

26. *RESULTS of an EXAMINATION of the CRYSTALLINE ROCKS of the LIZARD DISTRICT.* By Professor T. G. BONNEY, D.Sc., LL.D., F.R.S., V.P.G.S., and Major-General C. A. M^CMAHON, F.G.S. (Read April 22, 1891.)

[PLATE XVI.]

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I. INTRODUCTORY.

GEOLOGISTS during the last decade have devoted much more attention to the rocks of the Lizard than in previous years. At the same time the effects of pressure as an agent of metamorphism, especially in producing foliation and simulating stratification, have become increasingly appreciated. Hence it is not surprising that the correctness of the view advocated by Prof. Bonney in 1883*, viz., that the crystalline schists of the Lizard were in the main of sedimentary origin, has been contested, some writers even going so far as to express doubts whether the relation of these masses to the serpentine, gabbro, and other rocks of igneous origin had been correctly understood.

The results of work in other regions had raised suspicions in the author's own mind as to the trustworthiness of some of the data on which his inductions had been founded, and after spending several days in 1886 at the Lizard with Mr. Teall, who was more disposed than himself to regard pressure as a potent agent of metamorphism, he felt convinced that his earlier views would have to be modified, though to what extent could only be determined by further study of the district and by comparison with other regions.

In 1889 a paper was read before this Society by Gen. M^CMahon, in which the igneous origin of many of the foliated crystalline rocks was maintained, and an hypothesis put forward to

* Quart. Journ. Geol. Soc. vol. xxxix. (1883) p. 1.

explain, in certain cases, the banded arrangement of the constituent minerals *.

In the summer of 1890 the authors of the present paper met at the Lizard in order to discuss the whole question on the spot. They hoped by this means to bear united testimony as to the facts of nature and to avoid many opportunities for misunderstanding, while any diversity of opinion as to the interpretation of the former could be easily expressed. They were joined by the Rev. Edwin Hill, to whom they are indebted for constant help in field-work and in discussion, both by suggestions and by criticism. They believe that they may add his name as a witness to the facts recorded in this paper, and do not expect to find any serious difference of opinion on his part as to the main questions of interpretation.

During a fortnight's stay at the Lizard, followed by about four days at St. Keverne, they examined *de novo* almost all the more important coast-sections of the Lizard peninsula as far north as Mullion Cove on the west and the Nare Head on the east†. They had also the great advantage of going over some of the most critical sections with Mr. Teall, to whose views reference has already been made, and with Mr. Fox, to whose acute observation and conscientious work in this district geologists are so greatly indebted. The hours spent in frank interchange of opinion and in friendly discussion of views, sometimes divergent, were no less pleasant than profitable; for, in more than one instance, they removed misconceptions and demonstrated that the shield, if gold on one side, was silver on the other.

II. THE SERPENTINE.

In regard to the serpentine, the majority of competent observers are in general agreement. Hence it may be convenient to consider this rock first in order and use it as a kind of datum-line for the other rocks of the district, which will then be found to fall into two rather distinct classes. In dealing with the serpentine three subjects call for special attention:—(1) its origin and composition; (2) its relation to the rocks of earlier date; (3) the significance of its structures, if any.

(1) *Origin and Composition*.—These subjects have been so fully discussed by Prof. Bonney in his two papers and by Mr. Teall in his "British Petrography" that little more need be said. But, for convenience of reference, we have exhibited in tabular form the constituent minerals (other than serpentine) of the rocks noticed by these authors, to which have been added one or two varieties hitherto undescribed. The derivation of serpentines which exhibit

* Quart. Journ. Geol. Soc. vol. xlv. (1889) p. 519.

† Want of time prevented them from examining the cliffs for about a mile on either side of the Blackhead. These are rather difficult of access, and consist, according to the Survey map, of serpentine, so that they did not seem likely to throw additional light on any question except those on which the authors were already satisfied.

characteristics similar to those of the Lizard from some variety of peridotite may now be regarded as demonstrated to the satisfaction of all petrologists who have studied the rock in the field and with the microscope. It is of course true that other magnesian silicates, such as rhombic and some monoclinic pyroxenes, can produce serpentine; but the correspondence between rocks thus originated and those of which the Lizard serpentine is a type, if it exist in certain rare cases, is almost exclusively in chemical composition and is associated with marked diversity in other respects.

The Lizard serpentines can be roughly separated into two groups: in the one a foliated mineral of the enstatite group is a conspicuous accessory; in the other a colourless augite or hornblende, usually the latter. A few are non-porphyrific, and in some cases exhibit no certain traces of any pyroxenic mineral, rhombic or monoclinic, though of course a spinellid or some iron oxide is always to be detected, and in one instance (at the Rill, W. of Kynance Cove) the presence of a fair proportion of felspar has been asserted.

Of the tables annexed, one gives the mineral, the other the chemical composition of certain varieties of the serpentine. Chrysotile is almost always present as well as ordinary serpentine, so it has been thought needless to enumerate these separately. The more or less foliated enstatite (bronzite) is also more or less serpentinized; in most cases, if not all, it is probably bastite, as has been demonstrated by Mr. Teall*. The hornblende (except when specified) is a white variety; the iron oxide is generally magnetite, but in the red serpentines much hematite is present. The term "spinellid" includes all varieties, from those which are a very deep brown (barely translucent), probably chromite, to the translucent rich brown grains (picotite) present in several specimens†. Under the head "chlorite" is placed a colourless mica-like mineral, resembling that described by Herr Weigand‡. In some cases the included opacite suggests that it may be a bleached biotite. The figures within brackets in the column headed "Remarks" indicate the number of specimens on which the result is founded. The localities are arranged in order, beginning at the south end of the east coast and going round from the north to the west coast, which is followed southwards.

The annexed table of analyses contains, we believe, all that have been published, with four others, which, by the kindness of Prof. W. Ramsay, F.R.S., have been made in the chemical laboratory at University College (London). For these the authors are indebted to Mr. M. W. Travers, to whom they tender their best thanks. Numbers I.-V. doubtless represent varieties of the serpentine with conspicuous crystals of enstatite (bastite), chiefly used for ornamental purposes; VI.-IX. are from varieties of the Porthalla serpentine; X., XI. are varieties of the dull-coloured compact

* 'Brit. Petrogr.' p. 88.

† See also 'Picotite in Serpentine,' H. Fox, Trans. Royal Geol. Soc. Cornwall, vol. xi. pt. 5 (1891) p. 336.

‡ Quoted by Mr. Teall, 'Brit. Petrogr.' p. 112.

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.	XII.	XIII.
SiO ₂	38·86	38·58	40·40	38·29	38·50	38·60	37·15	39·50	43·35	41·43	42·89	40·29	58·90
Al ₂ O ₃	2·95	3·06	0·65	.....	1·02	0·10	5·60	5·08	4·08	7·29	0·76	5·10	3·99
Cr ₂ O ₃	0·08	0·08											
Fe ₂ O ₃	1·86	1·95	.....	.....	4·66	} 11·55	{ 1·10 8·80 }	} 8·12	10·74	{ 7·87 0·87 }	6·30	4·94	2·32
FeO	5·04	5·10	7·47	13·50	3·31								
NiO	0·28	0·30	0·15	.....	0·59								
CaO	trace	trace	.....	.....	1·97	trace	0·10	trace	1·51	1·88	.....	11·85	
MgO	34·61	34·32	37·43	34·24	36·40	33·62	32·80	34·65	28·43	32·73	38·09	25·67	26·80
MnO	trace	trace											
FeS ₂ ..	.....	.....	.....	.....	0·41								
Na ₂ O	0·77	0·76	.....	.....	.....	} 3·31	0·29	0·10	1·35				
K ₂ O	0·33	0·30	.....	.....	.....					
H ₂ O lost on ignition ...	} 15·52	15·52	13·90	12·09	12·35	12·82	{ 13·70 0·46 }	12·00	8·69	} 7·93	7·98	8·17	2·91
H ₂ O lost at 100° C.													
Insoluble in HCl .....	.....	.....	.....	.....	1·37								
Total	100·36	99·97	100·00	98·12	106·58	100·00	100·00	100·00	100·00	100·00	99·85	100·00	98·68
Sp. gr.	2·59		.....	.....	2·587	2·65	2·56	2·545	2·644	2·74	2·85	2·77	.....

- I. and II.

Ornamental serpentine from the Lizard. Dark green to black, thickly spotted with red ; enclosing imperfect crystals. [This analysis may be taken as representing a very common and characteristic variety of Lizard serpentine.] (Of the water, 2·06 was lost in the water bath.) Analysis by J. A. Phillips. Phil. Mag. 1871, (4) vol. xli. p. 101.
- III.

“ Clouded reddish brown and greenish serpentine containing small grains of diallage ” [bastite], said to be from the Lizard Point. [Probably from near Pen Voose.] The FeO includes also oxide of chromium. Analysis by T. S. Hunt. Am. Journ. Sci. vol. xxvi. (1858) p. 239.
- IV.

“ The red, earthy sometimes semi-crystalline base of the serpentine porphyry of Kynance Cove. ” Analysis by S. Haughton. Phil. Mag. 1855, (4) vol. x. p. 254.
- V.

Matrix of black serpentine from near [*i. e.* to the north of] Cadgwith. Contains porphyritic crystals of bastite. The SiO₂ includes traces of TiO₂. The rock was dried at 100° C. The H₂O includes traces of CO₂; and traces of sulphuric acid are also noted as present. Analysis by Mr. Hudleston, in Appendix to paper on serpentine of the Lizard district, by Prof. Bonney. Quart. Journ. Geol. Soc. vol. xxxiii. (1877) p. 925.
- VI.

Greyish green granular serpentine. Porthalla.
- VII.

Dark oil-green serpentine. Porthalla.
- VIII.

Reddish brown granular serpentine. Porthalla.
- IX.

Dull dark red serpentine. Porthalla. [This, I think, must be rather an abnormal specimen, for evidently it is almost a picrite.—T. G. B.]
- X.

The Rill. Supposed to contain felspar. See Geol. Mag. (1887) pp. 69, 137, 380. By Mr. M. W. Travers, of University College, London. A partial analysis is given in Geol. Mag. (1887) p. 380.
- XI.

Gew Graze. Red serpentine, minutely granular in texture. Described in Quart. Journ. Geol. Soc. vol. xxxiii. (1877) p. 918. By the same.
- XII.

Quarry near Lower Predannack. Reddish serpentine with numerous crystals of white hornblende. [Almost a picrite, though I have never seen any felspar.—T. G. B.] Described in Quart. Journ. Geol. Soc. vol. xxxiii. (1877) p. 918, and vol. xxxix. (1883) p. 23. By the same.
- XIII.

From a weathered portion of the same hand-specimen. By the same.

Analyses of Soapstones by S. HAUGHTON. (Phil. Mag. 1855, (4) vol. x. p. 255.)

	SiO ₂	Al ₂ O ₃	MgO	H ₂ O	Total.
From the vein at Kynance.....	42·47	6·65	28·83	19·37	97·32
From the vein at Gew Graze	42·10	7·67	30·57	18·46	98·80

ON THE CRYSTALLINE ROCKS OF THE LIZARD DISTRICT.

