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CONVOLUTE ZONING OF PLAGIOCLASE PHENOCRYSTS IN MIOCENE VOLCANICS FROM THE WESTERN SANTA MONICA MOUNTAINS, CALIFORNIA

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ABSTRACT

Plagioclase phenocrysts from a series of andesitic basalt flows, pyroclastics, and epiclastics in the Western Santa Monica Mountains of Los Angeles County, California, characteristically exhibit an unusual textural feature referred to here as "convolute zoning." Phenocrysts exhibiting this texture are embayed, the compositional zoning being thinner and "deflected" inward following the contours of the embayments. A possible explanation of this feature is that the embayments represent response by growing crystals to semiporous obstructions encountered during crystallization. This suggests that similar resorption textures reported for unzoned crystals, which may not have left a clear record of events, may not in all cases represent magmatic corrosion.

INTRODUCTION

An interesting textural feature, here referred to as "convolute zoning," has been observed in some plagioclase phenocrysts from the Miocene Conejo Volcanics of the Western Santa Monica Mountains, Los Angeles County, California (see index map, Fig. 1). A detailed study of the Conejo Volcanics in the Malibu Lake area (Blackerby, 1965) has shown that they consist of olivine basalt, basalt, andesite, and dacite flows, flow

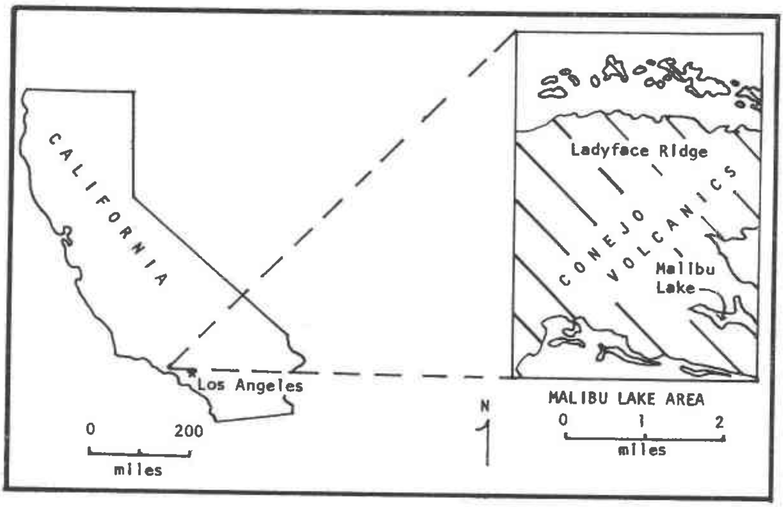

FIG. 1. Index map showing general distribution of the Conejo Volcanics in the Malibu Lake Area and the location of Ladyface Ridge.

breccias, pyroclastics, volcanic-derived epiclastics and associated intrusive-rocks of related compositions. The apparent thickness of the volcanic section here is between 11,550 and 13,750 feet. Chemical analyses indicate that the silica content of the rocks varies between 45.31 percent and 66.12 percent.

Although slight convolute zoning is found in plagioclase crystals of many of the rock units in this area, it is best developed in phenocrysts from a sequence of interbedded flows, agglomerates, and volcanic sandstones of a prophyritic andesitic basalt. This sequence is exposed on Ladyface Ridge in the Malibu Lake area and has a maximum thickness of 1,120 feet. A brief petrographic description of the rock is given in Table 1.

TABLE 1. PETROGRAPHY OF THE PORPHYRITIC ANDESITIC BASALT

Porphyritic Andesitic Basalt from Ladyface Ridge	
Porphyritic, with hyaloophitic to hyalopilitic groundmass	
Phenocrysts (average 3.2 mm in length, reach lengths of 9 mm)	
Labradorite-andesine	25.1–27.0%
(An_{54-44}, avg. An_{52})	
Characteristic convolute zoning	
Bronzite	13.3–10.6
(En_{71-79})	
Augite (or Ferroaugite ?)	4.4– 1.4
Groundmass	57.1–61.0
Pale brown glass, containing microlites of feldspar, some pyroxene	

DESCRIPTION

Phenocrysts exhibiting convolute zoning are all in the volcanic (high) structural state. Most of the compositional zoning is oscillatory, but some is normal or reverse. The individual zones vary in thickness from 0.007 mm. to 0.12 mm., averaging about 0.02 mm. They are generally very distinct between crossed nicols, but with little compositional difference, as a rule, from one zone to the next.

