

Simultaneous crystallization of feldspar intergrowths from the melt

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Abstract

Plagioclase–sanidine intergrowths that resemble perthite have been grown directly from ternary feldspar melts. Synthetic feldspar starting materials initially either saturated or undersaturated with water were cooled from a liquid and crystallized. The cooling histories were either continuous at some linear cooling rate or step-cooled at 50°C intervals with isothermal crystallization plateaus. The intergrowths occur as thin, parallel lamellae that resemble microperthite, or in patches that resemble patch perthite. The plagioclase in the intergrowths is $An_{26-15}Or_{5-20}$ and the sanidine is $Or_{75-50}An_{2-7}$. Both are often zoned normally within the stated ranges. The compositions, the presence of zoning, and the short run times indicate that the intergrowths grew directly from the melt and did not develop by exsolution. The lamellae most likely result from the breakdown of a planar plagioclase interface into a cellular interface comprising parallel projections. Not all lamellae can be explained this way, nor can the patches whose growth mechanism is not understood. Phenocrysts in volcanic rocks that show no evidence of an extended high-temperature, subsolidus history and have microperthitic or patch-perthitic intergrowths are likely candidates for natural occurrences.

Introduction

The simultaneous crystallization of two feldspar phases directly from the melt is commonly mentioned, but rarely seriously considered as an origin for perthitic intergrowths. In Smith's (1974a) review of perthites, he points out that little convincing evidence exists that perthite (including crypto, micro, and anti) can be produced by simultaneous growth. The evidence in natural samples is ambiguous, and Smith concludes that even if primary perthite had existed, subsequent solid-state reactions would have erased the original textural evidence. The only attempt to synthesize perthite discussed by Smith (1974a, p. 491) is the unpublished work of D. L. Hamilton and W. S. MacKenzie. They melted, then crystallized two feldspars simultaneously from a gel of composition

$Or_{81}Ab_9An_{10}$. X-ray scanning pictures for K and Ca revealed a coarse and irregular intergrowth unlike most perthites.

As part of a larger dynamic crystallization study of the ternary system, the formation conditions, textures, and compositions of feldspar intergrowths have been studied. The crystallization experiments were performed with feldspar compositions appropriate for monzonite and monzodiorite rock compositions. Intergrowths of plagioclase and sanidine have been produced that resemble some naturally-occurring microperthites and patch perthites. The compositions of the intergrown phases, however, reflect their melt growth history and are inappropriate for perthitic feldspars. Thus, these intergrowths are not perthites even though they are similar in appearance. The purpose of this paper is to detail the compositions of the melt-grown intergrowths and establish criteria to distinguish them from exsolution perthites in naturally-occurring feldspars.

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Experimental techniques

Ternary feldspar starting materials were prepared by the gel method (Luth and Ingamells, 1965) and their compositions are listed in Table 1. Approximately 70 mg of the gel was combined with a measured amount of water (Table 1) and sealed in a platinum capsule. The runs were made in internally heated pressure vessels (Holloway, 1971). The charges were first melted (6–24 hrs) and then the temperature was decreased either at linear cooling rates (1° to 20°C/hr) or in 50°C steps, with the temperature being maintained at each step for 4 to 6 days. Pressure was constant during melting, but decreased during cooling according to the PVT relations at constant volume (Table 1).

A polished thin section was prepared from a portion of each charge for examination of textures and phase chemistry. Analyses were made on an ARL-EMX-SM electron microprobe at an accelerating potential of 15 kV and a sample current of 0.02 mA. Analyzed mineral standards were used. Corrections were made for background, drift, and deadtime; matrix corrections were made using a Bence-Albee algorithm (Bence and Albee, 1968). Because of the mobility of Na and K in glasses under the electron beam, the glasses were analyzed by continuously moving the sample under the beam during each 20-second counting period. The glass analyses were reproducible, and the values are believed accurate to at least 5 weight percent of the oxide present. The glasses appeared homogeneous at distances of at least

TABLE 1. Run data and textural descriptions

Ab-An-Or Capsule No.	Wt.% H ₂ O	Cooling History/ Run No.	Pressure Variation (kbar)	Description of Intergrowth Texture
68-12-20(F-1)				
264	4.9	6.6°C/hr (40)	5.2 to 4.5	fibrous, rare
509	11.9	50°C drops (75)	5.3 to 4.4	fibrous, rare
510	6.0	50°C drops (75)	5.3 to 4.4	fibrous, rare
534	6.6	1°C/hr (77)	5.3 to 4.7	fibrous
553	3.9	2°C/hr (79)	5.5 to 3.2	fibrous, rare
60-20-20(F-7)				
265		6.6°C/hr (4)	5.2 to 4.5	fibrous, few
296	7.0	20°C/hr (44)	5.2 to 4.7	fibrous, rare
554	5.9	2°C/hr (79)	5.5 to 3.2	fibrous, rare
45-11-44(F-8)				
350	2.0	2°C/hr (49)	5.3 to 4.7	fibrous
512	12.0	50°C drops (75)	5.3 to 4.4	fibrous (radiate) and patchy or string-like
513	6.0	50°C drops (75)	5.3 to 4.4	fibrous and slightly patchy
524	12.0	50°C drops (76)	5.0 to 4.0	braid-like to patchy, rarely fibrous (sl. radiate)
525	6.4	50°C drops (76)	5.0 to 4.0	fibrous (coarsen outwards) or patchy
536	12.0	1°C/hr (77)	5.2 to 4.1	fibrous (radiate), patchy (rare)
537	6.0	1°C/hr (77)	5.2 to 4.1	fibrous (slightly radiate) blebby (rare)
555	4.0	2°C/hr (79)	5.5 to 3.2	fibrous (radiate), irregularly patchy
45-19-36(F-9)				
351	4.6	2°C/hr (49)	5.3 to 4.7	fibrous, some arranged in sectors about plag. core
514	11.7	50°C drops (75)	5.3 to 4.4	fibrous (coarsen outwards), patchy
538	11.9	1°C/hr (77)	5.2 to 4.1	fibrous, blebby
556	5.1	2°C/hr (79)	5.5 to 3.2	fibrous to extremely patchy in distinct domains, fibers rarely in sector distribution.
45-30-25(F-10)				
479	3.0	50°C drops (69)	5.1 to 4.8	fibrous, irregularly distri- buted in small clusters of fibers
557	7.9	2°C/hr (79)	5.5 to 3.2	fibrous, few, 2–7 μ; patches rare 5–15 μ
45-37-18(F-11)				
480	5.0	50°C drops (69)	5.1 to 4.8	fibrous, irregularly distri- buted in small clusters of fibers
558	9.6	2°C/hr (79)	5.5 to 3.2	fibrous, <4μ; no patches

