

THE NATURE AND ORIGIN OF LITHOPHYSÆ  
AND THE LAMINATION OF ACID LAVAS.

BY JOSEPH P. IDDINGS.

ART. IV.—*The nature and origin of Lithophysæ and the lamination of acid lavas* ;\* by JOSEPH P. IDDINGS.

THE Yellowstone National Park with its thousands of square miles of rhyolitic lavas, presents a splendid field for the study of the various forms of structure and crystallization assumed by acid lavas in cooling. And it is the investigation of these phenomena, observed while prosecuting the work of the U. S. Geological Survey within this region in charge of Mr. Arnold Hague, that has furnished the writer with the data upon which the conclusions here stated are based.

Among the many phases of crystallization so richly developed in the rhyolitic obsidian forming Obsidian Cliff, the most characteristic is the spherulitic, producing spherulites from microscopic dimensions to several inches in diameter. They are crystalline bodies with a radially fibrous structure, which is often accompanied by a banding in concentric layers of different color and density. In thin section under the microscope they are seen to be composed of sectors of fibers, which between crossed nicols do not extinguish the light parallel to the length of the fibers which would produce a distinct shadow-cross, but at different angles, making many rays of shadow, which in the smallest spherulites frequently approach the form of a cross. These spherulites have been traced through gradations of microstructure to groups of granophyre feldspars of extreme minuteness, which appear to be composed of intergrown quartz and acid feldspar, and enclose trichites and microlites which also occur in the spherulites, so that the mineral composition of the spherulites is most probably quartz, acid feldspar and trichites of magnetite with augitic microlites. Chemical analyses of the spherulites and the obsidian in which they occur show that the two are identical, and that a spherulite is only a particular form of crystallization of the once molten glass. The largest spherulites have an earthy texture and in thin section

\* Extract from article to appear in the Seventh Annual Report of the Director of the U. S. Geological Survey; published by permission of the Director.

are seen to be made up of jointed fibers composed of microscopic feldspar crystals; between these fibers are scales of tridymite with scattered grains of magnetite and microlites, besides innumerable gas cavities. Frequently the tridymite is aggregated into pellets which enclose several feldspar fibers, leaving quite porous spaces between. The centers of these larger spherulites often have the same structure as the smaller spherulites, and the fibers of one appear to be continued into the other, but to have formed under somewhat different conditions, since the cementing mineral is quartz in one case and tridymite in the other.

In the porous portions of the large spherulites, intergrown with the feldspar fibers and appearing to be of later crystallization is an occasional individual of yellow iron-olivine or fayalite. So that the association of minerals here developed, tridymite, acid feldspar and fayalite, is quite an uncommon one for an igneous rock.

The spherulites are frequently so porous as to be hollow in places. Sometimes a large cavity is situated in one side of a radially fibrous spherulite. In this case the fibers project into the cavity and are distinctly visible without the aid of a magnifying lens, the pellets of tridymite being also recognizable. The cavity may be near the circumference of the spherulite and adjoining the enclosing matrix, or lie nearer the center leaving a dense periphery or crust like the rind of a melon. This is the more usual form. Very often the central portion appears to have shrunk and cracked apart, the surface markings on the opposite sides of the gaping cracks corresponding exactly, and showing that the walls had once been united in a continuous mass. Another variety has the cavities in concentric layers, with delicate partition walls between them forming thin concentric shells. When these have been developed in a lava to which there is a laminated structure, marked by layers of microlites and other forms of crystallization, the concentric shells of the hollow spherulites are traversed by thin layers of crystals in continuance of the lamination in the matrix.

The large hollow spherulites are generally hemispherical, and the concentric shells and cavities produce very beautiful structures, which when broken across present roselike centers surrounded by delicate encircling rings. These forms are especially characteristic of the lithoidal portion of the obsidian flow at Obsidian Cliff and are the typical structures which have been called *lithophysæ* by von Richthofen\* because they appear to have been inflated by expanding gas, the word being derived

\* "Studien aus den ungarisch-siebenbürgischen Trachytgebirgen." Jahrb. d. k. k. geol. Reichsanst., 1860, p. 180. Also, The Natural System of Volcanic Rocks, San Francisco, 1868, p. 14.

from *λιθος*, a stone, and *φύσα*, a bubble. The term applies equally well to all the concentrically chambered varieties, and may be extended to all forms of hollow spherulites.

