31. *On the ERUPTIVE ROCKS in the Neighbourhood of SARN, CAERNARVONSHIRE.* By ALFRED HARKER, Esq., M.A., F.G.S., Fellow of St. John's College, Cambridge. (Read May 9, 1888.)

- I. Introductory.
- II. The Granite and Gneissic Granite.
- III. The Gabbro, Diorite, and Gneissic Diorite.
- IV. The Diabase.
- V. The Hornblende-Diabase.
- VI. The Hornblende-Picrite.
- VII. The Dolerite Dykes.

I. INTRODUCTORY.

THE district to be treated lies to the west and south of the village of Sarn *, near the south-western extremity of Caernarvonshire. The eruptive rocks there exposed, excluding outlying patches, occupy an area of irregular shape, which extends about $5\frac{3}{4}$ miles from north to south, and has a greatest breadth of about $2\frac{1}{2}$ miles. This part of the country has received but brief notice from Sir A. Ramsay in his memoir on the "Geology of North Wales" †, and from Dr. Hicks ‡, who claims a portion of the area for his Pre-Cambrian systems. Several specimens from the district have been described by Professor Bonney § and the late Mr. Tawney ||, and the latter has also made a few observations on the field-relations of some of the rocks; but with these exceptions we have no published information about the western part of the Lleyn peninsula, though there are probably few districts of equal size in Britain where so many interesting rock-types are to be met with.

The rocks will be discussed in the following order:—Granite and Gneissic Granite; Gabbro, Diorite, and Gneissic Diorite; Diabase; Hornblende-Diabase; Hornblende-Picrite; and Dolerite. Some of these, however, are but little developed, and, for most purposes, the rocks of the district may be divided into two groups—an acidic, developed in the north and west, and a basic and intermediate in the east and south. Mr. Tawney and Dr. Hicks have pointed out that the map of the Geological Survey does not correctly indicate the separation between the two groups, the extent of the "greenstone" being unduly enlarged at the expense of the "syenite." The accompanying sketch-map (fig. 1) is intended to show roughly the limits of the two sets of rocks; but much of the country is obscured by drift, and accuracy is impossible without better topographical maps to serve as a basis.

* Sarn Meyllteyrn on the Survey Map, one-inch scale, sheet 76.

† Mem. Geol. Surv. Gr. Brit. vol. iii. 2nd edit. (1881).

‡ Quart. Journ. Geol. Soc. vol. xxxv. p. 298 (1879).

§ Geol. Mag. dec. ii. vol. vii. p. 207 (1880); Quart. Journ. Geol. Soc. vol. xxxv. p. 306 (1879).

|| Geol. Mag. dec. 2, vol. vii. pp. 207–215, and p. 456 (1880); vol. x. pp. 65–68 (1883); see also Teall, 'British Petrography,' 1888.

Fig. 1.—*Sketch-map of the Sarn district.* (Scale $\frac{2}{3}$ inch=1 mile.)

Despite the superficial deposits, however, and notwithstanding the absence of exposures in some of the critical localities, it is possible to draw conclusions regarding the relations of the rocks, some of which may be considered reliable, while others are at least probable.

The age of the sedimentary strata is naturally the first question, and here unfortunately the evidence is very meagre. The fossils recorded by Mr. Tawney and Sir A. Ramsay from Penarfynydd and other localities near Llanfaelrhys are taken to indicate a horizon in the Upper Arenig, and, judging by the observed strike of the strata, there is no reason why the similar rocks (black shales, with occasional beds of sandstone) seen to the east of the granitic mass should not be referred to the same stage, although no organic remains have been found. If not Arenig, these strata must be referred to the lower part of the Bala series. The granite is bounded on the north and north-west by the problematical green schists, which extend from Bardsey to Porth-dinlleyn; but as the boundary is almost certainly a faulted one, it is needless to discuss here the age of those remarkable rocks. For our purpose it is sufficient to know that the beds in unfaulted contact with the eruptive masses are of Arenig or, at the latest, Lower Bala age.

II. THE GRANITE AND GNEISSIC GRANITE.

These rocks, the massive type largely predominating, cover a large area on the map. The granite builds the round hill of Mynydd Cefn-amwlch to the north-west of Sarn, and underlies the low ground towards Bryn-croes, ranging as far south probably as Meillionydd-bach, a distance of four miles. Around and to the west of Bryn-croes, where the Survey map shows "greenstone," there are no exposures; but, judging by the form of the surface, the whole is probably granite, like that to the north and south, and the two "syenite" areas of the Geological Survey are united. The outlying patch at Pyllau-giach, near Cefn-amwlch, also coloured as "greenstone," is granite, and a tongue of the same rock extends from half a mile south of Bryn-croes to the edge of the valley north of Mûriau. The only place where the gneissic type of granite is exposed is in a quarry at Meillionydd, in the extreme south of the mass; even there the character is only locally marked, and in the little hill to the east the rock is the normal granite of the district.

It is a biotite-granite or granitite, the mica partially giving place to hornblende in a few localities only. The minerals composing the rock are apatite, magnetite, pyrites, biotite, two feldspars, and quartz, with a chloritoid substance, epidote, actinolite, kaolin, leucoxene, and ferruginous matter. Apatite and original iron-ores are sparingly present. Biotite occurs in ragged flakes, often bent, and sometimes showing "*Gleitflächen*." It is normally deep brown, with the usual characters of dichroism, but changes to green, giving then a bright grass-green colour for vibrations parallel to the cleavage-traces, and

a very pale green for the direction at right angles. A further stage of alteration produces an indistinct brownish scaly mass, which finally becomes isotropic with the separation of magnetite-dust. The chief felspar forms rectangular crystals, with fine twin-lamellation and low extinction-angles, agreeing with those of oligoclase. Orthoclase occurs in large plates of later formation than the plagioclase; both felspars show kaolinization, beginning from the centre of the crystals. Quartz is abundantly present, often in composite grains, moulding the felspars; it contains many minute fluid-cavities of irregular shapes, with spontaneously moving bubbles.

