33. *On the SPHEROID-BEARING GRANITE of MULLAGHER, Co. DONEGAL.* By FREDERICK H. HATCH, Ph.D., F.G.S., of the Geological Survey. (Read May 23, 1888.)

[Communicated by permission of the Director-General of the Geological Survey.]

[PLATE XIV.]

ON returning from a recent inspection of the field-work of the Geological Survey in Ireland, Prof. A. Geikie brought with him some remarkable specimens of spheroidal concretions, which, on account of their interesting structure, he thought worthy of detailed examination and description. For this purpose they were entrusted to me, and the present paper records my observations.

These bodies were found by Mr. J. R. Kilroe, of the Geological Survey of Ireland, in granite at Mullagher, Dungloe, Co. Donegal. According to Mr. Kilroe, they occur in a mass, measuring 5 or 6 cubic yards, which lies in coarse granite. It consists "of concretionary balls, varying in size up to 6 inches in diameter. The balls are usually flattened and lie almost contiguously, the interstices being filled by granite, which is similar in character to, though much finer-grained than, that surrounding the entire mass."

In a letter I have since received from Mr. Kilroe he informs me that dykes are numerous in the locality where the spheroids occur. One of these passes quite close to the mass containing the concretions; but since the latter are confined to a small space and do not follow the dyke, I see no reason for connecting their formation with its intrusion*.

The Normal Granite.—Of the granite referred to above, Mr. Kilroe was kind enough to furnish me with specimens.

It is a coarse-grained rock, varying in colour from a pale flesh-tint to a reddish brown. The specimens in my possession have a somewhat loose and crumbly texture, which, if general, would

* I have examined a section of the rock from this dyke. It is a porphyrite, consisting mainly of a microcrystalline aggregate of felspar and quartz, the latter being subordinate. The sections of the felspar are bounded partly by rectilinear, partly by irregular contours. Some of the grains are striated; others, on the other hand, show no trace of twinning. It is therefore not improbable that orthoclase is associated with the plagioclase. The quartz-grains may be distinguished from the felspars by their greater pellucidity, their more irregular shape, and by the fact that occasionally a uniaxial interference-figure may be obtained. Traces of micropegmatite are not unfrequent.

Imbedded in this ground-mass are isolated porphyritic crystals of striated felspar, characterized by a marked zonal structure. The extinction-angles reach a rather high value; and from analogy with other porphyrites of this character, the felspar is probably labradorite. Scattered somewhat sparingly through the section are ragged blades and plates of a green small-angled mica. This mineral shows strong pleochroism:— α =pale yellow; β and γ =dark olive-green. Associated with the mica are scales of chlorite, grains of epidote and occasionally of sphene, iron-ore in isolated granules, and apatite in slender prisms.

considerably curtail its application as a decorative building-stone. Its essential components are quartz, potash-felspar, soda-lime-felspar, hornblende, and black mica, with sphene as an accessory constituent. Since there is no white mica the rock must be classed with the granites. It is in fact a *sphene-bearing hornblende-granite*. The dominant felspar occurs in irregularly contoured masses, which are sometimes of such considerable dimensions as almost to give the rock a granito-porphyritic structure. The colour of this mineral, which depends on the amount of weathering, determines the prevalent tint of the rock. Reflections from cleaved surfaces show that almost every crystal is made up of the two hemitropic components of a Carlsbad twin. Its specific gravity, determined by means of Sonstadt's solution and the Westphal's balance, is 2.57. These are the figures assigned by Tschermak to a felspar of the composition Or_3Ab_1^* .

Examined under the microscope, a considerable proportion of this felspar is found to be microcline, presenting, between crossed nicols, the rectangular intersection of spindle-shaped striae characteristic of this mineral. In addition to this structure, suitably directed sections (viz. those in the zone P:M.) show a system of small irregular lamellæ of triclinic felspar (albite or oligoclase), intercalated along the prismatic or macropinacoidal planes. To this intergrowth of orthoclase or microcline with a felspar of the albite-oligoclase series, F. Becke † has given the name of micropertite. Irregular grains of striated felspar (oligoclase) also occur as inclusions in the microcline; less frequent are lamellæ and grains of quartz. This is probably the "*quartz d'infiltration*" of French geologists.

