OBSERVATIONS ON SPHERULITES

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Introduction

Petrographic studies of rhyolitic rocks from Yellowstone Park, Wyoming; Mono Craters, California; and the Lipari Islands, have revealed additional features of interest concerning spherulites. Most of the specimens examined were selected from a collection of Yellowstone rocks made by the junior author in connection with a study of the problem of the history of Yellowstone Canyon, an investigation sponsored by the Princeton University Research Organization. The remainder of the specimens were selected from the collections at Columbia and New York Universities.

Curvature of Lines of Microlites Around Spherulites

The distribution of microlites in curved lines around spherulites is of interest in view of the generally accepted idea that spherulites form after the lava has come to rest. This feature was observed in the rhyolitic vitrophyre which outcrops immediately back of the rim of the Lower Falls of Yellowstone River. The rock consists largely of glass within which occur spherulites, scattered phenocrysts of quartz and sanidine, and abundant microlites which are strung out in flow lines. The section shows excellent perlitic structure. The perlitic cracks often traverse spherulites, indicating that the spherulites formed before the final contraction of the lava. The spherulites average slightly less than 0.1 mm. in size, and although too small and compact to show distinctly the individual crystal fibers, do show a clear black cross between crossed nicols. The spherulites, with few exceptions, contain scattered microlites which are always in haphazard arrangement within the spherulites themselves, although outside of them they show characteristic alignment. Commonly the lines of microlites bend around the spherulites. This feature is illustrated in Fig. 1.

This phenomenon admits of two possible explanations:

1. The fibers of the spherulites, growing in the hot, plastic glass following the extravasation of the lava, pushed aside or bowed out the streams of microlites in their path.

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2. Renewed local movements in the lava subsequent to the formation of the spherulites swirled the microlites around them.

To determine whether growing fibers in a spherulite can exert an outward push on microlites in their path, the following experiment was conducted. Crystals of menthol were heated on a glass slide and finely comminuted particles of pyroxene were sprinkled into the melt. Because of its acicular habit many of the pyroxene fragments closely resembled in shape the actual microlites of the vitrophyre. The fragments ranged in size from the lowest limits of visibility to 0.5 mm. The cooling process was observed under the microscope. It was found that as long as the melt remained sufficiently liquid the "microlites" were borne toward the growing spherulite with appreciable velocity by convection currents. As the "microlites" were met by the advancing spherulite front they

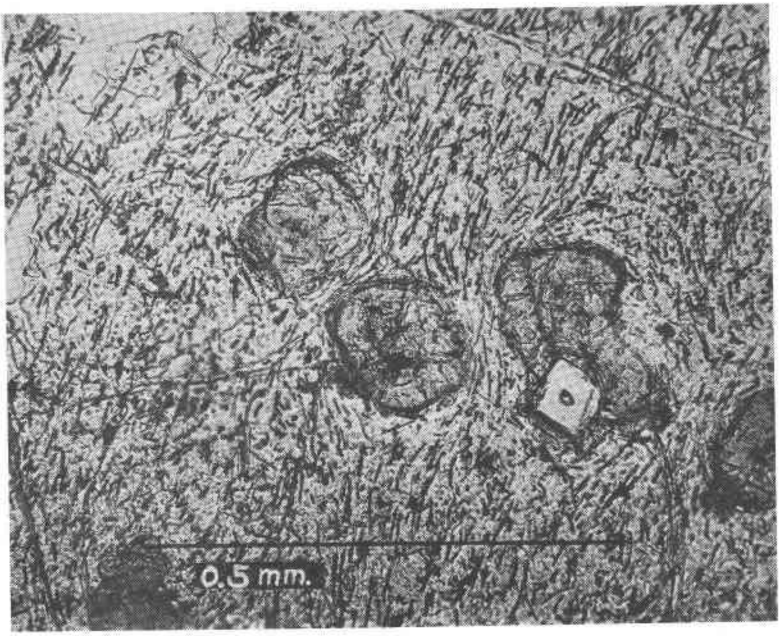

FIG. 1 (Specimen 78). Obsidian just back of the brink of the Lower Falls of the Yellowstone River, Yellowstone Park.