The granite has apparently undergone some degree of secondary change connected with the operation of mechanical stresses. Some of the fluid-inclusions in the quartz, as remarked by Mr. Tawney, occur in lines which pass from grain to grain. These lines of inclusions seem to be connected with roughly parallel cracks which traverse quartz and felspar alike. There are other cracks marked by a finely granular mixture of felspar and quartz, and sealed by epidote and irony staining; this appearance may perhaps be compared with the "*Mörtelstruktur*" of Törnebohm. The gliding-planes sometimes seen in the mica are probably another secondary phenomenon.

The granite and gneissic granite of Meillionydd have a character in some respects differing from the normal type. The constituents are the same as before, but their arrangement is anomalous, the usual order of consolidation being partly reversed. The felspars, chiefly a finely laminated acid plagioclase as before, are sometimes older, sometimes newer than the bulk of the quartz; a bipyramidal crystal of the latter mineral is occasionally seen included in felspar. The biotite is the latest-formed mineral. It moulds the earlier products of consolidation and fills the interstices between them, even sending out little tongues into cracks and irregular inlets in the quartz. A portion of the latter mineral, however, is sometimes of more recent formation than the biotite, and may even be posterior to the consolidation of the rock.

The occasional gneissic aspect of the granite at Meillionydd seems to have no necessary connexion with the peculiarities described. It consists in a local banded structure, with partial separation of the constituent minerals, seen only in large specimens. It is most probably to be referred to a certain amount of differential movement of the mass during the process of solidification, and cannot be due to any subsequent crushing of the solid granite. Little segregatory nests, rich in brown mica, occur in the rock, and these show no evidence of distortion.

The granite of Cefn-amwlch, Meillionydd, &c., is named syenite by the Geological Survey, a name which does not seem properly applicable; and it is stated that the "greenstone" of Mynydd-y-Rhiw "passes into" the "syenite." This idea of a passage, unlikely in itself, does not appear to be borne out by the evidence in the field.

Dr. Hicks, in 1879, put forward the view that the granitic mass,

which he speaks of as the "Rhos Hirwain* syenite," is of Pre-Cambrian age. Mr. Tawney apparently regarded this theory with considerable doubt, but Professor Blake †, if a passing allusion of his is correctly understood, endorses it.

An examination of the whole district leads to a conclusion in favour of the earlier view, that the granite is intruded through the shales. A good section is offered by the most southerly of the quarries near Cefn-amwlch. This was figured by Mr. Tawney, who was driven to some very unnatural suppositions in order to reconcile it with the supposed Archæan age of the granite. I give, in fig. 2,

Fig. 2.—Section in the most southerly Quarry at Cefn-amwlch. (Length about 30 yards; vertical scale slightly exaggerated.)

a different version of the section. The actual contact of the two rocks is easily found, and the granite is seen to send out little tongues between the laminae of the shale. Specimens of the latter rock, indurated and firmly adhering to the granite, may be obtained. At the back of the quarry the shale is clearly altered, and exhibits the little spots and nodules supposed to represent the incipient development of chialtolite. Another quarry, well within the boundary of the granite, shows entangled masses of baked shales. This is partly due to faulting; but here, too, good junction-specimens of the two rocks were procured. The granite in these quarries is quite typical of that which forms Mynydd Cefn-amwlch, and extends towards Sarn, Bryn-eroes, and Llangwnadl.

At Meillionydd the junction is not exposed; but the quarry must be near the boundary, and the presence of fragments of indurated shale included in the granite is sufficient proof of the intrusive character of the latter rock.

The granite is therefore of more recent age than the Upper Arenig strata. To assign an upper limit to the date of its intrusion is a

* Rhos Hirwain is the low-lying tract to the west, and the conjunction of this name with the word Syenite on the Survey map is apparently unintentional.

† Report Brit. Assoc. (Birmingham meeting) 1885, p. 669.

matter of mere conjecture; but the relation of the rock to subsequent earth-movements, of probably pre-Llandovery times, renders it likely that the granite belongs to the Bala age. It is impossible to say whether this plutonic mass was connected with volcanic centres; acidic lavas and ashes are found, however, less than five miles to the east, and are associated with Bala strata.

III. THE GABBRO, DIORITE, AND GNEISSIC DIORITE.

These rocks, grouped together for reasons which will appear, have not been noticed before. They occur only in two small patches, and are quarried in both places, viz. in the little hill of Craig-y-fael, two miles south-west of Sarn, and on the banks of the stream at Plas Llangwnadl.

The Craig-y-fael rock is, to the eye, a medium- or rather coarse-grained rock of granitic habit, apparently either a diorite or a gabbro. A similar or identical type is exposed above Plas Llangwnadl; but going north we find the rock assuming a more or less gneissic and even almost a schistose appearance, becoming, as it seems, a hornblendic gneiss. The microscope explains clearly the relations of these various types.

The typical rock of Craig-y-fael may be described as a partially amphibolized gabbro. It consists mainly of an aggregate of somewhat altered feldspars and grass-green grains of hornblende and augite, none of the constituents ever showing idiomorphic contours. The minerals seen in the thin sections are augite and diallage, hornblende and actinolite, feldspar, and a black opaque mineral, presumably an iron-ore, with some pale green decomposition-products, which mostly present the characters of chloritoid.

The black mineral forms shapeless patches without any indication of leucoxenic alteration, and is probably magnetite. The feldspar is a plagioclase, showing the usual albite-twinning, sometimes crossed by twin lamellæ on the pericline-law; the extinction-angles are those proper to labradorite. The crystalline plates are much strained and bent, so that the lamellæ are curved; it is possible, though not clear from the specimens examined, that the twinning may be in part induced by the strain.

The augite is in long plates of a very pale greenish tint. It shows sometimes the ordinary augite-cleavages, but other plates have a very marked diallagic structure. In spite of decomposition, it can be seen that both augite and diallage are converted at the margins into hornblende. The hornblende is of a dull green colour, and the pleochroism is expressed by:— α , very pale to almost colourless; β , grass-green, rather pale; γ , a rather deeper and bluish green. The usual prismatic cleavage-traces are seen in the more compact portions; but a part of the amphibole is in granular masses or in blade-like imperfect crystals with actinolitic structure.