Convolutions are shown where the phenocrysts have apparently been embayed magmatically. The compositional zones are then deflected inward conforming to a greater or lesser degree to the contour of the embayments. Usually the conformity can be observed for several zones away from the embayments (Pl. 1).

Inclusions in the phenocrysts are uncommon and consist of glassy groundmass material, in some cases accompanied by small subhedral crystals of clinopyroxene. It is possible that some of these inclusions represent embayments not shown in length because of the orientation of the thin section. Except where embayed, or slightly rounded by magmatic corrosion, the phenocrysts present sharp outer boundaries that are usually flat well-developed crystal faces.

The glass included in the embayments is optically very similar to the groundmass glass surrounding the phenocrysts, though the embayment glass may contain fewer microlites or be a lighter color (a very pale brown). The embayments are usually bulbous or tear-drop shaped. They do not appear to widen or follow selectively along any particular zone in a given crystal.

Discussion

Many other workers have observed inclusions of glass in plagioclase crystals of volcanic rocks. One explanation of these inclusions (*e.g.*, Rittman, 1962, or McCulloh, 1952) is that crystallization of the plagioclase occurred so rapidly that globules of glass were locally entrapped and retained. Others, (*e.g.*, Vance, 1965) regard similar inclusions as glass entrapped in corrosional embayments. Most of these descriptions do not suggest that the inclusions are connected with the groundmass of the rock; they are usually pictured as being entirely enclosed by the feldspar. No deflection of compositional zones in the plagioclase has been previously reported. The convolute-zoned crystals of the present study differ in this respect.

A structure similar to the present one was noted, however, in quartz phenocrysts studied by G. Laemmlein (1930). Using thick sections, Laemmlein was able to see truncation of growth zones in the quartz against glass-filled embayments; at places slight inward inflection of these zones was recorded. He suggested that growth had been initiated along an irregular crystal surface from many locuses ("mehrköpfigen Wachstum"), the irregular surface having been caused by an earlier period of magmatic corrosion or by mechanical separation of intergrown crystals. If the material added onto the crystal did not fill in the surface irregularities, glass-filled indentations, embayments or canals were preserved. Laemmlein's explanation thus interprets the embayments and canals now observed in these crystals as the result of growth, not corrosion.

An alternate explanation can be offered, based on the zoned plagioclase phenocrysts from the Malibu Lake area, which also interprets embayments as the result of growth. Under special circumstances during crystallization a crystal might have encountered a globule of glass which was not passively entrapped but acted as a semi-porous barrier, affecting crystal-

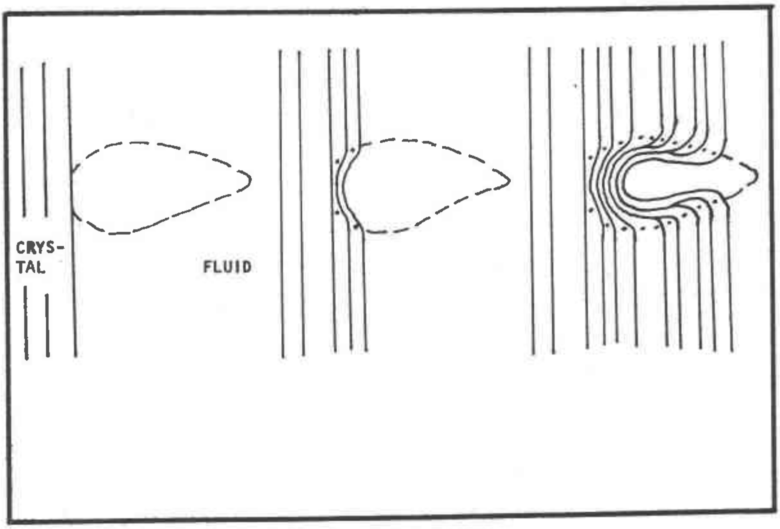

FIG. 2. Possible development of convolute zoning by enclosure of viscous globule. See text for explanation.

lization in its immediate vicinity. Something like the sequence described below is visualized (see also Fig. 2).

