10. *On the IGNEOUS ROCKS ASSOCIATED with the CAMBRIAN BEDS of the MALVERN HILLS.* By Prof. THEODORE T. GROOM, D.Sc., M.A., F.G.S. (Read December 19th, 1900.)

[PLATE VII.]

CONTENTS.

	Page
I. Historical Summary	156
II. Introduction	158
III. Amphibole-bearing Rocks of Andesitic Habit	158
IV. Augite-Basalt	167
V. Olivine-Basalts	168
VI. Olivine-Diabases	172
VII. Mutual Relations between the Rocks described	175
VIII. Comparison of the Malvern Intrusives with the Igneous Rocks of other Districts	177
IX. Supposed Pyroclastic Rocks	179
X. The Intrusive Character of the Rocks	180
XI. Date of Intrusion	181
XII. Relation of the Igneous Rocks described to those of the Archaean Massif	182
XIII. Conclusions	182

I. HISTORICAL SUMMARY.

THE crystalline core of the Malvern Hills was at first supposed by Horner¹ to be composed of igneous rocks intruded into the adjacent strata. Murchison at a later date imagined that the Hollybush Conglomerate and Hollybush Sandstone were submarine volcanic grits discharged from a fissure along which later the igneous mass of the Malverns burst through.² Phillips, however, adduced strong reasons for believing that the crystalline rocks had not been intruded into the Palæozoic strata³; he was, moreover, the first to recognize igneous rocks in the lowest portions of the latter. He described 'felspathic dykes' and 'interposed masses' in the Hollybush Sandstone; and 'porphyritic and greenstone-masses, which, erupted from below, have flowed in limited streams over the surface of the Black Shales.'⁴ He pointed out that neither dykes nor bosses of trap occur in any of the strata above the Black (and Grey) Shales; though some of them, including those near Bronsil (numbered 108, 247, 248, & 249 in the present writer's map⁵), are situated in, or on, the upper part of the Shales. In the vertical section (p. 51) in Phillips's work, and in the horizontal section (No. 13) accompanying the memoir,⁶ they are placed between

¹ Trans. Geol. Soc. ser. 1, vol. i (1811) p. 281.

² 'Silurian System' 1839, pp. 416, 418.

³ Phil. Mag. vol. xxi (1842) p. 288, and Mem. Geol. Surv. Gt. Brit. vol. ii, pt. i (1848) pp. 66 *et seqq.*

⁴ Mem. Geol. Surv. Gt. Brit. vol. ii, pt. i (1848) pp. 52, 53, & 56.

⁵ Quart. Journ. Geol. Soc. vol. lv (1899) pl. xiii.

⁶ Reproduced in Sir A. Geikie's 'Ancient Volcanoes of Great Britain' vol. i (1897) p. 170.

the Shales and the May Hill Sandstone. Phillips, with De la Beche, evidently believed that the igneous rocks were in part contemporaneous volcanic rocks, the outpouring of which, according to De la Beche, ceased with Llandeilo times.¹ Phillips, however, compares the igneous rocks of Tortworth with 'the greenstones of the lowest Caradoc Beds of Malvern,' remarking that the latter were 'effused on the sea-bed' during the 'early Caradoc' period.² Strickland imagined that the great movements which elevated the Malvern Chain and overturned the beds to the west were connected with this igneous action.³ In 1862 and 1867 Timins⁴ published chemical analyses of many of the igneous rocks associated with the Cambrian strata of the Malverns; and Holl in 1865 described them as a series of contemporaneous ashes, grits, and lavas.⁵ In 1869 Symonds,⁶ who had already⁷ supported Murchison's views, and had, moreover, maintained that submarine volcanic action was responsible for the production of the trap in the Black Shales, and for the volcanic grits of the Hollybush Sandstone, spoke of pumice and scorix in the shales, and imagined the former existence of an island-volcano surrounded by deep sea. In 1874 the same author⁸ referred to one of the igneous rocks (106 in the present writer's map⁹) as one of the outworks of a volcano the roots of which were situated in Raggedstone Hill. In 1884 he spoke of the Hollybush Sandstone as probably a consolidated mass of volcanic grit and ashes, erupted from a vent occupying the position of Raggedstone and Midsummer Hills, but he considered the traps of Fowlet Farm and White-Leaved Oak to be probably of later date than those interbedded with the Shales.¹⁰ He further stated that the igneous rocks near Bronsil and Howler's Heath occupy the position which in North Wales is taken up by the Lower Silurian Beds (*op cit.* p. 42). In 1889 Symonds further maintained that the old lavas erupted through the Hollybush Sandstone and Black Shales occupy the position proper to the Llandeilo and Caradoc Beds.¹¹ Mr. Teall in 1888 recognized the presence of ophitic diabases in the Malvern Cambrians.¹² In 1898 Prof. Lapworth considered the majority of the igneous rocks associated with the Cambrian strata to be intrusive.¹³ The present writer in 1899 and 1900 recognized in these igneous rocks a series of intrusive

¹ Mem. Geol. Surv. Gt. Brit. vol. i (1846) p. 38. The Malvern Black Shales were then regarded as of Llandeilo age.

² *Ibid.* vol. ii, pt. i (1848) pp. 194 & 195.

³ Phil. Mag. ser. 4, vol. ii (1851) p. 359.

⁴ Edinb. New Phil. Journ. ser. 2, vol. xv (1862) p. 1, and Quart. Journ. Geol. Soc. vol. xiii (1867) p. 352.

⁵ Quart. Journ. Geol. Soc. vol. xxi (1865) pp. 87 *et seqq.*

⁶ Trans. Woolhope N. F. Club, 1869, p. 6.

⁷ 'Old Stones' 1st ed. (1855) pp. 31 & 43.

⁸ Proc. Geol. Assoc. vol. iii (1874) p. 271.

⁹ Quart. Journ. Geol. Soc. vol. iv (1899) pl. xiii & p. 167.

¹⁰ 'Old Stones' 2nd ed. (1884) pp. 25, 26, & 30.

¹¹ 'Flora of Herefordshire' 1883.

¹² 'British Petrography' 1888, p. 245.

¹³ Proc. Geol. Assoc. vol. xv (1898) p. 338.

diabases and basalts,¹ and Prof. Watts² compared certain of the latter with 'diorites' associated with the Cambrian strata of other parts of Great Britain.

It will be seen from the foregoing summary that the igneous rocks in question have been, with few exceptions, regarded as due to contemporaneous volcanic action, supposed to have taken place either in Cambrian times or soon after.

II. INTRODUCTION.

The general distribution of the igneous rocks in the Cambrian strata of Malvern has been indicated in a former communication³; it will be sufficient, therefore, on the present occasion to point out that they occur at all horizons, and at all distances from the Archæan axis, though they are specially abundant at certain levels and in certain localities. They are found in the form of sills, small laccolites, bosses, or dykes. The preservation of the material leaves much to be desired, and it is only by having a large number of rocks sliced that it has been found possible to reduce the series to a few relatively constant types. I was formerly disposed to regard the more acid porphyritic members as amphibole-basalts (and andesites) of a peculiar type⁴; but a renewed investigation with the aid of further material has led me to doubt the propriety of these designations, and to regard the prevailing rocks of the district as ophitic olivine-diabases; olivine-basalts of somewhat unusual type; and amphibole-bearing porphyritic rocks of andesitic habit, but probably related, or belonging, to the camptonites.

III. AMPHIBOLE-BEARING ROCKS OF ANDESITIC HABIT.

(Pl. VII, figs. 5 & 6, & text-figs. 2, 5, pp. 161, 165.)

The igneous rocks prevailing in the Hollybush Sandstone are of a somewhat peculiar type. With two exceptions (M 236 & M 117b)⁵ all the intrusive masses in the Sandstone belong to this type. Similar rocks also occur in both the Black and the Grey Cambrian Shales. The type is characterized by the presence of needles and stout prisms of a species of amphibole, often accompanied by phenocrysts of augite and felspar, and sometimes, perhaps, of ilmenite. These are set in a fine-grained andesitic groundmass, the felspar-laths of which very generally exhibit flow-structure. According to Timins's analyses (see Table IV, p. 176) the percentage of silica

¹ Quart. Journ. Geol. Soc. vol. lv (1899) pp. 131, 141, 158 *et seqq.*, 164 *et seqq.*, and Rep. B. itish Assoc. 1900 (Bradford).

² Quart. Journ. Geol. Soc. vol. lv (1899) p. 169.

³ *Ibid.* pp. 133, 138, 141, 157 *et seqq.*

⁴ Rep. Brit. Assoc. 1900! (Bradford).

⁵ Throughout this paper the numerals in parentheses preceded by M refer to numbers in the writer's map, Quart. Journ. Geol. Soc. vol. lv (1899) pl. xiii, and to numbered specimens in his collection.

generally appears to range from 51 to 58; the specific gravity, so far as determined, ranges usually from 2·58 to 2·67.