Microlites in haphazard arrangement within the spherulites, but arranged in flow lines without and around the spherulites.

were enveloped by it, and their arrangement within the spherulite was haphazard. As the viscosity of the melt increased the movement of the "microlites" became slower. When the viscosity was such as to prevent further movement of the "microlites" still outside the spherulite, they in turn were overtaken and included within the growing spherulite. In all the various stages of viscosity observed movement of the "microlites" was either toward the spherulite or lacking. Provided the behavior of the acicular pyroxene fragments in the menthol melt is accepted as a sufficiently close analogy to the behavior of microlites in lava, it is judged to indicate that growing spherulites exert no push on obstacles in their path.

The same conclusion is inevitable from the theoretical viewpoint. It is apparent that the continuous growth of a spherulite depends on diffusion of substance from the surrounding magma toward the growing spherulite, and that any factor affecting the rate of diffusion will affect the rate of growth of the spherulite. Furthermore, any factor affecting the rate of diffusion toward a portion of a spherulite, or toward one fiber in a spherulite, will affect the rate of growth of that portion or fiber. An obstacle, such as a microlite or phenocryst, close to the growing front of a spherulite, may affect the growth of that portion of the spherulite by interfering with the diffusion currents supplying that portion with substance. It seems logical to suppose that as long as the obstacle and the spherulite are widely separated the rate of diffusion toward the spherulite will be uniform. This results in uniform growth. When, however, the spherulite front has advanced close to the obstacle, the fibers immediately to the leeward of the obstacle will obtain their supply of substance from currents sweeping around the obstruction. Since their source of supply is now no longer directly ahead of them, but to either side, further growth of these fibers will take place in the new directions. The ultimate result will be that the fibers will curve around the obstacle in their path. The curvature, however, since initiated before the growing fibers reached the obstruction, *is not due to actual impact with the obstacle.*

The third objection to the hypothesis of "push action" is the fact that the lines of microlites do not curve around all the spherulites. Why this "push action," provided there is such an action, should be selective is not clear, especially since the uniformity in size of the spherulites would seem to indicate that the spherulites all grew at about the same time, and since the haphazard arrangement of the included microlites seems to indicate that the lava, at the time of spherulite growth, was fairly liquid.

The alternative is that the curvature of the lines of microlites is a result of renewed local movements in the lava. That this feature is found in connection with only a portion of the spherulites would seem to indicate either of two histories:

1. After the lava came to rest, but while still more or less liquid, a first generation of spherulites was formed. These were caught up in slightly later local movements of the lava with the result that streams of microlites were drawn around them. Following these secondary movements a second generation of spherulites was formed.
2. After the lava came to rest *all* the spherulites were formed. Somewhat later, while the lava was still more or less liquid, small scale, perhaps even microscopic, movement of local character caused the swirling of microlites around *some* of the spherulites. Such localized movements may be due to convection currents generated as a result of variations in viscosity, composition, density, temperature, pressure, or to a "settling" of the lava body.

The uniformity in size of the spherulites in the sections examined is considered unfavorable to the first possibility because it seems improbable that the second generation of spherulites attained just the size of the first when growth stopped. In the writers' opinion, therefore, the curvature of the lines of microlites around the spherulites is due to renewed movements in the lava, local and small scale in character subsequent to the cessation of spherulite growth.

SPHERULITES WITHIN SPHERULITES

The western rim of the Grand Canyon of the Yellowstone about a half mile north of the Lower Falls is composed of a dense, porcelain-like, white, rhyolitic rock which is traversed by an intricate network of tiny fractures. Embedded in the porcelain-like matrix are occasional quartz phenocrysts rarely exceeding 2.0 mm. in size. In thin section the rock is seen to include within a complex matrix of glass, opal and microcrystalline silica, phenocrysts of quartz, abundant spherulites and an undetermined substance[3]

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[3] This substance is colorless, cryptocrystalline to almost isotropic, with an index

which is often pseudomorphous after feldspar euhedra (Fig. 4). The spherulites occur up to 8.0 mm. in size although averaging only about 0.1 mm. The larger spherulites often contain within themselves smaller spherulites, as well as occasional phenocrysts.