The phenocryst during crystallization encountered a small inhomogeneity in the groundmass liquid, perhaps a globule of glass more viscous than the surrounding magma. This globule retarded the movement of material toward the crystal surface but did not prevent movement entirely nor prevent formation of new zones. The phenocryst continued to grow by addition of new zones but at the globule each new zone tended to follow the boundary between globule and crystal where movement of material was easiest. Material was added more slowly behind the globule than where the crystal was in contact with the less viscous groundmass and consequently the zones are thinner there. If the globule was too viscous to allow migration of material zones could not form completely around the obstruction and now appear truncated or only slightly deflected by the embayment. The process continued until crystallization ceased or the globule was replaced or surrounded by crystalline material.

Small crystals—of pyroxene for example—adhering to the main crystal might also initiate embayments. A crystal would be a more effective barrier to material moving toward the growing crystal surface and would allow only slight deflection or else truncation of zones (see Fig. 4a or 4b).

Figure 2 shows that the crystal surface that first encountered the

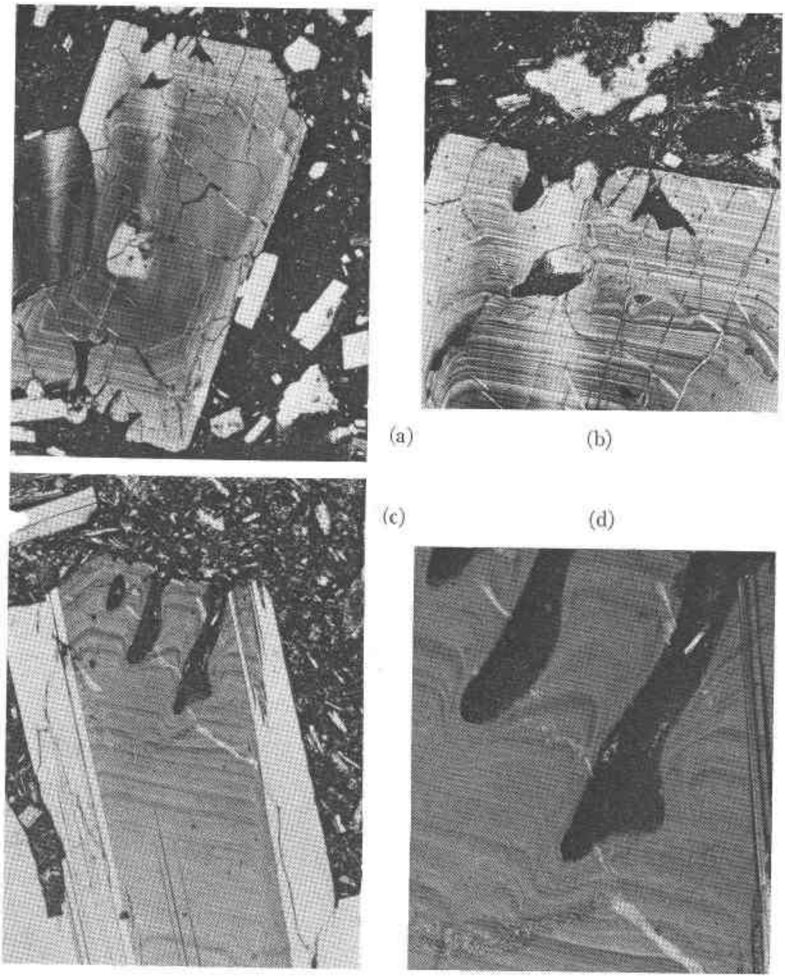

FIG. 3. (a) Porphyritic andesitic basalt; euhedral plagioclase phenocryst showing fine oscillatory zoning, embayment with convolute zones. 18×. (b) Same sample as (a) above. Detail of embayment, convolute zones. 45×. (c) Porphyritic andesitic basalt; euhedral plagioclase phenocryst showing fine oscillatory zoning, embayment with convolute zones. Note truncation of later zones against earlier ones. 45×. (d) Same sample as (c) above. Detail of embayment, reverse-truncated zones. 110×.

globule would not show deflection while all successive zones would show either deflection or truncation. This downward limit to deflection is shown especially well in Figs. 3b and 4d.

