Moreover, the fossils found at Barrow are on the whole the same, and show a similar distribution, so that the bottom beds at Owthorpe and Barrow must be homotaxial. This being the case, it is evident that the beds at Owthorpe can hardly be called "pre-*Planorbis*", for at the time of their deposition *Planorbis* was in existence a few miles away.

The character of the fauna in the lowest beds of all in the Owthorpe district suggests a possible explanation of the absence of *Planorbis*, for it is very impoverished, the only fossils being *Modiola minima* and Ostracods (*Cytheridea ellipsoidea*, Jones). This type of fauna is characteristic of lagoon phases, for, according to Mr. Dixon, these are "all distinguished in places by exceedingly fine-grained calcite mudstones with an impoverished fauna of Lamellibranchs (especially *Modiola*), Ostracods, and *Spirorbis*. A certain amount of terrigenous material, mud, and fine sand is found in them all".¹

Confirmatory evidence of such conditions in the Owthorpe district is seen in occasional worm bores and traces of ripple-marks. Further, the occurrence of insect-remains at Barrow, indicating the proximity of land, supports rather than opposes this view.

With regard to the underlying Rhætic beds, it might be here recorded that the top bed of Rhætic limestone at Cotgrave Gorse is cracked, the cracks being filled with calcite. The upper edges of the blocks often show a pitted and bored appearance, which may in some cases have been caused by worms. A similar bed has been described near Bath, and is there called the Sun Bed.²

I should like to express my thanks to numerous friends who at various times have assisted me in the field, and to Professor H. H. Swinnerton, of University College, Nottingham, whose inspiration and help are mainly responsible for this little paper.

IV.—THE INTRUSIVE ROCK OF MARSTON JABET, NUNEATON, WARWICKSHIRE.

By ALFRED BRAMMALL, B.Sc. (Lond.), F.G.S., Assistant Director of Education, Bury, Lancs.

(PLATE VI.)

1. *Introduction and References to Literature.*

THE intrusive rocks of Marston Jabet and Chilvers Coton, though probably of quite minor importance, have been rendered noteworthy by the variety of opinions held regarding their true position in a scheme of rock classification. This is especially the case as regards the rock quarried at Marston Jabet. Thus Allport³ comments upon certain remarkable features distinguishing this rock, which, however, seems to be covered by his general statement that the intrusive rocks of the Warwickshire Coalfield are for the most part ordinary diorites. Rutley⁴ concurs in the opinion expressed by

¹ Q.J.G.S., 1911, p. 571.

² *Geology of Wellington and Chard* (Mem. Geol. Surv.), pp. 27, 28.

³ Q.J.G.S., vol. xxxv, p. 637, 1879.

⁴ GEOL. MAG., 1886, p. 562.

Allport. Watts¹ calls attention to the lamprophyric aspect of the rock, which he terms a camptonite; and with this description Harker² agrees. Hatch³ admits the lamprophyric features and incidentally refers to the lack of recorded analyses.

The conclusions arrived at in this paper are based upon a detailed examination of the rock in situ, upon a microscopic investigation of a large number of thin sections, and upon a partial chemical analysis of the prevalent rock type.

2. *The Intrusive Character of the Marston Jabet Rock.*

There is no question as to the intrusive character of the rock; for completeness, however, the evidence for intrusion is set out below in some detail, the features described being those observed at the quarry in August and December, 1912.

The country rock is Coal-measure shale horizontally bedded. In the middle of the quarry is a horizontal platform of shale from above which igneous rock has been removed. At the quarry face the latter rock extends for several feet below the plane of the middle platform; it is therefore clearly transgressive.

At the north-east end the quarry face is a pillar of laminated shale continuous with the platform below and extending upwards to the ground level. The shale is injected with narrow veins and strings of 'white trap' along bedding- and joint-planes. The veins and strings are frequently transgressive, and may also be traced into the main mass of igneous rock.

To the east and south long slabs and smaller lenticular masses of shale are seen embedded in the igneous rock. In the southern face two constant horizons of igneous rock are separated by a shale band 2 feet thick; both the shales and the igneous rock sag slightly.

The shale bordering the tramway incline is baked a brick red for a distance of about 2 feet above the igneous rock. Shale at the contact is usually porcellanized for a distance of one inch, and indurated for a greater, though variable, distance beyond. *Lit-par-lit* injection of the shale is frequent. The texture of the igneous rock near its junction with the shales is compact and basaltic, whereas in the centre of the mass it is crystalline.

The rock is obviously a sill-like intrusion in the shale, which, however, appears to have suffered little or no disturbance.