100 μm from the larger crystals. For zoning profiles, only Na, K, and Ca were analyzed, and only background, drift, and deadtime corrections were made.

Analysis of the lamellar intergrowths presents a problem. The lamellar spacing is generally less than 5 microns, and it is thus impossible to analyze them individually. We have obtained what we consider to be good approximate compositions in the following way. An area of lamellar intergrowth in a given crystal is selected that is free of fractures and other surface imperfections and is at least 0.1 mm long. The lamellae are traversed perpendicular to their long dimension with a beam spot of approximately one micron. An analysis for Na, Ca, and K is made every two microns, and the molecular amounts of An, Ab, and Or are calculated and plotted. The data generally plot on a mixing line between the lamellae and host compositions. Data points that fall between the end members represent analyses where the beam spot overlaps significantly onto both the host and the lamellae, and data points at the endpoints of the mixing line represent analyses where the beam spot is centered as well as possible on either the host or lamellae. If the lamellae are significantly smaller than the volume of excitation of the microprobe beam, then the end-member analyses will be minimum values and the actual values must be along extensions of the mixing line established by the available data. The reproducibility of the mixing line for same traverse and the reasonable values obtained convince us that this is a viable technique to obtain compositional data on very fine, closely-spaced lamellae and host.

Experimental results

Textures

The experimentally-grown feldspar crystals are elongate, or tabular and nearly equant on (010). Nearly all crystals have plagioclase cores and sanidine overgrowths. Intergrowths of plagioclase and sanidine are present in crystals grown from each of the starting compositions listed in Table 1. The run conditions and a brief textural description for each occurrence are given in Table 1. The intergrowths are of two general types: regularly-spaced, parallel lamellae up to 10 μm wide that resemble microperthite (Smith, 1974a, p. 423) and irregular or patchy intergrowths that resemble patch perthite (Smith, 1974a, p. 410).

The fine lamellar intergrowths are most common in crystals grown from F-1, F-7, F-10, and F-11. The lamellae are generally perpendicular to the core

plagioclase and the crystal growth face they subtend (Figs. 1-4). The lamellae in some crystals are visibly connected to the plagioclase core (Fig. 2), but in many cases they do not appear to be connected. In other crystals, the lamellae terminate within the crystal (Fig. 5). The lamellae in F-9 (especially charge 351) are often arranged in sectors (Fig. 2) resembling compositional sector zoning in plagioclase and pyroxene. In step-grown crystals (Figs. 3 and 4), the lamellae terminate within each zone and apparently nucleate anew in succeeding zone. In charge 479 (Fig. 4), the lamellae are quite regular in the (100) direction, but occur only as isolated patches in the (001) direction.

The plagioclase lamellae do not always occur with regular spacing, especially in crystals that also have plagioclase patches. In the crystal shown in Figure 6 the plagioclase lamellae vary considerably in spacing and width, and in the crystal shown in Figure 5 they occur as isolated thin stringers. Some crystals have fine lamellae behind the (001) face and patchy intergrowths behind (010).



FIG. 1. Feldspar crystal with skeletal plagioclase core (light gray) and sanidine mantle (dark gray); overgrowth has fine lamellar plagioclase-sanidine intergrowth, Capsule 351.

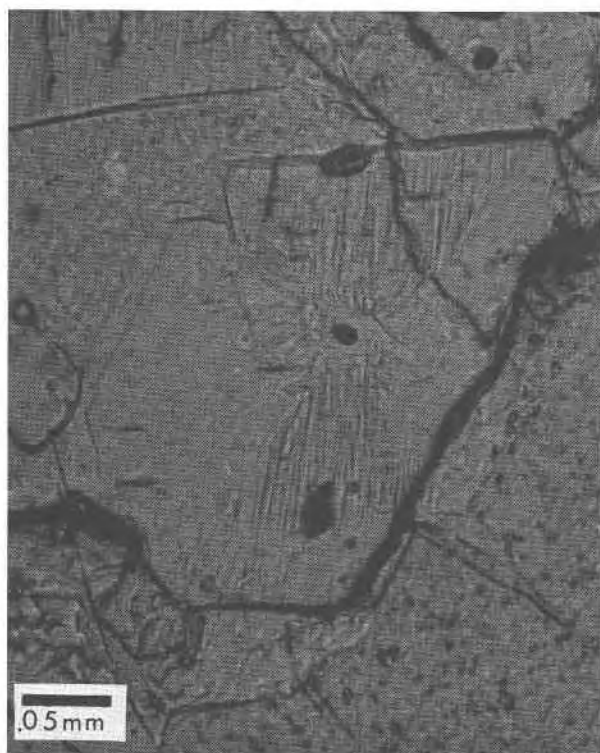


FIG. 2. Feldspar crystal with equant plagioclase core (dark gas bubble in center) from which fine lamellae extend in two sectors into the enclosing sanidine (lower relief). Capsule 351.