Felspar presenting no striated structure is also abundant. Such felspar, according to the usual practice, is to be referred to orthoclase. A. Michel-Lévy ‡ has indeed made it appear likely that orthoclase and microcline are identical, by showing that the optical properties of orthoclase are such as would be expected to result from an intimate intergrowth of microcline-lamellæ on the albite- and pericline-types. But the identity has not yet been *proved*.

A curious phenomenon, which has been described and figured by Becke §, is also well shown by an isolated section of this felspar. This section is nearly parallel to the orthopinacoid, since it presents the emergence of an axis of elasticity (*a*), and contains two sets of fine, sharply marked cleavage-lines, crossing one another at an angle of 106° . These are the cleavages of P and M, the divergence from rectangularity being caused by the position of the section. An

* Tschermak, "Die Feldspath-gruppe," Sitzungsber. der k. Akad. der Wissens. Wien, Bd. I. Abth. I (1864), p. 579.

"Or" stands for one molecule of orthoclase (K_2O , Al_2O_3 (SiO_2)₆), and "Ab" for one molecule of albite (Na_2O , Al_2O_3 (SiO_2)₆).

† "Die Gneissformation des niederösterreichischen Waldviertels," Tschermak's Min. und Petr. Mitth., Bd. iv. 1882.

‡ "Identité probable du microcline et de l'orthose," Bull. de la Soc. Minéralog. de Fr. (1879), tome ii. p. 135.

§ *Loc. cit.* p. 199.

examination in convergent polarized light shows that the trace of the optic axial plane is coincident with one of the cleavages (P). Parallel to the cleavage-lines are two sets of straight, strongly refractive markings, reticulated as in fig. 1. These lines are dark

Fig. 1.—Section of Felspar showing the cleavages P and M and the markings parallel thereto.

in transmitted, and white in reflected light. They do not extinguish with the main mass of the felspar, the latter becoming dark between crossed nicols at an angle of 5° , the former at one of 14° with the basal cleavage-lines. As Becke has already pointed out, this lination has nothing to do with micropertthitic structure. It may perhaps be due to a deposit of secondary crystalline material along the cleavage-planes.

The decomposition of the orthoclase shows itself in the formation of cumulous aggregates of minute flakes of a brightly polarizing substance—muscovite or kaolin.

The oligoclase occurs only in isolated crystals of rather small dimensions; in colour it is white. Easily recognized by its sharply defined twin-lination, its place in the soda-lime-series is at once given by its small-angled extinction. Its specific gravity is 2.648. These figures fall within the limits assigned by Tschermak and Max Schuster * to oligoclase, viz., 2.645, 2.671.

The quartz, distinguishable by its pellucidity and its numerous liquid-inclusions, belongs to two phases of crystallization, since it occurs both in large allotriomorphic masses and as infillings of the small irregularly shaped interspaces between the larger grains. This younger quartz, representing the residual magma of the rock, is also found sending tongue-like processes into the quartz of earlier origin, thus affording ocular demonstration of their separation in point of time.

The hornblende and mica are scarcely to be separated with the unaided eye. They are generally aggregated in little patches of black shining scales. Isolated and examined in convergent polarized

* "Ueber die optische Orientirung der Plagioclase," Tschermak's Min. und Petr. Mitth., Bd. iii. 1881, p. 153.

light, the mica presents an interference-figure which is practically uniaxial. It belongs accordingly to the biotite-group. Its absorption is exceedingly strong, viz., α =pale yellow; β and γ =black. The hornblende occurs either alone or associated with the mica or with a small quantity of magnetic iron-ore. Its maximum extinction-angle, measured to the vertical axis in the prismatic zone, is 17° . The pleochroism is marked, viz.: α =pale yellow,

Fig. 2.—A twinned Crystal of Hornblende, showing the extinction-angles of the two halves, measured to the trace of the plane of twinning ($\infty P \infty$).

