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CAVITY MINERALS AT SUMMIT ROCK, OREGON

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ABSTRACT

Gas cavities in the interior of an andesite plug dome contain a suite of fifteen minerals. Zoned plagioclase, zoned orthopyroxene, and augite are the most abundant minerals; ilmenite, apatite, tridymite, and magnetite are common; acmite, cristobalite, hematite, hyalite, rutile, hornblende, pseudobrookite, and quartz are minor to rare. The minerals probably crystallized from a late, interstitial, residual magma which oozed into gas-formed cavities. An increase in the volatile phase, perhaps because of the crystallization of anhydrous minerals, controlled the final stages of crystallization in the cavities.

INTRODUCTION

Summit Rock is a small andesitic plug dome in the High Cascade Range near Diamond Lake, Oregon. The upper 30 m of the interior of the plug were exposed in 1961 when it was quarried for crushed rock. This paper discusses the probable origin and occurrence of the minerals lining the cavities in the interior of the plug. The locality is particularly noteworthy because of the excellent development of the crystals.

Similar cavity mineral occurrences in this area are described by Dutton (1937), Williams (1933, p. 211), Williams (1942, p. 131–132), and Diller and Patton (1902, p. 146–148). Fries and others (1942, p. 317–318) list several additional localities having similar mineral assemblages.

EXPERIMENTAL

Optical properties of the cavity minerals were determined on crushed single crystals in index oils and on oriented fragments. The index oils were calibrated with a refractometer prior to use. Compositions of the minerals were determined by using curves from Deer and others (1966). The composition of the augite from the cavities and of the minerals in the rock was determined with a four-axis universal stage. Composition of the cavity plagioclase was determined by measuring extinction angles to {001} on sections of single crystals cut parallel to {010} and by measuring extinction angles on {001} and {010} cleavage fragments. Refractive indices above 1.707 were not determined. Powder method X-ray patterns were made for seven minerals; these patterns are on file at the Department of Geology, University of Oregon, Eugene, Oregon. Mineral percentages in thin section were determined by point counting, and mineral percentages in the cavities were estimated by point counting using a stereomicroscope.

GEOLOGY OF SUMMIT ROCK

Summit Rock is a plug dome about 200 m in diameter and about 60 m high. Williams (1933, p. 206, 211) briefly described Summit Rock and discussed the geology of the general area. The plug is mantled with red scoria and grades into light-gray andesite in the interior.

The scoriaceous zone may be as much as 40 m thick and is composed of fine-grained plagioclase, oxidized pyroxene, altered olivine, and hematite. The texture is microporphyritic and intergranular. Microphenocrysts of plagioclase and olivine are surrounded by smaller crystals of plagioclase and tiny granules of pyroxene. Little or no glass appears to be present.

The scoria grades into an intermediate zone which ranges between 3 and 30 m thick. This rock is dense, fine-grained, purplish-gray, microporphyritic, intergranular, and contains about 10 percent microphenocrysts of plagioclase and olivine. The rock contains 69 percent labradorite, 27 percent pyroxene (ortho:clino$\sim$1:4), 3.3 percent metal oxides, and 0.6 percent olivine.

The interior part of the plug is light-gray andesite containing about 15 percent microphenocrysts. It contains 72 percent normally zoned plagioclase (estimated average An_{65}, microphenocrysts commonly zoned from An_{75} to An_{55}), 24 percent pigeonite (approximately $Wo_{14}En_{58}Fs_{28}$), 2.1 percent magnetite, and 1.8 percent olivine (Fo_{70}). The texture is subophitic. The microphenocrysts of feldspar commonly range between 0.5 and 1.5 mm in length. The feldspar in the groundmass averages about 0.1 mm in length, and the grains of pyroxene are a little smaller. Scattered through the rock are slightly altered grains of olivine averaging about 0.5 mm in diameter. The andesite contains approximately 55 percent silica (silica bead method and curves of Kittleman, 1963).

The plug dome form of Summit Rock indicates that the magma was highly viscous at the time of extrusion, and the presence of phenocrysts in the quickly-chilled scoriaceous zone shows that the magma was partly crystallized before extrusion.