There appears to be no augite or diallage in the Llangwnadl rocks, but their essential identity with the amphibolized gabbro of Craig-y-fael can scarcely be doubted after an examination of the

specimens and the slides. The process of alteration has proceeded further in the rocks on the edge of the district than in those of the central part.

The rock exposed near the bridge where the main-road crosses the stream may be taken as a type of the massive diorite. The microscope shows but little of the black iron-ores, but there is a considerable quantity of sphene in brownish granules. These granules, with cleavage-traces and irregular fissures, are aggregated in small patches and strings between the grains of felspar and hornblende. The felspar is partly in granular patches, too much decomposed to show any structure. The hornblende is of a greenish-brown or brownish-green colour, and gives for the three axes of elasticity:— α , very pale to almost colourless; β , rather deep brown with greenish tinge; γ , slightly deeper tint of greenish brown. There are also very pale greenish actinolite-looking shreds amongst the felspar-grains.

Near Plas Llangwnadl the rock is more altered, and has in places a quasi-porphyrific appearance, owing to the granular felspar forming large patches. Here there is very little of the opaque iron-ore, but sphene is more abundant. The felspar has undergone a seemingly saussuritic change, but a little of it still preserves the original structure and appears to be labradorite.

Still further down the stream, approaching the boundary of the area, the schistose appearance becomes more pronounced. A slide from this portion shows no new characters, except that the black iron-ore has entirely disappeared.

The mode of occurrence of all these rocks, both at Craig-y-fael and near Llangwnadl, proves that they were intruded through the granite, doubtless in the form of gabbro. The hornblende may be supposed to be entirely of pseudomorphic origin, the change being probably assisted by the mechanical stress to which must be ascribed the schistose structure of the rocks about Llangwnadl. At Craig-y-fael, where the gabbro was protected by a large mass of surrounding granite, the amphibolization is still imperfect. In the other mass, where the conversion is complete, the schistose character becomes more marked towards the boundary, and it may reasonably be ascribed to the movements which produced the assumed fault. In confirmation of this, it may be remarked that the strike of the gneissic and schistose structures is the same as that of the fault, and the schistosity is shared on the other side of the boundary by the ashy-looking beds which represent, near Llangwnadl church, the so-called green schists. The production of sphene in connexion with this kind of metamorphism is too well known to require comment.

The date of the gabbro and diorites is, then, more recent than that of the granite, but earlier probably than the fault; the rocks may be referred with some doubt to the Bala age.

IV. THE DIABASE.

The main mass of diabase in the district forms the curious conical hill named Clipiau-cilfinhir, half a mile west of Rhiw, rises in the

long ridge of Mynydd-y-Rhiw to a height of 1000 feet, is quarried further north near Cadern-y-groes, and extends in a north-north-easterly direction to Tyn-y-coed, half a mile south of Sarn village. Besides this, several sheets and dykes occur just west of Sarn; and further west, at Ty-rutten, a tongue-shaped mass runs with the strike of the strata, leaving a narrow strip of shales between itself and the granite (fig. 3). This mass must abut at its southern extremity on

Fig. 3.—Section from Pen-Craig to south of Sarn.
(Length about $\frac{3}{4}$ mile.)

the tongue of granite a little north of Mûriau; but unfortunately their junction, on the right slope of the little valley, is not exposed. There are numerous diabase sheets and small bosses in western Lley, which will not be considered here, though some of them, such as the sheets at Llanfaelrhys and Tyn-y-rhedyn, have probably a cognate origin with the diabase of the Sarn district.

The rocks are sufficiently alike to be described together, and present no very striking peculiarities. In hand-specimens the rock appears as a diabase of medium grain, greenish from decomposition-products, and showing distinct crystals of felspar.

The microscope shows the original constituent minerals to be the usual iron-ores, plagioclase felspar, and augite; the secondary products, leucoxene, calcite, zeolites, quartz, chloritoid minerals, and ferric oxide, do not require special notice. The magnetite and ilmenite, constantly the first-formed minerals, are fairly plentiful in rods and skeleton crystals. One or other of these constituents is always present, and frequently both in the same slide: there are not wanting signs of an intergrowth of the two minerals, or perhaps of magnetite and titaniferous magnetite.

The plagioclase occurs in lath-shaped or, at least, elongated sections, showing twin-lamellation on the albite-law. In the dykes and sheets near Sarn the felspars are often once twinned only, but in general a fine striation is seen between crossed nicols. The extinction-angles agree with those of oligoclase and labradorite.

The augite is very pale brown or almost colourless in thin sections, with the prismatic cleavage pronounced, and rarely traces of a pina-

coidal cleavage. The well-known "hour-glass" structure is not uncommon. The mineral is either in ophitic plates or in grains between the felspars. Only occasionally, as at Castell Carron, does it appear with idiomorphic boundaries; sometimes it shows twinning on the orthopinacoid.

The structure of these diabases is rather variable. Sometimes they are ophitic, but the augite-plates are never of great size, and the more usual texture rather approaches the granulitic type. It does not appear that the basic rocks of this area bear out any rule associating the ophitic structure with the larger masses, and the granulitic with small dykes and sheets. The types of structure seem rather to be connected with the relative proportions of the two minerals, the ophitic rocks being those which have the most abundant augite.

These diabases afford fine examples of spheroidal jointing and the consequent weathering in concentric crusts. The spheroids vary in diameter from two or three inches to as many feet; often a cluster of small ones is included in one large shell. The spheroids are sometimes formed in the interspaces marked out by plane joints, but the most regular examples often have no such relation. The great mass of Mynydd-y-Rhiw, especially in its northern and southern portions, is largely built up of spheroidally jointed rock.

The contact-effects of the diabase upon the adjacent strata usually present no special features. In one case the strata of indurated shale show a curious modification. They are broken by joints parallel and perpendicular to the bedding into small rectangular blocks, in each of which lies an ellipsoidal nucleus. The ellipsoidal joints are from an inch or two to a foot in diameter. This is at the contact with a dyke 35 yards wide, about a quarter of a mile west of Sarn.