β =deep brownish green, γ =deep olive-green. Twinned crystals occur occasionally, the twinning-plane being $\infty P \infty (100)$. Fig. 2 shows such a twin. Traces of a cleavage parallel to a positive orthodome will also be observed in this figure. A cleavage parallel to the face $P \infty (101)$ has been observed in hornblende by C. Whitman Cross*.

Produced probably by the hydration of the mica, are scales of a bright green chlorite. Sphene occurs in large but isolated grains enclosing granules of magnetite and, in one case, a well-contoured crystal of oligoclase. Occurring as a secondary product in the altered felspar are granules of epidote.

Of all these minerals the oligoclase shows perhaps the greatest tendency to the assumption of crystalline contours. It is, however, nearly equalled in this respect by the hornblende. This, combined with the fact of its occurrence as an inclusion in sphene, should

* "Studien über bretonische Gesteine," Min. und Petr. Mitth. iii. (1881), p. 386.

place oligoclase high up in the order of consolidation of minerals in granite.

The matrix intervening between the balls differs but little from the granite just described. Its texture is a little finer, and it contains perhaps a somewhat greater proportion of oligoclase.

The Spheroids.—The most perfect of the concretionary bodies submitted to me for examination is a somewhat flattened spheroid, the greatest diameter of which is about four inches, and the smallest three. A thin layer of reddish felspar, with which abundant glistening plates of a dark-coloured mica are associated, is the only remnant of the enveloping matrix remaining attached to the peripheral surface. This felspar is orthoclase of specific gravity 2·571, which, it will be seen, is almost identical with that of the orthoclase in the surrounding granite. The mica, too, presents optical properties similar to those of the mineral described above.

In order to investigate its internal structure, the spheroid was cut through the centre, and one of the halves polished. Sections * showing both central and marginal portions of this and other spheroids were also prepared.

Two distinct parts were then clearly to be made out:—a pink felspathic nucleus, and a dark-coloured peripheral shell. Measured in section, the diameter of the nucleus is about $1\frac{1}{2}$ inch; while the width of the external zonal portion is about 1 inch. The outer periphery of the spheroid is regular and sharply defined, being marked off from the granitic matrix in which it is imbedded by the dark colour of the marginal portion. A closer examination discloses the fact that this dark colour is not, as at first sight appears, uniformly diffused; for the main mass is found to consist of a colourless and transparent mineral, enclosing innumerable granules of a black, opaque substance, with metallic lustre. Nor are the granules without order in their distribution, being disposed in more or less definite rings so as to produce a marked concentric structure (see fig. 1, Pl. XIV.).

The boundary of the nucleus, on the other hand, is irregular and wanting in sharpness. This is caused by an almost imperceptible transition (due to a gradual increase in the number of black granules) of the nucleus into the outer zonal portion.

Submitted to microscopic examination, the nucleus is found to consist of an irregular hypidiomorphic granular aggregate, chiefly of trichlinic felspar, presenting well-defined twin-striation often on both albite- and pericline-types. This twinning is extremely sporadic in its occurrence, one and the same grain often showing no trace of striation in one place, while in another the twinning is well marked. Though occasionally clear and fresh, the felspar has often suffered from kaolinization, turbid patches being developed in consequence. Such alteration generally follows the cleavage-cracks, but in some

* I have great pleasure in expressing my admiration of the way in which these sections have been prepared by Mr. J. Young in the laboratory of the Geological Survey at Edinburgh. Though of unusually large size, they are of sufficient thinness to show the minutest structural details.

cases prefers the twinning-planes. A few grains of unstriated felspar are possibly orthoclase. Wedged in between the felspar-masses, and evidently of later consolidation, is allotriomorphic quartz with liquid-inclusions. Accessory grains of sphene are also peculiar to this part of the spheroid.