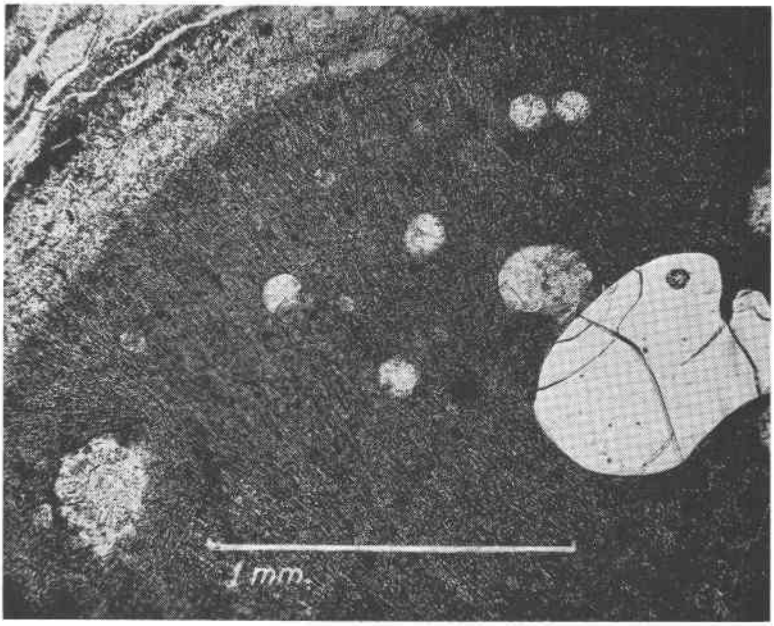

FIG. 2 (Specimen 93). Specimen from the western rim of the Grand Canyon of the Yellowstone at the head of Red Rock trail, Yellowstone Park.

Spherulites within spherulites. A number of small spherulites and a corroded quartz crystal are included in a large spherulite. The crystal fibers of the large host spherulite curve around the small included spherulite shown in the left lower corner of the photomicrograph.

The phenomenon of inclusions within spherulites has been noticed many times. Iddings,[4] in discussing the compound spherulites of Silver Cliff, Colorado, says "the plumose rays shut in as inclusions between them much magma that solidified in other ways." More recently Foshag[5] described spherulites "made up entirely of rod-

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between those of Canada balsam and quartz. It commonly contains threads and filaments of a component with a different index which polarizes differently. It is at present under investigation.

[4] Iddings, J. P., Igneous Rocks: I, p. 240, 1909.

like feldspar crystals and tridymite plates with occasional intratelluric feldspar and quartz phenocrysts embedded within their mass"; and further, "These pherulites appear to be the result of a progressing crystallizing process that started from a nucleus and spread outward through the glass and engulfed some of the phenocrysts." The phenomenon of "spherulite inclusions" within spherulites, (Fig. 2,) has never been described so far as the writers know. An understanding of the conditions productive of this phenomenon may shed light on some of the changes which take place in cooling rhyolitic lavas.

The spherulites, both large and small, are similar in every respect but size. It has been noticed that the crystal fibers of the host spherulite curve around the included phenocryst or spherulite. The curvature of the crystal fibers admit of two possible explanations:

1. The included spherulite is later than the host spherulite; in its growth it pushed aside the fibers of the host spherulite.

2. The included spherulite was captured by the host spherulite as the latter grew outward into the surrounding magma. The fibers of the later, host spherulite, on meeting the spherulite in their path, were deflected around it.

If the first explanation is true then we are forced to believe that the growing fibers of the included spherulite were able to push aside the previously formed fibers of the host spherulite. The objections to any such pushing action have already been discussed. A further objection arises when one considers that the included spherulite, if it is assumed to have formed later, must have drawn its supply of substance from its immediate surroundings; that is, from the host spherulite. Yet the host spherulite must have already used up all the substance necessary for the growth of its own fibers. It would appear, therefore, that the included spherulites are not later than the host, but had reached their present size before being overtaken and included within the host spherulite. The inclusion of the smaller spherulite may have occurred, conceivably, in any one of three ways:

1. Two spherulites may have started growth from two closely spaced centers at the same time. For some reason one ceased growing. The spherulite which continued to grow finally included its neighbor.