The substance of the lithophysæ occurring at Obsidian Cliff is usually light colored and distinctly crystalline with a beautiful frosted appearance. It is made up of minute crystals in well developed forms, which in places attain a considerable size, from 1 to 2<sup>mm</sup>. The minerals recognized are: quartz and tridymite, feldspar, fayalite and magnetite. The feldspar in some cases has the crystal habit of adular, and in others is in thin tabular crystals with the simplest combination of faces, flattened parallel to the base. They appear to hold an anomalous mineralogical position, being soda-orthoclase in composition (Al, Or,) and having the crystallographic habit of sanidin but an asymmetric optical character. The fayalite was described in this Journal for July, 1885. It appears to be identical in crystal form with the mineral occurring in the lithophysæ of the obsidian of Cerro de las Navajas which was measured by Gustav Rose,\* and determined to be olivine in 1827. The angles and habit of the crystals figured by him are almost identical with those obtained by Mr. S. L. Penfield from the fayalite at Obsidian Cliff, and it is highly probable that the mineral determined by Rose is also an iron olivine or fayalite. The magnetite occurs as microscopic grains and crystals.

Since the first application of the term lithophysæ to these hollow, chambered structures, and the expression of von Richthofen's views as to their probable mode of formation, petrographers have discussed their origin, wandering more or less from the position first held by von Richthofen, and it is with the belief that the material on which these recent observations have been made furnishes better ground on which to build a theory of the origin of lithophysæ than any heretofore studied, that the writer has endeavored to throw some light upon so obscure a subject.

It was von Richthofen's† opinion, expressed in the year 1860, that the concentric shells were produced while the rock was in a molten or plastic condition, by the expansion of gas bubbles which were successively disengaged from certain portions within the mass, in consequence of the diminution of pressure accompanying the eruption of the lava. The gases which were in large part aqueous, having most likely been absorbed, thereby forming a hydrated glass. He considered lithophysæ as quite distinct from spherulites, and suggested that only careful chemical analyses would settle their true nature.

\* "Ueber den sogenannten krystallisirten Obsidian." Pogg. Ann., 1827, Band 10, pp. 323-326.

† Loc. cit.

Six years later Dr. Joseph Szabó\* expressed the opinion that lithophysæ were only a stage in the mechanical and chemical alteration of spherulites, the bases being removed by chemical means, the insoluble particles mechanically, and silica being concentrated in the cavity.

In the same year Karl von Hauert† published the analyses of four rhyolites and the lithophysæ contained in them, which showed that the chemical composition of the lithophysæ and rhyolites were the same. He therefore held to von Richthofen's view that the cavities were the result of expanding gases, but thought that these gases had no metamorphosing action on the groundmass of the rock. Later on Justus Roth‡ adopted Szabó's views and recently repeated them in the second volume of his *Allgemeine und Chemische Geologie*.

Dr. Ferdinand Zirkel§ in 1876 described certain spherulites in the rocks from Shoshone Mesa, Idaho, which "have developed by decomposition a hollow concentric layer structure." These he considered the same as the lithophysæ of von Richthofen and that they in like manner were only the result of chemical alteration.

Dr. Ch. E. Weiss|| in 1877 suggested that the cavities of hollow spherulites play the same rôle as a solid body around which a spherulite forms, that the chambered spherulites were caused by several gas bubbles being near together when the spherulites were developed.

Mr. Grenville A. J. Cole,¶ in a paper recently published, concluded that the hollows are due to the decomposition of solid spherulites by chemical agents, the material having been carried out through cracks in the rocks.

Mr. C. A. Tenne,\*\* in describing the lithophysæ in the obsidian of Cerro de las Navajas, Mexico, says that the substance of the lithophysæ must be devitrified obsidian, and gives chemical analyses which show that both have the same chemical composition.

Mr. Whitman Cross,†† in a paper "On the Occurrence of Topaz and Garnet in Lithophysæ of Rhyolite" points out the fact that these minerals are not of secondary formation in the cavities, but primary, "produced by sublimation or crystallization from

\* "Die Trachyte und Rhyolite der Umgebung von Tokaj." *Jahrb. d. k. k. geol. R.-anst.*, 1886, p. 89.