Some of the best-preserved examples are seen in the Hollybush Sandstone; the intrusions in this rock appear as dykes and small bosses. The distribution of these is shown in fig. 1 of the writer's paper on the Southern Malverns.¹ At the south-western corner of Midsummer Hill the presence of a number of small intrusive masses gives the ground a somewhat hummocky character. The relation of the dyke (M 112) to the Sandstone is shown in fig. 9 (p. 140) of the paper just quoted. At the north-western corner of Raggedstone Hill the main road cuts through another dyke of greater length, though it hardly extends so far as Holl stated.² Near its southern end is a small boss, and a portion of a second dyke: both of these would seem to invade not only the Hollybush Sandstone but also the Quartzite.³ The Sandstone frequently seems to be much indurated and darkened in the neighbourhood of the long dyke, as Phillips evidently perceived.⁴ This dyke is probably about 90 feet thick.

The material of these small intrusives is very uniform. It is compact, varies in colour from reddish-grey to dark greyish-blue, and shows small black-green phenocrysts. It weathers to a reddish or dark greenish-brown. The rock exposed is as a rule badly preserved, but sounder examples may be obtained here and there.

Under the microscope the freshest specimens (M 112 & M 439a) show a reddish, fine-grained pilotaxitic (or hyalopilitic) groundmass (Pl. VII, fig. 6, and text-fig. 2, p. 161), consisting largely of small, turbid, mostly untwinned laths of felspar (andesine) showing flow-structure; numerous granules of augite; much scattered ilmenite and titaniferous magnetite; a little apatite, as well as pale serpentine, titanite, pyrites, and other products of decomposition. The serpentine occurs in small irregular patches; but, owing to the altered condition of the rock, it is impossible to determine its source. Glass may have been present originally, but it is questionable whether any traces of it exist (see p. 161).

The phenocrysts include small reddish felspars, both simple and twinned; small pale augites; long or short needles, and short stout prisms of amphibole; to these may be added ragged plates of ilmenite, which appear to be original constituents. No traces of quartz, olivine, rhombic pyroxene, or of other phenocrysts can be detected.

Sections of other rocks (M 160a & M 243) intrusive in the Sandstone show an essentially similar constitution, but they are still more weathered, and the substance of the phenocrysts is often decomposed to such an extent that these are barely distinguishable

¹ Quart. Journ. Geol. Soc. vol. lv (1899) p. 132.

² *Ibid.* vol. xxi (1866) p. 88. ³ *Ibid.* vol. lv (1899) fig. 1, p. 132.

⁴ Mem. Geol. Surv. Gt. Brit. vol. ii, pt. i (1848) p. 53.

from the groundmass, the ingredients of which have suffered similarly.

Of the two varieties of the rock M 112, the specific gravity of the darker is 2·67, and that of the reddish variety 2·62. Timins's analyses (XIX & XX) of these two varieties gave as silica-percentages 52·12 and 56·03 respectively.¹ Two other analyses (XVII² & XX³), which probably belong to intrusives in the Sandstone, show 54·01 and 48·25 per cent. of silica respectively. If we may rely on these analyses, it follows that the chemical composition of the dykes includes both basic and sub-basic varieties.

Rocks essentially similar to those intrusive in the Hollybush Sandstone are associated with the Upper Cambrian Black and Grey Shales (M 101a, 104, 117, 125, 157a, 160, 183, & 209). They take the form of circular bosses, or of small laccolites or sheets intercalated in the Shales. All the larger bosses in the Shales belong to this series. The sills in the Black Shales have sometimes bleached the latter. Possibly the sills are in some cases connected with the circular bosses, but in no single instance is the exposure sufficient to show the relation of the bosses either to the sills or to the adjacent Shales.⁴ The bosses possibly mark the position of the pipes which supplied the material for the sills and laccolites, or even for lavas poured out at the surface, and now removed by denudation.

Where best preserved, the material of these intrusive masses shows a purplish-grey (M 101a) or a bluish-grey coloration (M 104, 183, 209). More weathered examples (M 117) become greenish-grey, or dark-green (M 157a, 160a); and the most weathered assume a reddish-yellow (M 104), or an orange colour (M 160). The specific gravity of six of the rocks ranges from 2·58 to 2·67 (see Table I, p. 164).

Microscopically these rocks, for the most part, agree closely with their representatives in the Hollybush Sandstone (Pl. VII, fig. 5, and text-fig. 5, p. 165). The groundmass is nearly in an unaltered condition, the original minerals being invariably more or less decomposed, and replaced by serpentine, calcite, epidote, titanite, etc. The phenocrysts always include one or more of the following, or pseudomorphs after them:—amphibole, augite, feldspar, and ilmenite (see Table I, p. 164).

In all the rocks described above, among the secondary products

¹ Quart. Journ. Geol. Soc. vol. xxiii (1867) p. 355.

² *Loc. cit.*

³ Edinb. New Phil. Journ. ser. 2, vol. xv (1862) p. 3. Other analyses in the two papers by this investigator are stated to relate to igneous rocks in the Hollybush Sandstone. Of these, No. XVIII. in the Quarterly Journal almost certainly refers to a rock in the Upper Cambrian Shales (see p. 176); No. XVI. in the same Journal may refer to a grey variety of the Hollybush Sandstone, or to the long dyke on Raggedstone Hill. No. XXI. in the Edinburgh Phil. Journ. possibly relates to the green Hollybush Sandstone itself.

⁴ The Shales immediately north-west of M 183 [see Quart. Journ. Geol. Soc. vol. lv (1899) pl. xii] dip beneath the straight side of the semicircular boss, but the actual junction is concealed.

Fig. 1.—Cross-section of a completely-resorbed phenocryst of amphibole from camptonite (M 209), showing prisms and clinopinacoids. $\times 110$ diam.

Fig. 2.—Camptonite (M 439 a). $\times 22$ diam.

A needle of colourless amphibole, showing the asbestiform condition. Sections of other needles (including a cross-section near the bottom of the figure) are visible. Most of the grey granules in the groundmass are augite; the black are iron-ore. In places the flow-arrangement of the minute felspar-laths is shown. The white patch is an imperfection in the section.

Q. J. G. S. No. 225.

is a colourless substance, usually isotropic, or polarizing in weak tints, or occasionally more strongly, which occurs in irregular patches or small crystals in the groundmass, and sometimes in the phenocrysts. In the former case it often presents somewhat the appearance of a colourless glass. But apart from the improbability of a clear glass being present in greatly altered rocks of basic composition, the analogy of other rocks (see p. 171) makes it very probable that the substance is, at any rate in part, analcime.

A few details as to the character of the prevailing minerals may now be given.

The amphibole (Pl. VII, figs. 5 & 6; and text-figs. 1 & 2, also text-fig. 5, p. 165) occurs in two forms, both idiomorphic in the prism zone, with the prismatic faces well-developed and the clinopinacoids either large or small. The prevailing forms are short or long needles; less common are short stout prisms, apparently showing the shape of basaltic hornblende (Pl. VII, fig. 5) with terminal faces. These are generally larger than the needles, and are frequently corroded. They would appear to be undoubted phenocrysts.

The needles sometimes attain a considerable size (text-fig. 2), the largest seen measuring $\frac{3}{16}$ inch; but these are few in number, and the crystals are mostly small and not intricately corroded. It is difficult to say whether terminal faces are present or not. Two or three needles occasionally interpenetrate one another. The needles are usually very much

larger than the felspar-laths, and are often numerous (Pl. VII, fig. 6).

The outer border (and in many cases the whole crystal) has invariably been resorbed, with the production of grains of iron-ores, and probably of augite; and this renders the accurate measurement of angles a matter of impossibility. The faces of the prism meet at an angle of about 124° . When the substance of the crystal is preserved it is almost colourless, or of a very pale straw-tint, and accordingly shows no perceptible pleochroism. The substance is very fibrous, owing to the presence of two very close systems of cleavage parallel to the prisms, and intersecting at an angle of 124° . So close is the cleavage, indeed, that a relatively high magnification is required to detect it in cross-sections. A somewhat irregular jointing is seen in needles cut parallel to the vertical axis. The fibres are often of considerable length, and show strong refraction: they extinguish at an angle of about 18° . The amphiboles are evidently closely allied to, if not identical with, tremolite in the asbestiform condition.

Original tremolite in igneous rock is described by Becke in some of the Austrian serpentines.¹ Prof. Rosenbusch,² in speaking of the hornblende of diorites, says:—

‘Relatively seldom the hornblende is of a very light green colour, and almost devoid of pleochroism: it assumes then the character of “strahlstein,” and forms, not isolated crystals, but aggregates of needles.’