Patchy intergrowths are common only in F-8 and F-9 and are more variable in character than the lamellar intergrowths. Three major varieties are shown in Figures 5–7. The patches may be in optical continuity, as shown in Figure 5; all the patches on one side of the crystal extinguish simultaneously under crossed nicols, while those on the other also extinguish together, but at a slightly different angle. The patches appear to be connected by thin lamellae which may not appear continuous in the plane of the thin section (Figures 6 and 7). There were no crystals in which there were only patchy intergrowths. The patchy intergrowths are better developed in the continuously cooled runs.

There are no prominent plagioclase cores in the crystallization products of F-8. In charge 350, there are very small plagioclase cores, but in most other F-8 products the plagioclase and sanidine either nucleated and precipitated together or sanidine appeared slightly earlier.

Mineral compositions

The compositions of the intergrown phases most readily distinguish crystallization intergrowths from

exsolution perthites. The compositions of the intergrown phases are shown for each bulk composition in Figures 8–12. The complete zoning profiles are also shown, but they are included only to set the context for understanding the intergrowths and will not be discussed in detail in this paper. Nomenclature will follow Smith (1974b, p. 447). All cell edges and axial angles measured from X-ray precession photographs of the phases in Run 351 indicate that both the K-feldspar and plagioclase are in their high structural state (J. R. Smyth, personal communication). Since all the feldspars in the other runs were grown at similar temperatures for similar lengths of time, the crystals are most likely all in the high structural state. Thus, the adjective “high” will be assumed throughout this paper and not explicitly stated.

The crystal shown in Figure 3 comprises four zones that grew isothermally at 50°C intervals. Zones 1, 2, and 3 are reverse zoned, *i.e.*, they become continually richer in An from the inside to the outside edge (Fig. 8). Zones 1 and 2 are oligoclase and do not have intergrowths. Zone 3 is potassian albite, and parts of the zone contain fine lamellae (Fig. 3). The compositions of the lamellae and host are best estimated from the end points of the mixing line shown in the lower part of Figure 8. The lamellae are sodian sanidine (nomenclature after Smith 1974b, p. 447), and the host is similar in composition to the intergrowth-free parts of zone 3. Zone 4 is sodian sanidine, but has a complex zoning pattern (Fig. 8) which initially shows an increase in Or (reverse) followed by an increase in Ab (normal). Portions of zone 4 also have fine lamellar intergrowths (Fig. 3) with potassian albite lamellae in a host comparable to the intergrowth-free parts of zone 4.

Zones 3 and 4 are adjacent (Fig. 3b), and it is not clear whether they grew simultaneously or sequentially. The more Ab–An-rich composition of zone 3 suggests that it grew at a higher temperature and thus before zone 4. The lamellae in zone 4, however, are richer in An than the bulk composition of zone 3, suggesting the reverse order of crystallization. The bulk composition of each zone, however, should be diagnostic, and zone 3 probably crystallized before zone 4. The An-rich lamellae in zone 4 may result from An enrichment in the boundary layer preceding the crystal growth front. This possibility is not very satisfying, however, because a similar behavior is not observed in the zone 3 lamellae.

The temperature at which each zone grew can be determined only if the relationship between zones 3 and 4 is clear. Assuming zone 3 grew first, then zone 4 would have grown at the final isothermal plateau,

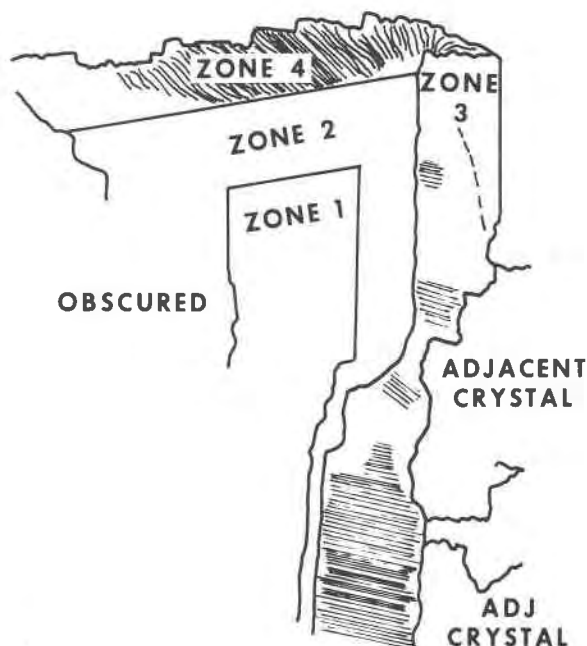


FIG. 3. Feldspar crystal with sharply defined zones that reflect the step-cooled history (see text for details): (a) photomicrograph; (b) sketch delineating the zones. Capsule 510.

650°C, and each preceding zone at successive 50°C higher increments. We have observed empirically that, once nucleation takes place and the crystal starts to grow at one isothermal plateau, each succeeding plateau will be represented by a zone of crystallization. Thus for this bulk composition, the crystal did not nucleate until the 800°C plateau was reached.

Bulk composition F-7 was cooled at a linear rate of 6.6°C/hr, and thus the zoning profile is continuous except for the abrupt change from oligoclase to sodian sanidine (Fig. 9). The lamellae are extremely fine, less than 5 μm , and are rare. The traverse used to analyze the lamellae crossed the profile at the x , but the composition is changing so rapidly that the limits of error in placing the x are shown by perpendicular hachures. It is thus impossible to define a host-lamellae relationship, and the compositions of the alternating fine fibers or lamellae are shown by the end points of the mixing line ($\text{An}_{10}\text{Or}_{10}$ vs. $\text{An}_3\text{Or}_{65}$).