† "Die Gesteine mit Lithophysenbildungen von Telki-Banya in Ungarn." *Verhandl. d. k. k. geol., R.-anst.*, 1886, p. 98.

‡ "Beiträge zur Petrographie der plutonischen Gesteine, 1869, p. 168.

§ "Microscopical Petrography," Washington, 1876, p. 212.

|| "Quarz porphyren aus Thüringen," *Zeitschr. Deutsch. geol. Gesellsch.*, 1877, *xxix*, p. 418.

¶ "On Hollow Spherulites," etc. *Quart. Journ. Geol. Soc.*, May, 1885.

\*\* *Zeitschr. Deutsch. geol. Gesellsch.*, 1885, p. 610.

†† *This Journal*, June, 1886.

presumably heated solutions, contemporaneous or nearly so with the final consolidation of the rock. The lithophysal cavities seem plainly caused by the expansive tendency of confined gases or vapors, while the shrinkage cracks in the walls and white masses of the Nathrop rock suggest the former presence of moisture."

It is seen from the foregoing that two distinct views of the origin of the cavities within the lithophysæ have been taken; one, that the hollows were of primary origin, formed while the lava was still plastic, and were due to enclosed gases or vapors. Among those who held this opinion some considered the lithophysæ as wholly distinct from spherulites, while others thought them simply hollow varieties. The second view was that the hollows had been produced in solid spherulites by chemical decomposition and alteration and were subsequent to the solidification of the lavas in which they are found. With the latter view, which may apply to some hollow spherulites in particular cases of decomposed rocks, the lithophysæ in the obsidian from the Yellowstone National Park have nothing to do. The extreme freshness of the whole rock and the absence of secondary alteration prevents the confusion which arises when these hollow forms are associated with decomposition products or subsequent metamorphism, as is the case with many ancient lavas, or even with recent ones which have been attacked by solfataric or hot spring agencies.

What, then, from a study of this exceptionally fresh and beautiful material, seems to be the most probable origin of lithophysæ, and how nearly the writer's views accord with those of von Richthofen will appear from the following considerations.

The association of fayalite; an iron-olivine, with abundant quartz and tridymite, and acid feldspar in a highly siliceous, igneous rock, containing less than two per cent of iron oxide, is quite contrary to ordinary experience and is not in accord with the generally accepted laws which appear to govern the crystallization of igneous magmas. Moreover, two of the accompanying minerals, prismatic quartz and acid feldspar, have not been reproduced artificially by simple igneous fusion, as has been demonstrated by the repeated experiments of MM. Fouqué and Michel-Lévy,\* who, though successful in obtaining most of the minerals found in igneous rocks, have failed to reproduce by dry fusion quartz, orthoclase and albite in forms similar to those in which they are found in acid eruptive rocks.

On the other hand quartz, tridymite, orthoclase and albite have all been obtained artificially by aqueo-igneous processes, on heating their chemical elements in the presence of water in

\* "Synthèse des Minéraux et des Roches," Paris, 1882.

sealed tubes. The experiments of MM. Friedel and Sarasin,\* upon the reproduction of orthoclase and albite are especially applicable to the case of lithophysæ. Among the forms of orthoclase produced was that of adular, also observed in the hollow spherulites. Along with orthoclase they obtained quartz and at higher temperatures tridymite. Other experiments, especially those of K. von Crustschoff,† have established the same relation between quartz and tridymite when formed in closed tubes. Tridymite being produced at a higher temperature than quartz, and frequently both occurring together within the same closed tube.

Magnesia olivine and magnetite have each been reproduced by aqueo-igneous methods, and fayalite is a common product of puddling furnaces. So that the group of minerals composing the lithophysæ in this obsidian are such as may be formed through aqueo-igneous processes.

