21. *On HOLLOW SPHERULITES and their OCCURRENCE in ANCIENT BRITISH LAVAS.* By GRENVILLE A. J. COLE, Esq., F.G.S. (Read March 11, 1885.)

[PLATE IV.]

It is now quite unnecessary to call attention to the fact that many of the Silurian "felstones" of North Wales were originally lavas of a highly glassy type. The investigation of their characters by Mr. Rutley* and Prof. Bonney†, and their comparison with volcanic rocks of far later periods, has fairly removed them from the convenient class of felstones, and given them a stricter position as altered rhyolites, trachytes, or obsidians. Perlitic, spherulitic, and banded structures have been recorded in them; the present paper deals with a structure which has been often noticed, and which is far more obvious to the eye, its original character being, however, veiled by much subsequent alteration.

Every one who has examined the group of Bala lava-flows in the Pass of Llanberis, notably at the foot of Esgair-felen, the great spur of the Glyder-fawr‡, or on the slopes leading to Cwm-glas, must have observed whole masses of the compact grey rock crowded with white or brownish spheroids. These are especially conspicuous on weathered surfaces, or where a great joint-plane has made a section through some hundreds, their diameters ranging from less than a tenth of an inch to fully two and a half inches. Some are evidently radial aggregates, whether concretionary or amygdaloidal it would be hard at first to say; but others, and by far the most striking, are mere hollow nodules, giving the rock a coarsely vesicular aspect. Clear quartz-crystals often line the inner surfaces, and it is noteworthy that the matrix has frequently the schistose character so fully described by Prof. Bonney in the case of felsites near Bettws-y-Coed§. This may admit of considerable percolation of water and the deposition of minerals in cavities already formed. That these cavities are not, however, produced by indiscriminate weathering of the matrix, but have some connexion with the original condition of the lava-stream, is in places shown by the sharp demarcation between a nodular bed and that immediately succeeding it.

The solid spheroids, as a rule, seem composed of dense felsitic matter; if, however, they are not the result of the process of infilling that is in progress in the hollow nodules, the passage from one type to the other is so gradual that a complete explanation of the structure should cover both extremes.

Before entering into any details with regard to these ancient examples, it may be well to look for similar structures among com-

* "On Perlitic and Spherulitic Structures in the Lavas of the Glyder Fawr," *Quart. Journ. Geol. Soc.* vol. xxxv. p. 508; "On Devitrified Rocks from Beddgelert and Snowdon," *Quart. Journ. Geol. Soc.* vol. xxxvii. p. 403.

† "On some nodular Felsites in the Bala Group of North Wales," *Quart. Journ. Geol. Soc.* vol. xxxviii. p. 289.

‡ See Geological Survey of England and Wales, Horizontal Sections, Sheet 31.
§ *Quart. Journ. Geol. Soc.* vol. xxxviii. p. 291.

$\times 12.$

$\times 7.$

$\times 75.$

$\times 1\frac{1}{2}.$

5.

$\times 5\frac{1}{2}.$

paratively recent lavas. It appears that until 1860, certain unusually large segregations in the glassy rhyolites of Hungary had been classed with ordinary spherulites. In that year, however, Von Richthofen, in his paper entitled "Studien aus den ungarisch-siebenbürgischen Trachytgebirgen"*, considering that many of these bodies were hollow in the centre, and in some respects resembled the vesicles of scoriaceous lava, described them under the name of "Lithophysen." He believed that inclusions or segregations of highly siliceous matter had been, during the consolidation of the lava, blown up into bladder-like forms by the steam that they contained. The toughness of the surrounding glassy matrix prevented the immediate escape of the steam, and caused these vesicles to accumulate as hollow spheroids, their walls being formed from the original segregated matter. When cut across, their cavities are seen to be divided into chambers by dome-like lamellæ, one above the other, as if produced by successive expansions of the gas. In some cases the solid part of the "Lithophyse" is in a loose and powdery condition. The glassy matrix shows pronounced perlitic structure, and is often reduced to a mere honeycomb by the abundant development of the cavities.