Two types of cavities occur in the interior of the plug. The cavities in the upper part are spherical gas cavities, and in places the rock contains as much as 30 percent of these vesicles by volume. The cavities in the lower part of the plug are irregularly lenticular and have two dimensions which are typically 10 to 100 times the third (Fig. 1). Apparently these cavities formed after the magma had substantially crystallized so that the exsolution of gas caused tearing of the semisolid material. The lenticular cavities normally range up to 5 mm in width and 0.5 m in length. Characteristically the rock from the lower interior includes about 10 percent lenticular cavity space by volume.

The Cavity Minerals

Drusy minerals line the cavities in the interior of the plug (Fig. 2). Fifteen cavity minerals that have been identified are described in Table 1. Plagioclase, orthopyroxene, and augite constitute 95 percent of the

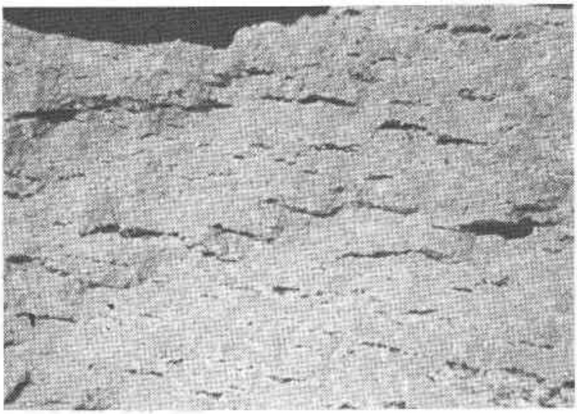

FIG. 1. Lenticular cavities with drusy minerals from the lower interior of the plug at Summit Rock. 1.5×.

cavity minerals. Ilmenite, apatite, tridymite, and magnetite are common but not abundant. The other minerals are minor to rare. Normally the cavity minerals form uniform linings between 1 and 2 mm thick, but locally this lining may be up to 5 mm thick. The composition of and the ratio between cavity minerals are relatively uniform throughout the presently exposed interior of the plug. Cavity minerals compose approximately 6 percent of the andesite. The minerals commonly occur as clean, well-formed crystals.

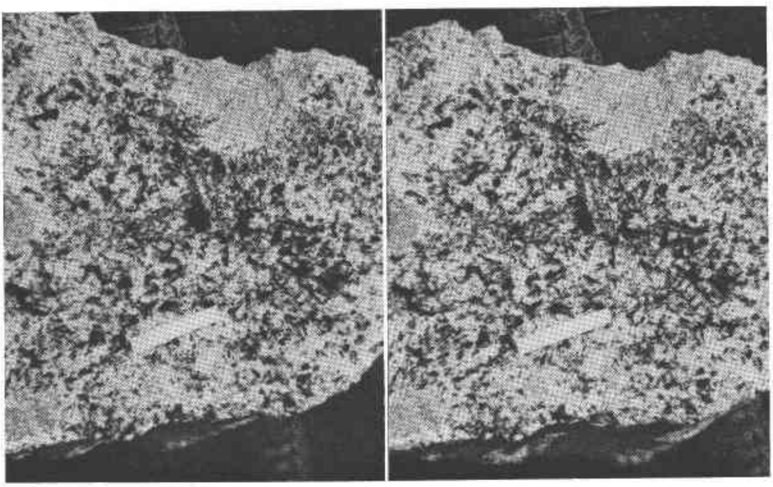

FIG. 2. Stereopair of a mineral lined cavity. Dark, bladed crystals are orthopyroxene; small, black, tabular crystals are ilmenite; the background of white crystals is composed of plagioclase. The white bar is 1 cm long.