The well-known experiments of Daubrée,‡ on the effect of superheated steam on a glass tube, have a special bearing on the question under consideration. The glass used by Daubrée differed in chemical composition from that of the obsidian, but the general nature of the results bears a striking similarity to many characteristic features of lithophysæ. The anhydrous glass was partly converted into a hydrous silicate, accompanied by considerable increase of volume; part was reduced to a white mass distinctly fibrous with a delicate banding parallel to the surface of the glass tube and across the direction of the fibres. The surface of the tube was in places warped, blistered and excoriated, and often full of cracks. There was, also, a delicate foliation parallel to the surface of the tube. Under the microscope the altered glass contained minute spherulites, microlites, and small crystals of pyroxene (diopside), and larger spherulites, probably chalcedony. The surface of the glass was covered with prismatic crystals of quartz. The transformation was wholly produced by the influence of superheated steam.

In the case of the obsidian from Obsidian Cliff, chemical analyses show a loss upon ignition of 0.66 per cent. That this loss is mostly due to water seems probable from the researches of MM. Boussingault and Damour, and others, whose very careful tests have shown the presence of water and a little chlorine in a number of obsidians. That this amount of volatile matter is sufficient to convert the dense obsidian into pumice like that on the surface of this lava flow, is shown by melting a frag-

\* Bull. Soc. Min., 1879, ii, p. 158, and 1880, iii, p. 171; also Comptes Rendus, 1881, xciii, p. 1374, and 1883, xcvi, p. 290, 294.

† Amer. Chem., 1883. Also Tschern. miner. u. petrogr. Mitth. iv, p. 536.

‡ Etudes Synthétiques de Géologie Experimentale, 1879, p. 154 to 179.

ment of the obsidian in the flame of an oxyhydrogen blowpipe, when it becomes a greatly inflated white glass filled with gas bubbles which arise from the expansion of the liberated vapors. This shows that the gases which escaped at the surface with the formation of pumice were imprisoned in the dense obsidian which solidified lower down in the mass. As already stated, the larger spherulites are filled with multitudes of gas cavities recognizable under the microscope.

These vapors were, undoubtedly, absorbed by the molten lava before its eruption, and were the only gases which may have taken part in the production of lithophysæ, for chemical analyses of the obsidian, spherulites and lithophysæ show that they have essentially the same chemical composition. The analyses of spherulites and lithophysæ which occurred isolated in dense, unfractured obsidian are enough alike to be duplicates. The composition of both being the same, the transformation of a spherulite into a lithophysa, can only be a modification of its structure or a rearrangement of its minerals without any chemical addition or loss. Moreover, it is evident that such a transformation was in many cases effected by agencies entirely within the area of the lithophysæ, for they often occur isolated in the dense obsidian having no connection with other cavities or sources of vapor.

The change took place before the surrounding matrix had solidified, for in some instances the lithophysæ have been crushed, probably from a change of equilibrium in the lava, and the plastic matrix has been forced part way into the cavity of the lithophysa, which indicates that the matrix was still viscous and at a high temperature when the modification of the spherulite took place. And finally, though the matrix was plastic at the time of the formation of the cavities of lithophysæ the liberation of gases did not expand or distend the substance so as to form the concentric shells, for where a lamination is present in the matrix it is also seen traversing the shells of a lithophysa without change of direction.

From the foregoing it seems reasonable to infer that these lithophysæ, composed of prismatic quartz, tridymite, soda-orthoclase, fayalite and magnetite, *are of aqueo-igneous origin, and have been produced by the action of the absorbed gases upon the molten glass from which they were liberated during the crystallization consequent upon cooling.*

Instances where the layers of thinly laminated rock arch over hollow lithophysæ and seem to have been pushed back by expanding gases, to which von Richthofen calls attention, are more probably slight flexures in the layers of the rock which have occasioned local relief of pressure and the disengagement of vapors which might give rise to the lithophysa,



than the result of the expansion of such vapors. For the field study of the rock at Obsidian Cliff shows that in places it was so stiff and viscous before coming to its final rest that some layers which were pulled apart in descending the underlying slope never closed together again. Hence it is likely that local inequalities of pressure might be brought about by the crumpling of so viscous a lava.