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Localities.	Olivine.	Enstatite.	Augite.	Hornblende.	Chlorite.	Iron Oxides.	Spinellds.	Remarks.
Balk Quarry	*	*	?	*	*	*	?	Red (2).
Cadgwith (above Frying Pan)...	*	*	*	*	*	*	*	Red.
do. , Quarry N. of	*	*	*	*	*	*	*	Red.
Enys Head, near	*	*	*	*	*	*	*	Black, abundant in this district (2).
Kennack Cove	*	*	*	*	*	*	*	Black, calcite or magnesite in veins.
Carn Spennic (quarry W. of) ...	*	*	*	*	*	*	*	Red (3).
do. shore beneath the same	*	*	*	*	*	*	*	Red (3, two normal, one more compact).
Lankidden Cove	*	*	*	*	*	*	*	Greenish-purple (3, one rather streaky, one with veins as above).
Coverack (by road above village) ...	*	*	*	*	*	*	*	Red.
do. in Cove	*	*	*	*	*	*	*	Red (3, two normal, one more compact).
do. Quarry W. of village	?	*	*	*	*	*	*	Dark, much disseminated opacite, ? affected by contact.
Polkerris	?	*	*	*	*	*	*	Reddish.
Porthalla (quarry by path).....	?	*	*	*	*	*	*	Greenish-purplish.
do. shore (ordinary)	?	*	*	*	*	*	*	Id.
do. do. (at contact)	*	*	*	*	*	*	*	Id., approaches Mullion type, but more compact.
do. do. (streaky)	?	*	*	*	*	*	*	Id., colours more separated. } 10 speci-
do. do. (banded)	*	*	*	*	*	*	*	Id., colours in bands. } mens.
Goonhilly Downs Quarry ...	*	*	*	*	*	*	*	Streaky, reddish—a brown hornblende.
do. do. do. ...	*	*	*	*	*	*	*	
Helston-Coverack road ...	?	?	?	*	*	*	*	Dark, much white hornblende, a little brown.
Helston-Lizard road (first outcrop).	*	*	*	*	*	*	*	Nearly black, much white hornblende (2).
Mullion Cove	*	*	*	*	*	*	*	Reddish, much white hornblende (4).
Lower Predannack Quarry	*	?	*	*	*	*	*	Black, rather compact, streaky, much chrysotile.
Ogo-dour Cove (near junction)	*	*	*	*	*	*	*	Striped, dark purple-grey, and light greenish-grey; (3), sphene in one specimen.
George's Cove	*	*	*	*	*	*	*	Reddish, a little brown hornblende; (?) trace of felspar.
Gew Graze.....	*	?	*	*	*	*	*	Dark, white spots; felspar or chloritoid (?).
The Rill.....	*	*	*	*	*	*	*	Rather dark; some of the chlorite is probably a bleached biotite.
Lawarnick Pit (W.N.W. of Kynance).	*	*	*	*	*	*	*	Striped reddish-brown and light greenish-grey.
Kynance Cove	*	*	*	*	*	*	*	Red, compact; ? fluxion structure.
do. (dyke N. of "the Steeple").	*	*	*	*	*	*	*	Greenish-grey, rather decomposed, veined with steatitic minerals.
Holestrow	*	*	*	*	*	*	*	Calcite or magnesite veins.
Pentreath Beach	*	*	*	*	*	*	*	

serpentine more common on parts of the west coast and on the north; while XII. is a variety almost confined to the west coast, rich in small crystals of colourless hornblende; XIII. is from a weathered portion of the same specimen as XII. It was made by

reason of a misunderstanding, but the difference is so remarkable that it seemed worthy of preservation, if only to indicate the caution which must be exercised in selecting a sample for analysis.

(2) *Relation to the older Rocks.*—The serpentine of the Lizard district, as stated by Prof. Bonney, is associated with the subdivisions of the crystalline schists which were named by him the Granulitic Group and the Hornblendic Group, but it has not yet been detected among either his Micaceous Group, or the gneisses of very ancient aspect which were discovered by Mr. Fox in the islands fringing the south coast*.

It will suffice for the present to say that both the Granulitic and the Hornblendic Group exhibit marked structural characteristics. In the former a dark dioritic rock is sometimes veined, sometimes banded, by one of lighter colour, which often closely resembles a granite; the latter is very frequently so regularly banded as to suggest an original stratification. Whatever be the significance of these structures—a question which we reserve for the moment—neither rock, in its present state, can be the result of a single operation.

It has indeed been suggested that all the rocks of the Lizard district are the result of some sort of segregation from one magma†. We do not propose to treat this hypothesis seriously; but there are three other hypotheses which call for discussion, and these appear to cover the field: that (a) the serpentine (with some of the later rocks) and the older series form an igneous complex which has been afterwards profoundly affected by earth-movements—as if a heterogeneous mass had been passed between a pair of rollers; (b) the serpentine is really intrusive in the older series, but the relations of the rocks have been so far masked by subsequent earth-movements as to obliterate any conclusive evidence of the intrusion; (c) the serpentine (as maintained by Prof. Bonney from the first) is intrusive in the older series, and the amount of subsequent disturbance has not sufficed in most places materially to disturb their relations.

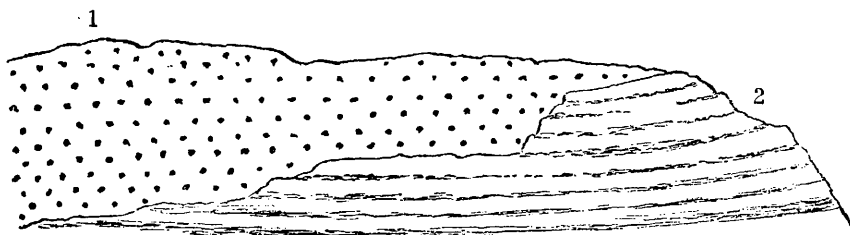
Along the eastern coast many sections can be found which exhibit the serpentine and the rocks of the Granulitic Group in intimate association, from Compass Cove to Polbream Point, also about the Frying Pan, and again from the north side of Polbarrow to the Balk. We do not deny that occasional sections may be found in which the present relations of the two are the result of faulting, or which, did they stand alone, might seem to support the view that the granulitic rock was intrusive in the serpentine; but, after again examining all the sections on both coasts described by Prof. Bonney in 1877, we have not the slightest doubt that the serpentine is intrusive in the granulitic rock, which was, at that time, substantially in its present condition, and that, as a rule, their relations have not been disturbed subsequently to any noteworthy extent. The serpentine has broken through the granulitic rock, some-

* Quart. Journ. Geol. Soc. vol. xliv. (1888) p. 309.

† Geol. Mag. (1888) p. 554, (1890) p. 505.

times apparently twisting up the ragged ends into dyke-like masses, sometimes perhaps breaking off and carrying up huge fragments. Here a dyke of serpentine parts two masses of granulitic rock, the outer margins of each being in contact with serpentine, which continues for some distance; there a tongue of serpentine is forced like a wedge into a banded mass of the granulitic rock, or is protruded between two of the layers. Here, in a similar mass, the bands are nipped up or cut off obliquely by the serpentine (fig. 1); there, in

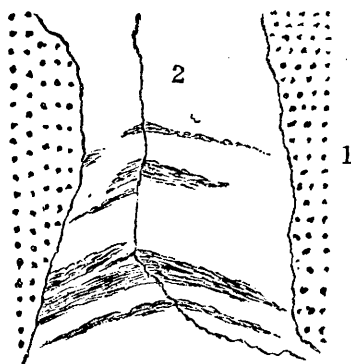
Fig. 1.—Section in Quarry near Kildown Point.



1. Serpentine.
2. Reddish granitoid rock, with dark bands (Granulitic Group).

one of less regular structure, the granitic veins may be seen to run up to the serpentine, and be, as it were, cut off by it (fig. 2). So far as structure goes, the relations of the Granulitic Group and the serpentine are identical with those which are exhibited by banded gneisses or schists, and granites intrusive into them.

Fig. 2.—Section near Cavouga Rocks.



1. Serpentine.
2. Granulitic Group. The darker part represents the dioritic, the lighter the granitic rock.

The serpentine, in the tongues, and near the granulitic rock generally, exhibits little indication of having been crushed: though now and then a faint resemblance to a foliation—recalling to some

extent a fluidal structure—may be detected. The rock, however, is usually rather rotten; very commonly there is a dusty-looking, pale-coloured, more or less chrysotilic layer between the two rocks, which is continuous with the serpentine, but does not adhere to the granulitic mass. Indeed we have never found the two rocks actually welded. Signs of crushing and slickensides may no doubt be not unfrequently seen at junctions. This is only to be expected, because the tenacity of the two rocks is so different that, even if welded, they would have parted here under strains from ordinary earth-movements. The serpentine also at the margins is often decomposed, and its structure is obscured by secondary chrysotile, steatite, and other like minerals. The serpentine, which seems to include these gneissoid masses, sometimes exhibits a slight streakiness, the significance of which will be considered presently. Sometimes this may be parallel to the apparent bedding of the granulitic rock, but at others the two structures are almost at right angles, so that evidently they are not necessarily connected.

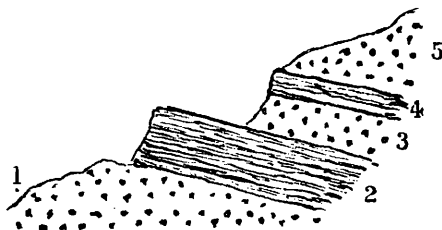
The relations of the serpentine to the hornblende-schist differ somewhat from those with the Granulitic Group. Masses of the latter, apparently included in or pierced by the serpentine, may be found by scores; with only one or two slight intervals, they literally fringe the eastern coast for a distance of three miles, measured along its curve, and they are not unknown, though much less common, on the western coast*. But the Hornblendic Group is not often seen actually cut by or entangled with the serpentine. This, however, may also be said in regard to the other intrusions. Dykes of any kind, so far as we know, are not very common in it. Still, though the serpentine and hornblende-schist in some cases may be faulted together, the relations in a few are clear. At Henscath, just north of Mullion Cove, we find it impossible to explain by earth-movements, or by any theory but that of intrusion, the position of the apparently insulated mass of serpentine on the little headland, and the two rocks, in at least one case, are still welded together. Again, the same holds good in regard to the junction exposed in the upper rocks near Parc Bean Cove (north of Ogo-dour Cove†). Strips of the hornblende-schist, regularly banded, are split off by or included in the serpentine, and the two rocks in more than one place are welded together, though the rottenness of the latter makes it impossible to detach and bring away specimens exhibiting the junction. Moreover, the hornblende-schist, thus included, exhibits

* The masses at Kynance Cove, mentioned in my paper, *Quart. Journ. Geol. Soc.* vol. xxxiii. (1877) pp. 884-928, certainly in some cases, and perhaps in all, are better referred to the Granulitic than to the Hornblendic Group. The road descending to the cove (p. 888) crosses a mass which, when less clearly exposed, was mistaken for a granite vein. There are other characteristic masses along the shore N. of Pentreath beach; some of these are mentioned as hornblende-schist in the above paper, in which no division of the schists is attempted; they were not again examined for the purpose of writing the second paper, the precise reference of every block being unimportant.—T. G. B.

† Bonney, *Quart. Journ. Geol. Soc.* vol. xxxix. (1883) p. 22 (referred to as being 'to the north of Ugethawr').

some peculiarities*, which we consider to be the result of contact-metamorphism. Again, in a little pit on Carnbarrow, at the top of the cliffs, a "slabby" piece of banded hornblende-schist, about 8 inches thick, is completely surrounded by serpentine. Lastly, there are the junctions at Porthalla, which must be described in rather more detail, as Prof. Bonney's interpretation has been questioned in the pages of this Journal by Mr. J. H. Collins†, who maintains that there is a gradual transition from the hornblende-schist to the serpentine, the latter being regularly interbanded or interstratified with the former. We find, instead of the orderly arrangement depicted in his published section‡, that a mass of serpentine breaks through the hornblende-schist, and runs diagonally, roughly in a westerly direction, up the craggy face of the hill§. Above it is a great mass of hornblende-schist, generally with little banding or foliation, and thus dioritic in character. At a short distance below it are exposed the rather fissile schists referred by Prof. Bonney to the Micaceous Group, the intervening space being concealed by débris. But in three or four places on the rocky shore, between tide-marks, or just above high water, the relations of the serpentine and schist are well displayed. For instance, rather on the western side of the serpentine, slabs of banded hornblende-schist occur in that rock, the lower about three feet thick, the upper about one foot; the intervening space, rather more than two feet thick, being occupied by serpentine || (fig. 3).

Fig. 3.—Section at the foot of the cliffs, Porthalla.



1. Serpentine.
2. Hornblende-schist, about 3 ft.
3. Serpentine, about 2½ ft.
4. Hornblende-schist, about 1¼ ft.
5. Serpentine.

* See below, p. 473.