The nearly equal proportions of the intergrown phases in bulk composition F-8 reflect the nearly equal proportions of the two feldspars in the starting material: Sanidine is slightly dominant in the crystal

(Fig. 6) and is considered the host. The oligoclase lamellae and patches are the same composition. The sanidine enclosing the patches is slightly more Or-rich than the sanidine intergrown with the oligoclase lamellae (Fig. 10). The crystal grew in a linear cooling experiment that covered nearly 250°C, but actual growth must have taken place within a more limited temperature interval to account for the narrow compositional range throughout the crystal.

The crystals grown from F-9 showed the widest variety of intergrowth textures. Analyses of the patchy intergrowths are shown in Figure 11a. The patchy intergrowths (Fig. 5) developed best in a step-cooled run. A separate plagioclase crystal with a sanidine overgrowth is significantly more An-rich than the patches, indicating that it nucleated and grew at a higher isothermal plateau than the intergrowths. The two tie lines join patch-host compositions from each side of the crystal.

Parallel lamellae are the dominant intergrowth in continuously cooled melts of F-9 composition (Figs. 1 and 2). Both the plagioclase cores and sanidine mantles are normally zoned (Fig. 11b). Analyses of the lamellar intergrowth close to the plagioclase core and near the edge of the crystal show that the la-

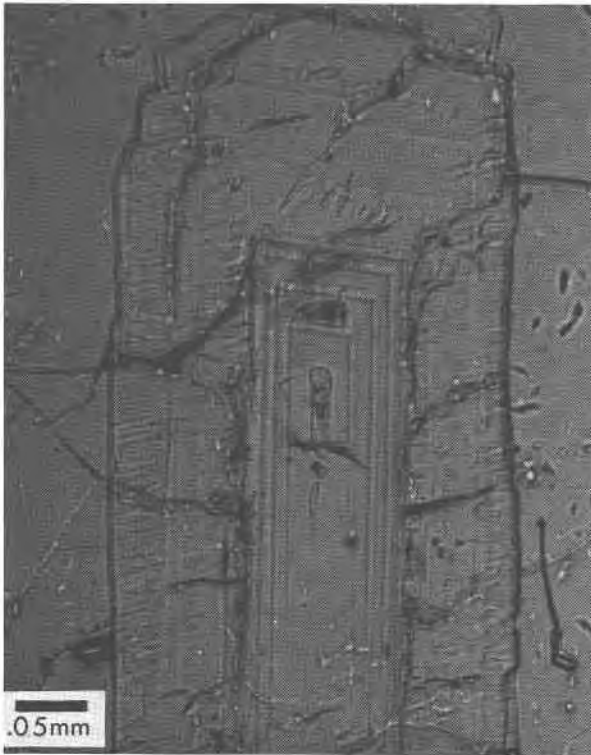


FIG. 4. Feldspar crystal with five plagioclase zones and three sanidine zones each containing plagioclase intergrowths. Capsule 479.

mellae and host are both normally zoned. The lamellae continue the normal zoning trend of the plagioclase core, and reflect the appearance of sanidine by trending toward the Ab corner. The zoning range of the host is the same as the parts of the sanidine overgrowths that have no lamellae, such as the crystals with the sector-arranged lamellae (Fig. 2).

Compositions F-10 and F-11 have high An contents and thus have large plagioclase cores (Fig. 4) and extensive zoning profiles (Fig. 12). The crystals analyzed were step-cooled in 50°C intervals. The plagioclase is reverse-zoned with each zone similar to the profiles in Figure 8, and the normal zoning trend indicated in the figure shows the decreasing average An content of each zone grown at decreasing temperatures. The plagioclase in the more Or-rich F-10 has a slightly higher Or content and three sanidine zones as opposed to one. The sanidines are complexly zoned; the initial trend is normal, followed by a reversal or enrichment in Or content. Individual profiles are not shown in Figure 12, in which the arrow indicates the overall trend for the three sanidine zones with de-

creasing temperature. The lamellae compositions in F-10 and F-11 are very similar to each other and to those for other bulk compositions.

Evidence for simultaneous growth

Several lines of evidence lead to the conclusion that the intergrowths develop by simultaneous growth and not through exsolution or replacement. Replacement can be ruled out, because the composition of the system remains constant and because of the short times available. Exsolution is not so easily dismissed, and the following discussion will hopefully resolve the question.

The intergrowths produced in the crystallization experiments possess several rare, if not unique attributes: (1) their thermal histories are accurately known; (2) both of the principal phases are extensively zoned; and (3) the compositions of these phases are unusual for exsolution perthites.

For exsolution to take place, a high-temperature feldspar must be cooled sufficiently slowly below the solvus. Based on the data of Yoder *et al.* (1957) and Morse (1970), which place the alkali feldspar eutectic within 5° of 700°C at 5 kbar, charges 351 and 350,



FIG. 5. Sanidine crystal with patch-plagioclase intergrowths; the patches on each side have a common extinction angle. Capsule 514.