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[5] Foshag, W. F., The minerals of Obsidian Cliff, Yellowstone National Park, and their origin: *Proc., U. S. Nat. Mus.*, vol. **68**, Art. 17, p. 6, 1926.

2. The smaller spherulite may have grown to completion first. Later crystallization from a nearby nucleus may have resulted in a second spherulite which grew to large size, including the earlier formed spherulite.

3. The larger spherulite may have started to grow first. Later, when the first spherulite had reached a fairly large size, crystallization from a nearby nucleus started. Continued growth of the larger spherulite resulted in the inclusion of the smaller.

With reference to the first possibility, it is considered unlikely that of two spherulites growing within a few millimeters of each other and which started to grow at the same time, that one should continue to grow and the other stop. Such a condition would require that the magma surrounding the spherulites was unable to further contribute substance to one spherulite, which, therefore, ceased growing, but was able to contribute to the growth of the second spherulite as the growing front of the latter reached this area. The same objection holds for the second possibility, where the smaller spherulite is assumed to have grown first, and later crystallization from a nearby nucleus to have resulted in a larger spherulite, which, as it grew outward, included the earlier formed spherulite. Furthermore, it is not clear why the renewed crystallization, following cessation of growth of the first formed spherulite, should start at a new locus only a few millimeters away, rather than at the locus already provided.

The probable answer appears to lie in the last alternative. According to this idea the larger spherulite is assumed to have grown to appreciable size before the initiation of growth of the smaller spherulite nearby. As it grew outward the larger spherulite included the smaller even though both may have been growing at the same rate. As soon as the smaller spherulite became included in the larger its growth stopped because of lack of substance, while the host spherulite continued to grow so long as diffusion from the surrounding magma continued. This conception, involving initiation of spherulitic growths in the magma over a period of time, can be taken as additional evidence of the heterogeneity of lava. It is somewhat more satisfactory than a concept involving simultaneous initiation of spherulite growth throughout the mass, as could obtain only in the case of a perfectly homogeneous lava under perfectly uniform conditions of cooling.

SIGNIFICANCE OF THE ARRANGEMENT OF MICROLITES IN SPHERULITES

If the manner of inclusion of "microlites" in artificial menthol spherulites is similar to that which occurs in glassy, volcanic lavas, then an additional point of interest arises.

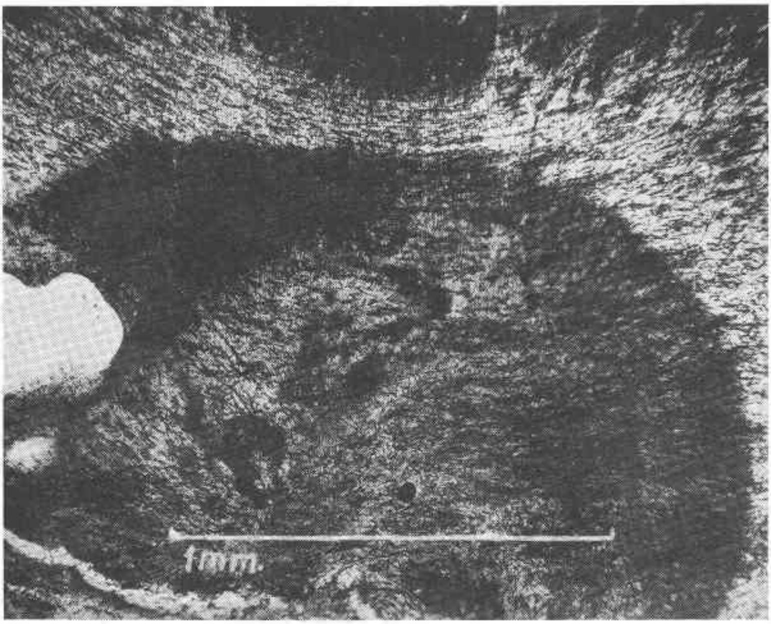

FIG. 3 (Specimen 234). Specimen from the west side of Gardiner River one mile north of Seven Mile Bridge, Yellowstone Park.