TABLE 1. CAVITY MINERALS AT SUMMIT ROCK

Mineral, Percent, Composition	Habit, Selected Properties, Dimensions
Plagioclase, 70 range An_{80} to An_0	Tabular to equidimensional crystals; tabular crystals are flattened on {010} and commonly are carlsbad twins; colorless; normally zoned; rare crystals may be zoned from An_{80} to An_0 (see Fig. 3); larger crystals are commonly zoned from An_{40} to An_{10}; some late clear, equidimensional crystals of low albite are present; maximum size ~3 mm, average ~1.5 mm.
Orthopyroxene, 20 range Fs_{27} to Fs_{45}	Bladed, commonly flattened on {010}, rarely on {100}; alters brick-red, dull-black, or to acmite; larger crystals commonly cavernous parallel to c; light to medium-brown; transparent; many crystals zoned with edge more Fe rich; on c maximum ~4 mm, average ~1.5 mm; X-ray pattern available.
Augite, 5 approx. $Wo_{30}En_{50}Fs_{20}$	Subhedral, locally euhedral; transparent green; $2V$ measured on one crystal$=37°$; maximum on c ~0.5 mm.
Ilmenite, 2	Thin tabular on {0001}; splendent; faces are commonly cavernous; locally as oriented growths on magnetite with {0001} parallel to {111}; on a maximum ~2 mm, average ~1 mm; X-ray pattern available.
Apatite, 1 primarily fluorapatite	Acicular, cavernous; colorless; rarely columnar, light-pink and containing 50–70 percent chloro and/or hydroxyapatite; on c maximum ~3 mm, average ~1.5 mm.
Tridymite, 1	Thin, tabular, six-sided plates; twinned wedge-shaped crystals; radiating groups of platey crystals; colorless; X-ray pattern is the S type of Hill and Roy (1958); maximum size ~0.5 mm.
Magnetite, 1	Corroded and rounded octahedrons; rarely as sharp octahedrons; locally has oriented growth of ilmenite; on a average ~0.5 mm.
Acmite, <1 approx. 0.7 Fe^{3+} ions per formula unit	Bluntly terminated acicular crystals; rarely bladed and flattened on {100}; locally on remnants of orthopyroxene with c parallel to c; rarely as acicular crystals on ilmenite with c of acmite parallel to c and to a of ilmenite; transparent-yellow; on c maximum ~5 mm, average ~0.5 mm; X-ray pattern available.
Cristobalite, <1	Commonly spherical aggregates; colorless; X-ray pattern indicates both high and low forms present; maximum aggregate size ~1 mm.
Hematite, <1	Corroded tabular crystals (?after ilmenite); stains and coating on acmite and orthopyroxene.
Hyalite, <1	Colloform masses; colorless; $n=1.451$; spherulitic structure under crossed nicols.
Rutile, rare	Short prisms terminated by single pyramid; light-pink, transparent; on c average ~0.2 mm.
Hornblende, rare Mg:Fe+Mn~9:1	Slender prisms with blunt terminations; transparent-brown; on c average ~1.5 mm.
Pseudobrookite, rare	Platy, rectangular crystals flattened on {100}; deep-red, submetallic; usually found on corroded ilmenite; maximum size ~1 mm; X-ray pattern available.
Quartz, rare	Low-quartz habit; on c maximum ~0.2 mm.

Typically the plagioclase and the orthopyroxene are zoned. Most of the orthopyroxene ranges from eulite (approximately Fs_{27}) in the crystal center to ferrohypersthene (approximately Fs_{45}) at the edge of a crystal. Most crystals of plagioclase are zoned from andesine (approximately An_{40}) to albite-oligoclase (approximately An_{10}). However, a few plagioclase crystals range from bytownite to albite (Fig. 3). Also present in a few samples are late-formed crystals composed entirely of unzoned, low-temperature albite.

The sequence of crystallization and the compositional changes of the minerals are depicted in Figure 4.

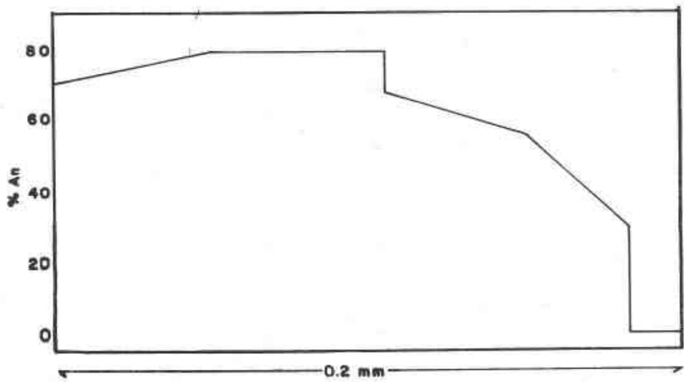

Fig. 3. Zoning in a single cleavage flake of plagioclase from Summit Rock. Composition was determined by extinction angles on a cleavage flake resting on (001) in oil with $n = 1.540$. Since the structural state was not determined and a low temperature curve was used, the graph may be in error by up to 10 percent.