The relations of the diabase to the other intrusive rocks can nowhere be demonstrated by actual sections, and the age of the mass is a matter for conjecture. It can only be said that the diabase cuts through Arenig or Lower Bala strata, while no rock of similar type is certainly known in Caernarvonshire of later age than the Bala. The presumption is therefore in favour of assigning the intrusion of the rock to the Bala age.

V. THE HORNBLLENDE-DIABASE.

Rocks of this family are largely developed in the southern part of the district. They are seen everywhere on Mynydd Penarfynydd, with the exception of the outcrop of hornblende-picrite on the west and south-west slopes. They form the whole of Mynydd-y-graig and its outlying spurs, the extent from south-west to north-east being about $1\frac{2}{3}$ mile. Hornblende-diabase may occur under the low ground north-west of Mynydd-y-graig, but probably the diabase extends as far as this. The same rock is found in force in the neighbourhood of Rhiw: it occurs a few hundred yards north of the

church, on the east side of the diabase-ridge, and can be traced southward to the coast at Tyn-y-borth, being quarried at Treheli.

The microscopic study of these rocks reveals features of considerable interest, and they will accordingly be treated in rather more detail than the foregoing rocks. Taking the hornblende-diabases of the district as a whole, the original constituent minerals are apatite, magnetite, picotite, ilmenite, felspar, olivine, augite, and hornblende. Among the secondary products we find in various slides leucoxene, kaolin, serpentine, magnetite, actinolite, a chloritoid substance, a radiating zeolite, calcite, and quartz.

Apatite occurs but rarely, in large cross-jointed prisms. Original magnetite grains are frequent, and belong to an early stage of the consolidation. A few rounded grains, brown and slightly translucent, which accompany the magnetite, are referred to picotite. Ilmenite, in skeletons of intersecting rods, is found in one variety, otherwise abnormal. On the whole these rocks are poor in accessory minerals.

A felspar of the plagioclase series is always abundant in good crystals, showing the usual forms. The crystals are sometimes simple, generally twinned once or twice, sometimes finely lamellated, and very rarely showing a cross-twinning corresponding to the pericline-law. The extinction-angles are usually nearest to those of labradorite, but some symmetrical sections extinguish at 40° from the twin-plane, indicating anorthite. Only one rock, that of Mynydd Penarfynydd, shows in places two distinct generations of felspar. With this exception the felspar is always of earlier formation than any of the augite or hornblende.

Olivine has probably been an occasional constituent of the hornblende-diabases here as elsewhere, but it is not now detected in any of the slides, and serpentine-grains which seem to result from it are not often seen. There is, indeed, plentiful serpentine in many of the slides; but in some cases this substance clearly results from the alteration of hornblende, in others it probably comes from a rhombic pyroxene, while the mesh-structure so characteristic of pseudomorphs after olivine is rarely indicated.

The augite is found either in good crystals or in ophitic plates and shapeless grains, the latter mode of occurrence being by far the more common. When crystals occur, they show in cross-section the usual octagon, the pinacoids being rather more developed than the prism-faces, while the terminal planes seem to belong to $(\bar{1}11)$ and (001) . The extinction-angle in a section parallel to the clinopinacoid is 39° or 40° . The prismatic cleavage is constantly well marked, and in a few cases pinacoidal cleavages were noticed, but never any diallagic structure. The augite is colourless or extremely pale brown in thin sections: only in one rock (summit of Mynydd-y-graig) is this seen to pass into augite of a deeper violet-brown with slight pleochroism. This and the occasional hour-glass structure recall the augite of some of the teschenites. Twinning on the usual law is sometimes observed, the orthopinacoid being twin-plane and face of composition.

The hornblende rarely forms imperfect crystals, contained by the clinopinacoid and prism-faces, without terminations: in the large

majority of cases it occurs as ophitic plates, commonly including grains, cores, or nuclei of augite, as well as feldspars and magnetite. The mineral is almost always deep brown in colour, with the usual pleochroism, the absorption being indicated by $\gamma \geq \beta > \alpha$. The maximum extinction-angle in vertical sections is 18° or 20° . A greenish-brown tint is occasionally seen with the brown. The hornblende is normally "compact" and well-cleaved, the green portions sometimes fibrous.

The relations of the hornblende and augite are worthy of notice, and prove that the same brown, compact hornblende may be either original or a product of amphibolization. When augite is included in the hornblende, there are three cases to be distinguished. In the first place, original hornblende may include augite-grains in the same way as it includes feldspar-crystals or magnetite. When this is so, the enclosed grains are generally of rounded shape with a very definite and comparatively smooth boundary; there is no crystallographic relation between the two minerals, and if two or more grains occur in the same plate of hornblende, they are differently orientated. Rarely, as in the quarry on Mynydd Penarfynydd, good idiomorphic crystals of augite are included in the hornblende.

Secondly, a crystal or plate of augite becomes partially converted into hornblende, chiefly round its margin, the two minerals then having the vertical axis and plane of symmetry common. Since this amphibolization probably involves a change of chemical composition, the term paramorphism is not strictly applicable, and we must call the process pseudomorphism, or where only the border is affected, perimorphism. If the original augite had crystal-contours the secondary character of the hornblende is obvious; in other cases it can generally be inferred from the extremely intricate and ragged appearance of the boundary between the augite-core and the investing hornblende. If the augite is twinned, the resulting hornblende is twinned about the same plane. Where several cores of augite are included in one hornblende-plate, they all have, of course, one orientation. The pseudomorphic or perimorphic hornblende has precisely the same characters as the original hornblende. Sometimes we may see a crystal of augite both moulded by hornblende and partially pseudomorphosed, the two kinds of hornblende being undistinguishable from one another.

There is a third way in which hornblende may include augite, and this has rarely, I believe, been specifically described in British rocks*. It appears that while a nucleus of augite was growing the magma became so altered that after a certain point of time hornblende-substance was deposited instead of augite, this hornblende growing upon the augite kernel with the usual crystallographic relation between the two minerals. This, if I understand aright, is what Rohrbach† has described in the teschenites of Silesia under the name of "*ergänzende*" or complementary horn-

* The picrite of Inchcolm exhibits good examples; see, *e. g.*, Teall, 'British Petrography,' plate vii. (1888).