Prof. Barrois, indeed, speaking of a ‘diorite’ of this kind intrusive in the Cambrian of Lago in Asturias, says that the long prismatic and fibrous amphibole must be tremolite.³ In view of the usual secondary nature of tremolite, it does not appear to be well-established in such cases that the original species was tremolite. Colourless hornblende is sometimes described as resulting from the bleaching of ordinary hornblende. Tremolite may arise from uraltite, or from green reedy hornblende,⁴ the latter itself being derived from ordinary green hornblende or from brown hornblende (*loc. cit.*). The Malvern tremolite might well be derived from a reedy form of amphibole. This appears to be borne out by a comparison with the amphibole of the Warwickshire ‘diorites.’ In these a colourless hornblende is described by Mr. Teall,⁵ and in the rocks as seen in the Allport Collection, as well as in slides kindly lent to me by Prof. Lapworth and Prof. Watts, all stages may be found between crystals consisting of a brown reedy amphibole and others composed of a reedy or asbestiform, colourless tremolite.

The substance of the amphibole in the Malvern rocks is never

¹ Tscherm. Min. & Petr. Mitth. vol. iv (1882) pp. 338 *et seq.*, 341 *et seq.*, & 348 *et seq.*

² ‘Mikroskop. Physiogr. d. Massigen Gesteine’ 3rd ed. (1896) p. 222.

³ ‘Recherches sur les Terrains Anciens des Asturies & de la Galice’ Lille, 1892, p. 124.

⁴ See Zirkel, ‘Lehrbuch der Petrographie’ 2nd ed. vol. i (1893) p. 304.

⁵ ‘British Petrography’ 1888, p. 251.

perfectly fresh. Even in the best preserved examples, fibres of a substance with parallel extinction, indistinguishable from bastite, run in between and parallel to those of tremolite, together with fibrous

Fig. 3.—*A phenocryst of augite from camptonite (M 209). × 72 diam.*

The phenocryst is traversed by serpentine (dotted), possibly pseudomorphic after intergrown hornblende. Granules of opacite have collected around the augite, an unusual phenomenon in the Malvern intrusives.

serpentine (presumably derived from the bastite) similarly orientated. There is generally also some structureless serpentine. In most of the rocks the amphibole is nearly or quite replaced by bastite, serpentine, epidote, calcite, and other secondary products. Bastite is very generally regarded as derived only from the rhombic pyroxenes. But M. Boule¹ describes a case, analogous to the present one, in which all stages may be detected in the transition from tremolite to bastite in the serpentines of the Allier.

The augite-phenocrysts (text-fig. 3) are usually far less abundant than those of amphibole. They are of a very pale brown, show the usual form and cleavage, and have an extinction-angle of about 42°.

The substance is better preserved than that of the amphibole. They may usually be distinguished at a glance from crystals of the latter, even when decomposed, by the absence of a resorbed border. They are sometimes honeycombed (see text-fig. 3) by spaces filled with serpentine (or bastite); but I suspect that in some of these cases the serpentine represents intergrown amphibole (see p. 164).

Fig. 4.—*Phenocryst of amphibole from camptonite (M 209). × 72 diam.*

The above figure shows the resorbed border and intergrown augite, the eight portions of which (outlined in black) all extinguish together. Serpentine unshaded, faintly outlined; opacite (and leucoxene) black.

The augite of the ground-mass is similar to that of the phenocrysts. It occurs in idiomorphic grains and crystals similar to, but less abundant than, those in the olivine-basalts. A number of granules are sometimes massed together into little accumulations, in the centre of which a serpentinous remnant of some ferric-magnesian mineral is occasionally seen (M 101a & 209).

¹ Bull. Soc. Géol. France, ser. 3, vol. xix (1891) p. 973.

Micrographic amphibole-augite phenocrysts.—In addition to the simple phenocrysts of amphibole and augite, there are a small number of tabular phenocrysts in at least two of the rocks (M 209 & M 101a) in which these two minerals are intergrown in an intimate manner. A pseudomorph after amphibole with a resorbed border may sometimes be seen to include a number of fragments of augite, all extinguishing together (text-fig. 4, p. 163, & text-fig. 5, below). The substance of the amphibole in these cases is replaced by bastite or serpentine. The bastite- and serpentine-

Fig. 5.—*A portion of M 101 a (camptonite). × 69 diam.*

The above figure shows a corroded amphibole, with scattered grains of intergrown augite, all extinguishing together. Three or four of these are seen in the figure as dark patches in the lighter oval space on the right-hand side. Most of the granules in the groundmass are augite; the darkest represent iron-ore. The flow-arrangement of the felspar-laths is seen in the immediate vicinity of the phenocryst. [From a photograph.]

fibres run parallel to the vertical axis of the augite, whence it may be concluded that the two original minerals had this axis at least in common. In other cases which are apparently similar (fig. 6, p. 165, & fig. 7, p. 167), the augite is more abundant, and is penetrated by a meshwork of fibrous serpentine; and the resorbed border is incomplete or absent. It is only short, stout, forms of amphibole that appear to be intergrown with the augite, and apparently in the main those that have been corroded.

The felspar-phenocrysts are small, few in number, and

often of a reddish colour. They commonly give tabular sections, and not infrequently show zonal growth. They are simple, twinned once or several times. Rarely both albite- and pericline-lamellation are seen. Well-preserved crystals are not sufficiently numerous to permit of a determination of the angle of extinction, but

Fig. 6.—*Semidiagrammatic figure of a phenocryst from camptonite (M 209). $\times 72$ diam.*

The above figure shows augite intimately penetrated by fibrous serpentine, probably pseudomorphic after tremolite. [The fibrous character of the serpentine is exaggerated in the figure.] The different portions of augite (outlined in black) extinguish practically together. There is no resorbed border. The felspar-microlites show a flow-arrangement around the whole. See also fig. 7, p. 167.

they are mingled with octahedra of titaniferous magnetite, and with irregular grains of one or both minerals.

Apatite is present, both in the form of long needles and short prisms.

It is not easy to see where, in a classificatory system, the amphibole-bearing rocks described in the foregoing pages should be placed. By some petrologists they would doubtless be termed porphyrites or andesitic amphibole-basalts; but, as I am unacquainted with any basalts or other rocks agreeing precisely with them, I have thought it best to place them among the lamprophyres as andesitic camptonites, or as camptonites of the Malvern type.

the largest angle observed was 44° ; others give quite small extinction-angles on the two sides of a plane of twinning. Probably more than one kind of felspar is present. Pseudomorphs containing calcite, serpentine, and opacite are not uncommon.

The felspars of the groundmass are frequently reddish, and usually show lath-shaped sections. The extinction of the laths is usually undulatory; but they appear to belong for the most part to a basic andesine. They often show a tendency to split up into thin fibres.

The ilmenite-plates, which are of any size, are usually very ragged, and rarely show any trace of the six-sided form. This is seen, however, much more frequently in the small crystals of the groundmass, where

TABLE I.—THE CHIEF ANDESITIC CAMPTONITES WHICH HAVE BEEN MICROSCOPICALLY EXAMINED.¹

No.	Locality.	Mode of Occurrence.	Colour.	Specific Gravity.	Percentage of Silica.	Phenocrysts definitely recognized.
HOLLYBUSH SANDSTONE.						
112	Hollybush.	Dyke.	Dark reddish-grey.	2.62	56.03	Amphibole, felspar.
112*	Hollybush.	Dyke.	Dark greyish-blue.	2.67	52.12	Amphibole, felspar.
160a	West of Midsummer Hill.	Boss.	Pink and dark-green.	2.62	.....	Amphibole, felspar.
243	Raggedstone Hill, north.	Dyke.	Dark bluish-grey.	.....	.....	Amphibole, felspar.
439a	Raggedstone Hill, north.	Boss.	Reddish-grey.	.....	.....	Amphibole, felspar, augite.
UPPER CAMBRIAN SHALES.						
101a	Near Martins.	Boss.	Purplish-grey.	2.67	.....	Amphibole, felspar, augite.
104	North of Peacock's Grove.	Boss.	Bluish-grey.	2.66	57.64 (?)	Amphibole, felspar.
117	Chase End Hill, north.	Sill.	Greenish-grey.	2.58	.....	Amphibole.
125	South of Fowlet Farm.	Boss.	Dark greenish-grey.	.....	.....	Amphibole.
157a	E.S.E. of Fowlet Farm.	Boss.	Dark green.	2.60	.....	Amphibole, felspar.
160	West of Midsummer Hill.	Sill.	Orange-coloured.	.....	56.12 (?)	Amphibole, felspar.
183	South of Coal Hill.	Laccolite (?)	Bluish-grey.	2.60	.....	Amphibole.
209	West of Midsummer Hill.	Boss.	Greenish-grey.	2.66	.....	Amphibole, felspar, augite.

¹ Altogether eighteen slices.

Fig. 7.—Portion of a phenocryst, similar to that sketched in text-fig. 6, p. 165, but larger, lying at the edge of the same slide as that one. ($\times 25$ diam.)

Considerable corrosion has taken place, as seen in the upper part of the diagram, and in places there is a resorbed margin. In this semidiagrammatic figure the minerals are represented as in fig. 6; the black is opacite. The dark line at the bottom of the figure is a portion of the edge of the section.