† Quart. Journ. Geol. Soc. vol. xl. (1884) p. 458; Geol. Mag. (1885) p. 298, and (1886) p. 359.

‡ Quart. Journ. Geol. Soc. vol. xl. (1884) p. 461, fig. 2.

§ Since the publication of Mr. Collins's paper, I have been thrice at Porthalla. On one occasion I had with me a copy of Mr. Collins's published section, and we sought to reconcile it with what we saw. After using our best endeavours, we were obliged to abandon the task as hopeless. Gen. McMahon had also visited Porthalla in 1887, and had met with no better success. The junction of the serpentine and hornblende-schist, which I saw in a quarry in 1882, had disappeared by 1886, and cannot now be found.—T. G. B.

|| Observed and drawn in 1886.—T. G. B.

These intercalated pieces of schist cannot be traced far. Again, near the eastern side of the serpentine, apparently enclosed in it, a mass of regularly "bedded" hornblende-schist* may be seen at the foot of the cliff. This is split by a wedge-like mass of serpentine, which narrows down to less than a foot across, on the western side of which comes a single "bed" of schist about 5 inches thick. Next comes a sheet of serpentine of about the same thickness, followed by another block of hornblende-schist. In this, if we mistake not, may be seen the end of another wedge of serpentine, coming in the opposite direction to the former†. Again, with regard to the asserted production of the serpentine from a stratified rock, bearing more relation to the hornblende-schist than to a peridotite, by some kind of transmutation not easy to understand, Mr. Collins's own analyses‡ indicate that the serpentine varies from a perfectly normal example of an altered peridotite to one which exhibits some approach to the picrites§, a variation which is far from rare.

It is true that near the junctions the serpentine sometimes becomes streaky or even somewhat banded in structure; the hornblende-schist also departs a little from the normal type, as at some other junctions, and is covered with a thin film of a steatitic mineral. Thus the two rocks occasionally so closely resemble one another that by the unaided eye alone they can hardly be distinguished; the difference is, however, quickly perceived by continued scratching with a knife, or by a few blows with the hammer, and is obvious on microscopic examination. In other cases, however, the two rocks are so clearly distinguished that the point of a knife may be placed on their junction-plane; while the changes in the hornblende-schist, which we pause for a moment to describe, are suggestive here, as elsewhere, of contact-metamorphism.

The hornblende-schist, in the localities where we examined it in contact with the serpentine, is considerably altered. Macroscopically, it assumes a rather grey and slightly "dusty" aspect: microscopically, it exhibits marked changes. We have examined slices from specimens obtained in three localities.

(1) Specimen in contact with serpentine at Porthalla. This rock exhibits a banded structure, and consists mainly of a colourless micaceous mineral, the flakes varying in size in different bands, which, with crossed nicols, gives low tints (white to milky grey) and straight extinction, and of hornblende, which, in form and structure, either resembles the last-named mineral or is somewhat acicular, the hue varying from a pale brown to almost colourless. The

* The 'beds' are almost vertical, and strike between W.N.W. and N.W.

† The serpentine is rather rotten; the section is, in places, obscured by shingle, &c.; and part of the hornblende-schist is stained of a reddish colour, so that it resembles the serpentine. The mass of the former on the one side of the first 'wedge' cannot exceed about four yards, and on the other about three from this distance brings us again to serpentine.

‡ See tables of analyses, facing p. 466.

§ The term is used, not for a variety of the true peridotites, but for one in which some felspar is commonly present.

former mineral is probably a chlorite, similar to that described by Herr Weigand.

(2) From the intrusive junction in Parc Bean Cove (2 specimens): one, "2 or 3 inches from contact-surface," consists of roundish or rather oblong grains of pale-brown hornblende and colourless augite in a minutely granular matrix; this is composed of a filmy brownish mineral, resembling the hornblende, and a colourless one (? feldspar), together with some scattered granules of brownish iron-oxide. Some transverse cracks are filled by secondary minerals, in part a flaky hornblende. The other specimen, "from a slab about 8 inches thick, enclosed in serpentine," is very like that from Porthalla, except that two or three bands in it are chiefly occupied by a dull green chlorite, which in places is iron-stained, and is associated with grains of magnetite; also one or two grains of decomposed feldspar can be detected.

(3) From a piece about the same thickness, similarly enclosed, from the pit above Carnbarrow. This, to some extent, combines in one specimen bands which respectively resemble parts of each of the above, but other bands are characterized by a fair amount of decomposing feldspar, and thus in structure it more closely resembles the normal rock.

In two of these the above-mentioned mineral changes might possibly be set down to ordinary decomposition, though we do not so interpret it; but this could hardly be asserted in the first and last specimens. The alterations, especially in the hornblende, so far as our experience goes, resemble those which have been produced in "greenstones" by contact-metamorphism. In each case, as it happens, the hornblende-schist is a well-banded variety.

Mr. Collins states that "the massive serpentine of Porthalla does not present that reticulated structure which has been regarded as the result of the alteration of olivine rocks"*. Either he must have examined a very small number of specimens and been singularly unfortunate in collecting them, or have had a limited experience in the structure of altered peridotites. It is quite true that there are differences between this rock and the serpentine at Coverack or farther to the south; the latter contains more bastite, and as it was once rather coarsely crystalline, the characteristic reticulated structure can be seen at a glance. The Porthalla rock, however, was evidently at the first a fine-grained peridotite †, but, making allowance for this, it presents no difficulties to an experienced eye. Occasionally the structure is as characteristic, though on a scale of about $\frac{1}{2}$, as in the normal rock to the south. In some parts, where the banding is most marked, there is considerably more variation in the mineral constituents; a white micaceous mineral in small flakes is occasionally rather abundant—possibly the variety of chlorite investigated by Herr Weigand in the Rauenthal serpentine—larger flakes of this are sometimes associated in nests, with grains of mag-

* Geol. Mag. (1885) p. 300.

† Probably very like that from St. Paul's Island, described by Prof. Renard.
Q. J. G. S. No. 187.

netite, or lie nearly parallel (with inclusions of the latter) so as to suggest the bleaching of a biotite *. Occasionally the remains of a pyroxenic constituent can be detected; sometimes it is probably an enstatite, but sometimes the oblique extinction of a remnant suggests a colourless hornblende. In some cases a considerable quantity of a semi-transparent mineral is present in minute granules, occasionally aggregated, which suggests the presence of an aluminosilicate. The banding is seen to be caused by the variation in the amount of this mineral, the opacite, and the chlorite. The most strongly banded variety, as we believe, is rather rare †. The structure in both is better seen in slightly weathered specimens than on freshly broken surfaces.

No sign of crushing can be discerned in these specimens. Both the variety with thin streaky lines and little rounded eyes of a mica-like mineral, and that with distinct bands of different colour and texture ‡, present macroscopically a very close resemblance to the fluxion-structure of a felstone or a rhyolitic rock. A very fine specimen exhibiting this structure (which is much more conspicuous on slightly weathered surfaces) is figured on Plate XVI.

The microscopic examination of thin slices shows that the apparent foliation is due to the streaky condition of the parent rock prior to its serpentinization—differences in the original composition of the streaks being now represented by slight mineral and structural differences in the resulting serpentine. In the opinion of the authors, the structure can only be explained as a fluxion-structure; that is to say, as being the result of traction acting on either an imperfectly blended mixture of two magmas, differing slightly from each other in composition, specific gravity, or fluidity, as in the case of a banded felsite or rhyolite, or on a mass, in which complete crystallization had been arrested by subsequent motion at a time when only a portion of the constituent minerals had separated themselves out from the magma.

The eruptive character of the serpentine (peridotite), which has been described above, as well as the microscopic evidence, shows conclusively that the original rock cannot have had a sedimentary origin.

(3) *The Structures of the Serpentine.*—A somewhat similar structure is exhibited by the serpentine in other parts of the Lizard district. Along the western coast this rock very commonly exhibits some approach to mineral banding. For instance, at Mullion sometimes, and rather more markedly at Lower Predannack, the crystals of colourless hornblende tend to lie parallel. But, on microscopic examination, we cannot discover that the constituent minerals exhibit any indication of having either been crushed or suffered any mechanical disturbance which cannot be explained

* As in the scyelite of Caithness, Judd, Quart. Journ. Geol. Soc. vol. xl. (1884) p. 406.

† One specimen, picked up on the shore by Prof. Bonney, suggests the possibility of the one variety being intrusive in the other (see Plate XVI. at the line AB).

‡ They are sometimes $\frac{1}{2}$ " wide.

by slight strains, either in cooling or in the alteration of the olivine constituent into serpentine. At Lawarnick Pit, near Kynance Cove, a faint banding is often perceptible in the compact serpentine, and a like structure is often developed rather conspicuously on the weathered surfaces of the rock, both in the neighbourhood inland and for some distance along the coast to the north. This structure commonly has a roughly uniform strike, and thus might naturally be interpreted as a result of pressure; but we noted variations in this district from a little W. of N., round by W. to W.S.W. The rock also is not rendered fissile by it. So, if a pressure structure, it is certainly anterior to serpentinization.

On the east coast this structure is much more rare and local. It may not seldom be detected on slightly weathered surfaces in the black serpentine S. of Kennack Cove, but the rock under the microscope does not give any indication of having suffered from a general crushing. Near Compass Cove we observed a sheet of compact-looking serpentine, from 4" to 8" across, in the ordinary serpentine; the latter being one of the usual red serpentines with fairly conspicuous but rather altered bastite-grains. This mineral also occurs in the former, but much more sparsely (being sometimes absent), and in grains less than half the diameter of the other. The compact rock under the microscope does not, however, show any sign of crushing, and presents the usual structures; indeed, the presence or absence of bastite is the main difference between the two slides.

On the E. side of Lankidden Cove, a rather compact serpentine exhibits grains of an iron oxide arranged in lines rudely parallel, and in the middle is a band about 4" wide, with a slightly streaky structure, containing bastite; the dominant colour in both being a greenish grey. Neither the grains of iron oxide, probably chromite, nor of bastite, in the latter, show any signs of crushing. The former indicates, by the parallelism of the "strings" of opacite, and the arrangement of the "rootlets" of flaky serpentine, that there has been originally a somewhat parallel arrangement of the olivine grains, but the resemblance is far greater to a fluxion- than to a crush-structure. A similar structure was noted in a second locality, but the serpentine generally is normal.

The following extract from Prof. Bonney's diary, describing a visit to the lherzolite of the Lac de Lherz, written in 1876 (June 27th), indicates the existence of a similar structure in a peridotite, which certainly appears quite free from the effects of dynamo-metamorphism:—"Occasionally also a sort of stratified appearance comes out in weathering, just as I have observed in some of the Lizard serpentines. I could not see that this corresponded with any marked internal structure." He states, in regard to this, in his account of his visit printed in the 'Geological Magazine' for Feb. 1877*, that the structure, in his opinion, has, like that at the Lizard, "some connexion with an internal parallelism," and thinks "it will prove to be connected with a fluidal structure."

* Dec. ii. vol. iv. p. 60.

A structure which would certainly leave its mark, and probably produce a serpentine, such as some of those mentioned above, is described and figured by Prof. Renard in his description of the peridotite of St. Paul's Island *. The rock is rather fine-grained and contains "eyes" of enstatite. The author, by an admirable piece of inductive reasoning, proves that the rock exhibits a fluxion structure and is of igneous origin, but abstains from accepting the conclusion because it has been asserted by certain authorities that some peridotites are metamorphosed stratified rocks.

III. THE ROCKS OLDER THAN THE SERPENTINE.

These were divided by Prof. Bonney, in 1882, into three groups, between which, however, no sharp line of demarcation was supposed to exist. Of these he considered the Granulitic to be the upper, the Hornblendic the middle, and the Micaceous the lower. He thought the series, as a whole, had been sedimentary in origin, but that the hornblendic rocks were probably altered tuffs, and, in some cases, might even have been basic lavas. In 1888, Mr. Fox † communicated to the Society the results of his examination of the islands fringing the south coast of the Lizard, together with petrographic notes by Mr. Teall; this was followed in 1889 ‡ by a paper from General M^cMahon on the granulitic and hornblendic rocks. It will, therefore, suffice on the present occasion to refer for details to these and other papers, and indicate in general terms the problems which are presented for solution.