The present explanation (of semiporous globules) differs from Laemmlein's mainly in two respects: (1) an irregular crystal surface is not re-

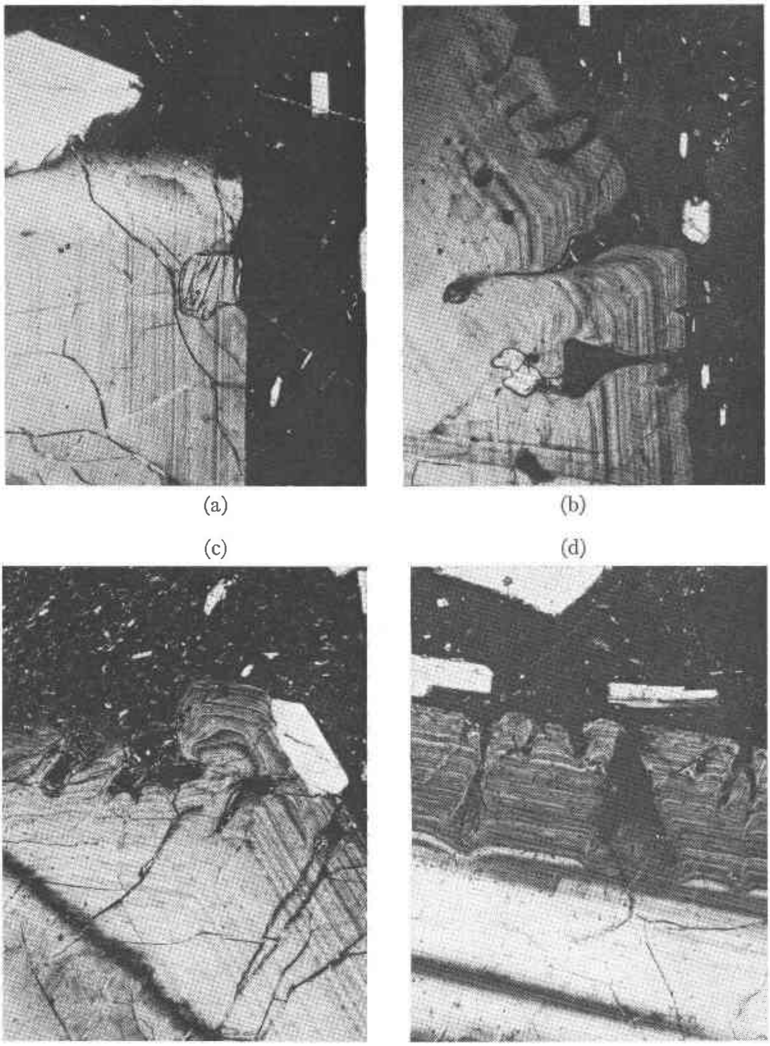

FIG. 4. (a) Porphyritic andesitic basalt; clinopyroxene inclusions in plagioclase phenocryst. Oscillatory zones terminate on meeting inclusion; only very slight inward deflection at one corner of clinopyroxene. 45×. (b) Porphyritic andesite basalt; embayed outer margin of euhedral plagioclase phenocryst. Two larger inclusions (?) are of clinopyroxene, smaller ones of glass. Inward deflection of zones near the embayment; slight interruption of zones behind inclusions. 45×. (c) Porphyritic andesitic basalt; embayment in euhedral plagioclase phenocryst, with convolute zoning. 45×. (d) Same sample as (c) above, on a different crystal. 45×.