As the outer zone is approached, granules of the black opaque mineral and plates of brown mica become more and more frequent; at the same time the quartz gradually ceases to occur. The bulk of this portion of the spheroid consists also of plagioclase felspar, differing from that of the nucleus only in the mode of arrangement. For the most part, it appears, under the microscope, in wedge-shaped sections, the longer sides of which converge towards the centre. Of the remaining two sides, the broader base forms part of the external periphery, while the other end terminates irregularly or unites with the felspar of the nucleus. This radial orientation of the felspar is distinctly indicated in certain parts of the section by an approximate coincidence of the twin-striae (when viewed between crossed nicols, or when marked by an alternation of turbid and clear lamellae) with the direction of the radii of the spheroid (see fig. 4, Pl. XIV.). Such cuneate sections must represent rudely conical or pyramidal masses of felspar which radiate from the nucleus, their broad bases forming part of the external surface of the spheroid. In the polished specimen the sections of the felspar-cones are easily recognizable by the unaided eye. They are distinguished from the intervening material by a faint chatoyant lustre, apparently caused by reflection from internal surfaces. When the conical masses are contiguous, the line of junction appears, in thin section, as a series of steps, which are well brought out by the contrast of the different polarization-tints. Cross-twinning, on the albite- and pericline-types, is not unfrequent, the more persistent striation being, almost without exception, in the radial direction. Many of the wedge-shaped masses are, however, entirely free from polysynthetic twinning.

Scattered plentifully through the sections are grains of the opaque mineral. These are of elongated form, being often 10 or 12 times as long as broad, and show, here and there, octahedral terminations. Disposed invariably with their long axes in the radial direction, they appear, at first sight, distributed irregularly over the section. A nearer examination, however, discloses the fact that, in more than one instance, they are ranged, at equal distances from the centre, side by side so as to produce the concentric marking referred to above (see figs. 1, 3, Pl. XIV.). This phenomenon clearly indicates simultaneous separation of the opaque granules in concentric zones of growth, the latter evidently proceeding from the central portion outwards.

More sparingly present are small plates of the brown mica. This mineral shows strong absorption, and, since it possesses an extremely small optic angle, may be classed with the biotites. Still less frequent are scales of a green chlorite-like substance, resulting, most likely, from the alteration of the mica. An isolated flake of colourless muscovite was also observed.

In order to determine the nature of the felspar and of the black opaque mineral, a portion of the spheroid was detached and, after being freed from its outer coating of orthoclase, crushed in a steel mortar. From the powder small fragments of about 1 cubic millim. were sifted out, and of these a few selected which were as free as possible from the opaque inclusions. Tested for their flame-reactions by Szabó's method, these fragments gave results indicating a lime-soda-felspar of intermediate composition. The fusibility, on Szabó's scale, is 4.

The fragments were now further crushed until the whole powder was sufficiently fine-grained to pass through a piece of fine cambric, stretched across the mouth of a beaker to serve as a sieve. On going over the powder carefully with a small bar-magnet, the black opaque granules were easily removed, and were found to be completely soluble in hot hydrochloric acid. These are properties of magnetic iron-ore. The total weight of the powder was 3.07 grm., that of the magnetite removed .37 grm., or 12.1 %.

The remaining powder was then introduced into a Sonstadt's solution of such strength that in it calcite (sp. gr. 2.715) just remained suspended. On standing, a dark powder separated, and was removed. This, examined under the microscope, was found to consist mainly of biotite, but mixed with fragments of felspar (rendered specifically heavier by minute inclusions of magnetite) and a small quantity of isolated magnetite.

The solution was then carefully diluted until the remaining powder (felspar) appeared neither to sink nor to rise. The specific gravity of this solution, taken at 15° C. by means of a Westphal's balance, was 2.649. This is almost identical with the result obtained for the specific gravity of the plagioclase of the surrounding granite (*vide ut supra*). In a solution in which orthoclase (of sp. g. 2.571) floated, the whole powder sank to the bottom, proving conclusively that no orthoclase is present in the zonal portion of the spheroid.

A chemical analysis of this powder gave the following results:—

SiO ₂	60.99
Al ₂ O ₃ (with a little Fe ₂ O ₃)....	25.56
CaO.....	4.88
Na ₂ O *.....	7.73
Loss on ignition	.84
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	100.00
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* By difference.