† Tschermak's 'Mittheilungen,' 1886, p. 84.

blende. It appears to differ from the more ordinary "intergrowth," in that the whole of the augite was formed before any part of the hornblende. When both the augite-nucleus and the hornblende-border are twinned, the twin-planes, though of course parallel, are not necessarily coincident. Sometimes, as on the south-east side of the crest of Mynydd-y-graig, the hornblende thus formed has idiomorphic crystal-boundaries, and its original nature is conclusively demonstrated. But when once admitted and looked for, this complementary hornblende is found to be by no means uncommon: it is distinguished from the perimorphic hornblende by its boundary against the augite being much less irregular, and from original hornblende enclosing augite-grains by the correspondence in crystallographic orientation of the two minerals. We must recognize, then, as distinct cases:—

1. Original hornblende enclosing augite-grains, without crystallographic relation;

2. Perimorphic hornblende (secondary) bordering augite-cores, with crystallographic relation; and

3. Complementary hornblende (original) surrounding augite-nuclei, with crystallographic relation.

One or more of these is found in all the slides examined; but I have not yet certainly recognized the first and third in the same specimen. This is, perhaps, in accordance with what might be expected; for we must suppose in the former case a pause between the consolidation of the augite and that of the enclosing hornblende, and such a pause would presumably be unfavourable to the formation of complementary hornblende upon nuclei of augite.

Another kind of amphibole may also be mentioned, though it is less common here than in some other hornblende-diabases, such as those of Pen-y-rhiwiau, near Clynog-fawr, Caernarvonshire, of Jersey, of Little Knott in Cumberland, and from near Llanerchymedd, in Anglesey*. This is the "secondary enlargement" hornblende of Van Hise†, first described in eruptive rocks by Becke‡. It is a growth of hornblende-substance entirely posterior to the consolidation of the rock, but proceeding in crystalline continuity with preexisting hornblende, so as to border the original crystals, fill the interstices between them, or form a narrow and ragged fringe inside the walls of an included grain of serpentine. Evidently its deposition can only proceed concurrently with the destruction of some other mineral. This later growth of amphibole is clear and colourless or pale green; it constantly gives rather higher polarization-tints than the brown hornblende: frequently it has the cleavage-traces but little pronounced. Such hornblende, forming a "secondary enlargement" of original and perimorphic crystals, is found in several parts of the district. Becke also describes a similar hornblende-growth bordering original augite-crystals; but of this I have found no evidence in the Sarn district, though it is well seen in a

* 'Geol. Mag.' dec. 3, vol. iv. p. 552.

† 'Amer. Journ. Sci.' ser. 3, vol. xxxiii. p. 385 (1887).

‡ Tschermak's 'Mittheilungen,' vol. v. part ii. (1883).

diabase from Bodowen, Anglesey, and in many of the diabbases of central Caernarvonshire.

The chief secondary products of the hornblende are magnetite, in dust and in granules, serpentine, often preserving something of the structure of the parent mineral, and sometimes a feebly polarizing pale green substance of the chloritoid family. One slide from Mynydd-y-graig shows, however, the brown compact hornblende passing over into a fibrous mineral presumably actinolite. The hornblende first becomes pale and greenish, and then breaks up into grass-green fibres, which from parallel become divergent, and are seen to be imbedded in a colourless, brightly polarizing mineral which has all the properties of the "secondary enlargement" hornblende already described. The change is accompanied by a copious separation of granular magnetite, which finally forms a dense border to the altered crystal. The augite of these rocks, being protected by the hornblende, is usually quite fresh.

All the rocks here described contain augite, as a rule partially amphibolized, and most, if not all, have original hornblende in addition. As some confusion exists with reference to the application of such terms as proterobase and epidiorite, I have judged it advisable to group all these rocks together under the more general title of hornblende-diabase. Their structure is almost without exception that of an ordinary ophitic diabase, but specimens taken at the summit of Mynydd Penarfynydd show a structure which must be called porphyritic in the sense of Rosenbusch*. There are not only two sets of feldspars, but the augite also appears of two generations, the earlier one being in idiomorphic crystals. A peculiar aspect is given to some of the more felspathic varieties by a tendency of the larger feldspars to collect in patches; this type of structure is, perhaps, comparable with that which Professor Judd has termed "glomero-porphyritic."

The hornblende-diabase often contains coarsely crystalline contemporaneous or segregation-veins. They are on the whole more felspathic than the surrounding rock, and contain crystals of hornblende up to one inch in length, often very perfectly formed. The geological relations of these rocks will be considered in connexion with those of the hornblende-picrite, which is intimately associated with them.

VI. THE HORNBLLENDE-PICRITE.

The rock which forms the western slopes of Mynydd Penarfynydd is unique in the district. Professor Bonney has given it the name of hornblende-picrite, and it must be regarded as the type of this well-marked and interesting species.

The rock occurs in distinct parallel banks to a total thickness of 200 or 250 feet, with a dip of 35° or 40° towards S. 30° E., the same as that of the neighbouring Arenig shales. Owing to this inclination, the picrite emerges from the sea under the precipitous cliffs of Trwyn-talfarach, rises on the south-west slope to a little

* 'Massigen Gesteine,' new ed., 1886.

below the signal-staff, follows the trend of the hill-side in a north-easterly direction, and crosses over the ridge, where it begins to sink towards its northern extremity. The topmost banks are overlain by the hornblende-diorite, which forms the greater part of the hill, and hornblende-diorite also occurs at the very base, thus intervening between the picrite and the subjacent strata.

In the field and in hand-specimens the appearance of this handsome rock is very striking. Most conspicuous is hornblende in large black crystals with lustrous cleavage-planes. On closer examination these planes are seen to be studded with rounded, dull spots, which represent grains of olivine more or less serpentinized. Besides this, flakes of a golden-brown mica are often plentiful, lying on the cleavage-planes of the hornblende, and some parts of the rock show white crystals of felspar.

