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Mantled feldspars and synneusis

ROBERT J. STULL

Department of Geology, California State University
Los Angeles, California 90032

Abstract

Synneusis, the drifting together and systematic attachment of crystals in a melt, is involved in three of the known origins for mantled feldspars: (1) overgrowth, (2) exsolution, and (3) filling of skeletal plagioclase.

Quartz latite dikes of the Chocolate Mountains, California, contain plagioclase crystals in parallel and twinned synneusis. Sanidine mantles consisting of segments, each crystallographically parallel to the adjacent plagioclase crystal, enclose synneusis structures. One-feldspar biotite granite of the Golden Horn batholith, Washington, has mantled feldspars with complex, multiple albite mantles formed by synneusis of zoned alkali feldspars followed by subsolidus exsolution. Skeletal plagioclase formed by resorption is filled with orthoclase in two-feldspar biotite granite of the Golden Horn batholith. Synneusis, before and after resorption, produced mantled feldspars with systematic crystal orientations. Wiborgite granite of Finland has anhedral orthoclase enclosed in large numbers of plagioclase crystals. An origin by synneusis is suggested for this texture.

Introduction

Mantled feldspars consist of K-feldspar enclosed in plagioclase or the reverse relationship. They are common in epizonal and hypabyssal granites and volcanic rocks of latite to rhyolite composition. Four origins have been proposed for mantled feldspars in igneous rocks: overgrowth (Tuttle and Bowen, 1958), exsolution (Gates, 1953), replacement (McDowell, 1978), and resorption (Stull, 1978). Each origin implies a different magmatic history. Consequently, characterization and proper interpretation of mantled feldspars is important to understanding magmatic processes.

Interpretation of mantled feldspars is often complicated by synneusis, the drifting together of crystals and attachment on prominent faces. Vogt (1921) introduced the term synneusis, and Vance (1969) greatly elaborated on the process. Synneusis may occur before, during, or after formation of a mantled feldspar; as a result, the mantled feldspar may acquire complex forms whose origin is not obvious.

This paper will illustrate the role of synneusis in formation of mantled feldspars. A limited number of examples will be presented; these should enable the petrographer to expand on the possibilities when making a petrologic interpretation. McDowell's (1978) example of peripheral replacement of sanidine by oligoclase will not be treated separately because, with regard to synneusis, this process is similar to overgrowth.

Analytical techniques

Feldspar compositions were determined with the fully-automated Materials Analysis Company model 5-SA3 electron microprobe at California Institute of Technology. Microprobe techniques and computer programs have been described by Chodos *et al.* (1973).

Overgrowth and synneusis

Previous work

Overgrowth of plagioclase on alkali feldspar has been the most popular interpretation of mantled feldspars (Popoff, 1903; Savolahti, 1956; Tuttle and Bowen, 1958; Stewart, 1959). In spite of the volume of literature, detailed textural information supporting simple overgrowth of plagioclase on K-feldspar has not been published. In contrast, reverse mantled feldspars, with sanidine enclosing plagioclase, are common, provide good evidence of overgrowth, and illustrate the effects of synneusis. An example of reverse mantled feldspars will be described.

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Quartz latite dikes of the Chocolate Mountains, California

Hypabyssal quartz latite dikes of the Chocolate Mountains, first described by Ehlig and Ehlert (1972), are glomeroporphyritic with individual feldspar clusters ranging up to 15mm. Sanidine mantles enclose single crystals and synneusis groups of plagioclase. Sanidine is slightly perthitic adjacent to the sharp feldspar interface.

Plagioclase crystals within sanidine mantles are commonly subhedral and have normal or oscillatory zoning. Each plagioclase within a synneusis structure has its individual zoning pattern. Plagioclase crystals are most commonly joined in parallel or twinned synneusis. Plagioclase composition at the interface with sanidine is An_{17}. Minor resorption at this interface indicates that plagioclase crystallization ceased before overgrowth occurred.

Sanidine mantles (An:Ab:Or = 3:54:43) which enclose several plagioclase crystals are segmented; *b* and *c* axes of plagioclase and adjacent sanidine are parallel. Mantles range in thickness from 0.10 to 4.10mm. The outer surface of thinner mantles parallels every irregularity of the plagioclase–sanidine interface; this parallelism diminishes with thicker mantles.