(1) *The Granulitic Group.*

This group, as has been said, is characterized by a dark dioritic rock, veined or interbanded by a lighter one, which resembles a rather fine-grained granite. The former is not seldom porphyritic, the structure setting in and disappearing in an irregular way, so that a mass is "scattered" with felspar crystals, as is the face of a rock by the marks of a charge of shot. A slight foliation can often be discerned in the groundmass. Porphyritic felspar, as we now know, makes an igneous origin at least probable; but the matrix (which consists mainly of rather rounded or slightly elongated grains of felspar and hornblende, with more or less biotite §), so far as we are aware, has not disclosed any characteristic structure. The lighter rock is very closely allied to a vein-granite. The felspars are not idiomorphic, but occur, like the quartz, in rather rounded or elongated grains. The history of the rock, so far as regards its macroscopic character, can be best studied in Kennack and in Pen Voose Coves. It will suffice to recapitulate the principal facts of which any theory as to the origin of the group must take account.

* 'Challenger' Reports, Narrative, vol. ii.

† Quart. Journ. Geol. Soc. vol. xlv. (1888) p. 309.

‡ *Ibid.* vol. xlv. (1889) p. 519.

§ Apatite, spheue, and magnetite are present in nearly all slices.

(1) In some cases the dioritic rock is pierced by veins of the granitic, which may be of any thickness from a few inches to a few lines; occasionally the former is completely brecciated and the pieces are separated by the latter rock, the intervals also varying in thickness in like way. Thus in the Granulitic Group we find sections which closely resemble those where an igneous rock breaks up and includes another igneous* or a massive sedimentary rock.

(2) In other cases the two varieties, for considerable distances, appear perfectly interstratified, and exhibit regular bands of the one or the other which vary in thickness from several inches to a small fraction of an inch, with occasional layers of a rather intermediate character†. In the latter case the lines of junction, though fairly sharp, do not resemble ordinary intrusive junctions—there are no indications that the one rock has been broken by the other. The structures of the two are similar, and the one seems to pass into the other by a very rapid mineral change.

(3) The thin slices under the microscope do not exhibit either that mixture of larger and smaller grains, or the peculiar minute “mosaic” structure, which commonly occur when a rock already crystalline has been crushed. The structure is not that characteristic either of the “newer gneiss” series of Glen Logan, or of one of the crushed granitoid rocks common in the Central Alps; though to these it occasionally presents a very faint resemblance. Nor is it that of the Saxon granulites. The present structure, whether original or secondary, seems to have been assumed *in situ*.

(4) Between the two extremes mentioned in (1) and (2), every intermediate form can be discovered. The angular dioritic fragments appear to be gradually flattened or elongated till they become lenticular streaks or even bands, and the vein-like intercalations of granite appear to be drawn out with them into similar bands, very much as a mixture of glass of two colours can be drawn out when it is heated until it becomes viscous.

These conditions appear to be best fulfilled by the following hypothesis:—that into a basic magma, which at any rate was sufficiently solid to break into fragments, an acid magma, at a very high temperature, was injected,—that either the more basic material was still somewhat plastic when this intrusion took place, or it was, by this accession of heated stuff‡, so far softened that it was drawn out into streaks, and was even sometimes slightly mixed with the other by actual fusion, when movements occurred in the mass; and

* This, so far as my experience goes, is rather rare and local in its occurrence. The most remarkable instance which I have seen of the brecciation of one igneous rock by another was at the Corporation quarries, Montreal, where the nepheline syenite is shattered by and embedded in a rather compact dark rock, perhaps a tephrite.—T. G. B.

I have seen some striking illustrations of the complete brecciation of gneiss by granite in Spiti.—C. A. M^cM.

† This structure is rather more conspicuous in Pen Voose Cove; the former in Kennack Cove.

‡ Probably the temperature of solidification in the basic rock would be considerably lower than that of the acid rock.

that afterwards, as the temperature gradually fell, the whole mass became crystalline*. Thus the banded gneissoid rock of the Granulitic Group is an example of a kind of flow-structure on a large scale, wholly or (more probably) in part antecedent to crystallization. As this rock, in its distinctive characters, agrees with a large number of "banded gneisses," in which the ordinary symptoms of pressure-modification cannot be detected, and which appear to have at any rate completed their crystallization *in situ*, this hypothesis may prove to be of wide application. If, however, the bands do not differ very materially in their mineral composition—as is often the case with the banded Archæan gneisses—the hypothesis may assume a simpler form, and with them it may be only necessary to suppose that, as in the case of many rhyolites, some differentiation of constituents had been set up in the magma, the one part becoming slightly harder than the other, though still capable of being drawn out, so that the whole mass assumed a coarse fluidal structure, and subsequently, since its environment was widely different from that of a normal igneous rock, took on a holocrystalline, yet still a peculiar structure, different from that usually found in granites and diorites.

(2) *The Hornblendic Group.*

That this group underlies the Granulitic, is, in most places, a probability rather than a certainty, the two commonly being separated by a fault or a mass of serpentine. But, assuming the Granulitic Group to occupy a definite horizon, its relations to the Hornblendic are suggested in more than one place, and are, we think, clear in the crags on the south side of Cadgwith Cove, where the latter rocks may be seen gradually rising up from beneath the former.

The Hornblendic Group exhibits structures curiously imitative, if not actually indicative, of stratification, certainly over a larger area and probably through a greater thickness than the Granulitic †. It includes fairly well banded schists almost everywhere from Porthalla to the Lighthouses on the one coast, and from Polurrian Cove to near Old Lizard Head on the other. Their structures have been described by the present authors, who have regarded them, though from somewhat different points of view, as indicative of stratification in the original materials.

This group has been again examined with considerable care. From the chemical analysis as well as the mineral composition it seems clear that its rocks must originally have been of igneous origin; the more massive may represent altered basaltic lavas, the more

* Probably it was a mixture of crystalline grains and half melted stuff rather than a true liquid, so that it was difficult for any mineral to assume an idiomorphic form. The larger porphyritic crystals in the diorite were probably anterior to the epoch mentioned above.

† The hornblende-schists are displayed, practically unbroken, in cliffs some 200 feet high, between points nearly a mile apart as the crow flies; the Granulitic Group, so far as we remember, seldom occurs without a break from top to bottom of such a cliff, or for more than a few dozen yards at most.

banded altered tuffs of similar composition. As regards the former, some of the "eyed" hornblende-schists mentioned by one of us, as for instance on the north side of Porthoustock Cove, may be a porphyritic dolerite which has been modified by pressure*, and converted into a slightly foliated epidiorite. Other masses again, as in the upper cliffs at Porthalla, are not at all banded and are even practically without foliation. It is, however, difficult to attribute the mineral banding and other structures in most parts of the mass to the crushing or shearing of a holocrystalline rock. Is it then to be explained as a kind of fluxion-structure, as we have already done in the case of the Granulitic Group? Some of the hornblende-schists present a very close structural resemblance to certain hornblendic bands in the latter group, and to some other rocks, hereafter to be mentioned, which are undoubtedly igneous. Moreover, the mineral banding—stripes consisting mainly of feldspar or epidote alternating with those mainly of hornblende—as at Cadgwith or to the S. of Church Cove, would lend itself very well to this explanation. Indeed, where the bands attain a considerable thickness, it is not very easy to explain them by segregation during metamorphism†. One case, indeed, where the thickness of the bands is perhaps at a maximum for the district, seems to require the former explanation. A pit has recently been opened by the side of the road leading down to Mullion Cove. The rock excavated is partly a coarse saussurite-hornblende rock, without definite structure, partly a well-banded variety of the same, some of the bands being full 3" thick; the one clearly passes irregularly into the other. The former under the microscope presents considerable resemblance to one of the east-coast gabbros, for it affords the remains of plagioclase feldspar, indications, and in one case at least a remnant, of diallage, and even a suggestion of the former presence of olivine. The banded variety contains the same minerals, and bears considerable resemblance to the *flaser-gabbros* described hereafter; its structure does not suggest crushing, and one or two of the thinner bands, where the two minerals are smaller in size, present a very close resemblance to an ophitic structure, in which there is a slight orientation in the feldspars. We do not think it possible to explain this structure by the shearing of a coarse holocrystalline mass. At any rate the rock must originally have been a variety of gabbro‡.

But in some members of the Hornblendic Group we have to explain, not only a banding, but also repeated resemblances to slightly irregular deposition, or even to "false bedding."

We did our best, during our study of these rocks, to apply either

* The larger feldspars, which are rendered distinct by saussuritization, are occasionally partly idiomorphic and seemingly crushed out.

† I collected a specimen, in 1888, from the hornblende-schists of Sark (which are practically identical with those of the Lizard), in which the bands attain a thickness of 5".—T. G. B.

‡ It might be urged that this rock did not belong to the hornblendic schists as here defined. It agrees, however, macroscopically with them, and differs rather markedly from the altered gabbros of the east coast, of which, moreover, we have not seen any instances on this side of the district.

of the above explanations to them. The ordinary cases, where the rock is foliated rather than banded, and the slabby bedding, which is commonly so marked a feature as to be the first thing that attracts the eye as the mass is approached, might be accounted for, like the structures in the "newer gneiss" series of Glen Logan and its vicinity, by the effects of shearing movements during a long continued process of thrust-faulting; but, in applying this hypothesis to some of the structures which are more especially suggestive of stratification, we were always encountered by difficulties which we failed to overcome. Again and again the gliding-planes, which we had devised in order to explain the oblique disposition of the apparent *stratulae* in the rock, were interrupted by some unbroken band which either forbade the idea of any displacement, or demanded for its manufacture a contradictory set of movements. In these cases the "fluxion hypothesis" also landed us in similar difficulties. Thus, although our reasons cannot be fully appreciated by those who have not followed our steps, we are at present unable to suggest any form of mechanical disturbance as a complete explanation of the more banded members of the Hornblendic Group, and think that for these the stratification of an ash (perhaps by the intervention of water*) is the better "working hypothesis."

Subsequently, of course, there must have been almost complete, if not quite complete, rearrangement of the constituents. The ash originally must have consisted of more or less fragmental felspar, augite, iron oxide, and possibly olivine, with bits of more or less scoriaceous tachylite or magma-basalt. Of the latter, at any rate, every trace has disappeared, the constituents have separated as from a molten mass, and the whole is a crystalline mixture of felspar, hornblende, &c.† In this hypothesis there are also difficulties, so that, until further evidence be discovered, it must be regarded as only tentative, for we now feel convinced that some members of the group were originally dolerites, and some structures are due to fluxion. Moreover, it must not be forgotten that the basic member of the overlying Granulitic Group often differs little from the more hornblendic part of the present one. The former appears to have been raised to a high temperature after it had at least begun to consolidate. It is then probable that the underlying rock was not less affected, and important changes may thus have been brought about.

(3) *The Micaceous Group.*

This—the talco-micaceous group of De la Beche—was retained by Prof. Bonney because of the presence of a mica-schist, and some other non-hornblendic rocks, among the green schists. The last

* Because by the action of currents the materials would be to some extent separated in accordance with their specific gravity, and their deposition at any spot would be varied by the constantly changing velocity of flow.