The microscope shows the original minerals of the hornblende-picrite to be magnetite, olivine, felspar, augite, hornblende, and biotite: among the secondary products are magnetite, serpentine, hornblende, biotite, asbestos, a mineral of the chloritoid family, calcite, and dolomite, with rarely an aggregate similar to that which has been named *saussurite*.

Original magnetite is not common; it sometimes occurs in cubes, and is the earliest-formed constituent. Picotite has not been observed.

Olivine is always one of the most abundant minerals present; it rarely shows crystal-contours, and is almost always in rounded grains imbedded in augite or hornblende. Twinning is rare. The grains sometimes show fissures corresponding to the two pinacoidal cleavages, but more commonly are traversed by irregular cracks. Under a high magnifying-power some of the olivine shows flat rectangular cavities or "negative crystals" containing dendrites of magnetite, identical with those figured by Professor Judd in a picrite from the Isle of Rum*. As the Penarfynydd rock is probably of Upper Cambrian (Bala) age, its resemblance to a Tertiary rock, extending to such minute details, is a point of some interest. The conversion of the olivine into serpentine is seen in every stage from fresh grains of olivine to complete pseudomorphs. The process begins along the fissures with the separation of magnetite dust, which, when plentiful, collects in clotted granules and strings. Serpentine is next formed on the borders of the fissures in fibres perpendicular to the walls. This serpentine is doubly refracting and apparently uniaxial: the remaining kernels of olivine are then gradually converted into serpentine, which either shows a confused structure or is sensibly isotropic. Sometimes, as a last stage, there is a seeming reabsorption of the deposited magnetite as described by Wadsworth†. Irregular fissures sometimes radiate from the altered grains, traversing the surrounding minerals, and these fissures are injected with serpentinous matter: they may be

* *Quart. Journ. Geol. Soc.* vol. xli. p. 385, pl. xii. fig. 5 (1885).

† 'Lithological Studies,' p. 172, &c. (1884).

ascribed to the increase in bulk of the grains consequent upon the process of serpentinization*.

Felspar, when it occurs in the hornblende-picrite, is either in small slender crystals, simple or once twinned, or in large irregular plates enclosing olivine. The extinction-angles observed agree with anorthite. The mineral is probably always of earlier consolidation than the augite, and is moulded by the plates of hornblende.

The augite is of the usual very pale brown tint or almost colourless, and has the prismatic cleavage well marked. It is almost always in the form of irregular plates, or forms a core to the hornblende. In rare cases, however, it has crystal-outlines, the cross section being a regular octagon due to the equal development of the prism and pinacoids. The hornblende is of the same rich brown colour as in the hornblende-diabases, but this passes occasionally into green, which gives, for vibrations parallel to the axes of elasticity:— α , very pale brown; β , pale olive-green; γ , rather pale grass-green. The brown hornblende also passes, in places, into a colourless variety. The usual prismatic cleavage is well seen in the slides, and occasionally a cleavage parallel to the clinopinacoid. Twinning on the orthopinacoid is only rarely seen.

The hornblende never shows idiomorphic boundaries, and it usually occurs in close relation with augite. Either a plate of augite has a partial or complete border of hornblende, or a hornblende plate encloses a core of augite, the boundary between the two being often exceedingly ragged and labyrinthine. The hornblende and augite of each plate have the vertical or *c*-axis and the plane of symmetry common, but are apparently in reverse position to one another. This appears from the fact, verified in several instances, that in a clinopinacoidal section the extinction-angles are about 40° for the augite and 20° for the hornblende *on the same side* of the cleavage-traces. Some slides show little or no augite. The relations of the two minerals are, on the whole, in accord with the idea that the bulk of the hornblende is a later formation at the expense of augite; but it is not safe to conclude that this is so of all. Indeed, that some of the hornblende is original, is evident from the fact that it not unfrequently encloses distinct grains of augite without any definite crystallographic relation.

A brown mica with the characters of biotite is almost always present, and sometimes in such quantity as to give a distinct varietal character to the rock in which it occurs. Normally the mineral is brown, with the usual intense dichroism, but it often becomes paler and even almost bleached. It also passes at the edges of the flakes into a mineral which gives a grass-green colour for vibrations parallel to the cleavage-traces and a golden-brown for the perpendicular direction: this seems to be the substance which Mr. Teall identifies as chlorite†. The biotite has two modes of origin. It is in part original, being then usually later than the

* Cf. Judd, Quart. Journ. Geol. Soc. vol. xlii. p. 86 (1886).

† British Petrography, p. 98, 1888.

felspar and earlier than the hornblende. Another portion seems to be of secondary origin, and connected with a special mode of alteration of the hornblende. In some cases this mineral, as a first stage, takes on a lamellar structure parallel to the orthopinacoid, and from this the biotite-flakes are developed*. More commonly the mica is developed on the cleavage-planes of the hornblende. It is possible that this should be regarded as an original intergrowth of the two minerals, the law of association being that given by Rosenbusch and others.

The ordinary secondary products from the felspar, hornblende, and biotite demand no special notice. We may remark, however, the presence in some slides of a rather pale-green actinolite in blade-like crystals with a pinacoidal cleavage.

The hornblende-picrite presents some peculiarities of structure due to the arrangement of its constituent minerals, and these variations are much more striking in the field than in hand-specimens or thin sections. The smooth surface of boulders, both of hornblende-diabase and hornblende-picrite on the beach below Mynydd Penarfynydd and at Y Graig-ddu, often show a curious mottled aspect, which consists in a mingling of dark and light patches or a separation of white spots on a black ground. This kind of aggregation of the several constituents produces on the rock-surfaces *in situ* a pitted or honeycombed appearance due to differential weathering. When the component minerals are more evenly distributed, the rock either weathers into compact blocks, or in some parts of the picrite-mass shows a fluted or grooved aspect. This last-mentioned appearance seems to be caused by the difference between bands alternately rich and poor in olivine, a character noted by Reusch in the saussurite-gabbros of the Bergen district†. There are even distinct dark bands less than an inch in width, which under the microscope appear as veins entirely composed of partially serpentinized olivine with much secondary magnetite.

