ORIGIN AND GEOMETRIC FORM OF CHALCEDONY-FILLED SPHERULITES FROM OREGON*

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Chalcedony-filled nodules, with interesting geometric forms, are finding their way into numerous mineral collections. Central Oregon is he outstanding producer of these specimens, but similar ones come from Nevada and California. Dake[1] has described the Oregon specimens as follows:

> The Central Oregon district has produced many thousands of these agate-filled nodules. Madras seems to be the center of production, but choice specimens are also found on the Warm Springs Indian Reservation in Wasco County. The area south of Antelope is also a good producer. The nodules, also known as "Thunder Eggs" . . . , seem to be associated only with rhyolitic rocks, . . . Generally the nodules have an average diameter of about six inches, although they are found in perfect specimens as small as one-fourth of an inch and as large as three feet in diameter, all alike in exterior and interior appearance. . . .
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> . . . Only about one out of five will prove an outstanding specimen, the others will be only mediocre. . . . The nodules appear to occur in lenses or "beds," probably in areas where the lavas were especially vesicular, presenting numerous cavities where deposition could take place. . . .
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> . . . Each locality appears to produce a distinctive type of nodule, instantly enabling experts to distinguish them as such. However, no two specimens are exactly alike in the interior colorings, markings, and patterns.

Recently, General J. S. Hatcher, an enthusiastic mineral collector, kindly presented a number of very fine specimens of the nodules for use in detailed study; and those illustrated in Plate 1 were cut and polished by him.

The great interest in the Oregon material has heretofore been as mineral specimens, showing striking geometric forms, but they are also outstanding in the detail of geologic history that is presented. The most interesting geometric forms assumed by the chalcedony fillings are five-pointed stars, some of which are very perfect. Two of these are illustrated in Plate 1, that in Fig. (*c*) having been cut nearly across the laminae of the chalcedony, and that in Fig. (*b*) roughly parallel. Those cut across the bedding make the most beautiful specimens but the position cannot be determined in advance of cutting. Figure (*d*) represents a filled cavity with roughly square outline.

The geometric form of a filled cavity which will give a five-pointed star in cross section presents an interesting problem. Any gas cavity which forms in a homogeneous medium will tend to have a symmetrical and

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[1] Dake, H. C., The gem minerals of Oregon: *Oregon State Dept. of Geol. and Mineral Industries,* Bull. **7,** 1–16 (1938).