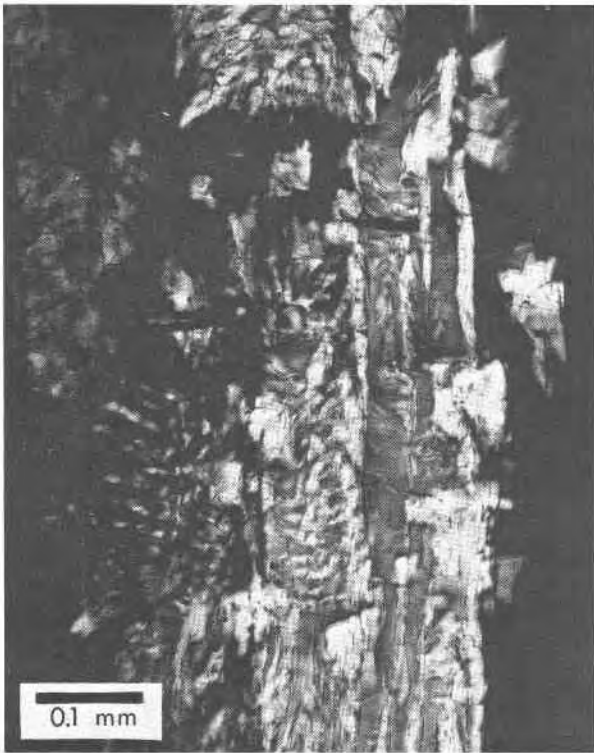


FIG. 6. Sanidine-plagioclase intergrowths, both patch and lamellar; sanidine is dark gray, and the plagioclase is lighter gray. Capsule 524.

which were quenched at 765°C, never entered the solvus region except on the quench. The crystals in all other charges must have entered the solvus region, but only for short periods of time. The three sanidine zones in 479 (Fig. 4) crystallized at 800°, 750°, and 700°C. The data of Morse (1970) show that only the 700°C zone could have possibly crystallized below the solvus. The 700°C zone shows the best intergrowth development, while the previous two zones, which had the advantage of the full time period at 700°C to exsolve, have poorly developed intergrowths. If exsolution were the mechanism, the opposite would be expected.

There are no distinctive differences between the intergrowths in runs that did not go below the solvus except on the quench and those that spent a few hours or days below the solvus; and there is no reason to suppose a different mechanism caused the remarkably similar intergrowths. Furthermore, it is unlikely that exsolution could take place rapidly enough for lamellae up to 10 μm or patches up to 50 μm to form in less than 10 days. The extensive zoning of the sanidine is also difficult to explain if an exsolution

mechanism is called upon. Diffusion sufficient to cause exsolution should certainly eliminate the zoning in sanidine, where it is not necessary to alter Si-O or Al-O bonds, especially when, as shown in Figure 11b, both the plagioclase lamellae and the sanidine host are normally zoned in the same range as the nonperthitic areas of the same crystals. The last and strongest point in favor of simultaneous growth is the composition of the sanidine host. The sanidine is zoned from Or₇₅ toward the Ab corner with an average near Or₅₀ to Or₅₅. Sanidines of this composition would be capable of exsolving the classical perthite compositions of greater than Or₈₀ and less than Or₁₀. There is little data on plagioclase lamellae compositions that have significant An content, but they certainly represent higher temperatures of formation than the usual Ab₉₈₋₉₄An₁₋₃ typical of exsolution perthites.

Growth model

The simultaneous growth of two phases from the melt is usually considered eutectic (or cotectic) crystallization. Because the liquid fraction does not ap-

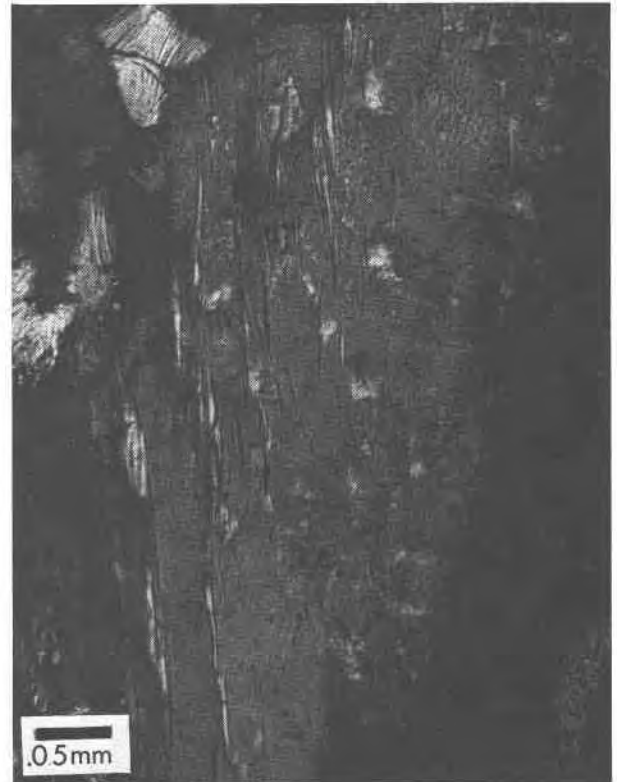


FIG. 7. Sanidine crystal with isolated lamellae connecting plagioclase patches. Capsule 512.

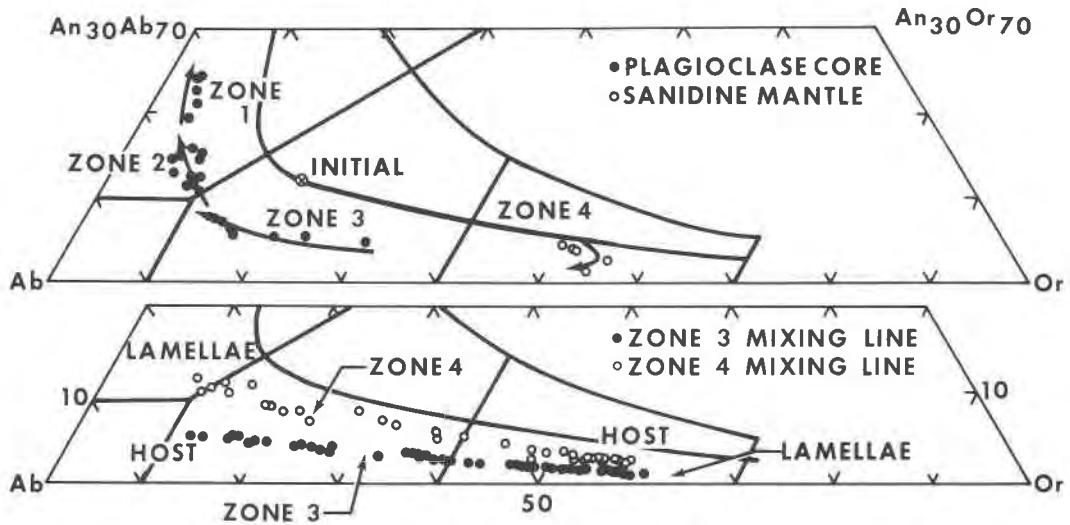


FIG. 8. Plot of microprobe analyses of the crystal in Fig. 3 grown from composition F-1. The open and closed symbols in the lower part define mixing lines as defined in the methods section. See text for further explanation.