† See, for a suggestion of the process, M'Mahon, Quart. Journ. Geol. Soc. vol. xlv. (1889) pp. 525-531.

are, indeed, the most abundant rocks, but they differ much in appearance from the normal hornblende-schists, in the minuteness of their constituents and in the presence of a more acicular variety of that mineral *. But the advance of our knowledge during the last few years leads us to doubt the advisability of making any definite separation. Three bands of brownish mica-schist, like that at Polpeor, have been discovered by Mr. Fox (and visited under his guidance by the authors), intercalated with the normal hornblende-schist in Polledan Cove, E. of Housel Bay †; and the character of the green schists may be accounted for by subsequent pressure and shearing. The whole region has evidently been greatly modified since its constituent rocks first crystallized. The mica-schist at Polpeor is crumpled, and the green schists often exhibit structures resembling the "mylonite" of the Highland thrust-fault region; tongues of a porphyritic diabase may be seen on the shore, so crushed and sheared as to be barely separable from the green schists ‡. On Old Lizard Head §, a cleavage foliation may be seen traversing the corrugated banded greenish schist at a high angle, and the rock below is in places a breccia of a gneissoid rock and of a rather soft "green schist" in hopeless confusion, very suggestive of faulting. Polkerris Cove (S. of Porthalla), in which some serpentine and a little gabbro occur, affords evidence confirmatory of this view. On the northern side we find a flinty-looking schistose rock (very similar to one variety at Polpeor), and can identify in one place a porphyritic dyke, rather like that named above. The flinty rock is sometimes porphyritic, and may be a modified dyke, but other parts suggest affinities with the hornblende-schist, into which there is a passage on the southern side of the Cove. A specimen from the northern side, which in the field seemed more nearly related to the hornblende-schist than to the diabase, has been examined. It shows marked indications of crushing and shearing; fragmental "eyes" of rotten felspar or of hornblende (sometimes very like altered diallage) occur in a sort of mosaic of minute hornblende and feldspathic grains (possibly also of quartz), with a sort of "fluxion structure." One part of the slide is coarser and still retains traces of a fragmental structure; another consists of thin bands of a mosaic, in which this or that mineral predominates. Thus the passage of the normal hornblende-schist into a rather flinty-looking schistose rock in consequence of shear seems to be demonstrated ||.

* See description of the principal varieties, Quart. Journ. Geol. Soc. vol. xxxix. (1883) p. 12.

† Described by Mr. Fox in Trans. Roy. Geol. Soc. Cornw. vol. xi. pt. v. (1891). A similar mica-schist occurs near Pisti! Ogo, but here in the 'green schist.'

‡ A larger and less disturbed mass occurs a little farther east, and is described in Quart. Journ. Geol. Soc. vol. xxxix. (1883) p. 4.

§ Name on the six-inch map; called 'The Quadrant' in Prof. Bonney's paper. That name is now applied to an island below.

|| The cliffs and shore do not afford a continuous section, so that a fault may escape notice. As there is a fault at Porthalla and must be one at Porthoustock, this, the only intermediate cove, may be also determined by a fault.

We therefore think that the rocks along the coast, from the coast east of Polpeor to Old Lizard Head, owe their peculiarities mainly to subsequent mechanical disturbances, probably the result of an overthrust, so that the distinctive name had better be abandoned. The coarsely crystalline gneissoid rocks discovered by Mr. Fox in the outlying islands, and so admirably described by him and by Mr. Teall, are situated, in our opinion, below the thrust plane, so that we have here an association similar to that which occurs in some parts of the N.W. Highlands of Scotland. At Porthalla, between the great fault and the typical hornblende-schist (with serpentine), a band of mica-schist occurs associated with fissile green schist. To this mass we should apply a similar explanation, and no longer desire to separate it from the Hornblendic Group*.

IV. IGNEOUS ROCKS NEWER THAN THE SERPENTINE.

(1) *The Troctolite.*

This rock was described by Prof. Bonney under the name of "the older gabbro," and its resemblance to the troctolite of Volpersdorf was pointed out. Subsequent analysis indicated that it might be thus named, though it was not so typical an example. It has also been described and figured by Mr. Teall†. Thus there is little left to be said. It has been found only at Coverack Cove, where it occurs both in irregular masses and in thin veins, with little difference in the texture of the rock, and very perfectly welded to the serpentine, which is practically unaffected by it. We cannot, however, regard the association of the two rocks as a case either of segregation or of veining strictly contemporaneous, for the serpentine occasionally has been completely brecciated. For instance, one block on the shore, which measured about $2' \times 1\frac{1}{2}'$, consisted of about equal parts of the two rocks, the serpentine being mostly in rectangular pieces, the largest about $8'' \times 5''$, the smallest about $1\frac{1}{2}'' \times \frac{3}{4}''$, the thinnest vein of the troctolite being about $\frac{1}{4}''$ thick, yet nearly as coarse as the rest.

* Prof. Bonney is now convinced that Mr. Collins was right in regarding the gneissoid band (described by him) as only a pressure-modified granite vein, but both the Authors fail to understand on what grounds Mr. Collins separates the hornblende-schists at Porthalla from those in other parts of the Lizard, and considers them to be metamorphosed Lower-Silurian rocks. He states (*Quart. Journ. Geol. Soc.* vol. xl. (1884) p. 466) 'that the hornblende schist of Porthalla is a very peculiar rock indeed.' We cannot understand how any one well acquainted with the hornblende-schists of the Lizard could make this statement. An exceptional specimen might be found anywhere, but speaking of the general character of the Porthalla schist, which it must be remembered cannot be separated from the mass which extends to Porthoustock Cove, we unhesitatingly affirm that we cannot detect in it any valid distinction, macroscopic or microscopic, from much of that which occurs in other parts of the Lizard peninsula.

† 'British Petrogr.' pl. viii. fig. 2.

(2) *The Gabbro.*

The principal mass of gabbro, as stated in a former paper, is rudely oval in form, the longer axis measuring full four miles, and the shorter about two. It rises in Crousa Down to a height of nearly 300 feet above the sea, by which it is washed for a considerable distance north of Coverack Cove. In the Survey map it is represented as giving place to greenstone in the little cove opposite to the dangerous skerries called the Manacles. This, however, is hardly correct, for though dykes of the latter rock become rather more frequent on this part of the coast, and perhaps ultimately occupy as much space as the gabbro itself, that rock continues to Porthoustock Cove, on the southern slopes of which it may be seen; though, as will be hereafter noticed, it does not, so far as we know, descend to the water's edge.

This mass of gabbro evidently throws off many veins on its southern flank, which cut both the troctolite and the serpentine in Coverack Cove. There is also the great dyke-like mass, nearly two miles long and about a furlong wide, according to the Survey map, which runs inland roughly in a N.W. direction from the skerries of Carrick Luz, and approaches at nearest within about a third of a mile of the former mass. On either side, in Lankidden Cove on the east and towards Compass Cove on the west, dykes are numerous, doubtless in some way connected with it. They disappear in Kennack Cove, but are found again about Enys Head, and then, after a considerable interval, at Polbarrow, becoming ultimately very numerous around Pen Voose. It is, however, only at the two first-named localities that the rock is found in masses of considerable size; generally it occurs in dykes or veins (at most only a few yards, and commonly only a few feet thick) which not seldom ramify and terminate in veins sometimes less than an inch in thickness.

The mineral composition of the rock and its changes have already received full attention; therefore it may suffice to say that in its normal condition it varies from a plagioclase-olivine-augite (or diallage) rock to a saussurite-hornblende rock, the last mineral being partly actinolite, and always one of the distinctly green varieties. It is impossible in this case to prove that olivine was an original constituent, but inasmuch as it is present in certain masses, which exhibit a transition from the normal gabbro to the ordinary saussurite-hornblende rock, there is no reason for supposing it to have been originally absent from the latter. In the great mass at Crousa Down the gabbro is often comparatively unaltered. In the dykes, including the large one at Carrick Luz, it is generally more or less altered. The olivine has usually disappeared, though occasionally its position is indicated (as is rather common at Coverack) by a blotch of hematite; the augite occurs as diallage, and every stage of the change from this mineral into hornblende can be observed. The felspar in like way passes gradually into saussurite; in most cases it appears to be less stable than the diallage, for a saussurite-diallage rock is common. The change to saussurite does not appear

to be connected with any mode of dynamo-metamorphism. It is quite true that it is very characteristic of the foliated masses, but it may also be observed, as, for instance, at Coverack, in rock of the most normal character. It is evidently due to the action of water, and might more correctly be designated meteoric metamorphism, for it evidently proceeds inwards from the exterior of the mass; probably being produced when this is at no great distance from the surface.

This gabbro occasionally is distinctly foliated or even banded, a structure which during the last few years has given rise to much discussion. Prof. Bonney, in describing it, regarded the structure as the result of crystallization under a pressure (or resistance) definite in direction. Mr. Teall ascribed it to pressure subsequent to solidification *, and compared it with the *flaser*-gabbro of the Germans, which has been similarly explained. But to this view, as pointed out by the former †, and subsequently confirmed by Gen. M^cMahon ‡, the absence of all signs of the effects of pressure in the associated serpentine seems a fatal objection.

One of the chief objects of our visit in 1890 was to study afresh this very remarkable structure, and the conclusion at which we arrived will be most readily indicated by giving a brief summary of our observations, though this may involve some slight repetition of statements already published.

The foliated and banded structure in the gabbro is most conspicuous in the Carrick-Luz dyke; it is also locally very well developed in the neighbouring dykes, especially on the western side, in the neighbourhood of Pen Voose and at Polbarrow. It may be observed, though it is not common, in the Crousa-Down mass, and elsewhere. Every variety may be found, from a slightly streaky or wavy foliation § to a distinct mineral banding, and not seldom the pyroxenic crystals appear as "eyes." Each of these two types is excellently figured by Mr. Teall ||, so that on the present occasion it is needless to do more than refer to his plates and to the descriptions already published. The results of our investigations may be thus summarized:—

(1) As will afterwards be more fully explained, the gabbro had assumed its foliated structure before it was cut by the later intrusives (dykes of diabase, &c.), which probably are of more than one age.

(2) Whatever be the origin of the quasi-foliated structure in the serpentine, this cannot be connected with the foliation of the gabbro. The former is most marked on the western coast and at Porthalla; but these cases cannot be cited in support of the pressure-hypothesis, because gabbro does not, so far as is known, occur in either

* *Geol. Mag.* (1886) p. 481.

† *Ibid.* (1886) p. 375.

‡ *Ibid.* (1887) p. 74.

§ We use this term as indicative of orientation rather than of linear aggregation of constituents, producing at most a slight and interrupted 'streakiness,' from which every stage exists to distinct bands mainly of different minerals, sometimes over a quarter of an inch thick.

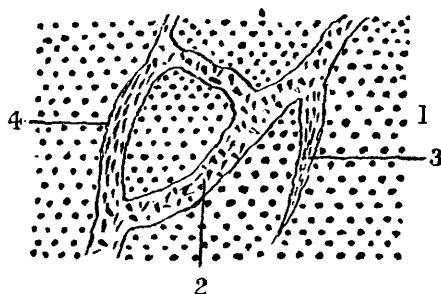
|| 'Brit. Petrogr.' pls. xxvi. and xliii.

district. The most streaky serpentine on the eastern coast, south of the Manacles, is the dark variety on either side of Caerleon Cove, but here the gabbro is not markedly foliated. The serpentine at Pen Voose, except for slight and very local crushing near faults, is perfectly normal. So it is in the neighbourhood of the great Carrick-Luz dyke, where the foliation in the gabbro is at a maximum. About Enys Head streaky serpentine and gabbro, sometimes foliated, occur together, but there does not appear to be any necessary connexion between the structures.

(3) The gabbro and serpentine are sometimes welded together, sometimes separated; the former condition is perhaps more common in Coverack Cove than elsewhere, and is more usual with the thin veins than the larger masses.

(4) The gabbro is often rather variable in texture. The great mass of Crousa Down appears to be the most uniform in this respect, and it consists of medium-sized grains, though occasionally small patches of coarser varieties occur along the coast. The Carrick-Luz mass is more coarsely crystalline. All the smaller dykes, as a rule, are coarse-grained, and even in the thinnest veins the rock generally does not become fine-grained, but maintains a medium texture. Some of the largest crystals of diallage occur in masses less than a foot thick. Even in the same mass the gabbro not seldom exhibits considerable variation in texture, the ordinary coarse kind being streaked or mottled with vaguely-defined patches of finer grain.