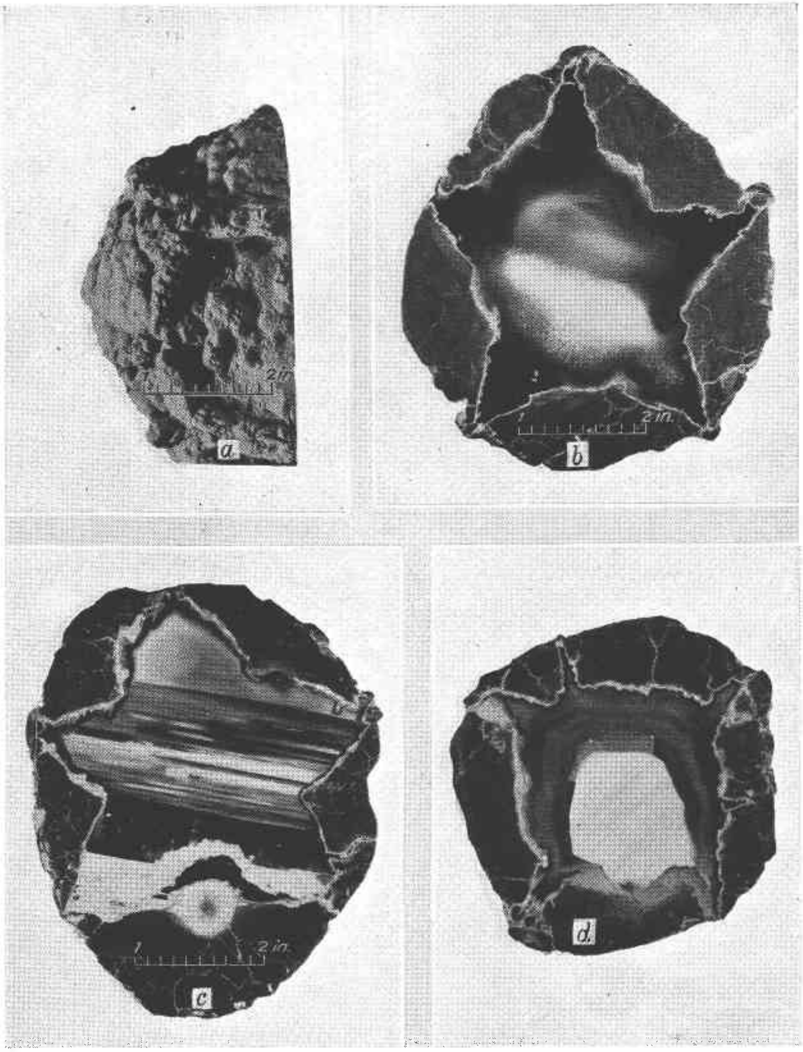

PLATE 1

FIG. (*a*) Exterior of filled vesicles represented in figure (*b*). Shows the cauliflower-like form assumed on the contact between devitrified and glassy material. Note ridges corresponding to points of star in (*b*). ×$\frac{2}{3}$

FIG. (*b*) Chalcedony-filled vesicle cut nearly parallel to lamination of the chalcedony. Gray outer portion is devitrified welded tuff. ×$\frac{2}{3}$.

FIG. (*c*) Chalcedony-filled vesicle cut across lamination in chalcedony. ×$\frac{2}{3}$.

FIG. (*d*) Chalcedony filling representing a roughly cubic vesicle. ×$\frac{2}{3}$.

equidimensional geometric form. With small cavities or in a medium that is not too viscous, the cavity will tend to have a spherical form. However, when the cavity is large and especially where it develops in a highly viscous or almost solid glass, the force required for spherical expansion is very great. In such a medium, expansion by rupture or tearing will require very much less energy, and the rupture planes will tend to symmetrically enclose the cavity developed.

Wright[2] has described hollow lithophysae from Iceland as follows:

> The cavities are in the shape of a cube about 25 mm. on a side. . . . The inner walls are not perfectly flat, but show strong diagonal ribs passing from one corner of a cube face to the opposite corner, as though each cube face had not been quite fully developed into a plane, but still has superimposed on it four negative triangular tetrahexahedral faces, each four-sided pyramid thus formed points toward the center of the cube and not away from the center, ... The fact that any irregularity on the one face finds its counterpart on the face adjacent to it and intersecting it at the edge of the cube proves that the faces were originally together and were gradually forced apart as crystallization proceeded. . . .

We may picture a cube as developed from six four-sided pyramids bounded by rupture planes, and with their apices meeting at the center. There will be 12 triangular planes (the planes of rupture), extending from the center to the 12 edges of the cube. If such a system of ruptures developed without expansion there would be six four-sided pyramids, their apices meeting at the center and their bases corresponding to the six sides of the cube. However, expansion of the gas cavity and rupture proceed together and the effect is as if the apices of the pyramids were pushed toward their bases with a flattening of the pyramid. In some instances a nearly cubic cavity is produced, but with each face marked with four triangles that represent traces of the rupture planes. In others, there remains a flattened pyramid projecting inward from each side of the cube (i.e., a negative tetrahexahedral pyramid), and the resultant form resembles the well-known hopper shaped halite crystals.