IV. AUGITE-BASALT.

One rock (M 101), intrusive in the Grey Shales near Martins, differs both from the type just described, and from the olivine-basalts. It is compact, purplish-grey, and, like the preceding type, shows a fine-grained pilotaxitic (or hyalopilitic) groundmass, with numerous augite-microlites and granules, and some apatite. No amphibole is seen, and the only phenocrysts are numerous small, pale, partly or wholly serpentized, augites. In its greater specific gravity (2.73), and probably in its lower percentage of silica and alkalis, and its greater percentage of iron, lime, and magnesia (see Table IV, p. 176), the rock differs from the andesitic camptonites, and approaches the olivine-basalts; but no olivine, or secondary biotite, is present. Serpentine and calcite, and probably analcime, occur among the alteration-products.

V. OLIVINE-BASALTS. (Pl. VII, figs. 2-4.)

Associated with the Upper Cambrian Shales, and to a much smaller extent with the Hollybush Sandstone,¹ are a series of sills and small laccolites which belong to a type different from any of the rocks already described. No example of a dyke crossing the bedding is known to the writer. These rocks are widely distributed in the Shales, which in many instances they have bleached, or indurated, sometimes to a distance of several feet, though in other places the contact-effect has been slight. They differ from the andesitic amphibole-rocks in the nature of the groundmass; in the presence of phenocrysts of olivine (now invariably replaced by serpentine); and in the entire absence of phenocrysts of amphibole, augite, and felspar. They vary in thickness from 2 inches to 75 feet or more.

Their relation to the Shales can seldom be determined directly, except in the immediate neighbourhood of White-Leaved Oak. In the path leading from this village towards Fowlet Farm thin bands from 1 foot to several yards thick may be seen intercalated between the Black Shales. In the road leading south-westward from the village nearly vertical Black Shales with intercalated thin sills are seen; one of these sills, 2 feet in thickness, completely thins out in the course of a few yards. The Shales and thin sills are here underlain by a thick igneous mass (M 119). This appears to be a laccolite, for the Shales both above and below are parallel to its surface, and in spite of the considerable thickness (75 or 80 feet) it evidently thins out rapidly south-eastward, as may be inferred from the relief of the surface in that direction and from the absence of any thick sheet of basalt in the lane leading southward from the village: in this lane the succession of Black Shales is interrupted only by two thin sills of olivine-basalt. Thicker basaltic masses evidently set in again immediately east of the lane.

At the top of the lane, near the cottage on Chase End Hill, basalts at the base of the 'Middle Igneous Band' alternate with Grey Shales. One of the former is only 2 inches thick. The ground occupied by the main mass of the igneous band west of the lane rises up into more or less distinct oval elevations, as though concealing a number of inosculating laccolites. Many small lenticular sheets or laccolites are seen near Brousil, where they form short wooded ridges. One of these (M 247), which is not less than 20 or 25 feet thick, is seen to be directly overlain by Grey Shales.

These basalts are of a fairly uniform type, both microscopically and macroscopically, but as the result of weathering they present very different appearances. In their freshest condition (M 117, 118, 175, 183, 214, 216, 218, 247, 249, 263, & 268) they are almost invariably compact, dark greyish-blue rocks, with small blackish-green phenocrysts. These latter are usually abundant, but become rare in some cases; and in others small phenocrysts, only to be

¹ Two of these rocks only (M 117b & 236) have been detected in it.

detected under the microscope, are alone present. Small rounded cavities filled with calcite, etc., which appear to be steam-vesicles, may be occasionally detected (M 231, 258, 269); but I have never seen the rock in the amygdaloidal condition mentioned by Phillips,¹ much less in the condition of 'pumice or scorïæ' described by Symonds.² Some of the rocks, even those of the freshest appearance (M 249), effervesce freely with acid. Surface-oxidation has almost invariably produced a thin brown crust; independently of this, the more exposed portions of the rock weather green, dark green, or brownish-green. Continued oxidation has produced in some cases a rusty brown or orange colour, but very frequently the gradual elimination of the green and red colouring-matter has caused the rock to assume a light greenish, brownish, or yellowish-grey colour. These greatly-weathered rocks often somewhat resemble sandstones, for which they appear to have been mistaken (p. 180). The phenocrysts at first showing black to the eye, under the influence of weathering lose their lustre, become dull green, then brown, and finally disappear, leaving small brown cavities, which have, I suspect, been regarded as vesicles. The rocks sometimes weather in a spheroidal manner.

The specific gravity in eight of the fresher examples (see Table II, p. 172) ranged from 2.61 to 2.82. A weathered example (M 117 b) gave 2.56.

Chemical analyses by Timins of three of the Bronsil masses (probably M 247, 249, & 108) gave as silica-percentages 42.42, 40.00, and 39.25.³ Three analyses of two other basalts gave from 46.27 to 47.17 per cent. of silica; and in two doubtful cases the percentages were 41.85 and 43.53 (see Table IV, p. 176). The rocks would accordingly appear to be of thoroughly basic, or of ultra-basic, composition.

Microscopic examination shows that although the original condition is never retained, the prevailing types exhibit considerable uniformity in structure and mineralogical composition.

The only phenocrysts are pseudomorphs after an olivine poor in iron: these show the usual crystalline form, and are generally not corroded. The crystals often occur in groups (Pl. VII, figs. 2 & 3). The original olivine is now completely replaced by pale green, weakly-polarizing serpentine, calcite, and other secondary products. The serpentine often shows beautifully the characteristic mesh-structure, and is sometimes exquisitely spherulitic. The groundmass commonly shows a confused aggregate of lath-shaped feldspars, iron-ores, and apatite, with serpentine, brown mica, calcite, epidote, titanite, and other secondary products. In the freshest examples (M 118, 214, 216, 218, & 268; Pl. VII, figs. 2 & 3, and text-fig. 8, p. 170) the original constitution can be fairly well made out.

¹ Mem. Geol. Surv. Gt. Brit. vol. ii, pt. i (1848) p. 56.

² Trans. Woolhope N. F. Club, 1869, p. 6.

³ These three analyses in any case refer with practical certainty to three of the four masses M 108, 247, 248, & 249.

In addition to the andesine felspar-laths, simple or twinned, and not uncommonly reddish along the borders, are small idiomorphic crystals and grains of a pale augite, with an extinction-angle of about 43° and good prismatic cleavage. These are often very abundant. The microlites are sometimes elongated, and lie parallel to the felspars. There is much scattered ilmenite and titaniferous magnetite, both in the form of irregular grains and small crystals. Long needles, or short prisms of apatite, are often enormously abundant, especially in the felspar; these are best seen in weathered examples (Pl. VII, fig. 4). There are also many scattered patches of clear isotropic serpentine, partly, and I believe largely, after augite. These patches in the more altered rocks are often impregnated with finely-divided calcite.

Some of the felspar-laths in the immediate vicinity of the serpentine-phenocrysts are almost invariably impregnated with serpentine, and in some of the more altered rocks, such as M 236,

Fig. 8.—*Olivine-basalt (M 118).*

Portion of the groundmass showing fibrous felspar-laths, iron-ores, augite-microlites (with refringent borders), and patches of serpentine (light in the figure). [From a photograph.]

the majority of the laths have been so affected, and give the impression of pseudomorphs after a ferromagnesian mineral.

In all the olivine-basalts there is a fair quantity of biotite, the fresh appearance of which at first sight seems to mark it out as an original constituent. In the fresher rocks, however, such as M 214, the mica is largely confined to the serpentine, and the size of the flakes is to a certain extent proportional to that of the patch of serpentine in which they lie; this mode of occurrence points definitely enough to the secondary, or rather to the tertiary, origin of the mica. The production of biotite has taken place most frequently in the

neighbourhood of the iron-ores, the grains of which it often fringes, or in ferruginous serpentine.

The groundmass, at any rate in the best-preserved rocks, is holocrystalline, and usually has an appreciably coarser texture than that of the amphibole-bearing rocks previously described. In this respect the groundmass approaches that of the more compact olivine-diabases of the district, but never shows the ophitic structure invariably seen in the latter. In some cases (M 102, 118, 119, 197, 248, 249, & 268) flow-structure is seen, but in the rest this structure is inconspicuous or absent.

Fig. 9.—*A pseudomorph, almost certainly after olivine, from an olivine-basalt (M 236). × 45 diam.*

The centre is occupied by a large crystal of analcime (unshaded) embedded in calcite (dotted). The pseudomorph is lined with confluent crystals of analcime introduced from without. In the surrounding groundmass the precise structure is not clear, and the arrangement of plagioclase (lined), serpentinous pseudomorphs after augite (outlined in black), and epacite (black) is semidiagrammatic.

crystals are seen these almost invariably give six-sided sections (text-fig. 9, above). In one rock (M 236) such crystals are common in spaces which, for the most part, and I think in all cases, mark pseudomorphs after olivine. Where the crystals are large, they often show under polarized light the peculiar division into fields characteristic of analcime and garnet. The refractive index is low, and in spite of the somewhat strong double-refraction (which, however, is not unparalleled) there can be no doubt that the substance, in part at least, is secondary analcime. The analcime tends to line the wall of the pseudomorph, but merges gradually into the groundmass: sometimes one or more large crystals have grown into the middle, where they lie partly surrounded by calcite, or serpentine, or by both. The free faces of the small crystals are usually parallel to the side of the attachment (text-fig. 9, above). The occurrence of analcime in a pseudomorph after olivine is not usual; it has clearly been introduced from outside.