The fine section of hornblende-picrite below the trigonometrical signal-staff on Mynydd Penarfynydd shows very clearly the stratiform alternation of the honeycombed and the compact and fluted varieties. The former is in greatest force in the middle half of the section. The picrite often contains coarse segregation-veins similar to those of the hornblende-diabase.

The intrusive nature of the basic rocks of this district has never been disputed. Wherever the Arenig strata are seen in the vicinity of the eruptive rocks, their contact-alteration is very evident. The shales become hard and flaggy, losing their finely laminated structure and changing colour, while grey spots and yellowish-grey granular streaks make their appearance.

The Mynydd Penarfynydd mass, exhibiting, as it does, the picrite as well as the hornblende-diabase, may conveniently be considered first. The boundary between these two rocks is a very definite one.

* This is well exhibited also in the hornblende-picrite of Schriesheim, where, however, both hornblende and mica are bleached.

† Fossilien-führenden krystallinischen Schiefer, &c., 1833.

We pass at once from perfectly typical hornblende-picrite to a rock in which no olivine can be detected, while felspar, instead of being locally and rather sparingly present, becomes essential and abundant. Nevertheless it cannot be doubted that the two rocks form parts of one and the same intrusive mass. Mr. Tawney, who noticed that the hornblende-diabase ("diabase" in his description) occurs both below and above the hornblende-picrite (his "olivine-diabase"), suggested doubtfully that the olivine-bearing rock was intruded into the other; but his examination of the locality was rather a cursory one, and he appears not to have distinguished between the hornblende-diabase and the felspathic variety of the picrite. The rocks have, indeed, many characters in common; but what unites most clearly the picrite and the hornblende-diabase as the products of one igneous intrusion or set of intrusions is the behaviour of the segregation-veins at the junction. These veins, already mentioned, pass from one rock to the other, so that it is impossible, where they occur, to draw any line of demarcation.

The direction of the plane of division of the hornblende-diabase and hornblende-picrite is also the direction of the banks or quasi-strata of the latter rock, marked by the alternation of different lithological types; also of the thin olivine-veins, and of the coarse segregation-veins when these show any regularity of disposition. Further, the base of the whole igneous mass is a plane parallel to the above and agreeing with the stratification of the sedimentary rocks below, so that the actual junction is a definite bedding-plane of the shales (fig. 4). The mode of occurrence of the mass is there-

Fig. 4.—Ideal section through the southern end of Mynydd Penarfynydd. (Length $\frac{2}{3}$ mile.)

- A. Upper Arenig strata.
- D. Diabase of Tyn-y-rhodyn sheet.
- HD, Hornblende-diabase, and P, Hornblende-picrite of the Penarfynydd laccolite.

fore similar to that of the well-known "laccolites" of Southern Utah*, with the difference that, instead of being homogeneous, it

* "Geology of the Henry Mountains," U. S. Geol. Surv. 1880.

presents a stratified arrangement of varying lithological types. Judging by the outcrop and observed dip, the Penarfynydd laccolite must have a diameter of not less than three quarters of a mile and a thickness of more than a thousand feet. These dimensions are exceeded by many of the trachytic laccolites described by Gilbert.

On Mynydd Penarfynydd the beds which formerly arched over the roof of this great "stone-cistern" have been entirely removed by denudation. There are also complications arising from the effects of the subsequent earth-movements by which the rocks of North Wales were disturbed from their horizontal position. The injection of the laccolite between Upper Arenig strata, doubtless a process accomplished by many successive influxes of magma of varying composition, clearly took place when the strata were horizontal; and the whole mass was afterwards tilted over into an inclined position without other disturbance. Under the laccolite the shales have been protected from the lateral pressure by the stubborn resistance of the overlying eruptive mass, and present accordingly a uniform inclination. To the west of Penarfynydd, on the other hand, the strata are much disturbed, with conflicting dips at high angles, the rocks here having been crushed by the thrust from the north-west against the unyielding igneous mass.

The Penarfynydd laccolite is the only one which can be clearly made out in the field. It is, however, a reasonable conjecture that the mass of hornblende-diabase constituting Mynydd-y-graig is another and larger laccolite, injected at a later time and on a slightly higher horizon, and modified in form at its south-western edge by the mass of Mynydd Penarfynydd. The field-relations of the rocks about Rhiw are too much obscured by surface-deposits to admit of any definite conclusions. Though the hornblende-diabase never exhibits the strikingly stratiform appearance of the hornblende-picrite, there seems to be a certain constant difference between different parts of the large masses. The rock which extends from Careg-llefain along the ridge of Mynydd-y-graig is readily distinguishable from that exposed on the south-eastern slopes. The hornblende-diabase north of Rhiw resembles that of the base of the Penarfynydd laccolite, while the rock of Plas Rhiw and Treheli is of the Careg-llefain type*.

The date of the picrite and hornblende-diabase intrusions is a matter for inference only. If we suppose, with Sir A. Ramsay, that the disturbance of the strata was effected in pre-Llandovery times, these eruptive masses, which share that disturbance, must be referred to some part of the Bala age. Assuming this, the absence from the district of any contemporaneous lavas of like composition is best explained by supposing that the whole of the hornblende-diabases were injected in the form of laccolites.

* Specimens from Treheli and from Mynydd-y-graig have been described by Mr. Tawney.

VII. THE DOLERITE-DYKES.

The last rocks to be described, and that very briefly, occur as dykes of no great width cutting through the larger igneous intrusions of the district. These dykes are seen in various localities to intersect the granite, the diorite, and the hornblende-diabase; and although I have not recognized them as yet in the diabase, this is owing, in all probability, to the difficulty of distinguishing in the field between the latter rock and the dolerite. The larger intrusive masses and the dykes and sheets of diabase we have seen reason to assign to the Bala age; the dolerite is most likely referable to a much later period.

In hand-specimens the dolerite is of medium or fine grain, with well-pronounced ophitic structure, and of a dark colour, becoming greenish in the most weathered parts. It appears to consist of felspar, magnetite, and augite, and the microscope does not discover any other constituents.