3. *Macroscopical Features of the several varieties of the Intrusive Rock.*

The prevalent rock is greenish-grey crystalline, of fine or medium texture, having a distinctly dappled or mottled appearance when wet, owing to concentrations of hornblende and of felspar as minute but discrete clots—glomeroporphyritic structure, which is assumed by both hornblende and felspar. Pyrites in specks and irregular strings is very abundant.

The mottled variety passes insensibly into a more homogeneous, finely crystalline rock, with the aspect of the Nuneaton and Atherstone 'diorites'. Both the varieties noticed effervesce slightly on

¹ Proc. Geol. Assoc., vol. xv, pp. 394-96, 1897.

² *Petrology for Students*, 1908 ed., p. 157.

³ *Text Book of Petrology*, 1909 ed., pp. 329-30.

treatment with dilute hydrochloric acid, owing to the presence of calcite in the rock-mass.

Another variety, occurring as a selvage in contact with the shale, is a dark-grey compact rock, often banded, but otherwise of basaltic aspect, though no crystals are visible even on examination with the lens. The material forming the veins and strings intrusive in the shales is an earthy substance with the appearance, texture, and 'feel' of hardening putty.

4. *Detailed Petrological Description.*

The felspar is mainly plagioclase, which forms slender idiomorphic prisms up to $\frac{1}{16}$ inch in length, usually less, showing between crossed nicols broad but inconstant twin laminæ of the albite type, occasionally combined with Carlsbad and pericline twinning; an extinction angle of 27° – 29° points to labradorite of basic composition. The well-individualized albite laminæ of the middle of the felspar prisms are commonly flanked by a narrow marginal band, the extinction axis of which appears to traverse the band from side to side as the stage is rotated—an optical feature due to zonal variation in chemical composition. Orthoclase is a very subordinate constituent of a scanty granular ground-mass.

The felspar has a pronounced yellow-brown tint due to iron staining, and has undergone considerable alteration, resulting in the development of granular calcite and epidote, aggregated mainly in the interior. The alteration has only slightly obscured the definition of the albite laminæ—the contour of the crystal not at all.

The prisms form an open framework, and are frequently interpenetrant at the nodes, where they tend to group themselves radially after the manner of the glomeroporphyritic aggregates common in intrusive and volcanic rocks. This framework, together with hornblende, calcite (in plates or granules), a little granular orthoclase, and rather conspicuous grains of magnetite, is embedded in a nearly colourless or pale-green serpentine associated with subordinate patches of a greenish dichroic substance referred to chlorite.

In the normal type of the rock the felspar prisms may be enclosed in hornblende; in some varieties the two minerals interlock along a sinuous or serrated line, a portion at least of the hornblende having been fluid at a stage when the crystallization of the felspar was incomplete. In yet another variety the hornblende is wholly idiomorphic and independent of the felspar.

Hornblende is very abundant as a dark-brown variety which, when unaltered, is quite transparent and shows intense brown absorption. Often, however, it is so dark as to be almost opaque, suggesting a somewhat advanced stage of alteration. The mineral is conspicuously idiomorphic, giving the usual lozenge-shaped basal sections (acute angles truncated by the clinopinacoid traces) and long prismatic sections. Twinning on the orthopinacoid is common. Hornblende may enclose plagioclase prisms ophitically, or may be conjugate with felspar along a straight, curved, or serrated junction line, or may be an entirely independent constituent. All stages of alteration to serpentine are observable; the serpentine either merely

pencils out the cleavages in basal and prismatic sections; or it occurs as coarse irregular ropes traversing the crystal plates in directions roughly parallel to the cleavages; or the original hornblende has been reduced to a meagre skeletal framework embedded in serpentine.

As the opaque brown masses, hornblendic in colour, were suspected to be, in part at least, limonitic, the cover glass of a section was removed, the section cleansed of balsam, and a drop of strong hydrochloric acid applied to the brown mass. In a very few seconds the drop had become coloured a distinct yellow, as shown on its absorption by white blotting-paper, thus proving the presence of iron in some very soluble form in the brown mass, which was therefore composed partly of limonitic matter.

The abundant development of calcite plates in close association with serpentine and limonite suggests its derivation from hornblende rich in lime as well as magnesia, and therefore of the 'basaltic' variety. Relics retaining parallel cleavage traces in single system (i.e. sections more or less nearly in the prism zone) give nearly straight extinction with reference to the cleavage traces. (Pleochroism: α = straw or pale yellow; β or γ = light brown or dark brown.) Narrow strips of a transparent substance, with recognizable cleavage traces, very pale yellow in ordinary transmitted light, and showing intense brown absorption in plane polarized light, appear to be unaltered portions of original hornblende which has suffered bleaching.

