also tends to be rim-like. Such growths may be made up of a single wart-shaped grain or a row of closely spaced, oriented laths of albite (Figs. 2a, 4d).

Strikingly, when a K-feldspar is mantled by a rim on its euhedral border, its anhedral neighbor generally exhibits no or little overgrowth (Figs. 2a, 4b, 4c, 4d). This is in sharp contrast to the granular type of intergranular albite, which usually consists of two rows of grains opposite each other across an irregular interface.

Interpretation of Form Development. The variation in form of the intergranular albite between K-feldspars may be explained in terms of the structural and growth characteristics of the substrate surfaces on which it has grown, for its growth can be considered a continuation of growth of these surfaces. Obviously, an anhedral border is not a structurally uniform surface but one consisting of various types of faces, probably mainly those of high indices, with lattice imperfections. It is conceivable that as such a surface grew by adding on albite, deposition would take place independently at many points at different rates and probably not by layer formation but rather in an indiscriminate manner due to the predominance of rapidly growing high-index faces (Bunn and Emmett, 1949, p. 128). Further, the growing faces would have the difficulty of spreading laterally because of the structural and energy differences between neighboring sites of nucleation; and unstable faces would eventually be eliminated in favor of the stable ones. The results of such an irregular growth would be expected to be an assemblage of separate grains of various sizes and heights scattered over the substrate surface, as is observed. The wart- and lath-like developments of the grains are evidently the result of growth along different crystallographic directions.

By contrast, growth of euhedral faces should occur at uniform rate with added layers spreading and piling up across the surfaces. Thus, there would be produced a regular rim. The reason for the absence or poor development of overgrowth on an anhedral K-feldspar adjacent to a rim-covered euhedral K-feldspar may be that less energy is required for the albite to form as a rim on low-energy habit faces than as irregular grains on high-energy anhedral surfaces.

Unlike the intergranular albite between adjacent K-feldspars, the albite grown on early plagioclase almost always assumes the form of a continuous rim regardless of the configuration of the plagioclase surfaces. Undoubtedly, its growth must also have been controlled by the surface structure of the substrates, for it tends to have a more regular width on euhedral surfaces than on anhedral ones (Figs. 1a, 1c). Its consistent rim-like development indicates that the surfaces of plagioclase are structurally and energetically more suitable for albite nucleation and growth than those of K-feldspar.

Intermineral Relations. Remarkably, the intergranular albite is restricted to the above-mentioned two types of grain boundary, although it is not found at all these contacts. But it is conspicuously absent at the boundary between K-feldspar and the late albitic plagioclase or quartz. The absence of intergranular albite at quartz contacts has also been noticed by Tuttle (1952), Rogers (1961), Ramberg (1962), and others in rocks they examined.

However, the intergranular albite at the two types of grain boundary is commonly found in contact with quartz or the late plagioclase. Where quartz is involved in such cases, it protrudes into the intergranular albite as well as its substrate (Figs. 1a, 2b, 3d). Not uncommonly, it forms tongues or rods extending into the albite along the interface. It is evidently a late mineral, thus explaining the absence of intergranular albite at its contacts with K-feldspar. But it should be pointed out that not all quartz is of late formation; some of it may have started to crystallize earlier along with K-feldspar, as the two minerals sometimes occur in micrographic intergrowths. The contact relationship of intergranular albite to biotite is similar to its relationship to quartz (Figs. 1b, 1c).

The intermineral relations between intergranular albite and the late albitic plagioclase are more complicated. Where this plagioclase occurs as oriented plates around K-feldspar or replaces it coaxially, it is found side by side in parallel orientation with the intergranular albite grown on the K-feldspar so that they appear to be continuous (Fig. 2). In other cases, one of the two feldspars may cut across the other; the boundaries between them are sharp and straight (Figs. 4b, 4c). Similar relations exist between the late plagioclase and the albite rims on zoned plagioclase, but such occurrences are rare. These relations strongly suggest that the two types of albite have formed simultaneously. If the albitic plagioclase were of earlier formation, there appears to be no obvious reason why its contacts with K-feldspar should not show albite rims.

