ART. V.—*The Minerals in hollow Spherulites of Rhyolite from Glade Creek, Wyoming;* by J. P. IDDINGS and S. L. PENFIELD.

THE occurrence of fayalite with quartz, tridymite and soda-orthoclase or sanidine in the lithophysæ and hollow spherulites of the obsidian at Obsidian Cliff, Yellowstone National Park,* has been described by one of the writers of the present paper, the mineralogical investigation of the fayalite and sanidine having been carried on by the other writer. Recently we have had occasion to call attention to the occurrence of fayalite in obsidian at Lipari and Vulcano in the Mediterranean,† and have observed that the modes of occurrence are alike in both regions, and that the causes leading to the crystallization of fayalite in these magmas must have been the same, namely: the action of superheated vapors, presumably of water, upon the magmas before their final consolidation and cooling.

In the present paper we wish to contribute further to the knowledge of these aqueo-igneous products in siliceous lavas, by describing a somewhat different development of hollow spherulites in rhyolite at the forks of Glade Creek, a tributary of the Snake River, just south of the boundary of the Yellowstone National Park. This locality was visited by us in the summer of 1886. The rhyolite forms a high bluff of massive rock, exhibiting great contortion of banding or planes of flow. The spur between the two branches of the stream rises some 1200 feet above the valley, and presents a section of the great rhyolite sheet which forms the mass of Pitchstone Plateau, lying to the north.

The rock at the forks of Glade Creek is dark gray, dull, lusterless and lithoidal, with a rough hackly fracture. It carries many phenocrysts of a white plagioclase, less numerous glassy sanidines and quartzes, and many rusted crystals, which prove to be more or less altered augites. Through this mass are scattered cavities with light gray or white walls, which are partially filled with crystals. The cavities vary in size from that of a walnut to almost nothing. They are irregular in shape, but the spherical form of the light colored walls suggests at once that they are the cavities of very hollow spherulites. They are, in fact, wide-gaping spherulites like some of those found at Obsidian Cliff.‡ Occasionally there are

*J. P. Iddings, Obsidian Cliff, Yellowstone National Park. Seventh Annual Report of the Director of the U. S. Geological Survey, Washington. 1888.

† Iddings and Penfield, Fayalite in the obsidian of Lipari. This Journal, vol. xl, July, 1890.

‡ l. c. p. 264, and Plate XII, figs. 1 and 5.

indications of spherical zones near the outer margin of the shell, but no radial fibration can be observed macroscopically. There is nothing in the arrangement of the comparatively large crystals within the cavity which suggests either a radiation from the center, or the concentric shelly structure of lithophysæ.

An examination with the microscope proves that there is a radial fibration in the outer shell of these spherulites. And since certain of the minerals which are characteristic of the central portion are found in the shell also, it is evident that the formation of the outer and inner parts of these spherulites was contemporaneous. There are also small irregular cavities containing the same well-developed crystals, which have no definite spherulitic walls, but are surrounded by white crystalline margins, which extend irregularly into the surrounding rock. The same thing also occurs in small crystalline patches and streaks in the ground-mass of the rock, like the more crystalline portions of the laminated lithoidite at Obsidian Cliff.* The massive rhyolite at Glade Creek also passes to the westward into laminated lithoidal rhyolite with open layers filled with the same minerals as those in the hollow spherulites.

The light colored crystalline portions just mentioned, when examined with a lens, are found to be dotted with minute round pits about as large as the point of a pin. At first sight they appear to be small colorless grains of some mineral like quartz, but closer investigation shows them to be hollow. Their relation to the crystalline material about them is revealed by a microscopical study of the rock.

Thin sections of the rock show it to be a rhyolite similar to much of the lithoidal rhyolite of the neighboring region, except for a greater amount of augite phenocrysts. The porphyritical quartz, sanidine and plagioclase need no special mention, being like those of most rhyolites. Magnetite forms quite large grains, associated with the augite, often having zircon crystals attached to them. The augite is light greenish yellow, and is somewhat rounded. It is partly altered to brown iron oxide, which penetrates cracks in the crystals. In some instances it is entirely decomposed, leaving a pseudomorph of brown iron oxide.

The ground-mass of the rock is spherulitic throughout, with here and there spaces between groups of spherulites which are composed of crystals of feldspar with tridymite or quartz. Short opaque trichites and sharply defined crystals of magnetite are scattered uniformly through the mass, or are arranged in lines which mark the flow structure. The microscopic spheru-

* L. c., p. 264.