The decomposition of the hornblende appears to have proceeded in two different ways—either (*a*) the whole mineral has altered by hydration to serpentine; this is the prevalent method; or (*b*) the magnesia alone has separated from the hornblendic molecule to form serpentine; the lime has formed calcite (as plates and granules) or epidote (as granules), the residual iron as the hydrated oxide retaining the form of hornblende.

In support of the latter suggestion it may be stated that the serpentine contiguous with opaque hornblende relics is usually only very pale green owing to its low iron content, whereas the colour of the serpentine which has originated by method (*a*) is always a pronounced green or yellow-green.

The proportion of serpentine is fairly constant, even when definite indications of original olivine are absent; moreover, it shows a characteristic fibrous or 'bladed' structure under crossed nicols; the major portion, at any rate, of the serpentine may be referred with confidence to hornblende.

The murky-grey colour and complete opacity of much of the limonite suggest admixture with leucoxene representing the titanium of the original hornblende molecule. Some leucoxene is certainly derived from the alteration of titaniferous magnetite.

Rounded or elliptical patches of serpentine showing the 'mesh' structure under crossed nicols occur embedded in the hornblende relics, or very rarely in the felspar; they appear to represent original olivine, very subordinate in quantity. Olivine is probably also represented in the serpentine of the base. The quantity of olivine present is somewhat variable and always small.

Magnetite is abundant in some sections, and present in all. It is titaniferous, as indicated by a greyish opaque outgrowth of leucoxene.

In more than a score of sections examined no augite or other pyroxenic material was observed. Mica is wholly wanting. Apatite is conspicuous as needles, from .025 mm. to .075 mm. in length, embedded in the other constituents. Pyrites in granules up to .3 mm. in length is also a notable accessory.

5. *Discussion of the Systematic Position of the several Varieties.*

Typically the felspar and hornblende show a marked tendency to idiomorphism. The low degree of mutual interference shown by the felspar prisms in particular, the almost total absence of the 'granitic', and the prevalence of the 'glomeroporphyritic' structure are incompatible with diorites. On the other hand, these features may be either hypabyssal or volcanic; the absence of a glassy base eliminates the latter as a probability, while the ophitic relationship of the felspars and hornblende, and the basic character of the former (labradorite), recall the structure of the typical dolerites, and the coming in of olivine suggests analogy with the olivine dolerite type. Dolerites, however, are typically pyroxenic, and in this rock pyroxenes appear to be wholly wanting, and no secondary amphibole, which might have been referred with reason to primary augite, was observed. The idiomorphism and the primary character of the hornblende are incompatible with the type dolerites.

On the other hand, individual femic clots may monopolize the whole of a field visible under the microscope; in such case the subordinate amount of the felspar visible, the serpentinous pseudomorphs of olivine, occurring as pœcilitic inclusions in the hornblende, recall the picrites; but even this resemblance is illusive, for the field adjoining such a femic patch may be entirely devoid of hornblende and even comparatively free from its serpentinous decomposition products. Moreover, the rock as a whole must be excluded from the picrite group by reason of the high proportion of felspar and the very small amount of olivine present.

The idiomorphism and porphyritic aspect of the hornblende, considered together with other hypabyssal features, admit the rock without question into the lamprophyre group. The red-brown hornblende, the essential absence of free silica, the conspicuous apatite and titanium content link the rock with the type camptonite of Campton Fells, N.H., and the classification of the main rock-mass as a camptonite is open to little objection. The olivine, too insignificant in quantity for the picrites, ranks as a noteworthy accessory when the rock is regarded as a camptonite. In the typical camptonite, however, hornblende recurs as microlites in the base. This is not the case in the Marston Jabet rock.

The camptonite rock forms the bulk of any one of the sheets of the intrusive mass. The olivine is more abundant in the centre of the mass than near the margin, and it is in the centre that the nearest approach to a picritic facies was observed.

A partial analysis of the mottled rock was carried out in the

laboratory of the Bury Technical School in consultation with Mr. G. M. Norman, B.Sc., F.I.C., A.R.C.S., and the results obtained, together with recorded analyses (cited by Hatch) of other camptonites and of a well-known pierite, are set out below:—

	Camptonite (Marston Jabet).	Camptonite (Ardmuchnish).	Camptonite (Orkneys).	Pierite (Blackburn- Bathgate Hills).
	%	%	%	%
Si O ₂	44·75	42·22	39·13	44·73
Fe ₂ O ₃	15·15	4·74	7·33	4·85
Fe O	(estimated as Fe ₂ O ₃)	6·18	8·13	6·61
Al ₂ O ₃	16·26	10·62	11·38	11·89
Mg O	11·72	8·68	8·64	10·77
Ca O	7·35	14·80	11·77	7·69
Na ₂ O	not estimated	2·46	2·47	2·77
K ₂ O		1·41	1·93	·89
Ti O ₂		2·49	4·02	1·53
C O ₂		3·57	2·41	—
H ₂ O		1·66	2·87	7·64
P ₂ O ₅	0·22			
Other constituents		1·59	0·42	1·06
		100·42	100·50	100·43

The selvaige rock, when examined in thin section, presents the ordinary features of an andesitic basalt and calls for no special description.