Szabó, however, in 1866 †, represented the hollow nodules as nothing but altered spherulites, the removal of the material from the interior, partly in solution, partly as fine powder, having left a series of chambers which often follow the lines of the original concentric structure. He states that every successive stage of alteration is to be found, and believes that a gradual concentration of silica occurs in the layers that remain. These become finally strengthened by a deposit of quartz-crystals upon their surfaces.

It might still have been argued that the material found partially or even completely occupying the centres of these Hungarian spheroids was merely a product of infiltration; but in addition to chemical evidence given by Szabó, Karl von Hauer ‡ published, a few months later, analyses both of the ground-mass surrounding the "Lithophysen" and of their contents. His results may be thus compared:—

	Average of three Analyses of the Ground-mass.		Contents of the Lithophysen.
Silica	76·72		75·91
Alumina	12·72	}	14·98
Ferric oxide	1·80		
Lime	1·46		0·94
Magnesia	0·26		0·34
Potash	4·10		3·07
Soda	2·88		3·36
Loss on ignition	0·74		1·30
			99·90

* Jahrbuch der k.-k. geol. Reichsanstalt, 1860, p. 180.

† "Die Trachyte und Rhyolite der Umgebung von Tokaj." Jahrb. der k.-k. geol. Reichsanstalt, 1866, p. 89.

‡ "Die Gesteine mit Lithophysenbildungen von Telki-Banya." Verhandl. der k.-k. geol. Reichsanstalt, 1866, p. 98.

There is, then, no essential difference between the composition of the matrix and the solid portions of the nodules, and the latter are therefore far more likely to have been produced from the rock by devitrification during cooling than by any subsequent alteration.

Two determinations bearing out this view are given of the specific gravity of the groundmass, viz. 2.410 and 2.403, that of the material of the "Lithophyse" being 2.420. The figures expressing "loss on ignition" in the analyses may, slight as the difference is, suggest that decomposition has already begun in the devitrified portions of the rock.

J. Roth*, commenting on Von Hauer's analyses, fully agrees with Szabó in regarding the hollow structure as the result of the decomposition of spherulites, and this opinion appears to be generally adopted. Zirkel† has thus referred to "Lithophyses" from the Yellowstone area as "sphaerolites nearly as thick as a walnut, that develop, by decomposition, the concentric layer-structure," all stages occurring "between sphaerolites in the natural state and cavities in which there are five or six shells with their isolated borders." Mr. William Semmons has kindly allowed me the use of specimens showing similar features, which he collected from the obsidian cliffs of Beaver Lake.

E. Weiss‡, dealing with a group of rocks from the Thüringian Forest, insists on the fact that here also the hollow spheroids met with are nothing but larger spherulites, and points out that the solid parts of both show radial structure in thin sections; but he returns towards the older theory of Von Richthofen in suggesting that material separating from a glass may be built up around a vesicle.

We are left, then, with two possible explanations of the hollow nodules found in lavas. Their outer and solid portion may safely be ascribed to spherulitic segregation from the matrix; but the inner cavity may be either the result of weathering upon a complete spherulite, or a steam-vesicle that has acted, like an included crystal or foreign body, as a centre of devitrification during cooling.

It does not appear that any real evidence has been brought forward in support of the latter view; but as a vesicular origin has been assigned to some of the Welsh nodular felsites§, and perhaps, by implication, to those of the Llanberis Pass, it may be well to inquire whether the decomposition of spherulites is not in reality sufficient to explain the characters of these rocks.

The determination of the conditions under which exceptionally large spherulites arise must be left to those who are studying the devitrification of artificial glass. Such forms are so frequently associated with small ones that the variation in size of the Silurian nodules is no evidence against their being all of common and

* Beiträge zur Petrographie der plutonischen Gesteine, 1869, p. 168. Also Allgemeine und chemische Geologie, 1883, vol. ii. p. 9.