Discussion of Origin

There have been several suggested explanations of the type of intergranular albite described here. Tuttle (1952) and Tuttle and Bowen (1958) believe that the albite represents the sodic phase originally held in solid solution in the associated K-feldspar and later unmixed at its grain boundaries, whereas the perthitic lamellae in the K-feldspar are due to unmixing within grains. This view, largely resting on the characteristic localization of the albite, has been accepted by Hutchinson (1956), Ramberg (1962), Phillips (1964), Hall (1966), Carstens (1967), and others. Rogers (1961), however, opposes such an explanation on the grounds that the albite is not found at all grain contacts involving K-feldspar, e.g. the contact with quartz, and that it is commonly myrmekitic in contrast to the non-myrmekitic nature of perthitic albite thought to have formed by exsolution. He (p. 186) maintains: ". . . much of the albite in granitic rocks has formed simply as a late-stage crystallization product of a granitic melt" and ". . . roughly synchronously with the K-feldspar." Other investigators have followed Colony (1923) and Alling (1932) in attributing the albite to end-stage magmatic or deuteric action. Still others (Deer, 1935; Schermerhorn, 1956) explain the albite rims on plagioclase as being due to replacement of the latter by K-feldspar. It seems that the intergranular albite in rocks of different environments may be formed by different processes and a single mode of origin may not be applicable to all occurrences. Ramberg (1962, p. 15) also suggests that albite rims on plagioclase ". . . may develop by various mechanisms, depending upon unlike history of the rocks. . . ."

Some of the features of the intergranular albite in the Hong Kong rocks, particularly its consistent localization at the borders of perthitic

K-feldspar and its close relationship to the albite lamellae in the K-feldspar, appear to fit the theory of unmixing just referred to. There are, however, significant facts which suggest the albite has formed by the replacement of the associated K-feldspar by a residual magmatic liquid and not by unmixing.

(1) If the intergranular albite is to be regarded as the result of unmixing, it would necessitate presupposing the associated perthite originates by the same process. The various types of perthite found in the rocks can, of course, be interpreted in several ways (Gates, 1953). As suggested by their regular forms and systematic orientations, the minor film and stringer perthites may be exsolution in origin. But the predominant vein and patch perthites are best explained by replacement for the following reasons: (a) the coarse, irregular veins and patches of albite are typical of the generally accepted replacement perthite (Anderson, 1928; Alling, 1932; Gates, 1953); (b) the albite fraction of the intergrowth varies greatly and irregularly in distribution and size even in adjacent grains; (c) different types of perthite occur side by side in the same thin section; and (d) the lamellae often extend in crystallographic and optical continuity into the late albitic plagioclase that replaces the K-feldspar host. This suggests that the intergranular albite is likewise a product of replacement and not of unmixing.

(2) The development of the intergranular albite is highly variable. Although the absence of the texture at quartz contacts, a point raised by Rogers (1961) against the theory of unmixing, can be easily accounted for in the present case because the albite formed before quartz, the theory still fails to explain the fact that the albite may be absent even at the K-feldspar interface and the boundary between K-feldspar and early plagioclase. Furthermore, the albite exists in various forms, may occur continuously or discontinuously along the boundaries, and is of variable size. Finally, it may be associated with any type of perthite and no correlation was detected between the development of the texture and the degree or type of perthitization of the associated K-feldspar. Such an irregular development of the albite cannot be adequately explained by unmixing. But it would be expected if the albite was derived from interstitial liquids, for its formation under such conditions would be determined not only by the structural suitability of substrate surfaces, as discussed above, but also by the amount of solutions available, which would conceivably vary from place to place.

(3) In all cases, the albite forms an oriented overgrowth on K-feldspar or on the early plagioclase and is crystallographically oblique to the adjacent K-feldspar into which it has grown by replacement. Furthermore, it occurs only along the interface. These relations are believed to preclude the possibility that the albite has formed by unmixing from the

associated K-feldspar. If it had formed in that manner, it would probably, like the exsolved phases observed in certain minerals and metals, to form within the parent crystal a more or less uniform shell surrounding coaxially a perthitic core. Ramberg (1962) noticed and discussed in detail the kind of orientation relationship under consideration in the intergranular albite of charnockitic rocks from Brazil, which he believed to have unmixed from adjacent K-feldspar and have grown into it through interdiffusion of Na and K ions and rearrangement of the $AlSi_3O_8$-framework. With reference to the albite at the K-feldspar interface, he (pp. 22–23) agrees that its growth into the differently oriented K-feldspar rather than the one it parallels is "contrary to what one perhaps would expect in view of the commonly occurring intergranular precipitation in supersaturated alloys . . . ," but he interprets the situation to mean that ". . . the growth of albite into microcline (or orthoclase) is energetically and/or kinetically much more favorable if the two structures are not aligned than if they are as nearly parallel as their unit cells permit." Although it is well known that alkali diffusion and reorganization of the Al and Si in the alkali feldspars may occur with ease at high temperatures and in the presence of flux (Goldsmith, 1952), it is difficult to envisage the possibility that such a process could be so effective as to cause the albite phase in one of two adjacent K-feldspars to be segregated to the interface and then grow into the other producing sharply defined crystals.