In some of the filled cavities from Oregon, the geometric form is roughly that of a cube, as shown in Plate ~~2~~, Fig. (*d*); but the star-shaped forms are sections across a modified pyritohedron, each of whose 12, 5-sided faces is represented by an inward projecting pentagonal pyramid. The form was produced by 30 triangular shear planes extending from the center and terminating at the edges of the 12, 5-sided faces along which shear occurred. Expansion, in effect, pushed the resulting apices of these pyramids toward their base (the faces of the pyritohedron), but not sufficiently far enough to eliminate the negative pyramid. Such a figure will give a 5-pointed cross section when cut in a number of directions,

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[2] Wright, Fred E., Obsidian from Hrafntinnullryggur, Iceland, its lithophysae and surface markings: *Geol. Soc. Am. Bull.*, **26**, 255–286 (1915).

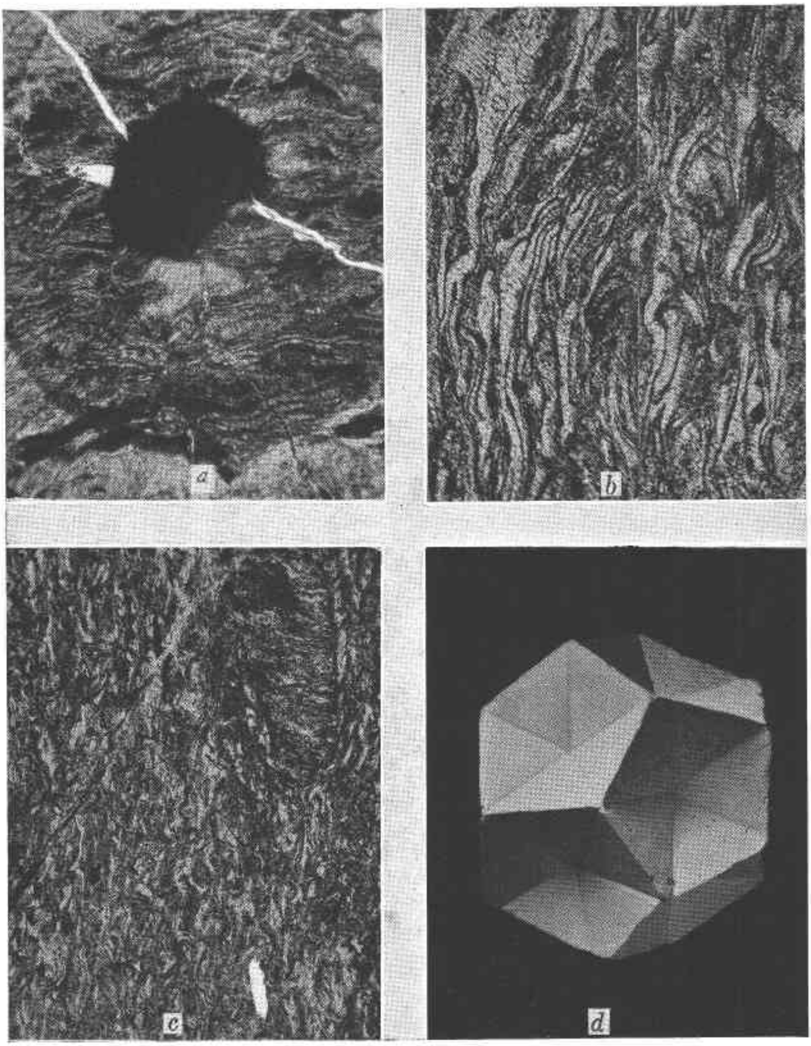

Plate 2

Fig. (*a*) Spherulite from welded tuff, American Falls, Snake River, Idaho, showing similarity to Oregon spherulites. Central area (black) represents a nearly circular cavity; dark gray zone is devitrified glass (feldspar+cristobalite); and the light gray portion at the bottom of the figure is glass. Shard structure shows in the devitrified portion. ×48.

Fig. (*b*) Shard structure is material surrounding chalcedony in Plate 1, Fig. *b*. Fine grained diagonal structure crossing shards is composed of the radial feldspar-cristobalite aggregate. ×54.

Fig. (*c*) Tuff structure as in (*b*) but with older tuff fragment near upper right corner. ×12.