This agrees very nearly with the theoretical composition of an oligoclase of the formula Ab₃An₁ †.

To sum up shortly these results, we find that the spheroids consist of two parts:—a pinkish central portion (the *nucleus*) and a

† Oligoclase of the formula Ab₃An, has the following composition:—Si₂O=61.9; Al₂O₃=24.2; CaO=5.2; Na₂O=8.7. Tschermak, *l. c.*

broad dark-coloured *peripheral shell*. They are evidently more basic than the surrounding granite; while of the spheroids themselves the marginal portion is more basic than the nucleus, the latter consisting principally of trichinic felspar together with a little quartz and possibly orthoclase, the former of oligoclase with abundant included plates of biotite and over 12 % of magnetic iron-ore. The felspar of the zonal portion is disposed radially, the iron-ore radially and concentrically, while no fixed law appears to govern the distribution of the mica. The concentric accumulation of the magnetite may be compared to the zonal inclusion of foreign minerals in leucite or in the felspars of andesitic rocks.

Literature.—Concretionary bodies have long been known to occur in granite; but these, though often of spheroidal shape, have generally been described as destitute of radial structure. A concentrically laminated structure, frequently only rendered visible by weathering, is, however, not uncommon.

The first mention I have been able to find of such bodies is in Leopold v. Buch's 'Geognostische Beobachtungen auf Reisen durch Deutschland und Italien'*. On p. 16 he describes, as occurring in an intrusive granite of the Riesengebirge ("Felsen des Kynasts" near Warmbrunn, Silesia), balls of a very fine-grained granitic material, which towards the exterior are richer in mica than in the central portion. Gustav Rose†, in 1842, gave a more detailed description of these bodies. His specimens were derived from Schwarzbach and the Kynast. He describes balls of 6 inches diameter. The central portion of these is formed by one or more twinned crystals of orthoclase, around which lies a narrow zone of albite and mica.

Curious concretionary spheroids in the granite of Chanteloube (Département de la Haute-Vienne) are described by Alluaud‡. The dimensions of these bodies are from 50 cm. to 1–2 metres. They consist essentially of a nucleus of orthoclase, surrounded by a finely granular aggregate of quartz and felspar, the quartz gradually diminishing in quantity towards the periphery.

Charpentier§, Collomb||, Jokély¶, and von Andrian** mention similar bodies.

Zirkel†† describes, in the granite of Clark's Peak, Medicine Bow Range, U.S., small aggregates of granular magnetite surrounded by a fine-grained zone of quartz, felspar, and muscovite.

Not unfrequently the concretions consist, for the most part, of

* Vol. i. (1802).

† Poggend. Ann. vol. lvi. 1842, p. 624; and J. Roth, Erläuterungen zu der geognost. Karte vom niederschles. Geb. &c. 1867, p. 63.

‡ Bull. de la Soc. géol. de Fr. (2), vii. 1850, p. 230.

§ 'Essai sur la constitution géognostique des Pyrénées,' 1823, p. 132.

|| Bull. de la Soc. géol. de France (2), vii. 1850, p. 297.

¶ "Geognost. Verhältnisse in einem Theile des mittleren Böhmens," Jahrb. k.-k. geol. Reichsanst. 1855, p. 375.

** "Beiträge zur Geologie des Kaurimer und Taborer Kreises in Böhmen," Jahrb. k.-k. geol. Reichsanst. 1863, p. 166.

†† Microscopical Petrography of the 40th Parallel, 1876, p. 53.

concentrically arranged scales of biotite or dark hornblende. This, for instance, is the case in the Pudding-granite of Craftsbury, Vermont*, where, in addition to the biotite, they contain small quantities of muscovite, quartz, felspar, and calcite †.