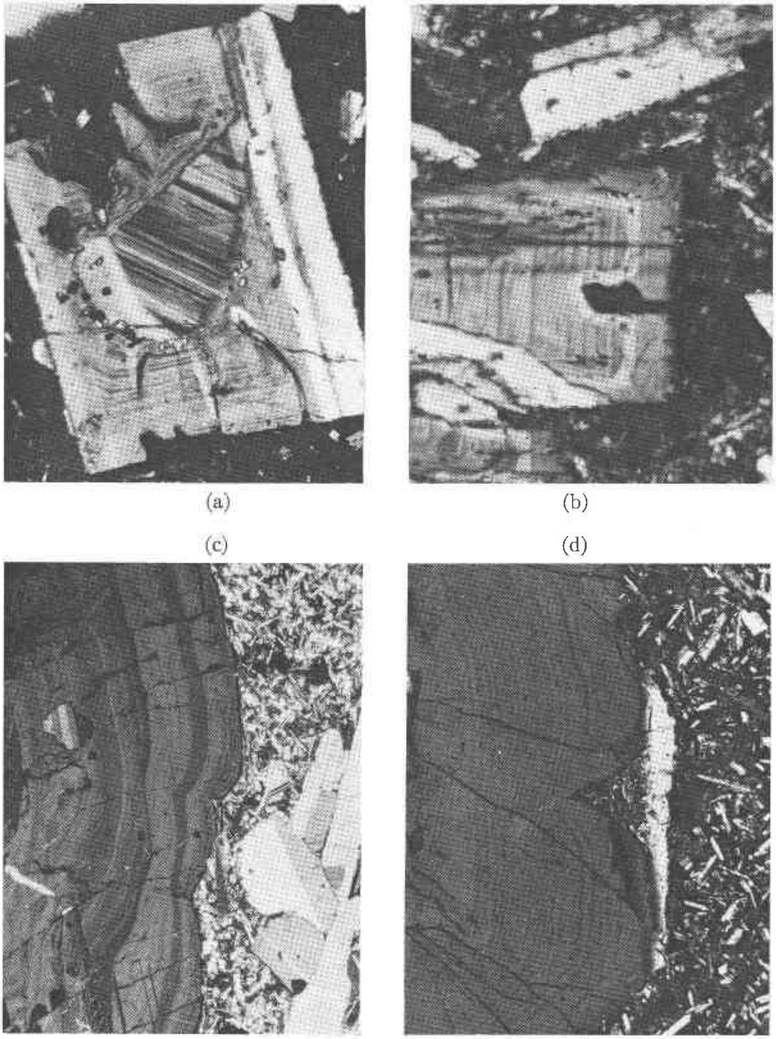

FIG. 5. (a) Porphyritic andesitic basalt; embayed euhedral plagioclase phenocryst. Earlier oscillatory zoned plagioclase crystal was largely resorbed then served as nucleus for renewed crystallization and embayment with production of convolute zoning. 67×. (b) Microporphyritic basalt; embayment of early-formed plagioclase microphenocryst with some deflection, some truncation of earlier zones. Later overgrowth follows contour of embayment. Zones of outermost margin terminate against groundmass glass now filling embayment. 235.2×. (c) Porphyritic basalt flow; subhedral plagioclase phenocryst exhibiting undulations in the oscillatory zones. 27.2×. (d) Porphyritic andesite basalt; undulations in oscillatory zones in plagioclase phenocryst and inward deflection of zones near groundmass embayment. 67×.

quired to begin the process, (2) with crystallization the globules are partially replaced by zoned crystalline material—giving rise to the deep convolutions or deflections.

A third explanation which might be suggested is that the embayments occurred after crystallization of the phenocrysts. But while a corroding tongue of magma entering a crystal might have caused migration of some material within the crystal for a short distance adjacent to the embayment, such a migration should have removed all traces of compositional zones in the vicinity of the embayment rather than perpetuating them, since only one composition would be in equilibrium with the magma at a given time. The infolded, usually oscillatory zones observed in these crystals are not only distinct, they are clearly connected to and related in origin to zones which are not folded farther away from the embayments. Production of these embayments by magmatic corrosion is thus unacceptable.

Conclusion

The convolutions appear to have been produced during crystallization because of inhomogeneities in the surrounding magma. If so, the embayments do not represent magmatic corrosion. This may well cast a doubt on interpretations of magmatic corrosion reported in many other rocks whose embayed crystals are unzoned and may not have left a clear record of events.

Since embayments apparently can be formed either during crystallization or after a period of crystallization by magmatic corrosion, the term "embayment" should be used only in a descriptive sense. Should a genetic connotation be desired and justified, terms such as "inclusion embayment" or "corrosion embayment" could be adopted.

Acknowledgements

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