Very little absorption of the shale by the igneous rock has taken place at the junction, and the absorption zone is probably not more than $\frac{1}{4}$ in. wide. In sections showing the igneous rock and the shale in contact, the former near its junction with the latter is very dark, almost black, and quite opaque, due probably to the presence of free carbon derived from the shale, on the solution of a very limited amount of its alumina. The frequent occurrence of a pencil-like vein of calcite crystals marking the contact plane indicates that the latter became a plane of discontinuity after the intrusion, and, therefore, that the intrusion was accompanied by a negligible amount of chemical reaction between the igneous mass and the shales.

The earthy material forming the veins and strings which penetrate the shales recalls the 'white trap' (kaolinized basalt) described by Geikie¹ as penetrating Lower Carboniferous shales in the Lowlands of Scotland.

6. *The Alteration produced in the Shales.*

In the main the alteration is of the low grade and small extent usual for similar intrusions; but a microscopic investigation of certain portions of these shales in thin section reveals the presence

¹ Q.J.G.S., 1892, Pres. Address, p. 136.

of embryonic crystals, the features of which so closely approach those of chiasolite as to render the identity highly probable. This 'unconventional' occurrence of chiasolite will be fully discussed in the May Number of the *GEOLOGICAL MAGAZINE*.

EXPLANATION OF PLATE VI.

STRUCTURAL TYPES.

FIG. 1.—A dioritic facies—but with pronounced hypabyssal features. Hornblende relics, of somewhat raggy outline, but tending to idiomorphism; cleavages pencilled out in serpentine. Base made up of much altered plagioclase as prisms and irregular plates, the clear interspaces being filled with chloritic and serpentinous matter; some calcite; abundant apatite; some titaniferous iron-ore (with leucoxene); grains of pyrites; and a little granular epidote in plagioclase, of which it is a decomposition product.

FIG. 2.—A picritic facies. The proportion of plagioclase is much lower than for No. 1; it occurs not only in the base but as minute prisms enclosed ophitically in hornblende. Clear patches represent crystals of original olivine now altered to serpentine, which also envelops plates and granules of calcite. Circular and elliptic 'lakes' of serpentinous matter enclosed poecilitic fashion in the hornblende appear to represent original olivine.

FIG. 3.—A coarse lamprophyric facies (camptonite). The idiomorphic hornblende is, in the main, phenocrystal, though the presence of small felspar prisms as enclosures in the hornblende is (for lamprophyres) an anomalous feature. This ophitic relationship of the felspar to the hornblende recalls the structure of typical dolerites (the hornblende playing the rôle of pyroxene in dolerites); and it may be that the fluid intrusive, potentially doleritic, has crystallized at a temperature too low to promote the formation of pyroxene, i.e. at a temperature at which hornblende can form and remain stable; in this sense the camptonite may be an abortive dolerite. But the phenocrystal aspect of the hornblende (with other hypabyssal features) insistently recalls the lamprophyres: the rock must be regarded as a variety of camptonite.

FIG. 4.—A fine-grained hornblende lamprophyre (closely related to the coarse camptonitic facies), in which the idiomorphic hornblende occurs as minute laths.

V.—THE ORIGIN OF LIMESTONE.

By H. WARTH.

ALTHOUGH the calcium oxide and magnesia of sedimentary limestone and dolomite must all be derived from pre-existing igneous rocks, it is not so easy to trace the origin of the necessary carbon dioxide. The solidified igneous rocks contain mere traces of free carbon dioxide and of calcite. During their weathering carbon dioxide is taken up from the atmosphere, replacing the silica of calcium silicate and magnesium silicate minerals, and forming the carbonates. Now, however, the quantity of carbon dioxide retained in the atmosphere is exceedingly small. It is difficult to credit, for instance that a layer of coal, $1\frac{1}{2}$ millimetres thick, covering the surface of the globe, on being burnt would yield as much carbon dioxide as the entire atmosphere now contains. A similar layer of limestone containing an equivalent amount of carbon dioxide would have a thickness of 5 millimetres. This is out of all proportion compared with the mighty beds of limestone and dolomite now forming part of the earth's crust. Nor would the carbon dioxide

A. Brummell, Photo.

Bale, Sons and Danielsson, Ltd.

Sections of INTRUSIVE ROCK of Marston Jabet,