Fig. 4.—*Gabbro veins near a 'natural arch' on the shore, west of the Carrick-Luz mass.*



1. Serpentine.
2. Coarse gabbro.
3. Moderately foliated gabbro.
4. Very foliated gabbro.

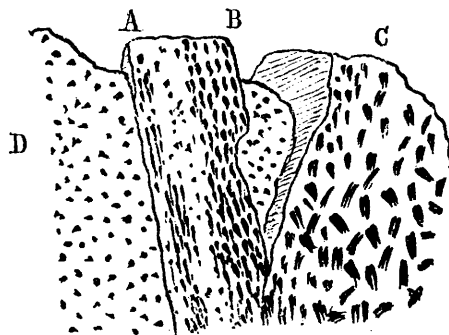
(5) The foliation sets in and disappears in a most capricious fashion. Part of a dyke, an arm of a vein, may be foliated (fig. 4), without any apparent reason or connexion with any structure in the adjacent rock (especially when this is serpentine), and the rest may be normal. The significance of the relations of the ordinary and the foliated

or banded structure, one with another and with the exterior of the mass, will best appear from a series of examples.

(a) In the Carrick-Luz dyke the strike of the structure appears to be fairly steady *, running rather W. of N.W., which is also the average direction of the dyke. It appears to dip at a rather high angle, 60° or more, on the northern side—that is, in the probable direction of the fissure. The mass varies somewhat in coarseness, and in the amount of foliation and of banding, the latter being more distinct on the western side, but here and there it seems inconspicuous. The felspar occasionally, the diallage frequently, are unaltered. Now serpentine yields readily to pressure. When this is moderate in amount the rock brecciates; when the pressure is more severe the fragments take a lenticular shape and become slickensided; when it is extreme, as may often be seen in the Alps, the rock assumes the appearance of a slaty schist, with corresponding changes in its microscopic structure †. Any conspicuous grains of bastite, augite, chromite, &c. are more or less crushed out. But in the Lizard serpentine these minerals, like the matrix, are in a normal condition, so that we are forced to conclude, if we adopt the pressure hypothesis, that the gabbro, one of the toughest of rocks, has been crushed into a kind of schist, while its comparatively brittle associate has undergone no structural change.

(b) Sometimes the foliated structure in the gabbro occurs near to and parallel with the edge of a dyke, but at others, though rarely, it is inclined at a high angle to it; it is also found in wisps or streaks in a non-foliated mass, as may be seen, for instance, at Crousa Down. The annexed diagram (fig. 5), representing part of a vein on the eastern side of Compass Cove, shows a wedge of serpentine

Fig. 5.—*Foliation of gabbro dyke east of Compass Cove.*



- D. Serpentine.
A, B. Moderately fine gabbro, with foliation; from A to B about $4\frac{1}{2}$ inches.
C. Coarse Gabbro.

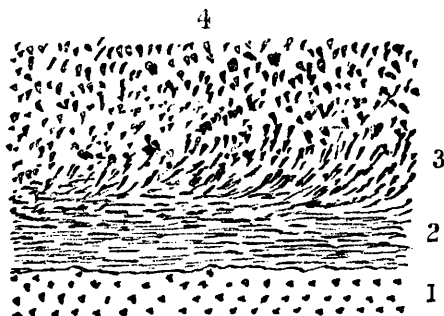
* We can answer only for the shore-section.

† Bonney, *Geol. Mag.* (1890) p. 533.

splitting an intrusive dyke of gabbro and enclosed in it. Of this rock the main mass is coarse, and in it foliation is either extremely indistinct or absent. In the arm we find on one side medium-grained gabbro, well foliated, passing into a compact gabbro, which is but slightly streaked with a foliated structure, as indicated. The serpentine, whether in the included block or in the main mass, shows no sign of crushing.

(c) Yet more significant is another mass nearer the Carrick-Luz dyke, the more important portion of which is represented in the annexed diagram (fig. 6). The face of a dyke of gabbro forms a crag about ten feet high, the lower edge resting on serpentine. Above this the mass for about two feet consists of a rather fine-grained gabbro,

Fig. 6.—*Foliation in gabbro between Compass Cove and Sperric Cove.*



1. Serpentine.
2. Foliated gabbro.
3. Partially foliated gabbro.
4. Unfoliated gabbro.

foliated or finely banded, “not unlike a piece of hornblende schist,” the bands being so thin that the mass, as a whole, is rather *foliated* than *striped*. The next two feet consist of ordinary and foliated gabbro, very irregularly mixed, but the streaks, as shown in the diagram, have in places a distinct tendency to sweep round into the fine foliated mass below. Lastly comes some half-dozen feet of sporadically coarse or slightly foliated gabbro, in which occurs now and then a thin wisp-like band of the fine foliated rock, resembling that at the bottom, but not parallel with it.

Microscopic examination of these foliated gabbros has not led to any very definite results. The constituent minerals have been so much altered since the structure was produced as to obliterate any distinct indication of the agent by which it was caused. The original plagioclasic felspar has been almost wholly replaced by secondary products. Occasionally some diallage may be detected. In the *augen-flaser* gabbros the larger grains of diallage still remain comparatively unchanged, though they also often have a

border of, or are partially replaced by, secondary hornblende. Here and there, in other parts, and in the ordinary *flaser-gabbros*, some trace of the original diallage may be found amid a crowd of hornblende grains*; the former occasionally exhibit some traces of mechanical disturbance, such as a slight bending of the cleavage-planes or pinching up of an end. These indications, however, are suggestive of a strain, due to a tensile movement of the mass rather than of a crushing down of the grains. The cleavage-planes in the different grains generally, but not always, exhibit a tendency to parallelism.

The saussuritic constituent is at times fairly clear and transparent, at times brownish, varying from moderately translucent to almost opaque. The former, with crossed nicols, appears as aggregates of rather bright-coloured specks, and the original mineral seems to have occurred in rather polygonal grains, often about .01 inch in diameter; traces of this structure also can be occasionally detected in the more opaque patches. It might be argued that this "mosaic" is a proof of crushing, but the uniform general distribution of the structure appears adverse to this idea, and it might be explained either as the result of secondary change in an original larger felspar grain †, or as an original microgranular structure ‡.

This more opaque part occurs in irregular rounded patches, in rudely rough-edged oblongs, or in streaky clots. Assuming them to represent a felspar of slightly different composition, as is rendered probable by their mode of occurrence, these patches on the whole are not at all suggestive of crushing, for though the last mode of arrangement might be so interpreted, it would be equally possible with a fluxion-structure.

(d) Near the Sperric Arch there are several thin veins of compact diorite intrusive in gabbro. One of these veins, about two feet thick, splits up into minor veins a few inches thick, which run with the foliation of the gabbro in a way that reminds one of the alternating white and black parallel bands of the granulitic series; but when the dioritic veins are followed up, they are seen to cut obliquely across the foliation of the gabbro at a low angle. Yet though the gabbro is *intensely* foliated, the compact trap does not give, under the microscope, any indication of crushing or any more parallelism of structure than is usually presented by the flow of

* A white or very pale augite in roundish grains is present in some examples.

† Prof. Judd on the replacement of labradorite by scapolite, *Min. Mag.* vol. viii. p. 186.

‡ I collected, during a visit to the "norite region," N. of St. Jerome in Canada (in 1884), a specimen of a fine-grained norite, which showed on weathered surfaces a faint structure much resembling a fluxion-structure. Microscopic examination shows that the felspar (which is well preserved) occurs chiefly in small polygonal grains (about the above-mentioned size), mixed with larger grains, often about three times the diameter, but sometimes more. The mass does not give the slightest hint of having been crushed, and we appear to have a record of crystallization *in situ*, analogous to that of a microgranite. The pyroxenic constituent, which is not abundant, is less well preserved, and irregular in outline, but appears to have formed, as best it could, *in situ*.—T. G. B.

igneous rocks. The diorite is certainly not derived, in this case, from the gabbro by shearing, and its intrusion was subsequent to the epoch when the gabbro had attained a maximum foliation.

(e) One more typical case may be given. On the top of the cliffs above Polbarrow there is a boss of gabbro perfectly unfoliated. A few feet below this a vein of gabbro appears in serpentine, and takes a course parallel to the top of the cliff for a few feet and then dies out. This vein is decidedly foliated, the foliation running with the direction of the vein. Down below, on the beach of Polbarrow itself, between high- and low-water marks, there is another outcrop of what appears to be a continuation of the intrusive dyke seen at the top of the cliff. A gabbro vein about a foot and a half thick runs a course nearly parallel to the beach for 31 feet, and no portion of it exhibits any trace of foliation. Here the onward passage of the gabbro appears to have been barred, and, after an ineffectual attempt to force a passage upwards, the vein turned sharply down at right angles to its former course, and finally broke into a spray of finer veins. Just at this elbow the gabbro is intensely foliated, resembling, if one may use the comparison, streaky bacon. It seems clear that pressure after consolidation can have had nothing to do with the foliation of this rock. Such pressure, had it been applied, must have affected the serpentine as well as the gabbro, but there are no signs of it. Then the pressure that converted a coarse-grained gabbro, in one portion of the vein, into an intensely foliated streaky-bacon-like mass, ought to have corrugated or streaked the other portion of the vein immediately in contact with it, but it has not done so. It ought also to have foliated the boss on the top of the cliff. It is also to be noted that the two veins which are foliated, namely the one at the top of the cliffs and the one at the bottom, run in directions at right angles to each other, the foliation in each case being parallel to the direction of the vein. These facts, which seem inexplicable on the hypothesis of crush or shearing after consolidation, seem perfectly natural on the supposition that the foliation was the result of traction or the resistance offered by the serpentine to the passage of the gabbros.

The evidence summarized above makes it impossible, in our opinion, to explain the foliation in the gabbro as a result of pressure-metamorphism subsequent to the solidification of the rock *. The structure cannot be later than this epoch, and the following hypothesis appears to comply best with all the conditions of the problem. Suppose that the mass at the time of intrusion was not at

* It must be remembered that mineral banding, which there is no reason to connect with crushing, has already been not seldom observed. It may be noted in the syenite of the Plauen'schengrund, where the usually orientated feldspars occasionally form short streaky bands. It is noticed as occurring in certain granites (Hatch, 'Introduction to the Study of Petrology,' p. 83), and in the hornblende-pierite of Penarfynydd (Alfred Harker, *Quart. Journ. Geol. Soc.* vol. xlv. (1888) p. 457). We have mentioned it in this paper as occurring in serpentine (*i. e.* peridotites), and have seen it in diorite and other holocrystalline rocks.

a very high temperature *, that mineral separation had already commenced, and that it consisted of crystals of felspar and pyroxene †, or—which perhaps is more probable—of completed pyroxenes and inchoate felspars, floating in a magma (having in the latter case the composition of felspar) which was already not very liquid. When the temperature was slightly lowered, as for instance near the faces of a fissure, the magma might become sufficiently viscous to exercise considerable strain upon the included crystals; they would be occasionally cracked, deformed, torn up, and aggregated in streaks; the mass also would become ill mixed; in short, it would exhibit on a large scale the phenomena of a fluxion-structure, which would be most conspicuous towards the surface, but might set in here and there in any part, or might occur like a foreign fragment owing to rupture and entanglement of portions of an outer “crust.” As consolidation proceeded, the magma would sometimes continue to augment the crystals already formed, and the coarser varieties be produced; sometimes it would independently crystallize, and thus a fine-grained variety be produced or a quasi-porphyrific condition be retained ‡. In short, we offer for this rock an explanation which is in some respects similar to that which we have proposed for the banded granulites §. At any rate it is an hypothesis which meets all the conditions of the problem at present known to us, and this certainly cannot be said of the dynamo-metamorphic one.

(3) *Varieties of Gabbro.*

As a rule, except for the above-named mineral changes, the gabbro seems fairly uniform in composition, though varying in structure and in coarseness, but a few exceptional cases have been noted. A dyke, about 2 feet thick, on Enys Head consists mainly of the saussuritic mineral; one, composed largely of rather well-preserved labradorite, occurs in Lankidden Cove ||, and another was found this year on the north side of Kennack Cove. The last does

* The coarse condition of the gabbro, even in very thin veins, might be held to indicate a very high temperature and very slow cooling, but this does not, in our opinion, accord so well with some of the other conditions.