Figure 1 illustrates an example of this texture. Four plagioclase crystals (A, B, C, and D) form a synneusis structure enclosed in a segmented sanidine mantle. All crystals are cut approximately parallel to (010). Crystals B and C are attached in Carlsbad twin relationship; (001) cleavages form the exact angle of 53° which Turner (1951) found to be characteristic of Carlsbad twins in this orientation. Crystals A and D are attached in parallel synneusis to crystals B and C respectively. The entire synneusis structure is enclosed in a sanidine mantle whose individual segments are crystallographically parallel to adjacent plagioclase.

Some glomeroporphyritic clusters in dikes of the Chocolate Mountains have only partial mantles. These result from breaking of mantled synneusis structures. Vance (1969) suggested that boundaries between crystals in synneusis are weaker than crystallographic planes within single minerals. Disaggregation could result from mechanical forces or preferential resorption along synneusis boundaries.

Exsolution and synneusis

Previous work

Gates (1953), after investigating the Waupaca intrusions of Wisconsin, first proposed exsolution as an origin for mantled feldspars. The Waupaca rocks have clusters and single crystals of perthite mantled by plagioclase that is crystallographically parallel to adjacent albite exsolution lamellae.

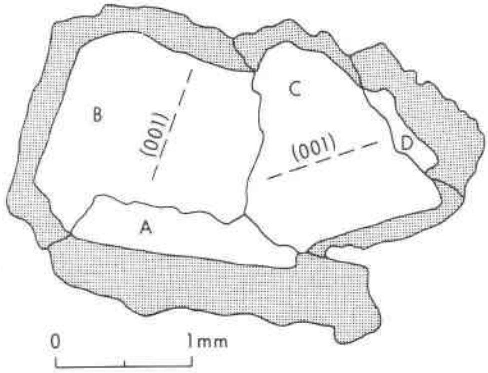

Fig. 1. Quartz latite dike, Chocolate Mountains, California. Plagioclase crystals A, B, C, and D are attached in parallel and twinned synneusis. Segmented sanidine mantle encloses synneusis structure. Section cut parallel to (010) of all grains.

Golden Horn batholith, Washington

One-feldspar biotite granite of the Golden Horn batholith has mesoperthite mantled by albite which may be enclosed in an outer mesoperthite zone. The albite mantle is anhedral or rarely subhedral and may have albite twinning. Albite mantle and adjacent string or patch-type exsolutions are optically parallel. Exsolution lamellae and albite mantle are compositionally identical and fall within the limited range of An_4 to An_6.

Mantled feldspars with two or more partial or complete albite zones are attributed to synneusis and exsolution. Figure 2 illustrates a possible origin for this texture. Early-formed alkali feldspar crystals floating in the magma join in synneusis. A more sodic zone, destined to be an albite mantle, encloses the synneusis structure. Alkali-feldspar crystallization continues, and magma solidification eventually occurs. During exsolution, albite is concentrated in the more sodic zones of the alkali feldspar. Complex albite mantles within mesoperthite result.

Intersection of open albite mantles (Fig. 2) indicates that synneusis occurred early in magmatic history. Synneusis at later magmatic stages resulted in two or more separate, complete albite mantles within mesoperthite synneusis structures.

The morphology of open, intersecting albite mantles is identical to the outer portions of zoned plagioclase synneusis structures described by Vance (1969). This suggests that the original alkali feldspar was

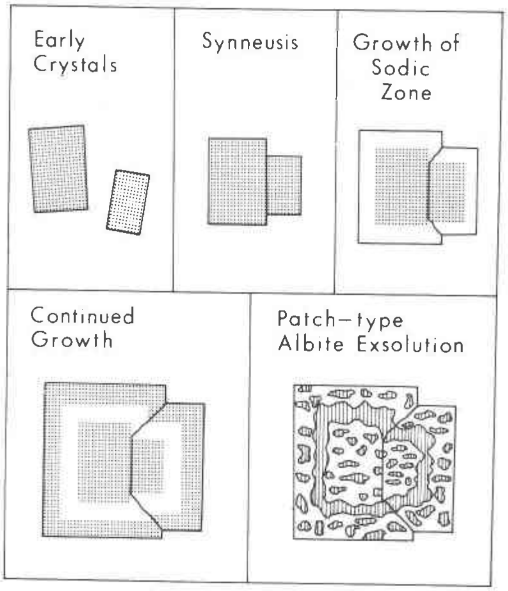

Fig. 2. Model for the origin of mantled feldspars in one-feldspar biotite granite of the Golden Horn batholith, Washington. Synneusis structure with compositionally-zoned overgrowth experiences subsolidus exsolution and development of albite mantle.

zoned and that sodic zones were selectively enriched in albite during subsolidus exsolution.