The order of crystallization has been: apatite and iron-ores; olivine - phenocrysts; augite; and finally, felspar.

Among the secondary products in the more altered basalts (M 117b, 236, etc.) is a colourless, sometimes rather cloudy, material which occurs in patches both in the groundmass and in the serpentinized olivines. It is frequently isotropic or nearly so, but at other times exhibits fairly strong double refraction. The patches often show a polysynthetic structure. Where distinct

TABLE II.
OLIVINE-BASALTS WHICH HAVE BEEN MICROSCOPICALLY EXAMINED.¹

No.	Locality.	Probable Mode of Occurrence	Colour.	Specific Gravity.	Per- centage of Silica.	Pheno- crysts.
HOLLYBUSH SANDSTONE.						
236	Raggedstone Hill, west.	Boss.	Dark greenish- grey.	2.70		
117b	Northern end of Chase End Hill.	Sill.	Brownish-green	2.56		
UPPER CAMBRIAN SHALES.						
102	West of Pendock's Grove.	Laccolite.	Dark green.	2.66		
108	Near Bronsil.	Laccolite.	Dark bluish- grey.	2.73	39.25	
117a	Chase End Hill, north.	Sill.	Light bluish- grey.			
118	South of White-Leaved Oak.	Sill.	Dark greyish- green.	2.75		
119	Roadside south-west of White-Leaved Oak.	Laccolite.	Dirty greenish- grey.			
197	West of Pendock's Grove.	Sill.	Dark greyish- green.			
214	North-west of White- Leaved Oak.	Sill.	Dark greyish- blue.	2.82		
216	Little south-west of 214.	Sill.	Greenish-blue.			
218	Western spur of Chase End Hill.	Sill.	Bluish-grey.			
247	North-east of Bronsil.	Laccolite.	Greyish-blue.	2.71	42.42	
248	North of Bronsil.	Laccolite.	Greenish-grey.	2.62		
249	North of Bronsil.	Laccolite.	Greyish-blue.	2.76	40.00	
263 ^f 263 ⁱ 263 ^u	} Immediately north- east of Coal Hill.	} Lacco- lite.	} Greyish-blue.	{ 2.67 2.61		
268						
268	Small quarry, by cottage, south-west of White- Leaved Oak.	Laccolite.	Greyish-blue.			

Olivine only.

VI. OPHITIC OLIVINE-DIABASES. (Pl. VII, fig. 1.)

With two doubtful exceptions (M 372 & 447) the diabases appear to be confined to the Coal-Hill band² of the Grey Shales. They occur as sills, and probably as small laccolites and bosses. The relation of the sills to the Grey Shales is admirably seen at Coal Hill Cottage (fig. 10, p. 173).

¹ Altogether twenty slices.

² This analysis may refer to No. 248.

³ Quart. Journ. Geol. Soc. vol. lv (1899) p. 159.

Fig. 10.—Section of Grey Shales and diabases at Coal Hill Cottage.

Here five sills, *a*, *c*, *e*, *g*, and *i*, are intercalated in shales, as follows :—

		Thickness in feet and inches.		
M 182.				
<i>a</i>	.....	1	6	Diabase (top not seen) ; sp. gr.=271.
<i>b</i>	.....		9	Indurated shale splitting into small rectangular blocks.
<i>c</i>	 1½ to	2	0	Diabase, rotten; fine-grained at the top; sp. gr.=251.
<i>d</i>	at bottom ...		9	Indurated shale, like <i>b</i> .
<i>e</i>	.....	2	3	Diabase, fine-grained at the top and bottom; sp. gr.=261.
<i>f</i>	.....	5	0	Shales, baked yellow; top and bottom more baked than the middle; top very hard, hornstone-like.
<i>g</i>	.....	3	6	Diabase, fine-grained at the top; sp. gr.=269.
<i>h</i>	.....	1	0	Shales.
<i>i</i>	.....	2	5	Diabase.
<i>j</i>	.....		10	Shales (bottom not seen).
		20	0	

The baking of the lower part of *f* proves the intrusive nature of the diabase. Outside the garden of the cottage higher rocks are seen, consisting of a thick sill of diabase overlain by thinner bands of shale and diabase. At the south-eastern end of Coal Hill a similar succession of diabases (M 184) and shales is seen. In the garden of the roadside cottage immediately south of Coal Hill the top of one diabase-sill not less than 6 feet thick, and the bottom of a second not less than 3 feet thick, are seen, separated by about 6 feet of Grey Shale. The beds (M 459) dip E. 30° N. at about 48°, and are presumably inverted like those on the road a little farther south. At this point (M 261),¹ marked in the writer's map by the dip-arrow 45°, three sills of diabase are seen, the middle one 1 foot thick, overlain and underlain by *Dictyonema*-bearing Grey Shales 2½ feet and 14 inches thick respectively. The localities just mentioned are the only ones in which the relation of the diabases to the Shales is shown. Thicker masses than those mentioned occur, as, for instance, M 106, where a thickness of perhaps 15 or 20 feet is indicated. Holl also mentions a sill 35 feet thick in Coal Hill.

The diabases include coarse-grained (M 106, 182, 372, 459, etc.), medium-grained (M 182, 184, etc.), and fine-grained (M 182, etc.)

¹ See also Holl's section, Quart. Journ. Geol. Soc. vol. xxi (1865) p. 89.

types. Where freshest, the rocks are of a dark bluish colour; they often weather in a spheroidal manner, the weathered portion assuming greenish, brownish, or yellowish colours. The medium-grained kinds, when weathered, often resemble ashly sandstones.

The specific gravity of the diabases investigated, with the exception of the rotten diabase M 182c (which has a specific gravity of 2.51), ranges from 2.61 to 2.75. The higher figure (M 106) is probably nearest to the original, for this rock is one of the freshest, most of the rest being considerably altered.

The percentage of silica in the specimens analysed by Timins² (M 106 & 182) ranges from 43.22 to 45.22. The rocks would then appear to be of thoroughly basic, or even of ultrabasic, composition. In all probability (see p. 179) the supposed ash-bands (IX, X, XI, & XII) of Timins (*loc. cit.*) are weathered diabases: the silica-percentage in these ranges from 35.12 to 48.00.

One of the freshest diabases in the district is M 106; Mr. Teall refers to this rock as a typical ophitic diabase.³ M 372 is essentially similar. Under the microscope both these rocks are seen to consist of pale brown allotriomorphic augite, with an extinction-angle of about 41° and prismatic cleavages; pale green idiomorphic, hypidiomorphic, or allotriomorphic pseudomorphs after an olivine poor in iron, and now consisting chiefly of serpentine (with mesh-structure) and calcite; hexagonal corroded plates of ilmenite, now largely replaced by leucoxene; some apatite; and large laths of tolerably fresh or decomposed plagioclase, probably andesine: these latter are twinned once or many times. In M 106, brushes of long fibres, the microscopic characters of which are those of natrolite, have invaded the feldspars; they are grouped in large fan-shaped or sheaf-like bundles. The apatite and iron-ores, the feldspar, the olivine, and the augite have crystallized out in the order named. The feldspar and olivine were the most abundant ingredients, the ilmenite the least. Octahedra of magnetite and secondary flakes of biotite are occasionally seen in the serpentine. In a more weathered but otherwise similar rock (M 182c), the ferromagnesian minerals are altogether replaced by serpentine, calcite, etc. Varieties of fine grain (M 103, 184) show a similar constitution; in M 184 there is much calcite.

The marginal facies of a sill observed at Coal Hill Cottage (top of M 182c, Pl. VII, fig. 1) shows numerous large isolated lath-shaped and tabular crystals of clear feldspar, mostly untwinned, but sometimes twinned several times; less abundant than these are serpentinous pseudomorphs apparently after olivine, sometimes penetrated by the feldspar-laths, and masses of iron-pyrites. These are embedded in a very fine-grained groundmass of extremely minute laths of feldspar, with small patches of serpentine, and many minute

¹ See also Mem. Geol. Surv. Gt. Brit. vol. ii, pt. i (1848) p. 56.

² Quart. Journ. Geol. Soc. vol. xxiii (1867) p. 353, Nos. I (= M 182), and V, VI, & VII (= M 106).

³ 'British Petrography' 1888, p. 245.

granular patches of sphene probably after ilmenite. The diabase at its margin thus acquires an andesitic texture. It differs from the olivine-bearing porphyritic rocks in several points, notably in the very fine character of the groundmass.