† Doubtless with olivine and iron oxide, but we omit them as immaterial for the present purpose.

‡ Possibly also in some cases, when the gabbro may have been intruded between fault planes, a movement or movements of one or both of the walls of the fault might take place when the final stage of consolidation was setting in, and marginal shearing and foliation would be the result. Some internal shearing might also result from the same cause.

The coarseness of the rock in the thinner veins may be explained thus:—The front portion of the advancing mass would probably contain rather more crystals (as it would be rather cooler) than the rest. Thus it might for a time be arrested at the entrance of a narrow fissure, but when ruptured (owing to the pressure of the mass behind it) the fissure would be filled by a squirt of the more liquid magma, which would sweep along with it the minerals in the more crystallized portion.

§ The occurrence of an analogous structure in granite was described, and a similar explanation was suggested, by Gen. M^cMahon, *Geol. Mag.* (1887) p. 76.

|| *Quart. Journ. Geol. Soc.* vol. xxxiii. (1877) p. 905.

not exceed 1 foot in thickness, and is bordered apparently by rotten serpentine; but within a few inches on the south side is a thin mottled band, which may be a rotten gabbro. The rock externally is generally light-coloured, but within is seen to consist of a smoke-grey coloured felspar, with slightly oily lustre, probably labradorite, in fairly large crystals, and of a few conspicuous flakes of a dark mica. Its microscopic structure is difficult to describe. There are some flakes of mica—one or two being biotite, the rest a white mica, with inclusions of iron oxide between the cleavage-planes, and so probably a “bleached” biotite; one or two tufts of a nearly colourless mineral in more or less acicular fibres, most likely actinolite; a grain resembling a serpentinized olivine (it is not quite normal in character), the rest being a closely connected group of minerals, feldspars or their alteration-products. This consists partly of fair-sized grains of a felspar which, in general appearance and extinction, corresponds with labradorite, but does not exhibit the usual oscillatory twinning: partly of a mosaic of crystals and crystalline grains, which in places assume the “saussurite” condition already described. The mode of occurrence and association of these with the larger crystals does not suggest that the latter have been broken up by mechanical pressure; rather that parts of them have undergone a molecular re-arrangement. They project irregularly, sometimes with rectilinear outlines, into the larger grains, and sometimes a single grain or group of grains, with either form of outline, appears insulated in the felspar, like an island near a coast-line. One is reminded of the formation of scapolite from labradorite described by Prof. Judd, though these grains are not the former mineral, but seemingly are also felspar. Cleavage-planes can be seen, and the line of extinction makes with them angles varying up to at least 30° .

V. MANACLE POINT AND PORTHOUSTOCK COVE.

Prof. Bonney was unable, when working for his former paper, to make more than a hasty traverse of the rocks of Manacle Point, so we examined the coast-sections from a cove on the south to Porthoustock Cove*. Over the greater part a gabbro dominates, generally about as coarse as the normal rock of Crousa Down, though occasionally a very coarse variety is found. Sometimes also it becomes rather fine-grained, the change from one to the other being often fairly rapid. A foliated structure occurs, though but rarely. As at Pen Voose, the gabbro is broken into by a granular rock, sometimes porphyritic, sometimes green-spotted, sometimes dull greyish and speckled. Both these are cut by a rather compact greenstone, which is occasionally slightly porphyritic; of this not much is seen on the south side of the Point, the quantity seeming to increase as we go northwards†.

The south side of the actual cove at Porthoustock is very puzzling, and in places the crags could only be examined from a boat in very

* That is, the whole area coloured as ‘greenstone’ in the Survey map.

† We reserve the details of these rocks for the next section.

calm weather. We had to restrict ourselves to what could be seen by working along their face; so we cannot attempt more than to give a general sketch. Gabbro of the ordinary type can be traced at intervals on the slope above the cliffs, certainly to within a furlong, and probably to within a hundred yards of the water's edge.

These cliffs, as far as we could get at low water, were found to consist of a greenstone (epidiorite)*. This is cut by veins of a felspathic rock, which must be classed with the actinolitic gabbros, since it consists mainly of moderately coarse plagioclastic felspar and small patches of an actinolitic mineral, probably replacing augite. Sometimes the veins are very thin and might be infiltrations. One or two indeed appeared to contain quartz, and if so the rock might almost be called a felspathic pegmatite. This rock and the greenstone are closely welded; the former differing markedly from the normal gabbro, which, as mentioned above, occurs on the hillside at a short distance. Both are traversed by dykes of compact greenstone, macroscopically indistinguishable from that which cuts the ordinary gabbro about Manacle Point, but in one of them a porphyritic structure occurs. This variety, under the microscope, is found to be a compact epidiorite, containing large crystals of plagioclase felspar. There can be little doubt that the matrix was formerly a minutely crystalline, or possibly even a vitreous, basalt.

The relations of the first and second rock much resemble those of the Granulitic Group, but in the present state of our knowledge it would be rash to do more than note the resemblance; certainly, as the gabbro-like rock proves to be so different from the ordinary gabbro of the district, we are not justified in regarding them, without further proof, as of the same age. One difficulty in the identification of the first two rocks with the Granulitic Group is that they are little, if at all, foliated, while the crags facing them across the narrow cove are "slabby," and sometimes well-banded, hornblende-schist. Much minute study and repeated visits will be necessary in order to clear up the difficulties of this section of the coast.

VI. OTHER INTRUSIVE ROCKS.

As has been often remarked, the schists, the serpentine, and the gabbro are alike cut by intrusive dykes. These are more numerous along the east coast than on the west, being especially common between Caerleon Cove and Porthoustock. To classify and describe them fully would require a separate memoir. On the west coast the serpentine is not seldom cut, as described in Prof. Bonney's paper, by dykes and small masses of a reddish, rather fine-grained granite, which generally is distinguishable, macroscopically and microscopically, from the granitic rock of the Granulitic Group, which,

* It consists chiefly of plagioclase felspar in good condition (probably labradorite) and a fibrous hornblende mineral, clearly of secondary origin. Probably the original was a rather fine-grained dolerite with a structure inclining to ophitic. Larger idiomorphic crystals of rotten felspar occur rather sparsely.

as already stated, also occurs on that coast. One or two intrusions of the same rock are found on the east coast. For instance, there is a well-marked vein in a cove north of Pen Voose *, and another (badly exposed and so not quite certain) south of the same, at the farther end of the beach. Dykes of a porphyritic diabase are occasionally found cutting the Hornblendic Group, as, for example, near Polpeor (where it has been already described), on Carnbarrow, near Ogo-dour Cove, and at the headland to the south, where there are two dykes, one fine-grained, the other (and later) porphyritic with a compact base. This very interesting section has been described by Mr. Fox, with notes by Mr. Teall †. The granite veins which we have noticed above in the Hornblendic Group are more probably approximately synchronous with those in the Granulitic Group, and so are anterior to the date of the serpentine. The last rock and the gabbro are repeatedly cut by basic dykes, many of which have been noticed by previous writers. Of these there are numerous varieties; most of them are now hornblendic rocks, but it is probable that many, if not all, were originally augitic. In a few cases, as once or twice in Kennack Cove, they are practically indistinguishable from the dioritic members of the Granulitic Group, and we have to rely upon field evidence, but in many no such difficulty exists. Occasionally they exhibit an approach to foliation, as in the well-known dyke on the south side of Caerleon Cove, the exterior of which exhibits a slightly foliated structure; this we now consider, after careful re-examination, to be due to differential movements during solidification, not to subsequent pressure, for the mode in which the structure occurs agrees better with the former hypothesis, and there is nothing to support the latter. The dykes in the serpentine at Coverack, and in the Crousa-Down gabbro, have already received some notice, but one or two additional details concerning the latter may be worth adding. As already stated, it is frequently traversed by dykes of a basic rock, which varies from compact to granular, and is sometimes slightly porphyritic. Of these dykes, however, we have not thought it necessary to examine more than about a dozen specimens in all, four or five of which are from the gabbro. The former have been magma-basalts, and sometimes at the edges almost tachylytes. They are more or less altered, but numerous lath-like crystallites, with occasional small scattered crystals, of plagioclase can still be recognized, and small oval or oblong greenish patches, occupied by an aggregate of flakes giving bright colours with the crossed nicols, probably indicative of the former presence of larger grains of an augitic mineral. Others, fine-grained but holocrystalline, may be classed as epidiorites; one at least is still an ophitic dolerite.

But the gabbro is also cut by another rock, which, though similar,

* This was discovered by Messrs. Fox and Teall; we have not seen it, for the rock-face is only visible from the sea, but they secured photographs which we have examined. This is an interesting case, because the granite cuts the gabbro, as it was said to do by De la Beche, a fact of which Prof. Bonney did not succeed in finding a proof (*Quart. Journ. Geol. Soc.* vol. xxxiii. (1877) p. 915).

† Traus. Roy. Geol. Soc. Cornwall, vol. xi. pt. iv. (1890) p. 213.

appears separable from the above-named groups of dykes. It seems often to break up the gabbro, and then to cement the fragments, so that the two form one mass, while the above-mentioned cut clean, as dykes, through both, being sometimes welded, sometimes separable. It is slightly speckled, somewhat dark on freshly fractured surfaces, weathering a rather warm grey, sometimes porphyritic (felspar), sometimes green-spotted. A specimen from near Manacle Point consists of plagioclase, augite, partly altered into a brown hornblende, altered olivine, and granular magnetite; it is therefore a fine-grained gabbro. The boundaries of the grains are very irregular, and the augite not seldom includes either lobes or grains of the felspar*. The normal gabbro presents a similar structure, but has less magnetite, and the pyroxenic constituent is either diallage or is altered to a fibrous actinolite, with a little of the brown hornblende; the felspar also is more decomposed. The boundary between the two is not very sharply defined under the microscope. Macroscopically the dark rock at Pen Voose, which is similarly associated with the gabbro, much resembles the above, but in the three specimens examined hornblende (green) alone is present; magnetite is scarce in this rock. This also has a granular structure, but the individual grains are smaller and rather more regular in shape, so it differs more conspicuously from the adjacent gabbro (in which also the augitic constituent is replaced by hornblende). This rock was probably an early intruder; nevertheless, at that time the gabbro was not only crystalline but foliated, as can be seen on careful scrutiny in one or two instances at Pen Voose, for the subangular fragments of foliated gabbro are scattered in the dark matrix as if they were bits of a schist†.

Lastly, there are two dykes which differ in some respects from all those already mentioned. The others have a distinctly rhyolitic aspect. One occurs on the road leading from Landewednack to the back, or sea-face, of the serpentine quarry between Church Cove and Pen Voose, forming a vein a few inches thick in serpentine. As it weathers to a similar colour, the outcrop is easily overlooked‡.

* Compare plate iv. figs. 2, 3, illustrating Prof. Judd's paper on 'Tertiary Gabbros,' &c. in Scotland and Ireland in *Quart. Journ. Geol. Soc.* vol. xlii. (1886).

† I made a mistake in regard to the relations of these two rocks at the time of my earlier visits, which affects a few lines in my first paper, viz. those on p. 894:—'The gabbro and hornblende-schist are here mixed up intrusive.' The close resemblance, macroscopic and microscopic, of the rock described above to some of the less foliated and unbanded varieties of the hornblende-schist (or the darker part of the Granulitic Group) led me to suppose that the gabbro was the intruder, and had acquired its foliation from pressure in cooling; but, on re-examination, I find that there are difficulties which did not then occur to me (for parts of the supposed hornblende-schist closely resemble an unmodified igneous rock), and that the foliation in the gabbro cannot be thus explained. The evidence, even at Pen Voose, now appears to me more favourable to my present view; and that which we obtained in the neighbourhood of Manacle Point, where there are similar appearances in a less altered rock, seems convincing. This, however, does not affect the general argument of that part of the paper.—T. G. B.

‡ It has been examined by Gen. M^cMahon.