Resorption and synneusis

Previous work

Formation of skeletal plagioclase crystals by preferential resorption of calcic cores of zoned plagioclase during magmatic ascent of water-under-saturated magma is supported by textural observations (Vance, 1965; Wiebe, 1968) and experimental studies (Lindsley, 1966). Vance (1965) concluded that patchy zoning in plagioclase results from filling of partially resorbed, skeletal crystals with a more sodic plagioclase. Stull (1978) found that mantled feldspars in the Golden Horn batholith, Washington, resulted from crystallization of orthoclase plus trace amounts of quartz, biotite, and magnetite from residual melt within skeletal plagioclase.

Golden Horn batholith, Washington

Two-feldspar biotite granite of the Golden Horn batholith has mantled feldspars, ranging up to 10mm in overall diameter, which formed after partial resorption of plagioclase and filling of skeletal crystals with orthoclase (Stull, 1978). Synneusis of plagioclase, both before and after resorption, has locally complicated the mantled feldspar texture.

Plagioclase synneusis before resorption is common in two-feldspar biotite granite. Figure 3 illustrates interaction of synneusis and development of mantled feldspars. Early-formed plagioclase is euhedral and compositionally zoned. Parallel or twinned synneusis occurs and growth continues while the magma is deep in the crust. Magmatic ascent of water-under-saturated granite melt follows and causes preferential resorption of calcic cores; resorption channels and an irregular space filled with melt appear within skeletal plagioclase. Plagioclase in granitic magmas commonly ceases crystallization at shallow crustal levels (Yoder *et al.,* 1957). Only alkali feldspar, quartz, biotite, and magnetite precipitate from residual magma. These minerals fill the skeletal plagioclase, and a mantled feldspar with poikilitic inclusions of magnetite, biotite, and quartz results.

Involvement of synneusis with mantled feldspars after resorption is rare in the Golden Horn granite, due to rapid crystallization and progressive solidification of magma. Figure 4 shows a broken mantled feldspar structure consisting of a large skeletal plagioclase (crystal A) partially enclosing anhedral orthoclase; plagioclase and orthoclase have parallel *b* and *c* axes. Smaller plagioclase crystals with individual morphological features have joined in parallel and twinned synneusis with both the plagioclase mantle and enclosed orthoclase. Crystals A, B, and C are in parallel synneusis. Crystal D is a Baveno twin

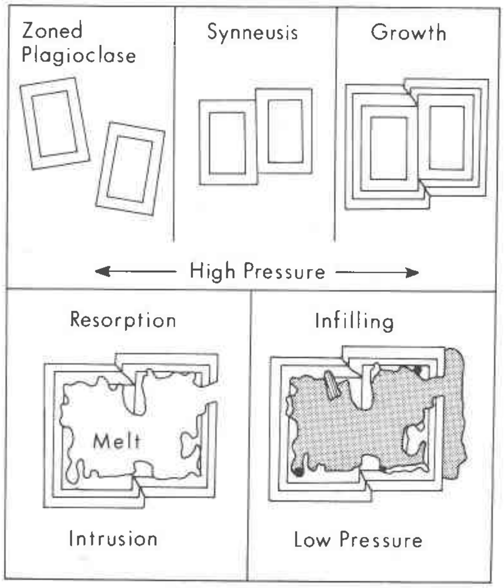

Fig. 3. Model for the origin of mantled feldspars in two-feldspar biotite granite of the Golden Horn batholith, Washington. See text for explanation.

of the Banat type with respect to crystals A and C. This type of Baveno twin is characterized by an irregular composition surface, prominent reentrant angles, (010) on (001), and parallel *a* axes. Crystal E is close to the Baveno twin relationship.

Mantled feldspar formed by synneusis

The foregoing examples of synneusis all involve attachment of identical minerals. If K-feldspar and plagioclase combine in synneusis, the possibility exists of mantled feldspars forming by synneusis alone. Vance and Gilreath's (1967) study of the probability of synneusis between unlike minerals revealed a tendency of like minerals to form synneusis and a general antipathy of unlike minerals to each other. In contrast to most unlike mineral pairs, Vance and Gilreath found that synneusis between plagioclase and K-feldspar is common. This suggests that mantled feldspars may result from synneusis.

Mantles consisting of several plagioclase crystals enclosing a single orthoclase were first reported by Holmquist (1901). Additional examples have been reported by Wahl (1925) and Terzaghi (1940). Smithson (1963) described oriented plagioclase inclusions forming partial mantles within a microcline megacryst of a porphyritic granite.