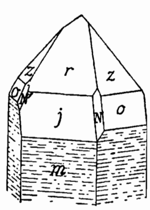
lites are distinctly radially fibrous, the rays being relatively coarse or prismatic. The outline of the spherules is not evenly circular, but irregularly jagged, especially when they adjoin areas of tridymite and quartz. Here the rays of the spherules develop into definite prismatic crystals, and have the optical characters of orthoclase in prisms elongated parallel to the inclined axis, $\grave{a}$. They have a slight extinction angle, reaching 10°, and have the axis of greatest elasticity parallel to the length of the prism. The spherulites, therefore, behave as though made up of optically negative prisms. In one rock section they appear to have more of a granophyric structure, with a feather-like texture within the feldspar prisms. The fine fibers producing this effect do not reach the end of the best developed prisms, leaving them terminated by clear feldspar substances, as in the case of the granophyric phenocryst in the rhyolite of Eureka, Nevada, described in the article on Obsidian Cliff already referred to.* In these spherulites the presence of quartz within the feldspar is indicated by this micro-structure, but in the first mentioned spherulites there is nothing to suggest its presence, except the highly siliceous nature of the rock. Since it is only the marginal terminations of the feldspar prisms which are determinable as such, the central portion of the spherulites may be more complex without its being recognized, for a small amount of quartz would not materially affect the optical character of the feldspar. The light colored, crystalline portions of the rock with the minute pits are seen under the microscope to be more highly crystallized parts of the groundmass. They combine the spherulitic structure with a more or less granular one. The little cavities are found to be hollows at the centre of small feldspar spherulites, which are made up of feldspar prisms whose ends project irregularly inward into the cavities and outward into the adjoining minerals. The cavities appear to be minute spots once occupied by vapor or some liquid, around which feldspar crystallized in prisms radiating outward. In the crystalline patches the tridymite lies in various orientations, and through it in all directions run what look like transparent needles, which in some cases also radiate out from the coarser micro-spherulites. They are dull between crossed nicols, and might easily be mistaken for apatite, but their optical characters are also those of sanidine prisms that have developed parallel to the axis of greatest elasticity. This is shown to be the case in a thin section of another rhyolite in which the same structure has been developed on a somewhat larger scale. In the rhyolite from Glade Creek, quartz some-

* L. c., p. 275, Plate XV, fig. 5.

times occupies the place of tridymite between the feldspar crystals.

The mineral which is most abundant in the hollow spherulites is quartz, occurring in stout crystals, seldom over 2^{mm} in diameter (in one instance 5^{mm}), very transparent and with a pale smoky color; also in slender white prisms, 10^{mm} long. The latter are sometimes clear and transparent in part, but are mostly full of cracks, and many of them are covered with a crust of hyalite. The hyalite is isotropic, and has minute microlites of feldspar scattered through it. Both the stout, clear quartz crystals, and the slender white prisms occur together in the same spherulite, and in a number of instances it was observed that the clear crystals are deposited on a nearly flat side of the cavity, while the white prisms, intersecting in all directions, make up a sort of net work which rises above it in a dome-shaped mass. The first impression is that the transparent quartz crystallized in a shallow basin in a liquid while the upper portion crystallized in a vapor. This hypothesis is, however, untenable, since in some cases, the transparent crystals in the hollows of one rock specimen,

1.



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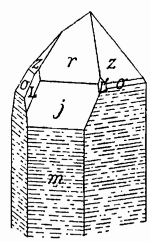

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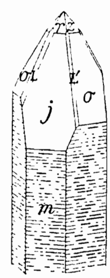