Fig. (*d*) Model of the form of the cavity giving the star-shaped chalcedony fillings. A shallow negative pyramid marks each of the 12 pentagonal pyritohedral faces.

the most perfect star being given when the cut is made about one-third above or below the equator of the spherical mass. Of course, the geometrically perfect figure outlined here will be produced only under ideal conditions. In nature there will be various modifications, and distortions due to a lack of homogeneity of the enclosing media will modify or destroy the ideal symmetry. However, the perfection of some of the stars shown in cross section indicates a close approximation to the ideal form.

In some of the nodular masses, the boundaries between the twelve pseudopyritohedral faces are marked by irregular ridges on the outer surface and these outline 12 approximately equal areas, in some of which a roughly pentagonal shape is observable. Such ridges and one-half of such a pentagonal area is illustrated in Plate 1, Fig. (*a*). The ridges are also represented by the small protuberances at each star point in Fig. (*b*).

The material surrounding the chalcedony is gray-brown in color and without structure visible to the eye, but thin sections show that this is composed of welded tuff fragments as illustrated in Plate 2, Figs. (*b*) and (*c*). The tuff structure is very perfectly preserved despite distortion and flattening due to elimination of interstitial pores and subsequent crystallization. Near the center of the figure are several shard structures that are folded back on themselves as a result of compression of fragments that were originally *Y* shaped, being formed by the walls between three adjacent bubbles. The fine-grained pattern that extends diagonally across the figure represents the radially fibrous structure of the spherulite. Figure (*c*) shows a small fragment of an earlier welded tuff enclosed in the younger one, and a number of such enclosed fragments occur in each slide studied. The radial structure of the spherulite extends without interruption across the older fragment, showing that devitrification was subsequent to consolidation.

A glassy volcanic ash evidently fell in so hot and plastic a condition that welding was complete and a nearly homogeneous material was produced, but even after this it retained volcanic gases in solution in the glass. These gases began to collect locally at centers of crystallization and, as crystallization proceeded, more and more gas collected and enlarged the cavity. This crystallized portion is made up, as is usual in such spherulites, of radial aggregates of feldspar and cristobalite, and the outer boundary of the spherulites has a cauliflower-like habit although roughly spherical in shape. Thus the nodules represent hollow spherulites that were subsequently filled with chalcedony. The material enclosing the crystalline spherulites has entirely broken down, and as it is reported to be a clay, it is probably a bentonite, that is, an alteration product of glass. The part that crystallized resisted weathering and lies imbedded in clay.

Material similar to the devitrified, welded tuff from Oregon is illustrated in Plate 2, Fig. (*a*). This is from American Falls, Snake River, Idaho, and has been described by Mansfield and Ross.[3] This specimen shows the central cavity; a nearly circular area of enclosing material, composed of radial aggregates of feldspar and cristobalite; the whole enclosed in glass that is still fresh.

The following geologic history is, therefore, revealed by the Oregon "thunder eggs." Explosive volcanic activity produced finely divided glassy ash, which fell in a hot plastic condition that permitted its rewelding into a homogeneous material. While still hot, local centers of crystallization were set up, around which spherulitic masses of intergrown cristobalite and feldspar were formed. The formation of these anhydrous minerals released volatiles originally in solution in the glass. The gradual collection of volatiles exerted a pressure, which combined with the cooling shrinkage of the enclosing material, forced the walls of the cavity outward, expansion being by rupture along symmetrically arranged planes. The more perfect of these cavities had the geometrical symmetry of a modified pyritohedron bounded by 12 inward projecting, 5-sided pyramids, formed by the shear along 30 triangular planes. The resultant cavity was later filled by chalcedony that was probably deposited during the alteration of the enclosing material to a clay.

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[3] Mansfield, G. R., and Ross, C. S., Welded rhyolitic tuffs in southeastern Idaho: National Research Council, *Trans. Am. Geophysical Union,* Part I, 308–391 (1935).