Wahl (1925), in his report on the Precambrian wiborgite granite of Finland, described ovoid orthoclase phenocrysts mantled by up to 60 crystals of plagioclase. Petrographic observation of examples found in wiborgite granite and review of Wahl's

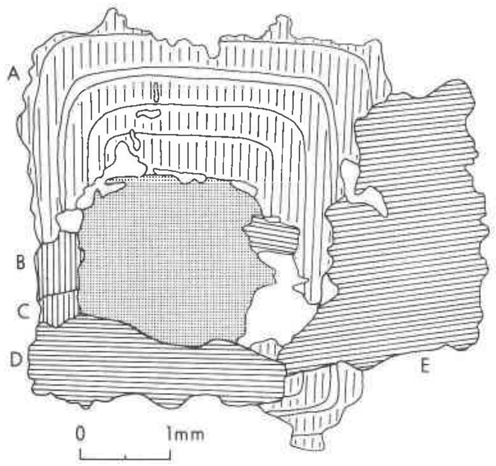

Fig. 4. Two-feldspar biotite granite, Golden Horn batholith, Washington. Complex mantled feldspar with all plagioclase crystals cut close to *a*-normal orientation. Plagioclase crystals A, B, and C are in parallel synneusis. Crystal D is a Baveno twin of the Banat type with respect to crystals A and C. Quartz occurs locally at the orthoclase–plagioclase interface.

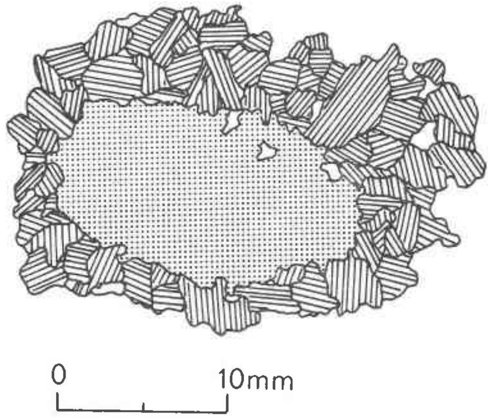

Fig. 5. Wiborgite granite, Finland. Plagioclase mantle displaying complex twinned and parallel synneusis encloses anhedral orthoclase. Modified from Wahl (1925).

(1925) report suggests that synneusis has played a major part in producing this texture. Figure 5, modified from Wahl (1925), shows orthoclase with an anhedral, interlocking contact against a plagioclase mantle. The anhedral form of orthoclase has been attributed to resorption (Wahl, 1925) and irregular crystal growth (Sederholm, 1928). The mantle consists of diversely-oriented crystals joined in complex twinned and parallel synneusis. Tight nesting of plagioclase crystals could result from synneusis alone or additional crystal growth. The interlocking contact between orthoclase and mantle suggests continued orthoclase growth until all available space was filled. In wiborgite granite, quartz occurs as large separate crystals and small anhedral inclusions in orthoclase and its mantle.

Conclusions

Problems presented by mantled feldspars have been debated for nearly a century. Recognition of synneusis should facilitate interpretation of the origin of mantled feldspars.

Sanidine mantles on plagioclase synneusis structures in quartz latite dikes of the Chocolate Mountains have features characteristic of overgrowth. The two most distinctive features are: (1) parallelism of the outer surface of the mantle with the plagioclase–sanidine interface; and (2) presence of a segmented mantle with individual sanidine segments being crystallographically parallel to the adjacent plagioclase crystal.

Interaction of synneusis with mantled feldspars formed by exsolution has produced open, intersecting albite mantles in the Golden Horn batholith. This distinctive morphology suggests early synneusis of alkali feldspar crystals followed by compositionally-zoned overgrowth. Albite was selectively concentrated in sodic zones during subsolidus exsolution.

Formation of mantled feldspars by filling of skeletal plagioclase with orthoclase plus minor amounts of quartz, biotite, and magnetite may be common in epizonal plutons of granite composition. Synneusis may complicate the texture and render interpretation more difficult. In the Golden Horn batholith, early-formed plagioclase crystals joined in synneusis and continued growth until magmatic ascent caused resorption to produce skeletal crystals. Orthoclase and quartz filled skeletal plagioclase crystals during shallow-level crystallization. Synneusis produced relatively larger mantled feldspars with exterior forms typical of plagioclase synneusis structures.

Synneusis of plagioclase and K-feldspar is common and may be an origin for some mantled feldspars. Although other examples have been described in the literature, the most notable example is in the Precambriam wiborgite granite of Finland (Wahl, 1925). Some orthoclase phenocrysts in wiborgite granite are mantled by up to 60 plagioclase crystals in complex synneusis.

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