In an interesting paper read before this Society in 1879 the late Mr. J. A. Phillips ‡ gave the results of a series of careful investigations into the nature of the dark-coloured, so-called "concretionary patches." His conclusions show that these bodies differ from the enclosing rock, first, by containing a larger proportion of dark mica and hornblende; secondly, by their greater basicity, the orthoclase of the matrix being replaced by plagioclase in the concretion, or by the latter being poorer in quartz than the matrix. Although several of the concretions described by this author are spheroidal or ovoidal in shape, they present neither radial nor concentric structure.

Vom Rath § has mentioned the occurrence of flattened spheroids, of 6–8 centim. diameter, in the hornblende-granite of Slätmossa, Kirchspiel Järeda, Kalmalen, in Sweden. These bodies have a granular nucleus, composed of the granite-forming minerals, and a narrow peripheral zone, showing radiate structure. The latter is further subdivided into an inner felspathic layer and an outer darker shell rich in biotite and hornblende. The same author || has described similar bodies in the granite of Fonni, in Sardinia. They were originally discovered by Prof. Lovisato ¶, while on a visit to the island. The balls occur, as at Mullaghderg, packed together in a small space, scarcely exceeding two cubic metres in extent.

The spheroids from Fonni have quite recently been submitted to a careful examination by Fouqué **, and his description of them shows that they exhibit several striking points of resemblance to the Irish specimens. Like the latter they consist of two parts:—(1) a nucleus, similar in composition to the surrounding rock; (2) a marginal portion composed of plagioclase felspar (albite) and biotite, the felspar being in divergent rays, and the mica in concentric zones, in which the individual plates are disposed in a tangential manner with respect to the nucleus ††.

* Report on the Geology of Vermont, by Ed. Hitchcock and others, vol. ii. (1861), pp. 564, 721.

Also, G. W. Hawes, Concordia, 1878, pp. 190–204.

† M. K. de Kroustschoff, Bull. de la Soc. Minéral. de Fr., vol. viii (1885), p. 138.

‡ Quart. Journ. Geol. Soc. vol. xxxv. 1879, p. 1.

§ Sitzungsber. der niederrhein. Ges., Dec. 1874, p. 206. See also a paper by N. O. Holst and F. Erichstädt—Geol. Fören. Stockh. Förhandl. No. 86. Bd. vii. Häft. 2 (1884), p. 134—where the Slätmossa rock is incorrectly designated *Klotdiorit*.

|| Sitzungsber. der niederrhein. Ges., Juni 1885, p. 201.

¶ *Ibid.*, Juni 1883, p. 131.

** "Sur les nodules de la Granulite de Ghistorrai près Fonni (Sardaigne)," Bull. de la Soc. Minéral. de France, tome x. (1887), pp. 57–63.

†† Prof. Judd has kindly lent me, for comparison, a specimen of these spheroids. It is considerably flattened: the largest diameter is about $4\frac{1}{2}$ inches, the shortest not more than 2 inches. The zonal portion, which is about 1 inch in width, contains dark mica, but only in the outermost layers, the remainder being composed of pure felspar in divergent rays.

An interesting variety of spheroid has lately been discovered in the Stockholm granite of the Scandinavian peninsula, and has been the subject of a searching examination and detailed description by W. C. Brögger and H. Bäckström*. The spheroids occur in several distinct masses in a granite consisting of orthoclase (in part microcline), oligoclase, quartz, and dark mica. Each ball is made up of a dark nucleus and an outer light-coloured zone. The former is composed of the same minerals as the surrounding rock, the latter principally of felspar (plagioclase, orthoclase, and microcline) together with quartz. Dark minerals (mica, &c.) are entirely absent from this portion of the spheroid. The texture of the outer zone is granular, but finer-grained than the nucleus or the surrounding granite. A radially divergent structure was observed by Brögger in one instance only. The nucleus passes by imperceptible gradations into the peripheral portion; the latter, however, is sharply separated from the granite. No fixed proportion exists between inner kernel and outer zone. In some few cases the granitic material of the nucleus was found to be replaced by a single large individual of felspar (microcline), as in the spheroids described by G. Rose (cited above).

Conclusions.—The concretionary bodies, briefly described in the above *résumé*, may be classed as follows:—

I. Local accumulations of dark mica, hornblende, and a little triclinic felspar, generally of irregular shape, but sometimes rudely spheroidal. These are the "*concretionary patches*" of Phillips.