The magnetite, either in granules or in octahedral crystals, is one of the first-formed products of consolidation, though occasionally it is seen to be penetrated by some of the smaller felspars. Of ilmenite there is no indication in the slides examined.

The felspar is constantly of two distinct generations. Of these the earlier is clearly anterior to the augite in the order of consolidation. It offers elongated sections with a fine lamellation on the albite-type and frequently Carlsbad-twinning in the same crystals. Judged by the extinction-angles the felspars are between oligoclase and labradorite. The later generation of felspars occurs in more equidimensional crystals, with rarely any trace of idiomorphic boundaries. They are never so closely lamellated as the earlier felspars, but are marked by a strong zonary banding or shading in polarized light. They belong to about the same stage of consolidation as the augite.

The augite, though pale brown, is never so nearly colourless as the augite of the diabases and hornblende-diabases of the district. It even shows in some cases a scarcely perceptible dichroism, changing from a rosy to a yellowish tint. The mineral, with the usual cleavage well pronounced, occurs in crystalline grains or ophitic plates moulding and enclosing the earlier felspars, and occasionally moulding to some extent the later felspars also.

The structure of the rocks is commonly ophitic, though there is sometimes a tendency to pass into a partly granulitic type.

Not recognizing geological age as an essential factor in lithological classification, I have applied the name dolerite to these rocks, because, by the development of a later generation of felspars, they exhibit the "porphyritic" structure of Rosenbusch, and are thus separable from the diabases, in which the felspars belong all to one stage of consolidation. From the type of diabase so largely represented in the Sarn district these rocks differ, not only in this recurrence of felspar in a second generation, but also in the characters of the felspars, in the deeper colour of the augite, and its frequent occurrence in ophitic

plates of considerable extent, and in the absence or rarity of ilmenite in the dolerites. In all these and other characters the rocks in question have close affinity with the dolerites of other parts of Caernarvonshire and Anglesey. Similar dykes on the shores of the Menai Straits cut through Carboniferous strata*; and others in the Anglesey coal-field are demonstrably post-Carboniferous and pre-Permian†. Such evidence as is obtainable points, then, to the conclusion that the dolerite-dykes of the Sarn district, to which we may add some of those which intersect the neighbouring "green schists"‡, were injected in the interval between the deposition of the Carboniferous and the Permian formations.

Waiving this point, however, and excluding the dykes and minor eruptive masses from consideration, we find that the district of Sarn, probably during the age in which the Bala rocks were laid down, was the theatre of igneous activity on a large scale. The strata were invaded by eruptive magmas of very different chemical constitutions, and rocks of widely diverse characters have resulted from the consolidation of those magmas; so that we find, speaking broadly, acidic rocks occupying the northern and western portions of the district, intermediate or sub-basic forming a broad band across the middle, and basic and ultra-basic developed in the south. These latter, the heavier materials, appear to have spread in the form of laccolites, possibly at a considerable depth; the magma which was the origin of the granite may, on the other hand, have been in connexion with some of the extrusive or volcanic outflows which are so striking a feature of the Bala stage in Caernarvonshire.

The isolated intrusions of gabbro cannot safely be correlated with other rocks in the area: their passage into hornblendic rocks, and the evident relation of that change to the coming in of the schistose character, though points of novelty in North Wales, are closely paralleled in many other districts with which geologists have been made familiar.

[*Note*.—The specimens and slides illustrating this paper are in the Woodwardian Museum at Cambridge.]

DISCUSSION.

Mr. TEALL would have been glad to have heard more of the details of the paper before attempting to criticize it. As a point of nomenclature it would be satisfactory to know if we should have different names for rocks containing primary or secondary hornblende. In the mass of diabase and picrite there seemed to be a differentiation and coming in of parallel structures; in this direction we may hope for a solution of the problem of the origin of gneisses.

* *Geol. Mag.* dec. 3, vol. iv. p. 409 (1887).

† Ramsay, *loc. cit.* p. 264.

‡ The igneous mass south-west of Aberdaron, terminating in the headland of Pen-y-cil, also has two generations of felspars, but differs in other respects from the dolerite of the dykes in question.

462 ON THE ERUPTIVE ROCKS OF SARN, CAERNARVONSHIRE.

Prof. BLAKE had already committed himself as regards these particular rocks. His views and those of the Author in the main agreed and were adverse to Dr. Hicks's interpretation, but he had not previously known of the evidence of their being intrusive into the later formations. He doubted if the difference between the granite and the diorite was well made out. The "granite" becomes a hornblende-gneiss near the ashy series, where he thought the junction was not a faulted one. He also had his doubts as to the diabase being strictly intrusive. On the whole his conclusions were not very different from those of the Author.

Mr. WATTS regarded the paper as a description of a petrographical complex, of the nature required by modern theories of metamorphism. He agreed in the making use of cleavage to ascertain the age of the rocks. As regards structural relations, he rather doubted the analogy with laccolites, which generally occur in the main anticlines of strata. The question of segregation towards the bottom of the mass was interesting if the same intrusion is really more basic towards the bottom, but there may have been distinct intrusions. Judging from recent experience in Shropshire, there appeared to be evidence of a sequence in rock-series with a regular fall in the percentage of silica.

Prof. HUGHES referred to the protrusion of solid granite in explanation of some marginal faults, and to certain fossiliferous zones which defined the stratigraphical position of the sedimentary series in which the rocks described by Mr. Harker occurred. He spoke of the intermixing of the hornblende-diabase and the picrite, and thought that the boulders of hornblende-picrite of North Wales represented only portions of the well-known hornblende-diabase-dykes of the district.

Mr. RUTLEY said that the comparison with laccolite rather troubled him. These might be lenticular patches rather than laccolites.

The AUTHOR was disposed to accept Mr. Teall's suggestion with respect to nomenclature. The schistose granite mentioned by Prof. Blake he had not seen; he thought it might be simply fluxion-structure. Referring to the stratified appearance in the hornblende-diabase and hornblende-picrite, he thought there was no great division in time. Some small masses resembling laccolites do occur in relation to earth-movements elsewhere in Wales. His section was an ideal one; the pipes were not always laid down even in exposed laccolites. The Anglesey rocks were only locally picrites.