Origin of the Cavity Minerals

Little has been written on the general origin of such cavity suites. Tridymite and cristobalite in cavities can be deposited from a vapor phase (Barth, 1962, p. 73; Deer and others, 1966, p. 354; Larsen and others, 1936, p. 693; Williams and others, 1955, p. 41). Fries and others (1942, p. 322) attribute cavity pseudobrookite in rhyolite to escaping vapors. Larsen and others (1936, p. 692–693) present evidence for the magmatic origin of some tridymite.

The writer proposes that at Summit Rock the plagioclase, orthopyroxene, augite, ilmenite, and magnetite have crystallized from a late, residual, interstitial magma which oozed into the cavities and then crystallized. This is the same mechanism proposed by Smith (1967) for the formation of segregation vesicles. The remaining cavity minerals were deposited from a volatile phase or were deposited because of its presence. Justification for this proposal is as follows:

1. The greatest percentages of the cavity minerals are anhydrous, and the cavities contain essentially the same mineral assemblage as the andesite.

2. Although not commonly attributed to deposition from a volatile phase, hornblende (Shand, 1949, p. 49), acmite (Shand, 1949, p. 49), hematite (Verhoogen, 1962, p. 178), rutile (Verhoogen, 1962, p. 178), and apatite (Wyllie and others, 1962) have been observed as deposits resulting from the presence of a volatile phase. At Summit Rock these minerals

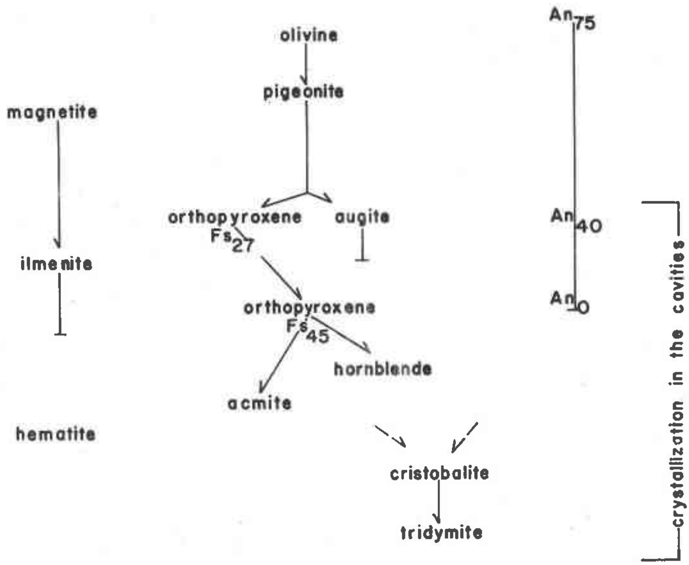

FIG. 4. Sequence of crystallization and compositional changes at Summit Rock.

are late in formation and compose less than 5 percent of the cavity filling.

3. In general the cavities are coated by a thin uniform layer of minerals, and there is little variation in mineral assemblage or degree of mineralization throughout the interior of the plug. If fluids had moved through the cavities and deposited the cavity minerals it seems likely that there would be some variation or local concentration of mineralization. Since this is not the case extensive circulation is improbable.

4. It is unlikely that all of the lenticular cavities were sufficiently interconnected to allow circulation of fluids. Certainly there could be little

circulation of fluids among the vesicles in the upper part of the plug because each cavity is essentially an enclosed space. Since the vesicles and the lenticular cavities contain the same assemblage, a similar origin for the minerals in both types of cavities is indicated.

5. The gas occupying the cavities shortly after cavity formation can account for only a small percentage of the cavity minerals. If one uses the equation of state and the extreme upper and lower limits reasonable for this environment (temperature 1000 and 100°C, pressure 1 and 50 atm), calculations indicate that the cavities would have contained at