pear to have reached the cotectic in this system before nucleation and growth of sanidine, and because the compositional variation of the intergrowths is considerable, it is difficult to call on eutectic growth to explain the intergrowths. There are lamellar intergrowths similar to eutectic crystallization, however, whose growth is kinetically controlled and not an equilibrium process (Tiller, 1964; Lofgren, 1974). This kinetic process combined with the cotectic nature of the ternary feldspar system may produce intergrowths similar to those found in eutectic growth.

During growth of the plagioclase, a boundary layer

of melt rich in rejected K-feldspar components develops adjacent to the plagioclase. The presence of such a zone, 10 to 20 μm wide, has been documented by analyses of the glass immediately adjacent to the plagioclase crystals that do not have sanidine overgrowths. Sanidine nucleation will occur first in this boundary layer, because this liquid approaches the cotectic composition in the ternary system before the bulk liquid and is at all times more highly supercooled and supersaturated (Tarshis and Tiller, 1967). It is impossible to say whether nucleation takes place at the plagioclase melt interface or a few microns

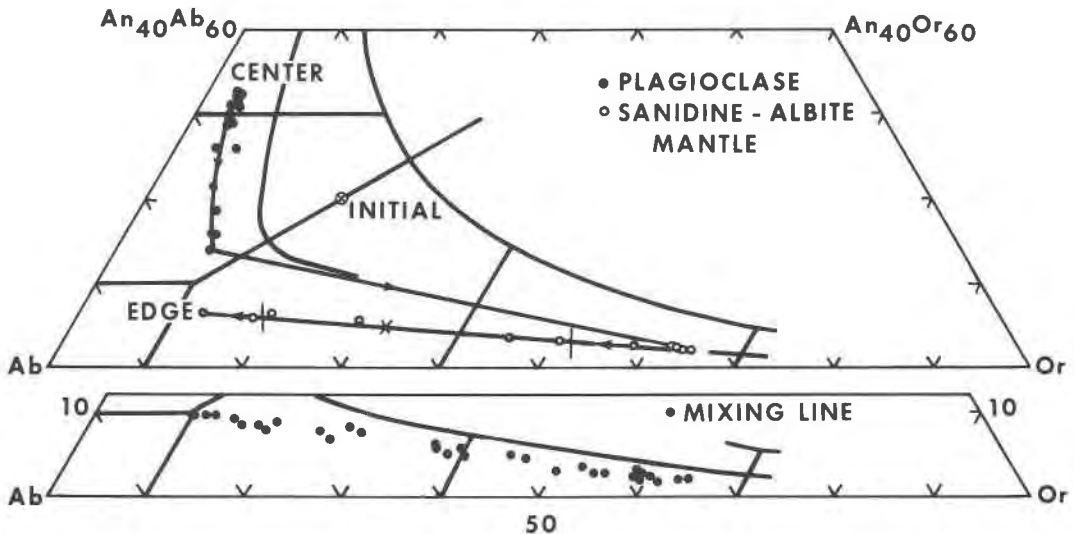


FIG. 9. Plot of microprobe analyses of a crystal from charge 265 grown from F-7.

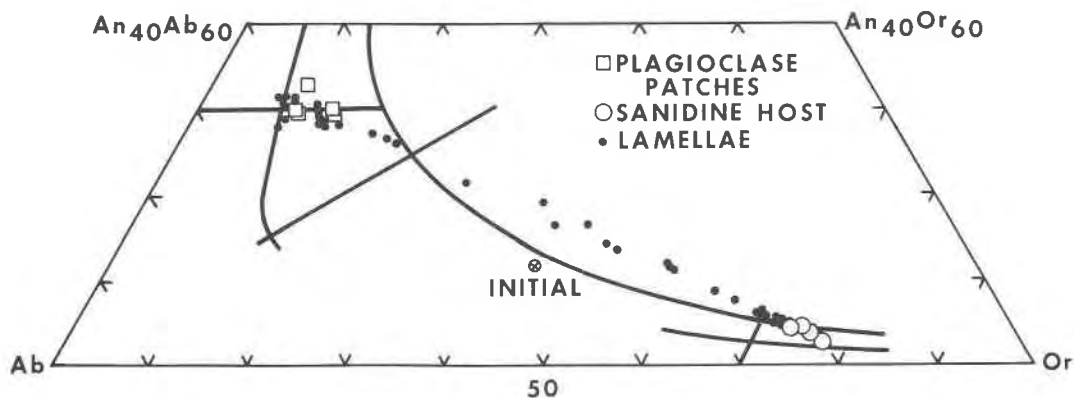


FIG. 10. Plot of microprobe analyses of the crystal in Fig. 6 grown from F-8.

away. The crystalline boundary is very sharp, however, so that once sanidine nucleates, it takes over instantaneously and completely. Sanidine growth must be metastable, because the bulk liquid is not within the two-feldspar stability field as defined by Yoder *et al.* (1957).