coat walls which are not symmetrically disposed to one another and hence could not represent the same water level. Transparent, stout, quartz crystals are attached to the walls of the cavity so that only one termination or one side of the prism is free; in the net work of slender white prisms, however, doubly terminated crystals occur. These quartz crystals proved on examination to be very interesting. They are not highly modified, but possess some faces with very simple indices which are exceedingly rare, even on highly modified quartz crystals, giving therefore a type of crystallization which, to our knowledge, is altogether new for this common mineral. They all show, in addition to the common quartz forms (prism *m*, $10\bar{1}0$, I, always horizontally striated, and the rhombohedrons *r*, $10\bar{1}1$, 1 and *z*, $01\bar{1}1$, -1) steep rhombohedrons j, $30\bar{3}2$, $\frac{3}{2}$ and σ, $03\bar{3}2$, $-\frac{3}{2}$ and narrow trapezohedral faces N and L $\pm$ $\frac{3}{2}$–$\frac{3}{2}$, which lie in the zone between j and σ and also in the zone z, r and m. The rhombohedrons j and σ are not mentioned by G. Rose* in his classical paper on quartz. Des Cloizeaux,† in his very extensive monograph on the crystallization of quartz was the first to observe these forms. During his investigation he added twenty-one new positive rhombohedrons to the seven which were already known. Of the + $\frac{3}{2}$ rhombohedron j he says: "this has been found on two crystals from Traversella, on a large crystal from Brazil, and upon a little crystal from Ala. Its measurement is a little uncertain as it always presents rounded faces. Among the considerations which favor the acceptance of this rhombohedron is the occurrence of the negative $\frac{3}{2}$ form." He also added twenty-five new negative rhombohedrons to the five which were already known. Of the $-\frac{3}{2}$ rhombohedron σ he says: "this rhombohedron has been observed upon twenty-three crystals from Traversella, and upon many crystals from Valais. The mean of fifty-four measurements, in spite of a slight rounding of the faces, leaves no doubt of its symbol." On the crystals from Glade Creek both j and σ are perfect as regards luster and freedom from striations. They may be detected on nearly all crystals and sometimes they are largely developed. Figures 1 and 2 represent the relative size and development of these faces on two of the transparent stout crystals which were detached for measurement, and figure 3, the greater development of them at one end of a slender white prism. In the majority of cases, the edges between j and σ are replaced by trapezohedral faces having the simple parameter relation $\frac{3}{2}$–$\frac{3}{2}$; moreover all of the four possible trapezohedral forms with the above parameter relation were observed. On the right-handed crystal represented in fig. 1, N, $21\bar{3}2$, $+r$ $\frac{3}{2}$–$\frac{3}{2}$, and N′, $3\bar{2}\bar{1}2$, $-r$ $\frac{3}{2}$–$\frac{3}{2}$ occur, while on the left-handed crystals represented in figs. 2 and 3, L, $3\bar{1}\bar{2}2$, $+l$ $\frac{3}{2}$–$\frac{3}{2}$ and L′, $12\bar{3}2$, $-l$ $\frac{3}{2}$–$\frac{3}{2}$ occur. DesCloizeaux also observed these forms and says of N + $\frac{3}{2}$–$\frac{3}{2}$ "this very rare form has been observed only upon the very remarkable crystal from Brazil. As it is very narrow and a little rounded its measurement could not be made very exactly; however its angle upon r, calculated for the symbol here adopted, differs very little from the mean of the observation and its very simple symbol, being the inverse of the probable face L, $-\frac{3}{2}$–$\frac{3}{2}$, point to its existence." Of L, $-\frac{3}{2}$–$\frac{3}{2}$, indicated by DesCloizeaux with (?) as a probable but not certain form, he says: "this very simple symbol can be applied to a face observed upon many

* Abh. Akad. Berlin, 1844, p. 217. † Ann. Ch. Phys., 1855, p. 129.

crystals from Traversella. This face is always brilliant but so much rounded that upon measuring upon z one can indifferently arrive at a number of approximations according as one stops at the upper, central or lower part of the broad reflection which it furnishes." On the crystals from Glade Creek, N and N′ and L and L′ are faultless as regards luster and absence of striations and rounding. An idea of the prominence of these faces may be obtained from figs. 1, 2 and 3 where their relative size and development on three of the measured crystals has been preserved as far as possible. They undoubtedly occur both as positive r and negative r, and as positive l and negative l; their persistency in replacing all of the edges between j and σ would indicate this as well as the results of an experiment in etching one of the crystals with hydrofluoric acid. The crystal represented in fig. 1, was thus proved to be a right-handed twin. The greater part of r and j in front, and all of N were positive, as was also the greater portion of the faces lettered z and σ, the twinning boundaries running very unequally over these faces; while the face lettered N′ was both positive and negative, the positive part being deeply etched while the acid had almost no action on the negative portion. Left-handed crystals were not etched, but it is safe to infer from the development of L and L′, that they are both positive and negative. Right and left forms were not observed in the same crystal. On the goniometer the reflections from all of the faces except m were very perfect, and the following measurements were made.