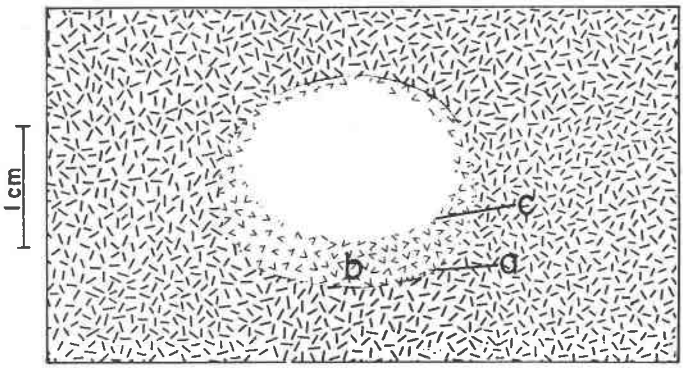

Fig. 5. Diagram of a segregation vesicle at Summit Rock. *a*=principal surface, *b* =lining of cavity minerals, *c*=subsidiary surface. The terminology is that of Smith (1967). Such accumulations commonly have a diktytaxitic texture. The shape and thickness of the filling indicates some degree of fluidity for the cavity magma.

extreme maximum 0.002 moles/cm^3 of gaseous material (less than 0.04 g of H_2O/cm^3). Providing there was little circulation among the cavities, this amount can account for only a fraction of the cavity minerals.

6. The distribution of the contents of a few vesicles (Fig. 5) and the presence of a few, small, vesicular veins composed of the cavity mineral assemblage are consistent with the former presence of residual magma and gas.

Two additional mechanisms are possible for the formation of the cavity minerals, diffusion of ions to the cavities through a crystal mush and recrystallization of the cavity walls. One or both of these mechanisms could operate alone or in conjunction with the process proposed in this paper. However, there are significant objections to both of these as major mechanisms.

Two observations seem to invalidate diffusion as a major mechanism. The occurrence of formerly liquid-filled vesicles and fractures definitely indicates the presence of a melt. The sequence of crystallization typical of the cavity minerals is essentially the same sequence that would result from crystallization of a melt.

Two objections to recrystallization of the cavity walls are apparent. An insufficient amount of a fluxing agent was present to cause recrystallization; evidence indicates that the magma was relatively dry (equation of state calculations, plug dome form of Summit Rock, and lack of abundant hydrous minerals). If the cavity minerals resulted from recrystallization, one would expect the same bulk composition in the cavities as in the rock; however, the composition of the cavity minerals differs from the rock minerals (for example, An_{65} for average rock plagioclase compared to An_{30} for average cavity plagioclase).

Several more points are worth comment. The extreme zoning (bytownite to albite) of some of the cavity plagioclase does not seem reasonable for the residual melt system proposed in this paper. This zoning may have resulted from crystallization of the residual melt around projections or fragments of the rock plagioclase. Incomplete reaction between the residual melt (containing about An_{30}) and the crystal fragments (about An_{75} maximum) would result in depletion of the anorthite content of the melt as the cavity plagioclase crystallized. Under these conditions the melt could be completely depleted of anorthite leading to the crystallization of nearly pure albite.

Three pyroxenes occur at Summit Rock-pigeonite in the groundmass of the rock, augite and orthopyroxene in the cavities. Perhaps pigeonite crystallized in the rock as a metastable phase while the melt was highly viscous. Later, more stable phases crystallized within the cavities because of lower temperature and/or higher volatile content. Larsen and others (1936, p. 700) present a similar conclusion.

Mineral sequences indicate three trends at Summit Rock. Titanium apparently was concentrated in the cavity magma as evidenced by the crystallization of magnetite primarily in the rock and ilmenite in the cavities; however, there is little apparent difference between the rock and the cavities in total Fe+Ti content. There was a minor concentration of silica in the cavity melt as evidenced by the presence of minor amounts of tridymite and cristobalite in the cavities. Oxygen fugacity underwent a minor increase late in the crystallization of the cavity magma as indicated by the sequence ilmenite→hematite and rutile (Verhoogen, 1962) and by the oxidation of some of the orthopyroxene.

The sequence of crystallization at Summit Rock (see Fig. 4) probably represents oxygen fugacity conditions someplace between Osborn's (1962) high and low oxygen partial-pressure reaction series, but nearer the high series.

Conclusion

The probable sequence of events at Summit Rock was: extrusion of a partly crystallized, viscous magma to form a plug dome mantled with scoria; formation of vesicles in the upper interior of the plug; crystallization of about 80 percent of the magma; formation of the lenticular cavities by tearing in the lower interior of the plug; oozing of part of the remaining interstitial magma into the cavities; crystallization of this residual, slightly more fluid magma in the cavities; crystallization of a small percentage of minerals from a volatile phase or because of its presence.

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