The presence of the boundary layer is instrumental in causing a breakdown of the planar interface of a growing crystal to an array of parallel projections for a variety of materials (Tiller, 1963; Keith and Pad-den, 1963; Lofgren and Weeks, 1969). The planar interface becomes unstable when the crystal growth rate is sufficiently rapid so that the constitutional supercooling gradient is steep within a narrow boundary layer. When the boundary layer is sufficiently narrow, random nucleation clusters on the crystal surface that might otherwise relax and dis-

appear will encounter a large gradient in supercooling and begin to grow rapidly. The diameter and spacing of the resulting projecting fibers will depend on the nucleation density and diffusive properties of the melt and so on the temperature and growth rate of the crystal. Thus for rapid growth rates the lamellae will be finer and more closely spaced than for slower growth rates; the lamellae will no longer be stable if growth slows sufficiently. This is consistent with the observation that the lamellae generally coarsen outwards in a crystal and often cease within the outer boundaries of the crystal. If the plagioclase lamellae form in this manner, then sanidine nucleation must occur within the three-dimensionally continuous melt enclosing these fibers and grow nearly simultaneously with them.

In many crystals, plagioclase lamellae are appar-

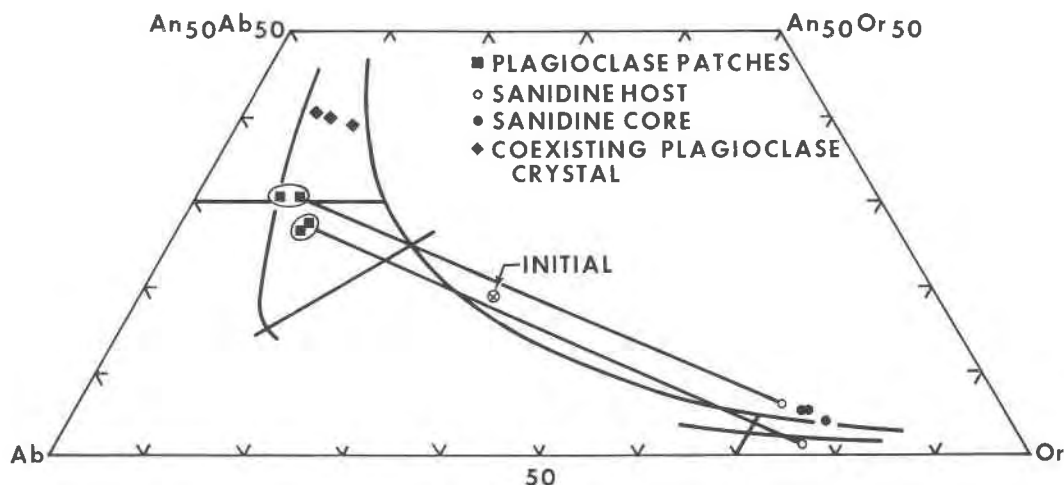


FIG. 11a. Microprobe analyses of crystals grown from F-9. Analyses of crystal shown in Fig. 5 (the tie lines connect analyses of plagioclase patches and the enclosing sanidine from each side of the crystal).

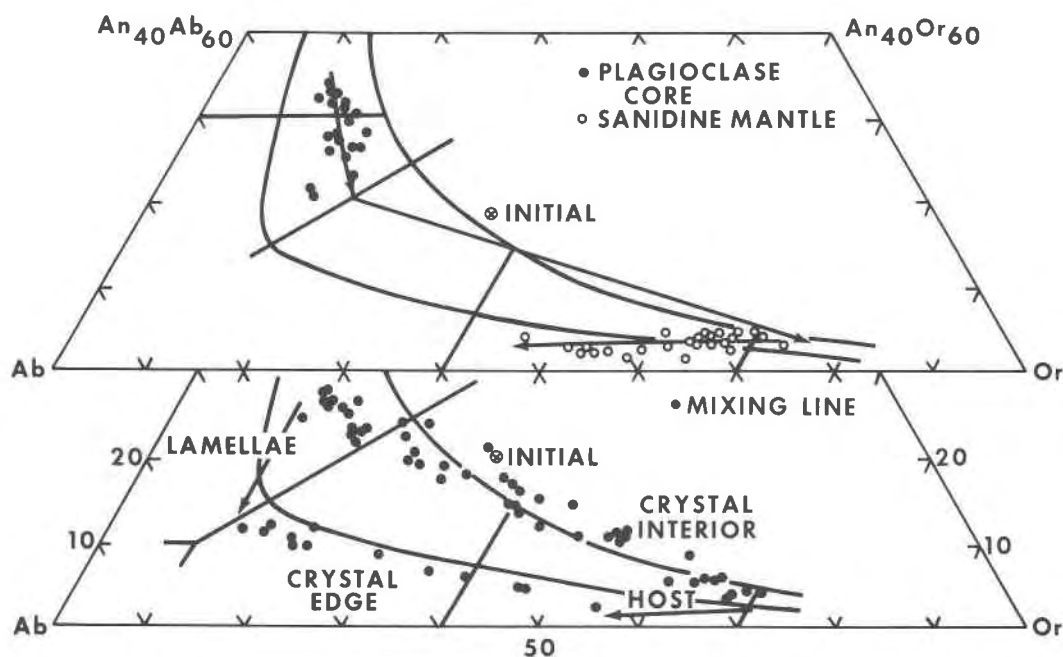


FIG. 11b. Microprobe analyses of crystals grown from F-9. Analyses of crystals shown in Figs. 1 and 2.

ently not continuous with or projecting from the plagioclase core. This may be only apparent, because the lack of crystalline continuity between the core and the lamellae might be an artifact of the particular plane of the thin section. Alternatively, the plagioclase core and lamellae may be continuous, but below the resolving power of the microscope. The lamellae coarsen away from the plagioclase core and become resolvable. If they are, indeed, not continuous, the mode of growth must be somewhat different. The lamellae must nucleate within a boundary layer enriched in plagioclase component that encloses the recently nucleated and growing sanidine, rather than on, and projecting from, a crystalline plagioclase host. The details of such a growth process are not well understood.