The rock has a specific gravity of 2.59. The microscope proves it to be composed of two imperfectly-mixed glassy magmas, exhibiting very typically the fluxion-structure of a rhyolite. In transmitted light one of these magmas is quite colourless, the other has a buff-coloured porcellaneous appearance. Under crossed nicols the slice breaks up into a cryptocrystalline matrix, showing minute irregular-shaped flecks of doubly-refracting matter. Here and there, more particularly in the colourless portions of the magma, the matrix becomes microcrystalline, showing very minute doubly-refracting dots, presumably quartz, on a dark ground. The slice is dappled with chlorite and contains some magnetite, ferrite, a misshapen porphyritic felspar, and polysynthetic granules of quartz.

The second dyke is at Housel Cove. This, in petrological character, is closely related to the last one; it cuts right across the bedding of the hornblende-schists, and is in contact with these schists along its western margin. On its eastern side it is separated from the schists by a few feet of breccia, made up of fragments of the felsite and doubtless of "mechanical" origin, for it is parted from the solid rock by a fault, the walls of which are clearly indicated by well-marked slickensides. On the western margin of the dyke the hornblende-schists are somewhat crushed and rotten, and have acquired by weathering a superficial resemblance to the felsite breccia.

Examined under the microscope, this rock has quite the aspect of a rhyolite, and its structure so closely resembles the rock above described that the details would be a mere repetition of those already given. Granules of quartz and felspar may be made out in the base here and there, but they rarely present anything like crystallographic outlines. The slices are sprinkled with leucoxene and they are full of dots and strings of magnetite partially converted into ferric oxide. Fluxion-structure is pronounced. In some cases the dots of iron have been removed by aqueous agencies, giving the slice a pseudo-vesicular character. The Housel-Cove rock contains more iron than the Landewednack specimen, and so has a slightly higher specific gravity, viz. 2.62.

VII. SOME FRAGMENTARY INCLUSIONS.

(1) Fragment (about 3" in diameter) included in dioritic rock (Granulitic Group), Kennack Cove. The rock resembles a hornblendic gabbro. It is very slightly streaky in structure. Under the microscope it is found to consist of plagioclase felspar almost replaced by the usual filmy decomposition-products, of aggregated green hornblende, usually in rather small, rudely shaped prisms, some grains of brownish iron oxide, and a fair amount of sphene and apatite. The gabbro-like rock on the south side of Porthoustock Cove, it may be noted, also contains these two minerals, which, so far as we have seen, are rare in, if not absent from, the ordinary gabbro (that intrusive in the serpentine).

(2) From a slab-like fragment, a few yards long and less than

a foot thick, included in the great mass of gabbro near Carrick Luz. This was shown to one of us in 1886 by Mr. Teall. The rock is of a pale pinkish red colour and looks like a felstone or microgranulite, being much more fine-grained than either the granitic rock of the granulite, or the granite which is intrusive elsewhere in the serpentine. Under the microscope it exhibits a microcrystalline structure, the quartz and felspar (rather decomposed) forming a mosaic of rather polygonal grains; but there are one or two larger grains of felspar with an irregular outline indicative of a porphyritic structure, and in one or two instances the grains of this mineral are arranged in short "streaks." There is some little iron oxide, a flake or two of colourless mica, and a grain or two of (?) zircon. The evidence as to the relation of this rock to the gabbro is not decisive, but appearances, macroscopic and microscopic, favour the idea of its being an included fragment.

(3) A fragment of slaty rock of a pale greenish grey colour, somewhat splintery in shape, in the same mass of gabbro on the west side of the headland. The line of demarcation between it and the gabbro is sharp, and it is obviously not a concretionary patch. The slaty fragment is perfectly compact*. It has a sp. gr. of 2.90, a hardness of 5 to 5.5, and it fuses very readily with intumescence to a dark brown coloured glass which is not magnetic. It is partially soluble in hot hydrochloric acid, and still more so in hot sulphuric acid, the solutions yielding lime, magnesia, alumina, and a little iron. The residue was readily soluble in hot hydrofluoric acid.

A thin slice of the slaty inclusion examined under the microscope is seen to consist of a colourless hornblende, profusely dotted over with granules of sphene. The hornblende, being without colour, does not exhibit any pleochroism. The refraction-index is normal, judged by the relief and the well-marked character of the outlines; but the double refraction, indicated by the colours in polarized light, is unusually weak. The mineral is closely packed together in small lath-shaped, irregular club-shaped, and in idiomorphic prisms; here and there it is somewhat platy, or even leafy, in form. A cleavage, running with the length of the prism, is often well developed; but occasionally the prism is divided by a single transverse cleavage. One well-developed idiomorphic prism gives the typical prismatic cleavages intersecting each other at angles varying from 123° to 125°. Extinction, measured from a single cleavage, ranges from 13° to 19°, and averages 16°. Cross-sections exhibit an optic axis in polarized light inclined to the plane of the section, and prisms and sections showing a single cleavage have the major axis of elasticity at an angle of about 74° to the plane of cleavage on the side of the prism. The whole of the groundmass appears to be composed of this lime-magnesia-alumina hornblende, very poor in iron.

Hornblende, as is well known, when melted under the conditions which obtain in a laboratory, consolidates in the form of augite—never as hornblende; and the existence of augite crystals surrounded

* Examined by Gen. M Mahon.

by secondary hornblende in igneous rocks would seem to indicate that, in *some cases* at all events, partial refusion near the earth's surface may account for the formation of such an amphibolite. Hence one observer* has remarked:—"Where the composition of both minerals [viz. augite and hornblende] is identical, temperature alone is sufficient to determine which crystalline form is assumed." Without wishing to dogmatize on a matter regarding which our information is at present imperfect, the authors think that the slaty inclusion affords good *prima facie* evidence that the gabbro, after it caught up the fragment of slate, was never in a highly heated condition.

VIII. SUMMARY OF RESULTS.

The chief results of the investigations described in this paper may be briefly summed up under the following heads:—

(1) That the Hornblendic and Granulitic Groups, whatever their genesis may have been, were substantially in their present condition at the time when the rock, which is now a serpentine, was intruded.

(2) That this rock was formerly some variety of peridotite—dunite, saxonite, lherzolite, &c., occasionally a picrite†; that the foliated or banded structure, which is perceptible in it in certain districts, does not result from pressure posterior to solidification of the rock-mass, but from movements in it while it was still in a molten or partially molten condition.

(3) That the foliated or banded structure sometimes present in the gabbro does not result from pressure subsequent to the solidification of the rock, but it also is a kind of fluxional structure, due probably to movements when the rock was in a condition of rather imperfect fluidity, and consisted of a mixture of crystals and of a magma more or less viscid.

(4) That the Granulitic Group consists of at least two distinct rocks, one acid, the other basic, of which the former was intrusive in the latter, but that, either in consequence of this or from some other cause, the temperature of the whole mass became sufficiently elevated in certain localities to allow of movements as in the last-mentioned cases, which have produced the remarkably uniform and stratified aspect of the two varieties; this movement being followed by crystallization, or completion of crystallization, in the constituents.

(5) That the Hornblendic Group consists in part of igneous rocks; that it may be indebted for its structure partly to movements anterior to consolidation, partly to pressures of later date, but that it is difficult to explain all the phenomena either by the one or the other cause, so that at present the possibility of some portions having resulted from the alteration of a stratified basic ash must not be left out of sight.

* G. H. Williams on Baltimore Gabbros and Diorites, Bull. U.S. Geol. Surv. vol. iv. (1886) p. 46.

† Viz. an augite-olivine or hornblende-olivine rock, in which a small and rather variable proportion of felspar or an aluminous silicate is present.

(6) That earth-movements have produced marked effects only at the extreme north and the extreme south of the district; these, in the former, modify the rocks for a very limited distance from the boundary faults. In the latter the results appear to be on a somewhat greater scale. To this cause we attribute the "slatiness" characteristic of the so-called Micaceous Group. Probably the latter rocks are separated from the coarse gneisses of the outlying islands on the south coast by a fault of low hade towards the north, which emerges near the base of the present cliffs.

EXPLANATION OF PLATE XVI.

Fragment of banded serpentine (natural size) picked up at foot of cliffs, Porthalla (p. 474). C is a joint-face, from which cracks, now closed by light-coloured steatite, run for some little distance into the mass. Below AB is a similar structure which, together with the change in the character of the serpentine, suggests the possibility of one variety being intrusive into the other. It may, however, only be another old joint-plane now closed. This structure is described in *Quart. Journ. Geol. Soc.* vol. xxxix. (1883) p. 22.

DISCUSSION.

Mr. TEALL said that he had no general theory as to the relations of the Lizard rocks. The views of the Authors as to the origin of the Granulitic Group were not opposed to those which he had expressed. They went farther than he had done, and maintained that the deformation was connected with the intrusion of the granite. There was a difference between him and the Authors as to the origin of the foliation in the gabbro; but, as he had no new facts to offer, he did not wish to reiterate or to retract his opinions on this subject.

The Rev. EDWIN HILL had accompanied the Authors with preconceived opinions that the Granulitic Group had something sedimentary in it, and that the gabbro-banding had something to do with cooling at the surfaces of the intrusive masses. But he had been constrained to admit that the granulitic banding was due to injection by one rock into another. This other possibly had a pre-existing structure sufficient to determine the lines of injection; but it was not necessary to assume such. So with the banded gabbro, the evidence for the Authors' conclusions seemed complete. Though "convinced against his will," he did not remain "of the same opinion still."

Prof. HULL wished to call attention to the remarkable resemblance between some of the geological phenomena described so lucidly by the Authors of the paper and those of some parts of Ireland, particularly in the Connemara and Donegal highlands. This resemblance might be recognized in the cases of inosculation of granitoid with hornblendic masses, and the presence of serpentine breaking through in dyke-like manner the older rocks. In Connemara there were two varieties of serpentine: first, the dense, heavy, dark green variety, which was, in all probability, a transformed augitic or



BANDED SERPENTINE FROM PORTHALLA.

olivine rock, of igneous origin; and, secondly, the opicalcite, consisting of calcite and serpentine intermixed and generally banded. He was glad that the Authors maintained the original igneous origin of the Cornish serpentine, which most resembled the former variety in the West of Ireland. With regard to the banding of the dykes of gabbro where they were in contact with the walls, he observed that this was a structure not uncommon amongst dykes of igneous rock, and he believed it to have originated during the cooling process. These bands were, in fact, planes of cooling, and the structure of the rock along the walls of the dyke contrasted with the central portions, where the cooling process was slower, and allowed the formation of a more crystalline rock in which these planes were absent.

The PRESIDENT remarked that the questions discussed in the paper had far more than a mere local interest. In particular, the problem of the banded structures among crystalline schists touched some of the profoundest difficulties of the theory of metamorphism. There was ground, he thought, for believing that mechanical deformation had been rather too freely appealed to as an explanation of the general banded and schistose structures of the older rocks. This cause had unquestionably been largely instrumental in the production of such structures; but, as he had stated in his Anniversary Address, there were features of the more ancient gneisses which it was hard to imagine could be due to anything else than some original variations in the arrangement of the materials of the rock before solidification. He had been much struck with the extraordinary way in which some of the Tertiary gabbros of Skye simulate the rudely-parallel wavy lenticular banding of different materials in many gneisses; and he thought it was rather among such examples of flow-structure in eruptive rocks that the analogies of some of the structures of the gneisses were to be sought. The Authors had, therefore, in his opinion, done a service in recalling the attention of geologists to this view of the subject.

General McMAHON said that, as those who had taken part in the debate appeared to agree generally with the conclusions arrived at by the Authors, he would confine himself to calling special attention to one of the specimens exhibited, and to a brief description of a section which he thought had an important bearing on the subject under discussion.

Prof. BONNEY stated that the theory suggested by Prof. Hull had been, in substance, formerly held by himself, but that he had found cases for which it did not suffice. The case quoted by the President was of great interest, and he might add that since the paper was written he (the speaker) had seen others. He could not sit down without testifying to the value of Mr. Teall's work at the Lizard, and begged the Society to remember that General McMahon was the originator of the right idea (as the speaker believed it to be) as to the foliation of the gabbro.