The diabases appear to have had a more marked contact-effect upon the shales than had the olivine-basalts. The Grey Shales are in many places baked yellow, or indurated into a rock resembling hornstone (see p. 173). Spotted indurated shale may be observed in debris near M 106. [For chemical analyses, see Table IV, p. 176.]

TABLE III.

OLIVINE-DIABASES WHICH HAVE BEEN MICROSCOPICALLY EXAMINED.

No.	Locality.	Texture.	Specific gravity.	Percentage of Silica.
103	South of Fowlet Farm.	Medium - grained ; ophitic.	2.67	
106	On the road between Eastnor and Hollybush.	Coarse - grained ; ophitic.	2.75	$\left\{ \begin{array}{l} 45.22 \\ 43.99 \\ 43.22 \end{array} \right.$
182 $\left\{ \begin{array}{l} a \\ c \\ e \\ g \end{array} \right.$	Coal Hill Cottage.	$\left\{ \begin{array}{l} \text{Coarse-grained to} \\ \text{fine - grained ;} \\ \text{ophitic (to an-} \\ \text{desitic)} \end{array} \right.$	$\left\{ \begin{array}{l} 2.71 \\ 2.51 \\ 2.61 \\ 2.69 \end{array} \right.$	$\left. \right\} 44.65$
184	Southern end of Coal Hill.	Medium - grained ; ophitic.	2.64	
372	Close to Fowlet Farm.	Coarse - grained ; ophitic.		

VII. MUTUAL RELATIONS BETWEEN THE ROCKS DESCRIBED.

The porphyritic and the ophitic olivine-bearing rocks of the district are mutually related, both in chemical and mineralogical composition and distribution. In each group the chemical composition appears to range from thoroughly basic to ultrabasic, and the characters of the olivine and augite appear to have agreed in the two series. Both series are developed chiefly in the southern part of the district, but the diabases, unlike the porphyritic rocks, are chiefly confined to a particular horizon in the Grey Shales. The chief distinction lies in the generally coarser grain and the early appearance of the felspar in the diabases; these assume a porphyritic form only at the margin, and then the type produced differs from the ordinary olivine-basalts of the district. I have been able to detect no transitional types between the two series.

The amphibole-bearing rocks of andesitic type are quite distinct from the olivine-bearing rocks. They differ from the porphyritic members in their colour, chemical composition, and lower specific

TABLE IV.—CHEMICAL ANALYSES BY TIMINS RELATING TO IGNEOUS ROCKS IN THE MALVERN CAMBRIANS.¹

No. of Analyses.	Camptonites.						Augite-Basalt.		Olivine-Basalts. ²								Olivine-Diabases.							
	XXI ³	XVI4	XVIII4	XX4	XVII4	XIX4	XX3	XVIII3	VIII4	XVII3	XIV4	III4	XV3	XVI3	IX4	V4	I4	V14	VII4					
SiO ₂	58.61	58.07	57.61	56.03	51.01	52.12	48.25	42.30	47.17	43.53	42.42	41.85	40.90	39.25	45.75	45.22	44.65	43.96	43.22					
Al ₂ O ₃	13.35	19.14	17.31	18.51	17.45	18.18	20.42	20.24	17.97	13.48	18.49	17.80	18.15	15.26	17.91	14.08	19.26	18.72	17.56					
Fe ₂ O ₃ & FeO....	8.59	5.90	7.71	6.14	8.05	8.91	8.17	10.33	14.25	12.23	14.40	11.14	12.44	12.97	11.34	11.88	10.18	11.39	11.58					
CuO.....	.....	.....	0.20	0.40	.....	0.25	.....	.....	.....	.....	.....	.....	.....	.....	0.22	0.80	.....	.....	.....					
MnO.....	1.75	0.25	0.15	.....	.....	0.20	1.00	0.75	0.50	1.75	.....	.....	.....	1.50	1.50	0.58	.....	.....	.....					
CaO.....	2.31	1.46	2.12	2.39	2.36	2.52	3.45	3.20	1.92	10.22	9.96	8.17	6.70	6.97	2.05	6.73	4.28	5.05	6.14					
MgO.....	3.29	1.00	0.60	2.69	3.53	6.24	5.45	10.41	7.57	7.80	4.40	5.56	7.40	9.87	9.01	9.81	9.93	11.16	8.29					
K ₂ O.....	0.15	11.73	10.34	11.39	11.65	6.78	2.60	3.08	7.55	4.26	3.31	8.03	4.47	5.15	7.18	5.88	5.87	3.61	7.39					
Na ₂ O & loss.....	2.63	.....	.....	.....	.....	.....	2.60	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....					
Loss on ignition....	3.77	1.46	3.60	2.45	2.43	4.50	4.38	5.58	6.04	5.53	7.02	7.45	7.27	5.51	5.96	6.20	5.90	6.08	5.82					
Loss at 212° F. ...	3.22	.....	.....	.....	.....	.....	1.98	3.51	.....	1.70	.....	.....	.....	2.07	3.52	.....	.....	.....	.....					
Locality of Rock {	? Long dyke, on Ragged-stone Hill.						? Long dyke, on Ragged-stone Hill.						From White-Leaved Oak igneous band.						M 248 or M 249 M 108 M 108					

1 The author regrets that he is unable to furnish any new chemical analyses of these rocks, and those reprinted in this table are given in the absence of any more recent.
 2 Two analyses of one of the olivine-basalts (M 214) yielded to Mr. Cecil Duncan 46.55 and 46.27 per cent. of silica.
 3 Edinb. New Phil. Journ. ser. 2, vol. xv (1862) pp. 3 et seqq.
 4 Quart. Journ. Geol. Soc. vol. xxiii (1867) pp. 353, 355.

gravity; also in their structure, mineralogical composition, distribution, and to a certain extent in their mode of occurrence. While the olivine-bearing rocks are chiefly characteristic of the Upper Cambrian Shales, in which they take the form of sills and small laccolites, the amphibole-bearing rocks also invade extensively the Hollybush Sandstone, chiefly in the form of dykes and bosses; and even where the Upper Cambrian Shales are invaded the form assumed is often that of a boss. The groundmass is usually much finer grained than in the olivine-basalts, and flow-structure is invariably seen; the phenocrysts in the two series differ entirely, and secondary biotite, abundant in the basalts, is rare in the amphibole-bearing rocks. A fourth type of rock (augite-basalt) presents resemblances on the one hand to the 'andesitic camptonites,' and on the other to the olivine-basalts (see p. 167); but it is not intermediate between these types, for it contains neither amphibole nor olivine.

VIII. COMPARISON OF THE MALVERN INTRUSIVES WITH THE IGNEOUS ROCKS OF OTHER DISTRICTS.

The Malvern diabases described in the foregoing pages in some respects resemble the olivine-diabases and dolerites which have invaded the Old Red Sandstone and Carboniferous rocks of Herefordshire, Worcestershire, the Cleve Hills, the Forest of Wyre, and the Central English Midlands. Mr. Teall, however, points out that as a whole the olivine in these rocks is rich in iron, and that the augite is deeply coloured.¹ The Malvern diabases do not share these features. They differ from the Ordovician diabases of the Lake District, North Wales, and Shropshire in the presence of olivine, and in other respects.² They differ also from the Warwickshire ophitic 'diorites' in containing augite in place of hornblende.

Similar statements may be made with reference to the olivine-basalts. The Malvern examples belong to a somewhat unusual type, and differ from the usual Ordovician basalts of the Lake District and North Wales in the presence of olivine (Teall and Harker, *loc. cit.*). Olivine-basalts of Cambrian or slightly earlier age, and again of a different character, have been described by Sir Archibald Geikie from South Wales.³ Olivine-basalts in the form of flows and dykes, more nearly allied to the Malvern basalts, abound in Scotland and Ireland, and occur to a more limited extent in the English Midlands⁴; but these newer rocks, where porphyritic, appear to differ for the most part in the greater variety of the phenocrysts.

¹ 'British Petrography' 1888, p. 214.

² *Ibid.* pp. 214 *et seq.*; Harker, 'Petrology for Students' 1895, pp. 113 *et seq.*; Watts, Proc. Geol. Assoc. vol. xiii (1894) p. 338.

³ Quart. Journ. Geol. Soc. vol. xxxix (1883) p. 304; see also Harker, *op. cit.* p. 175.

⁴ Teall, 'British Petrography' 1888, pp. 186 *et seq.*; and Harker, 'Petrology for Students' 1895, pp. 177-79.