† U.S. Exploration of the 40th Parallel, Microscopical Petrography, p. 212.

‡ Zeitschrift der deutschen geol. Gesell. 1877, vol. xxix. p. 421.

§ Quart. Journ. Geol. Soc. vol. xxxviii. p. 295.

spherulitic origin. There may be made out, however, among later lavas two classes of large spherules, which are merely extensions of structures familiar enough upon an ordinary scale.

We know, for instance, how in many obsidians the spherulites prove on microscopic examination to be mere cloudy aggregations, with perhaps the faintest trace of radial structure. Thus in a beautiful example from Iceland, numerous brown irregular patches are seen separating out along the lines of banding; since crystallization has not gone so far as to condense into microliths the globulites of which they are formed, these little nodules show the banding and even the fluidal structure of the matrix passing uninterruptedly through them. Their relation, indeed, to these probably earlier structures is that of concretions in sedimentary rocks to the beds in which they lie (Pl. IV. fig. 1).

In proportion as slower cooling allows of the radial grouping of the constituents, so the drawing together of the material towards a centre tends to sharpen the limit between the spherulite and the glass, until a crack is often the result. Usually, however, the outer border of even these well-marked forms contains a large amount of glass, and frequently concentric coats of similar cumulitic and glassy matter intervene between the radial zones.

Taking now sections of the obsidian with "Lithophysen" from Beaver Lake, we find in places no distinct boundary between the grey nodular aggregations and the banded structure of the glass (Pl. IV. fig. 2). The lines of minute spherulites run into the larger felsitic masses; and the latter, though probably somewhat altered since the consolidation of the lava, contain throughout the same rod-like form of crystallites as is abundant in the surrounding matrix. The felsitic substance is distinctly cryptocrystalline, its ill-defined particles polarizing in colour; and a very rough attempt at concentric arrangement occurs in portions of the nodules, the lines being brought out in hand-specimens by unequal weathering. Such irregularly bounded nodules may be broadly regarded as segregations of rhyolite in rhyolite-glass. They are localizations of such stony material as, in longer process of cooling, might have finally spread throughout the mass.

The equally irregular central hollows bear no resemblance to steam-vesicles, while signs of alteration are very evident in the felsitic matter round them. Flakes of hæmatite, red by transmitted light and giving an iron-reaction before the blowpipe, are developed in the powdery mass; and the beautiful rod-like crystallites, clear and colourless in the matrix, have, in these decomposing nodules, been either converted into or replaced by a red-brown ferruginous product. While the specific gravity of the glass is 2.41, that of the nodule, obtained by means of the bottle, is only 2.31, a result pointing towards hydration of the constituents rather than towards such a concentration of silica as Szabó refers to in the case of the Hungarian "Lithophysen" *.

If, then, the nodular obsidian of Beaver Lake appears to reproduce

* Jahrb. der k.-k. geol. Reichs. 1866, p. 89.

on a large scale the imperfect type of spherulitic structure, the famous Hungarian examples bear the same relation to the concentric and well-marked radial types. The "Lithophysen" in a rhyolite brought by Prof. Judd from Lipari have affinities with both groups; and reflection will show that towards the centre of such a felsitic segregation as has been described the material may often tend to become more and more fully crystalline. Thus in smaller cases—an obsidian from Vulcano, for example—the colourless radial groups of crystallites form independent well-bounded spherulites in the midst of brown clouds of globulitic dust.

A superb example of hollow spherulitic structure occurs in an obsidian brought from Iceland by Mr. J. Starkie Gardner. The brown spherules, sometimes single, sometimes intergrown, show radial structure to the naked eye, and, as might perhaps be expected, a sharp crack divides their outer surfaces from the glass. Even in the cases one may meet with in breaking the specimen across, the inner cavities are often very large in proportion to the fibrous shell; but here, again, we see nothing of the smooth curving surface of a steam-vesicle. The microscope shows the solid portion of the spherules to consist of delicate radially grouped fibres, with some trace of a concentric structure near the outer margin. The inner extremities of these fibres are, as it were, frayed out, with signs of the formation of secondary minerals between them (Pl. IV. fig. 3). Everything, indeed, again points to the conclusion that the hollow structure is only a result of decomposition.