Microlites passing through a large spherulite in undisturbed flow lines.

It has been shown that so long as the menthol remains quite liquid the microlites move toward the growing spherulite and are incorporated in it in haphazard arrangement. When the menthol becomes highly viscous, however, there is no movement of the microlites and they are incorporated in the spherulite in the arrangement they had when viscosity overtook them. The arrangement of microlites in spherulites is, therefore, an index of the viscosity of the lava at the time of spherulite growth, i.e. immediately after the lava came to rest. In making use of this criterion it is essential that a sufficient number of thin sections be available so that an accurate cross section of the character of the lava is obtained. It is realized, in view of the heterogeneity of lava, that certain portions of the flow may cool more rapidly than others, so that in some portions of the flow the microlites may occur in flow lines in the spherulites, while elsewhere they may occur in haphazard arrangement.

When the microlites are included within a spherulite in undisturbed flow lines, as is the case in the rhyolitic lavas at several localities in the Yellowstone (Fig. 3), in many of the obsidians from Mono Basin, California, and in some of the lavas of the Lipari Islands, the inference is that at the time of emplacement the lava was so viscous that the microlites were unaffected by diffusion toward the centers of spherulite growth. On the other hand, when microlites are included within spherulites in haphazard arrange-

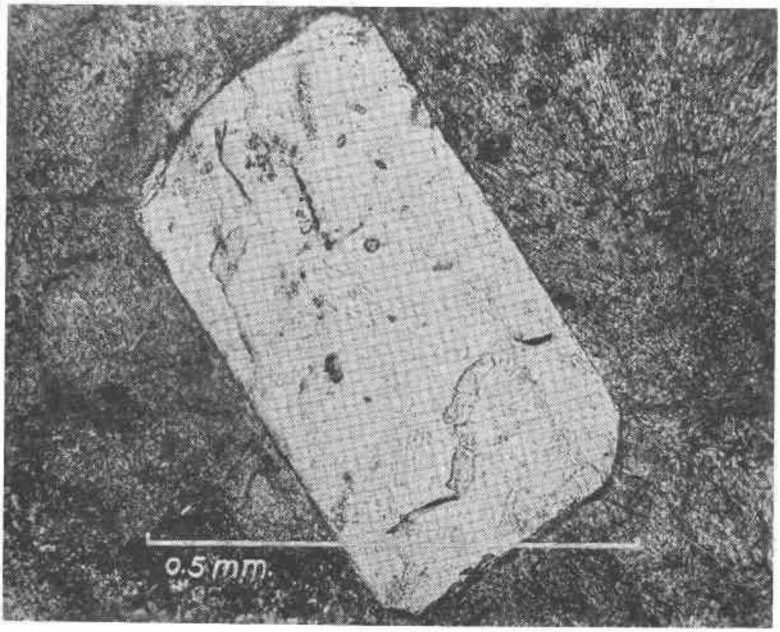

FIG. 4 (Specimen 93). From the western rim of the Grand Canyon of the Yellowstone at the head of Red Rock Trail, Yellowstone Park.

The undetermined substance, pseudomorphous after an idiomorphic feldspar crystal, showing the minute filaments of a second substance with a different index. The mass as a whole is almost isotropic.

ment, while arranged in flow lines outside the spherulites, the inference is that at the time of emplacement the lava was sufficiently liquid so that the microlites were disturbed by the diffusion currents set up in reponse to spherulite growth. This condition obtains in the rhyolitic vitrophyre back of the Lower Falls of the Yellowstone, and is shown in Fig. 1.

Because of the close relationship between viscosity and the rate of cooling the arrangement of the microlites in the spherulites may be used as an indication of the comparative rates of cooling of similar lavas.