(4) It is significant that the intergranular albite and much of the late albitic plagioclase are similarly localized at the borders of the dominant K-feldspar and both replace it. This strongly indicates that they are genetically connected and have crystallized from the residual liquid interstitially distributed in a crystal mush at the late stage of crystallization. The perthitic albite veins and patches in the K-feldspar which are so closely related to them were probably derived from the same source. The three types of albite may have formed at about the same time; but the albitic plagioclase apparently started crystallizing earlier, judging by its much larger grain-size, better developed crystal form, and slightly more calcic in composition. It is true that they show certain mineralogical differences; for example, the albitic plagioclase is commonly sericitized in contrast to the clean appearance of the other two and only the intergranular albite may display myrmekitic texture. These differences may reflect changes in the character of the residual liquid.

The crystal mush containing the residual liquid must have consisted essentially of K-feldspar and the zoned plagioclase, for they are the only major minerals first formed in the rocks. Petrographic study shows that the zoned plagioclase is much less abundant, smaller in grain-size, and of earlier formation than the K-feldspar so that it often occurs as single crystals surrounded by K-feldspar grains or as inclusions in them (Figs. 1, 2a). These relations imply that in the original crystal mush there should have been more K-feldspar interfaces in contact with the liquid phase than the boundaries between K-feldspar and the zoned plagioclase, and contacts between grains of the zoned plagioclase should have been uncommon. This may explain why the integranular albite is typically found at the first two types of grain contacts.

To summarize, all available evidence suggests that the intergranular albite has formed along with the late albitic plagioclase and most of the perthitic albite and that they represent the effect of the residual liquid in the late stage of crystallization.

Acknowledgments

The writer wishes to express his appreciation to Prof. S. G. Davis for permission to use his collection of specimens from Kowloon Hills, Hong Kong, and for his interest in this study. He also extends thanks to Profs. G. C. Amstutz, W. A. Deer, R. C. Emmons, and R. M. Gates for stimulating discussions during his visit to their institutions.

References

Alling, H. L. (1932) Perthite. *Amer. Mineral.* **17,** 43–65.

Colony, R. J. (1923) The final consolidation phenomena in the crystallization of igneous rocks. *J. Geol.* **31,** 169–178.

Bunn, C. W. and H. Emmett (1949) Crystal growth from solutions; (I) Layer formation on crystal faces. *Discuss. Faraday Soc.* **5,** *Crystal Growth,* 119–132.

Carstens, H. (1967) Exsolution in ternary feldspars; (II) Intergranular precipitation in alkali feldspar containing calcium in solid solution. *Beitr. Mineral. Petrog.* **14,** 316–320.

Deer, W. A. (1935) The Cairnsmore of Carsphairn igneous complex. *Quart. J. Geol. Soc. London* **91,** 41.

Gates, R. M. (1953) Petrogenic significance of perthite. *Geol. Soc. Amer. Mem.* **52,** 55–69.

Goldsmith, J. R. (1952) Diffusion in plagioclase feldspars. *J. Geol.* **60,** 288–291.

Hall, A. (1966) A petrogenetic study of the Rosses granite complex, Donegal. *J. Petrology* **7,** 202–220.

Hutchinson, R. M. (1956) Structure and petrology of Enchanted Rock batholith, Llano and Gillespie counties, Texas. *Geol. Soc. Amer. Bull.* **67,** 763–806.

Phillips, E. R. (1964) Myrmekite and albite in some granites of the New England batholith, New South Wales. *J. Geol. Soc. Aust.* **11,** 49–59 [*Mineral. Abstr.* **17,** 88, (1965)].

Ramberg, H. (1962) Intergranular precipitation of albite formed by unmixing of alkali feldspar. *Neues Jahrb. Mineral. Abh.* **98,** 14–34.

Rogers, J. J. (1961) Origin of albite in granitic rocks. *Amer. J. Sci.* **259,** 186–193.

Schermerhorn, L. J. G. (1956) The granites of Trancoso (Portugal): a study of microclinization. *Amer. J. Sci.* **254,** 329–348.

Tuttle, O. F. (1952) Origin of the contrasting mineralogy of extrusive and plutonic salic rocks. *J. Geol.* **60,** 107–124.

———, and N. L. Bowen (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. Amer. Mem.* **74,** 153 p.

Manuscript received, February 24, 1969; accepted for publication, October 4, 1969.