Now lava-streams are especially subject to the attacks of acid vapours, of steam, and of water of high temperature, during the later stages of eruption *, and the numerous cracks of the glassy varieties will afford access to all portions of their mass. The parts most likely to be affected are any feldspathic crystals that may be included, the crystallites of magnetite that may have separated out, and the spherulites that are most differentiated from the glass.

Long ago Scrope † pointed out that such "globular concretions" are first acted upon by decomposition, and give rise to some of the forms of "variolite," though he does not definitely refer the hollow spherulites that he noticed in the perlites of the Ponza Isles ‡ to any process of alteration. The more developed their radial structure, the more planes of weakness will the spherulites contain; and at the very centre, where the individual fibres terminate, the decomposing agents will probably find good hold. At the same time the outermost layer of the spherule, between which and the glass there is often small cohesion, will become reddened with iron alteration-products and perhaps appreciably dissolved. Where radial and partly vitreous layers alternate, the former perish while the latter remain. This may be illustrated by banded obsidians from Lipari, in which all stages of the process can be made out easily with a

* Compare Judd, "Volcano of Schemnitz," *Quart. Journ. Geol. Soc.* vol. xxxii. p. 322.

† Considerations on Volcanoes, 1825, p. 118.

‡ *Trans. Geol. Soc.* series ii. vol. ii. pp. 202 and 218.

lens; and there can be little doubt that the original "Lithophysen" are records of exactly the same action. It is interesting to find very similar appearances in our ancient rhyolites of the Wrekin, the roughly concentric cavities formed by the weathering of large spherules becoming lined with crystallized quartz (Pl. IV. fig. 4). The red earthy fibrous centres of the ordinary Wrekin spherulites*, contrasting with their clearer borders, are probably similar evidence of the more ready decomposition of the radial and perhaps more basic portions.

The one difficulty of this view of the formation of hollow spherulites is the getting rid of the kaolin that will, in all probability, be formed. But, even if the alumina is not removed in soluble combinations, the extreme minuteness of kaolin-particles will enable them to enter and pass along the cracks of a vitreous lava with comparative ease. Perlitic fissures, to which the more obvious joints of a hand-specimen are veritable gullies, may at last become choked, but are none the less active as transporting channels. Some of them, in an interesting specimen brought by Mr. Caruthers from the Yellowstone area, measure from .02 to .06 millim. across; and the sharpness of their edges removes the suspicion that they may have been much widened by decomposition. Now large particles of kaolin, such as one may rub off altered felspar with the finger, may measure .01 millim. and more; but the material washed down naturally from a granite area is seen to consist of specks far smaller, .004, .002, .0015 millim. or less in diameter. The way in which kaolin-dust penetrates all the cracks of a decomposing granite, and even the planes of separation between different minerals, is fair evidence of its capacity for wandering from its parent source; and the frequent occurrence of "Lithophysen" in rocks showing perlitic structure may be due to the greater number of channels there provided through which the alteration-products may run their course†.

To return at last to the Silurian felsites of the Llanberis Pass, we find in microscopic sections ample proof of their spherulitic character and of the community of origin of both solid and hollow nodules (Pl. IV. fig. 5). The relics of radial structure are faint but indubitable, and the junction of the spherules and the glass is usually well defined. Quartz may be seen developing among the crypto-crystalline fibres, and brilliantly surrounding the central hollow when it occurs. But in place of this cavity in several cases are the remains of original smaller spherulites, apparently of more complete development than the surrounding felsitic nodule, and therefore more liable to decay.