II. Spheroids composed of quartz, felspar, and mica or hornblende (*i. e.* the same minerals that compose the surrounding rock) in granular aggregation. These bodies possess an inner kernel and an outer zone, the latter sometimes exhibiting concentric structure. Brögger † subdivides them into (1) those having a nucleus relatively rich in dark minerals (biotite, hornblende, &c.) with a peripheral portion relatively poor in, or free from, dark minerals; (2) those with a peripheral zone rich in dark minerals. The whole group may perhaps be classed with Vogelsang's *granospherites* ‡.

III. Spheroidal aggregations of triclinic felspar with dark mica, hornblende, or magnetite around a central nucleus. This variety is characterized by the possession of both radial and concentric structure, and may be referred to the *belonospherites* of Vogelsang §. To this group belong the spheroids from Mullagherg, as also those from Fonni.

The nucleus of the spheroids is extremely variable, both as regards size and composition. It may consist of a portion of normally con-

* "Om förekomsten af 'klotgranit' i Vasastaden, Stockholm," Geol. Fören. Stockh. Förhandl. no. 110, Bd. ix. Häft. 5, p. 307.

I am indebted to Prof. Törnebohm for directing my attention to this important paper, as also for kindly supplying me with specimens, for the purpose of comparison, from both the Swedish localities (Slätmossa and Vasastaden).

† *Loc. cit.* p. 351.

‡ 'Die Krystalliten,' Bonn, 1885, p. 134.

§ *Loc. cit.*

stituted granite, or of one or more crystals of orthoclase; or, again, of an aggregate of plagioclase grains. Sometimes it is an accumulation of granules of magnetite*; sometimes one of the dark micaceous nodules of group I†. As the concretion forms round the original nodule, its irregularities are gradually equalized; so that the spheroidal or ellipsoidal character is soon acquired.

With regard to the genesis of the spheroids, there can be little doubt that they have been formed by concretion during the consolidation of the granite-magma; they must, consequently, be regarded as an example of zonal and, in the case of the belonospherites, radial crystallization around an earlier-formed nucleus. As one of the conditions for the development of such a crystallization a quiescent condition seems *à priori* to be essential. Differential movements in the granite-magma, which have resulted in a considerable distortion of the spheroids, must in some cases, however, have taken place before the final consolidation of the rock‡. We have here an instance of fluxion-structure, which, in granite, is undoubtedly a rare phenomenon. Chemical composition appears also to be a determining factor; for in at least two of the above classes the concretions are more basic than the enclosing granite, the intervening material, on the other hand, being of normal constitution. A deficiency in silica would thus seem to favour the development of spheroids in granite. Whether the occurrence of basic patches be due to the absorption of pre-existing basic material or to some process of segregation, must remain, for the present, an open question. Brögger§, on the other hand, hazards the conjecture that the spheroidal structure is preferably developed along the marginal portion of the granite area, *i. e.* in those portions where the magma first consolidates. This, he says, would be analogous to the occurrence of granophyric or porphyritic structure in the marginal portions or in the apophyses of granite or syenite. The balance of evidence however, scarcely seems to favour this hypothesis. It certainly will not explain, for example, the occurrence at Mullaghderg, Co. Donegal; for this locality lies right in the midst of the granite-area||.

With reference to the formation of these remarkable bodies, perhaps it would be not unprofitable to recall to mind Vogelsang's explanation of similar phenomena, given in his admirable paper describing the concretionary balls of the *Kugeldiorit* (Napoleonite) and *Kugelporphyr* of Corsica¶:—"When a molten magma consolidates, an irregular (*ungleichmässig*) cooling may produce greater contraction of the mass at certain points; and this may lead, later on, to a spheroidal separation. If this condition is arrived at after

* Zirkel, *l. c.*

† Vom Rath, *l. c.*

‡ Brögger, *l. c.* pp. 323, 327.