The amphibole-bearing rocks of the Malvern Hills do not resemble the ordinary hornblende-basalts, andesites, or porphyrites. They appear to find their closest analogues in the Warwickshire 'diorites,' originally described by Samuel Allport.¹ The name camptonite has been suggested by Prof. Watts for these Warwickshire rocks.² He has kindly examined some of my slides, and considers that they conform to the Nuneaton type. Brief descriptions of some of the Warwickshire rocks have been published by Messrs. Teall,³ Waller,⁴ Rutley,⁵ and Prof. Watts (*loc. cit.*). The last-mentioned has kindly sent me a number of slides belonging to Prof. Lapworth and himself; and, thanks to the courtesy of Mr. Teall and Mr. Prior, I have been able to examine many other slides of these rocks. One of the commonest types in the Warwickshire district has been figured by Mr. Teall.⁶ This consists of idiomorphic needles of brown hornblende, with iron-ores and apatite, set in a holocrystalline coarse- or fine-grained matrix of more or less lath-shaped feldspars. This type of rock perhaps corresponds most nearly with the Malvern amphibole-bearing series, but phenocrysts of augite are absent. Equally common is a type which differs from the foregoing in the presence of phenocrysts of olivine, which are often grouped together. These rocks seem to correspond with the Malvern olivine-basalts, but they possess amphibole instead of augite. One rock (554) from Dosthill, in the Allport Collection in the Natural History Museum, seems to connect the two Malvern porphyritic types: in a groundmass which much resembles that of these rocks, and of the augite-basalt (M 101), phenocrysts of olivine and augite are seen, but no amphibole.⁷

Taking the rocks as a whole, in spite of differences of development, there seems to be a considerable analogy between the rocks of the Malvern and Nuneaton areas. In both cases we have a series of small intrusive masses chiefly in the form of sills and dykes of more or less basic material which have invaded the Cambrian, but no later formations. Amphibole, augite, and olivine are characteristic minerals, and the amphibole was probably of the same peculiar character, and has undergone similar modifications in each case. There is, moreover, a marked tendency in both cases for the ferromagnesian minerals to give rise to serpentine rather than chlorite. In each district camptonitic features are developed in some of the rocks. This is seen in the complete absence of quartz, the rarity of phenocrysts of feldspar, and the prevalence of the ferromagnesian minerals; among which biotite is absent in each case. Moreover, ophitic rocks, such as commonly are associated with camptonites, and which indeed are sometimes classed with them, are present in both areas.

¹ Quart. Journ. Geol. Soc. vol. xxxv (1879) p. 637.

² Proc. Geol. Assoc. vol. xv (1898) p. 394.

³ 'British Petrography' 1888, pp. 250-51.

⁴ Geol. Mag. 1886, p. 322.

⁵ *Ibid.* pp. 557 *et seqq.*

⁶ 'British Petrography' 1888, pl. xxix, fig. 2.

⁷ It is interesting to note that of all the localities in which Cambrian rocks are exposed in Warwickshire, Dosthill is the nearest to the Malverns.

Under these circumstances it seems permissible to suggest that we are dealing with an assemblage of rocks which have had a common origin. The most striking difference between the two districts consists in the greater abundance of hornblende in the Nuneaton area, and of augite in the Malvern district. In addition, a porphyritic character and flow-structure seem to be much more pronounced in the Malvern rocks. These three features give to the latter a more basaltic or andesitic habit. Some of the differences may be due to differences in chemical composition, but it seems possible that the Nuneaton rocks may have consolidated at a somewhat greater depth than did those of the Malvern area, and that the material which in the former crystallized out largely as hornblende, in the latter mostly took the form of augite. This hypothesis may, perhaps, account for the sharper separation of the different Malvern types; for differentiation may be supposed to have progressed with increasing distance from the more deeply-seated source.

According to this view the rocks may be contrasted as follows:—

NUNEATON.	MALVERN.
1. Amphibole-camptonites devoid of olivine and augite.	1. Amphibole-camptonites and augite-basalt, both of andesitic habit, devoid of olivine, but with augite in the groundmass.
2. Olivine-camptonites with amphibole-needles.	2. Olivine-basalts, often andesitic, with augite-microlites in the groundmass.
3. Ophitic olivine - amphibole - diabases.	3. Ophitic olivine-diabases.

It should be observed that in some of the Nuneaton camptonites and diabases, augite is an important constituent; such rocks serve to connect the two districts.

Rocks of the Nuneaton type are not limited to the two districts compared. Prof. Watts records allied rocks in Shropshire,¹ and it is probable that certain rocks occurring in the Scottish Highlands, Anglesey, North Wales, and Charnwood, belong to the same category.²

IX. SUPPOSED PYROCLASTIC ROCKS.

Allusion has already been made to the fact that Murchison and Symonds regarded the Hollybush Sandstone as a volcanic grit (pp. 156 & 157). Phillips did not accept this view,³ and I shall endeavour to show in a later communication that the Sandstone has not the least claim to this title and furnishes no evidence of contemporaneous volcanic action. Timins in 1867 analysed 'some thin beds, apparently formed by the deposition of felspathic ash.'⁴ He

¹ Proc. Geol. Assoc. vol. xiii (1894) p. 336, & Quart. Journ. Geol. Soc. vol. lv (1899) p. 169.

² J. J. H. Teall, Geol. Mag. 1886, pp. 351 *et seqq.*

³ 'Geology of Oxford & the Valley of the Thames' 1871, p. 66.

⁴ Quart. Journ. Geol. Soc. vol. xxiii (1867) p. 356.

remarks that 'one of these may be observed on the east side of the quarry at the south-west base of Midsummer Hill'; he states, however, that the ash 'is, in part, of the structure of sandstone, and in part felspathic, with traces of epidote.' The analyses of this rock (XXIII & XXIV) show it to be of a decidedly more acid character than any of the igneous rocks associated with the Sandstone or with any of the Malvern Cambrians. I have nowhere been able to recognize in the Sandstone beds which resemble tuffs, and have examined what I believe to be the particular layer spoken of by Timins. It occurs along one of the joint-planes which run parallel to the surface of a dyke (M 112), and crosses the bedding, which is here very obscure. The supposed ashy layer appears to be nothing but a portion of the Sandstone, modified along a line of crushing and displacement.

After careful search in the Black and Grey Shales I have been equally unable to detect any traces of pyroclastic rocks. Crush-breccias are occasionally seen on a very small scale, and some of the rocks have somewhat the appearance of sandstones and fine tuffs. Indeed, Phillips speaks of sandstones interbedded with the shales,¹ and Holl describes ashes and grits in the 'Coal-Hill Band.'² Symonds also mentions volcanic grits in the Black Shales.³ Microscopic examination shows that the supposed sandstones, grits, and ashes are nothing but weathered diabases and basalts (see pp. 169, 174).⁴

It must be concluded, then, that pyroclastic rocks are probably altogether absent from the Cambrian Beds of the Malvern area.

X. THE INTRUSIVE CHARACTER OF THE ROCKS.

The camptonitic dykes and bosses in the Hollybush Sandstone must evidently be removed from the category of lavas, and so must the bosses in the Black and Grey Shales. There remain only the sheets and supposed laccolites intercalated in the Shales, and more rarely in the Sandstone. Of these the diabases, as might be expected from their general occurrence as dyke-rocks, are at least in part intrusive (p. 173). In the case of the basalts the question is more difficult; the materials are such as might belong either to a lava or to a small sill: the absence of glass, and the rarity and small size of the steam-vesicles rather support the idea of an intrusive origin. The basalts in many cases do not appear to have greatly affected the Shales, as was observed by Symonds (*loc. cit.*); but in other cases the Black Shales have been bleached in a somewhat sporadic manner, and

¹ Mem. Geol. Surv. Gt. Brit. vol. ii, pt. i (1848) p. 54.

² Quart. Journ. Geol. Soc. vol. xxi (1865) pp. 89 & 90.

³ 'Records of the Rocks' 1872, p. 73.

⁴ It may be pointed out here that, although the grits described by previous observers appear to be non-existent, a series which could hardly have been seen by them has been detected by the writer, but these are in no way pyroclastic: see Rep. Brit. Assoc. 1900 (Bradford).

in a certain number of instances the basalt has bleached, not only the Shales below, but also those above, a circumstance which proves that at least some of the sheets are sills. But perhaps the strongest piece of evidence for the intrusive nature of the basalt-sheets is the complete absence of tuffs or, indeed, of pyroclastic materials in the Cambrian sediments. The available evidence points, then, to Prof. Lapworth's conclusion that of the igneous rocks in question 'the majority are certainly intrusive' (see p. 157). We may note, as in agreement with this conclusion, that the igneous rocks associated with the Cambrian of other parts of the Midland district are intrusive, and that, as pointed out to me by Prof. Watts, Cambrian volcanic rocks nearer than South Wales are not known.

XI. DATE OF INTRUSION.

The rocks described in the foregoing pages have apparently shared the foldings and dislocations which affected all the older rocks of the Malvern district. I maintained on a former occasion¹ that these movements dated principally from Coal-Measure times. The olivine-diabases which have invaded the Carboniferous of the English Midlands possibly date in part from this period, for they seem to have invaded the Lower and Middle Coal-Measures, but not the Upper. The igneous rocks intrusive in the Malvern Cambrians bear the stamp of greater antiquity. Rocks which, to the eye seem fresh and unweathered, show under the microscope considerable physical and chemical changes. The olivine-diabases are never so well preserved as the very similar Carboniferous diabases. The felspars of these and the olivine-basalts so commonly show undulatory polarization that the determination of the species is generally a matter of difficulty. The olivine is invariably serpentinized, and the serpentine has given rise to tertiary minerals such as biotite.² If it be granted that the olivine-diabases and basalts and the andesitic camptonites are intrusive, it follows that the intrusion took place, at any rate in part, in late Tremadoc or in post-Tremadoc times, for all three types invade the uppermost Tremadoc Shales seen. On the other hand, as Phillips pointed out, the igneous rocks do not invade the May Hill Sandstone.³ It follows, therefore, with high probability that injection took place in Ordovician times, or at least not before the deposition of the uppermost Tremadoc Beds, and not later than that of the lowest May Hill Beds in the district. This is in agreement with the fact that the allied rocks of other districts are not known to invade any rocks later than the Cambrian.