* S. Allport, "On certain ancient devitrified Pitchstones and Perlites from Shropshire," *Quart. Journ. Geol. Soc.* vol. xxxiii. p. 454.

† I cannot refrain from here referring to a case bearing, perhaps distantly, on hollow spherulites. In much-altered granite (luxullianite) boulders on the slopes above the inlet of Nanjisa, near the Land's End, many of the felspar-crystals are found to be nothing but hollow shells lined with well-developed quartz. In places this infiltrated silica has entirely replaced the orthoclase and formed solid pseudomorphs that are completely deceptive at a distance.

Sometimes singly, sometimes in groups, these centres of the larger nodules point to the origin of much of the hollow structure ; while in other cases, just as in the Yellowstone obsidian, the decomposition may have ramified through fairly uniform segregations.

The matrix, now much altered, is magnificently perlitic, and the removal of any kaolin would thus prove easy ; but the rock is also rudely cleaved, the spherules themselves have occasionally been faulted, and ample time has been allowed since the dying-out of Snowdonian fumaroles and hot springs for the work which, doubtless, began to be silently carried on to our own day. If, as I hope, one of the more perplexing structures of our ancient lavas may be adduced as additional evidence of their similarity to those of modern days, the object of these notes will have been amply served. It is probable, however, that no petrographical characters, nothing, indeed, short of stratigraphical evidence and comparison from point to point, can absolutely define the relations of an igneous mass. The orbicular segregations of a deep-seated rock, classed as spherulites by Vogelsang, but defined as "belonospherites" rather than "felsospherites" *, might in time give rise to hollow nodular structure. On the other hand, the complete demolition of the spherulite, an operation going on in the Icelandic specimen of Mr. Starkie Gardner, may in future ages reduce such a rock, whether it occur as an interbedded or intrusive mass, to the level of a scoriaceous obsidian or an amygdaloid.

In conclusion, my best thanks are due to Prof. Judd for kind help and many illustrative specimens, and also, as before mentioned, to Mr. William Semmons. Most of the rock-sections referred to have been prepared in the Geological Laboratory of the Normal School of Science and Royal School of Mines.

EXPLANATION OF PLATE IV.

- Fig. 1. Section of obsidian from Iceland, with ill-defined spherulites developing along the lines of banding. $\times 12$.
2. Section of obsidian from Beaver Lake, Yellowstone Park, for comparison with the above, showing part of the outer margin of a large hollow spherulite, with the banded structure of the glass passing into it without interruption. Some of the bands are composed of minute spherulites. $\times 7$.
3. Section of part of the inner margin of a large hollow spherulite in obsidian from Iceland, showing a tendency to the formation of secondary minerals between the fibres of which it is composed. $\times 75$.
4. Broken surface of altered rhyolite from the Wrekin area, showing large spherulite with structure characteristic of "Lithophysen," the cavities being lined with crystallized quartz. $\times 1\frac{1}{2}$.
5. Section of large hollow spherulite in altered perlitic from Esgair-felen, Pass of Llanberis. The left-hand portion contains an inner nucleus with well-marked radial structure ; the right-hand portion contains an irregular cavity partly filled with quartz. $\times 5\frac{1}{2}$.

* Die Krystalliten, p. 134.

DISCUSSION.

Mr. RUTLEY bore testimony to the careful observations of the author of the paper. The only cases in which he felt any doubt were those in which the irregular form of the nodules did not seem to be altogether reconcilable with their spherulitic origin.

The PRESIDENT was not able entirely to agree with the author ; for while his explanation might account for some of the structures, yet many seemed to be due to an original vesicular character of the lava. He adduced cases which he thought could only be accounted for by the expansion of vapour-bubbles in a glassy rock, disturbance of equilibrium being capable of inducing crystallization.

The AUTHOR stated that he did not intend to apply his explanation generally, but only to the cases he had examined. Some of the irregularities in the form of the spherulites are due to crushing and faulting of the rock in which they are enclosed.