	Calculated.	Measured.			
$z \wedge r$	46° 15′ 52″	46° 15′			
$r \wedge$ (N or L)	17° 22′ 43″	17° 24′			
$j \wedge \sigma$	52° 33′ 20″	52° 32′	52° 33′	52° 32½′	52° 35′
$j \wedge$ (N or L)	16° 56′	16° 55½′	16° 57′	16° 57′	
$r \wedge j$ or $z \wedge \sigma$	10° 31′	10° 33′	10° 32′		

We have also examined the quartz crystals in the lithophysæ of Obsidian Cliff, Yellowstone National Park, and find that they too have the habit which we have just described. They are always very small, seldom over $\frac{1}{3}^{mm}$ in diameter, but some were found which were so perfect that they gave excellent reflections and could be accurately measured on the goniometer. They generally have the habit represented in figs. 1 and 2, although sometimes j and σ were as fully developed as in fig. 3. The N and L faces seldom failed. The crystals were so small that the positive and negative character of the rhombohedrons could not well be distinguished. In most cases however a $\frac{3}{2}$ rhombohedron was observed between the unit rhombohedron and prism. Measurements were mostly made in the vertical zone m, j, r, over the apex of the crystal on z, σ, m. The prism faces were always so much striated that no satisfactory measurements could be made from them. The measurements are as follows:

	Calculated.	Measured.						
$r \wedge z$ over base.	103° 34′	103° 35½	103° 33′	103° 34′	103° 35	103° 35′		
$r \wedge j$ or $z \wedge \sigma$,	10 31	10 42	10 47	10 35	10 29	10 45	10° 35′	10° 19′
$r \wedge z$ adjoining,	46 16	46 17						
$r \wedge$ N,	17 23	17 19						

On several crystals a second rhombohedron having the symbol $\frac{10}{7}$, $(10\cdot0.\ \bar{1}\bar{0}\cdot7)$ was observed, occurring either alone with r, z and m, or between j and r and σ and z. It had a relatively large size and gave distinct reflections; its measurement on to r and z, is as follows:

Calculated.	Measured.				
9° 21′	9° 45′,	9° 25′,	9° 38′	9° 52′,	9° 43′.

The occurrence in the hollow spherulites of this very unusual development of quartz, as well as its association with the rare mineral fayalite, may be taken to indicate that the crystals were formed under conditions which do not usually prevail. On the highly modified quartz crystals from Alexander Co., N. C., j, σ and L were frequently observed by vom Rath,* but the crystals from Glade Creek, and Obsidian Cliff, are very different in showing these rare forms well-developed on otherwise very simple crystals.

Tridymite is present in some of the cavities in characteristic crossed twins, and is abundant in thin sections of the rock.

The most noticeable mineral next to quartz is fayalite. It forms stout crystals about 1^{mm} long with very much the same habit as those represented by fig. 2, in our paper "On the occurrence of Fayalite in the lithophysæ of obsidian and rhyolite in the Yellowstone National Park,"† or by fig. 54 in the paper on Obsidian Cliff already cited.‡ They have undergone more or less alteration to iron oxide and are now opaque and black. Some are still transparent at the centre. When tested chemically they give decided reactions for both iron and magnesium. This may indicate that the unaltered fayalite is rich in magnesium. There is not sufficient unaltered material at hand to undertake a complete chemical analysis. The occurrence of the fayalite at Glade Creek is quite the same as that in other hollow spherulites in the rhyolites at various localities in the Yellowstone National Park.

* Zeitschr. Kryst., x. p. 156.
† This Journal, vol. xxx, July, 1885, p. 59.
‡ L. c. p. 271.

In some of the more irregular cavities of the rock, at Glade Creek, there are accumulations of sanidine crystals of very small size. Occasionally they exhibit a blue iridescence, and when magnified are seen to have the same crystal habit as those in the lithoidite of Obsidian Cliff,* that is, they are thin tablets parallel to the basal plane, with the clinopinacoid, prism and two orthodomes less highly developed. The chemical analysis of these uncommon sanidines from Obsidian Cliff showed the presence of one molecule of soda to one of potash. In some of the hollow spherulites there are very small crystals of hornblende about $\frac{1}{2}^{mm}$ long. They form stout prisms with brilliant faces, and appear to be terminated by the basal plane and unit pyramid. In thin section they are brown. They are not found in most of the cavities. Biotite is also observed, in a few cases, in very small particles built up of thin hexagonal crystals with parallel orientation. They yield an almost uniaxial negative interference figure between crossed nicols. Both the hornblende and biotite occur sparingly in small crystals within the groundmass of the rock. These minerals are not found in the same cavities with fayalite.

In conclusion, we find that in the rhyolite of Glade Creek, as in the obsidian of Obsidian Cliff, fayalite occurs in association with abundant quartz, as the result of the mineralizing action of vapors in the cooling acid lava. The quartz in both localities has a peculiar development, remarkable alike for its simplicity, rarity and perfection. These minerals are accompanied by an uncommon form of sanidine, and by tridymite. Moreover in certain hollow spherulites the fayalite is wanting, and in its place are hornblende and biotite.