¹ Quart. Journ. Geol. Soc. vol. lvi (1900) pp. 175 *et seqq.*

² It must be noted, however, that the imperfect preservation of the Malvern rocks is doubtless due in part to the absence of deep or recently-worked quarries.

³ Mem. Geol. Surv. Gt. Brit. vol. ii, pt. i (1848) p. 57.

XII. RELATION OF THE IGNEOUS ROCKS DESCRIBED TO THOSE OF THE ARCHÆAN MASSIF.

Seeing that the intrusive rocks which have invaded the Cambrian strata must have passed through the underlying Archæan, it might be expected that representatives of them would be found in the neighbouring Archæan complex, and that the latter should, therefore, contain not only pre-Cambrian but also later igneous masses. The circumstance that the three chief types of rock—namely, diorite, granite, and felsite, which according to Dr. Callaway¹ enter into the composition of the Malvernian complex, have undergone an apparently pre-Cambrian foliation, militates against the idea that either the granite or the coarser diorite can be the plutonic representative of any rock seen in the Cambrian strata. It is, however, conceivable that certain of the rocks regarded as diorite may belong to the same series as the hornblende-rocks in the Cambrian Beds; but, until the diorites of the Malvern chain are better known, it will be impossible to deal with this question. Augite-bearing rocks appear to be rare in the Malvernian. Proterobases and epidiorites are described by Mr. Teall,² but rocks of this description do not invade the Cambrian. The same writer, however, detected among the rocks on Swinyard Hill an ophitic diabase precisely similar to those seen in the Cambrian.³

Augite-bearing rocks occur in the Warren House (Uriconian) Series,⁴ but from Mr. Rutley's descriptions and from a personal examination of Mr. H. D. Acland's slides by the present writer, it appears that these rocks are of a type different from any seen in the Cambrian.

We have, then, no certain proof that, with the exception of the olivine-diabase, any of the rocks described in the foregoing pages have invaded the Archæan. Prof. Watts informs me that this is also the case with the allied intrusive rocks of other parts of the English Midlands.

XIII. CONCLUSIONS.

The Cambrian of the Southern Malverns is associated with a series of igneous rocks which have commonly been regarded as volcanic. There are, however, among them no truly vesicular rocks and no tuffs such as have been mistakenly described, and the rocks are probably all intrusive.

Petrographically the assemblage may be divided into three, structurally and mineralogically very constant, types, and a fourth

¹ Quart. Journ. Geol. Soc. vol. xliii (1887) pp. 526 & 527.

² 'British Petrography' 1888, p. 245.

³ *Loc. cit.* The rock (1140) to which reference is made may be seen in the Natural History Museum: it contains abundant serpentinized olivine.

⁴ F. Rutley, Quart. Journ. Geol. Soc. vol. xliii (1887) pp. 497-99, and H. D. Acland, *ibid.* vol. liv (1898) pp. 559 & 561.

subordinate type. To these belong a series of ophitic olivine-diabases; a related series of porphyritic olivine-basalts; and a series of amphibole-bearing porphyritic rocks, probably to be regarded as camptonites. These types are not connected by intermediate gradations; all three show a different distribution; and the olivine-bearing and the amphibole-bearing rocks have a different mode of occurrence. According to existing analyses the former range in chemical composition from thoroughly basic to ultrabasic; the latter are generally more acid, and include sub-basic varieties.

The rocks appear to find their nearest analogues in the camptonitic 'diorites' of Warwickshire and other parts of the British Islands, and like these occur only in association with Cambrian rocks; but the whole assemblage has the stamp of a local character. The Warwickshire rocks, to a certain extent, appear to bridge over the gap which exists between the Malvern Amphibole-bearing Series and the Olivine-bearing Series.

Intrusion took place in times later than the deposition of the Tremadoc Beds of the Malvern district, and probably earlier than that of the Upper May Hill Sandstone.

In conclusion I would express my sincere thanks to Prof. Watts and Prof. Sollas, who have given me the benefit of their opinions on some of the more obscure rocks. To Mr. Cecil Duncan I am indebted for the determination of the percentage of silica in one of the rocks; to Prof. G. Paton for kind assistance in photographing some of the rocks; to Mr. G. T. Prior for references to the literature of the subject, and much courtesy shown to me during my examination of the rocks in the Allport Collection; and to Mr. H. D. Acland for the kind loan of rock-sections.

EXPLANATION OF PLATE VII.

Fig. 1. Portion of the marginal facies of olivine-diabase (M 182e), showing small phenocrysts of felspar in a groundmass containing minute laths of felspar, etc. $\times 72$.

2. Olivine-basalt (M 214), showing a group of phenocrysts of serpentinized olivine in a groundmass of felspar-laths, augite, ilmenite, etc. $\times 15$.

3. Olivine-basalt (M 214) with a small group of phenocrysts (after olivine), in a groundmass showing clearly the augite- and felspar-microlites and iron-ores. $\times 33$.

4. Olivine-basalt (M 249). Portion of the groundmass showing felspar-laths, some very fibrous; needles of apatite; iron-ores; and patches of serpentine, probably after augite. $\times 67$.

5. Andesitic camptonite (M 101a), showing dark bastite-and-serpentine-pseudomorphs after amphibole, set in a fine-grained groundmass. Most of the small dark patches seen are sections of needles of amphibole, but a stout phenocryst is shown at the bottom of the figure. $\times 10$.

6. Andesitic camptonite (M 439a), showing long and sometimes interpenetrating crystals of nearly colourless amphibole, with a resorbed border. $\times 16$.

DISCUSSION.

Mr. PRIOR congratulated the Author on obtaining such interesting results from what at first sight appeared to be very unpromising material. As regarded the 'camptonitic group' he felt some doubts concerning the nomenclature. In the case of many of the Nuneaton rocks the name *camptonite* appeared to be justified; but the Malvern rocks, in their structure and in the character of the hornblende, seemed to be more closely related to hornblende-basalts than to typical *camptonites*.

Prof. WATTS pointed out that Allport had indicated that the Warwickshire 'diorites' were a group of rocks distinct from the dolerites of the Midlands. Similar rocks had since been found associated with Cambrian strata in a variety of districts. In the Nuneaton region the *camptonites* were not associated with olivine-dolerites or diabases, and it was difficult to say to what this type of rock in the Malvern area was related.

Dr. J. W. EVANS referred to the fact that a similar association of calcite and analcime had been described by Glocker from the Moravian *teschenites* in 1852. With regard to the use of the term *camptonite*, he had always understood that it denoted a subdivision of the mica-trap or lamprophyre-group, and, therefore, implied a predominance of ferromagnesian silicates.

The PRESIDENT and Mr. CUNNINGHAM-CRAIG also spoke.

The AUTHOR said, in reply to the President and to Mr. Prior, that he did not think the amphibole-bearing rocks described greatly resembled the *vesegites* or the typical hornblende-basalts. They appeared to be more acid than the latter, and the abundant felspar of the groundmass was chiefly or wholly *plagioclase*. Some of the amphiboles might be the small representatives of the large corroded phenocrysts of the hornblende-basalts, but most of them showed the needle-like form so common in the lamprophyres; though, as Mr. Prior had pointed out, a resorption-border was always present. It was doubtful whether more than one generation of amphibole was present or not, and the rocks appeared scarcely to conform to the strict definition of *camptonite* as given by Prof. Rosenbusch; and it was with some hesitation that the Author had regarded them as peculiar members of this group, rather than as forming a new type. In reply to Dr. Evans, the Author said that he had not thought it well to place too much reliance on the chemical analyses given, as they had been made many years ago. While recognizing the differences mentioned by Prof. Watts between the olivine-bearing rocks of Malvern and Nuneaton, the Author said that olivine-augite-rocks, apparently devoid of hornblende, one of which approached the Malvern olivine-basalts in several respects, occurred at Dosthill, though still undescribed. He could give no satisfactory answer to Mr. Cunningham-Craig's question as to the order of intrusion of the different types described, since in no case known to the Author were two rocks of different type seen in mutual contact.

FIG. 1, X 72.

FIG. 2, X 15.

FIG. 3, X 33.

FIG. 4, X 67.

FIG. 5, X 10.

FIG. 6, X 16.

T. T. Groom, Photo-micro.

Bemrose, Collo., Derby.