§ *Loc. cit.* p. 344.

|| Mr. Kilroe writes:—"The mass of spheroidal concretions does not occur at or near the margin of the granitic area. The point is almost equidistant from quartzite, occurring in mass some miles away on either side, through which the granite has been intruded. Small isolated masses of quartzite and schist are included in the granite in various places, but none near the special point referred to."

¶ Sitzungsber. d. niederrhein. Ges. 1862, xix. p. 185.

the point of consolidation of the several minerals has been passed, and, therefore, after their separation is complete, we get, indeed, a concentrically laminated body, but one without a definite arrangement of the constituents: this is the well-known spheroidal structure of many eruptive rocks. If, on the other hand, the tendency to form spheroids is developed during the period in which a differentiation of the magma into the various minerals can still take place, the latter will naturally undergo a definite arrangement with regard to the central point."

The first case, as pointed out by Vogelsang, offers a rational explanation of that form of spheroidal structure in which there is no definite arrangement of the constituents *. The latter case describes what most probably took place during the formation of spheroids with zonal or radial structure.

EXPLANATION OF PLATE XIV.

Fig. 1. A portion of a spheroid, cut through the centre and polished. It shows the light-coloured nucleus, the dark zonal portion, and a small quantity of the granitic matrix attached to the periphery. (Nat. size.)

- 2†. A portion of the nucleus, viewed in thin section under a low power and between crossed nicols. The striated mineral is oligoclase; the interstitial colourless substance, quartz; and the opaque grains, magnetite.
3. Section through the zonal portion of the spheroid, seen under a low power. The light portions are felspar (oligoclase); the black grains, magnetite. The latter have their long axes in the direction of the radii of the spheroid. The dark line in the zonal portion of fig. 1 traverses here the middle of the field, and is seen to be produced by the approximation of the black grains.
4. Section through the zonal portion of the spheroid, viewed under a low power and between crossed nicols. As in fig. 3, the main mass is oligoclase, and the black grains are magnetite. The felspar is seen to be twinned, the twin-lamellæ being orientated in the direction of the radii of the spheroid.

DISCUSSION.

Mr. RUTLEY spoke of the difficulty of doing justice to the immense amount of careful work involved in this paper. The Author had wisely avoided theoretical views, and yet it was tempting to speculate on the causes which set up crystallization, and to inquire why there was no radial structure in the central portions of the spheroids.

Prof. BONNEY regarded the paper as a very useful piece of work. He thought difference of structure proved a discontinuity of some

* In connexion with this point, Prof. Bonney's papers on "Columnar, Fissile, and Spheroidal Structures" (Q. J. G. S. xxxii. p. 140) and "On certain rock structures as illustrated by the pitchstones and felsites of Arran" (Geol. Mag. 1877, iv. p. 429) should be consulted.

† The microscopic sections are drawn, with the kind assistance of Mr. J. G. Goodchild, F.G.S., of the Geological Survey, from photographs taken by Mr. G. Barrow, F.G.S., of the Geological Survey.

560 SPHEROID-BEARING GRANITE OF MULLAGHER, CO. DONEGAL.

sort. The concentric concretionary structure is not confined to melted rocks. He referred to certain slates in the Lake District in which such a structure occurs. In the case of these spheroids a molecular movement had taken place, showing that a certain amount of plasticity had been retained in a rock which had never been in a fluid condition.

Dr. Hicks suggested that the proximity of intrusive rocks might have set up some action of this kind by the production of cavities; that the spheroids may therefore be considered as of secretionary rather than of concretionary origin.

Prof. Judd remarked that this was the first occasion in which both radial and concentric structure had been found in any spheroids in granite in the British Islands. The Society was to be congratulated on these specimens having fallen into such good hands, and being so admirably described. He asked if the micropertthitic structure occurred in the felspars of the granite, and not in those of the nodules.

The Author observed, with regard to the suggestions of Dr. Hicks, that the spheroids occur in a very small compass, and probably bore no relation to the dyke. The minerals were not secondary products. Prof. Judd was quite correct in supposing that there was micropertthitic structure in the granite, but none in the spheroid.