The patchy intergrowths may also represent nucleation of plagioclase at or near the interface of a growing sanidine but the nucleation sequence is less clear. Patchy as opposed to lamellar morphology probably represents local differences in the crystal growth conditions. The optical continuity of the patches suggests that they are connected in the third dimension by the thin stringers evident in Figure 7 such that they are a single crystal. The presence of both patchy and lamellar intergrowths in a single crystal indicates that the crystal growth conditions in these runs must be near the transition between the

two modes of growth. The association of these differing intergrowth morphologies with different growth sectors of a single crystal suggests that different crystal faces do encounter different kinetic growth problems.

Petrologic applications

The lamellar and patchy intergrowths grown directly from the melt can be distinguished from exsolution micro- and patch perthite by determining the compositions of the two feldspars. The feldspars grown from the melt will generally show higher degrees of solid solution than feldspars that exsolved to form perthite; the plagioclase will be more An- or Or-rich, and the sanidine will be much more Ab-rich. The intergrown feldspars may also show zoning that is incompatible with an exsolution origin. The shapes of the crystals can also be diagnostic. Skeletal plagioclase cores, for example, suggest that the original growth shape has not been subsequently modified, as it probably would be by exsolution.

Feldspar phenocrysts in volcanic rocks with plagioclase cores and sanidine rims similar to ones produced in this study have been reported by Tuttle and Bowen (1958), Carmichael (1965), Rahman and MacKenzie (1969), and Ridley (1971). The zoning in the plagioclase varies from strongly normal to non-existent, while the sanidine is unzoned or only weakly

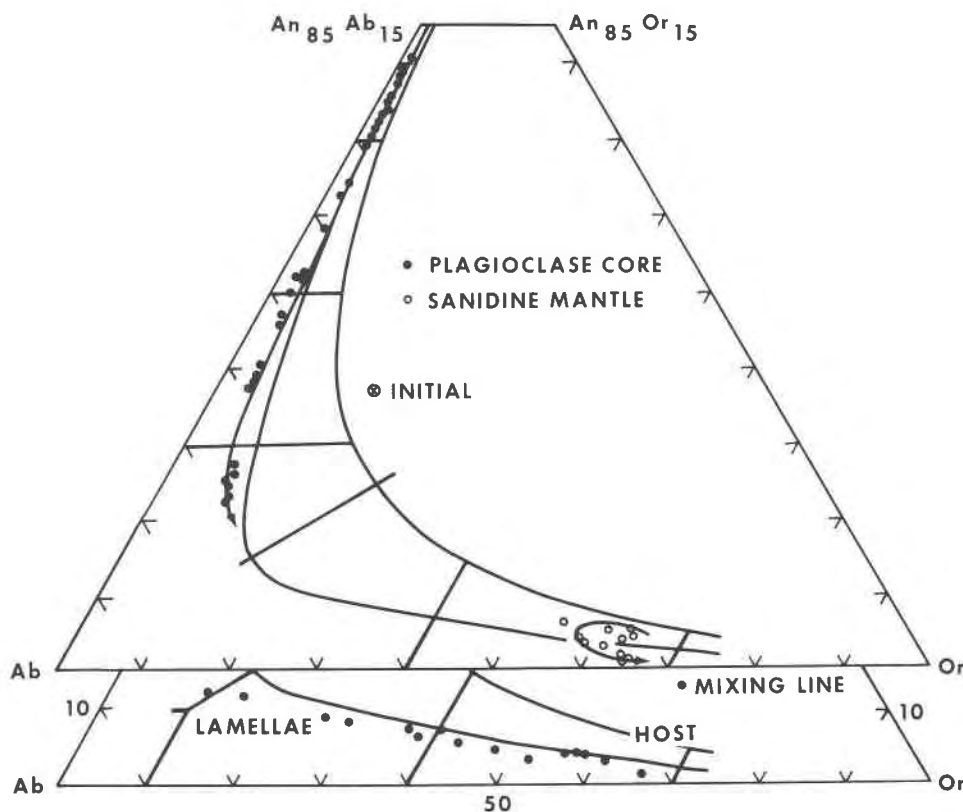


FIG. 12. Microprobe analyses of a crystals from charge 479, one of which is shown in Fig. 6 and grown from F-10.

normally zoned. Rahman and MacKenzie (1969) show a photomicrograph of a sanidine phenocryst with a patch of lamellar intergrowth that resembles the experimentally grown lamellar intergrowths shown in Figure 2. Microperthitic sanidine enclosing a plagioclase core has also been reported in dolerites and syenites by Buddington (1939) and Yagi (1953); these are likely candidates for melt growth.

Feldspars that crystallized within the upper portion of the melt sheet at Manicouagan Crater, Quebec, have fine lamellar intergrowths (R. Floran, personal communication). The composition of the lamellae have not been determined, but the intergrowth-free plagioclase is approximately $An_{20-25}Or_{5-10}$, and the sanidine is $Or_{60-75}An_{1-5}$. These compositions are similar to the experimentally grown crystals that contain lamellar intergrowths, and it is unlikely that exsolution has occurred.

These experiments cannot set lower limits on the cooling rates at which the intergrowths could develop. If they were produced in plutonic rocks, it is unlikely that they would be preserved throughout the subsolidus cooling history during which exsolution or

other solid-state reactions would tend to eliminate the original intergrowth (Smith, 1974a, p. 505). It is possible, however, that the texture of the original intergrowth may affect the nature of the exsolution texture and could be identified in that way.

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