We may imagine the process of formation of a lithophysæ to have been somewhat as follows: In the still plastic glass from a center of crystallization a multitude of incipient microlites of feldspar radiated through a sphere of glass. As these anhydrous microlites increased in size the nature of the cementing paste was changed. Being impoverished of alumina and alkalis, it became more siliceous and relatively more hydrated. A point was reached where the absorbed vapors could no longer be retained in combination, but were released in innumerable bubbles which were either uniformly disseminated through the paste or aggregated into larger bubbles. The gas thus liberated acted as superheated steam and eventually produced the separation and crystallization of all the elements of the original sphere of plastic glass. Before the final crystallization of the paste when the hydrated glass gave up its combined vapors and became anhydrous, it shrank in consequence of the reduction of volume and produced in some cases the cracks so frequently observed. That these cracks were formed before the final crystallization of the cementing paste is shown by the deposition on their walls of crystals of quartz, tridymite and fayalite. The conditions which produce a concentrically banded structure in some solid spherulites are most likely the same as those which lead to the formation of concentric shells in many lithophysæ. It is evident that the development of lithophysæ in a lava will depend upon a number of conditions both chemical and physical, the discussion of which is omitted from this paper.

*Laminated structure.*—The lithoidal portion of the obsidian flow which forms Obsidian Cliff is beautifully laminated in thin layers of light and dark shades of a purplish gray color, which differ in their relative denseness and degrees of crystallization. The more crystalline layers are full of minute cavities and thus become planes of weakness in the rock, which splits into thin plates, often not more than  $\frac{1}{16}$  of an inch thick. So that the lithoidal rock is traversed by a multitude of nearly horizontal cracks which follow the planes of flow through all their contortions. It is this inherent lamination or layer structure, so commonly observed in the more acid lavas and especially the rhyolites of the Yellowstone National Park, which was alluded to in the paper on columnar structure published in

this Journal in May, 1886 (page 325.) It was there considered to be of different origin from the tabular parting produced by rapid cooling near the surface of a body of molten rock.

The origin of the more general lamination which in one form or another usually extends throughout the whole mass of many lava flows will be readily understood from the following:

In a fluid free to flow over a horizontal surface the movement of its molecules will meet with least resistance in directions parallel to the plane of that surface, the fluid will therefore spread horizontally, and its molecules will move in planes parallel to the underlying surface. Particles suspended in the fluid will be carried along these planes, and portions of the fluid which contain different amounts or different kinds of suspended matter will be spread out in layers along these planes of flow.

In volcanic lavas the production of such layers will depend on the lack of homogeneity and viscosity of the magma, and the distance over which the lava flows. The more basic lavas are usually more liquid and consequently more homogeneous at the time of eruption, and show little if any signs of layer-structure in the solidified rock. But acid lavas such as rhyolite appear to be more viscous and less homogeneous when erupted, and slight variations in the consistency or composition of the mass show themselves as bands and streaks of colors or as layers of differing microstructure and degree of crystallization. These layers of different consistency were probably lenticular or quite irregularly shaped portions of the magma near the place of its eruption, and are more perfectly and thinly laminated the farther from the source.

The nature and cause of such local differences in the magma is suggested by a consideration of the structure of the various layers of the rock forming Obsidian Cliff. The lithoidal rock presents layers which differ in their degree of crystallization, some being wholly uncrystallized and glassy. Some are finely spherulitic, others coarsely so and porous; and others are quite granular and full of cavities. In the obsidian the differences find expression in layers of spherulites, and bands of lithophysæ; in layers more or less rich in granophyre feldspars, microspherulites, microlites and trichites; that is, in the different phases and amount of crystallization developed. Nearer the surface of the obsidian flow there is less crystallization, but the lamination of the rock is quite as noticeable in the more marked differences in the amount of microlites in the various layers and in the abundance of gas cavities which produce alternating bands of vesicular and dense glass and pumice. While at the surface of the flow the whole rock is openly pumiceous.

From the different extent to which the various layers of this glassy rock have been inflated by the expansion of gas near the surface of the flow it is evident that there was a difference in the amount of vapors previously absorbed by these layers. And from the part which superheated water has undoubtedly played in the development of lithophysæ and the larger, porous spherulites, and from the aqueo-igneous conditions deemed necessary for the production of the granophyre groups of quartz and feldspar, it seems highly probable that *the differences in consistency and in the phases of crystallization producing the lamination of this rock were directly due to the amount of vapors absorbed in the various layers of the lava and to their mineralizing influence.*