3. *The SERPENTINE, GNEISSOID, and HORNBLENDE ROCKS of the LIZARD DISTRICT.* By T. G. BONNEY, D.Sc., LL.D., F.R.S., F.G.S., Professor of Geology in University College, London, and Fellow of St. John's College, Cambridge. (Read November 6th, 1895.)

[PLATE I.]

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I. INTRODUCTORY.

IN 1891 a communication on the rocks of the Lizard from General McMahon and myself was honoured with a place in the Society's Journal.¹ As therein stated, we were of opinion, at the time of our visit to Cornwall (August, 1890), that to regard the banded members of 'the hornblendic group' as stratified basic tuffs, subsequently metamorphosed, was 'the better working hypothesis.'² But, even in that interval, as will be seen by a note appended to the paper,³ some doubts as to the correctness of this conclusion had already arisen in my mind, for a visit to Sark in the spring of 1891 had suggested explanations of certain difficulties which hitherto had seemed insuperable in an alternative hypothesis. Accordingly I became anxious to see how the old puzzles looked in the new light, and besides this a very important paper by my friends Messrs. Howard Fox and J. J. H. Teall,⁴ subsequently published in this Journal, made it a necessity for me to study the sections of which they had given so lucid a description. For, if their interpretation of these were correct, the geology of the crystalline rocks of the Lizard peninsula would be thrown (as it seemed to me) into hopeless confusion. The authors, indeed, restricted their conclusions to the sections which they had described; but it appeared to me, for reasons which will be given hereafter, that no such limitation was possible, and that if they were right I must have misinterpreted the evidence in other localities. I felt, indeed, so much confidence in the general

¹ Quart. Journ. Geol. Soc. vol. xlvii. (1891) p. 464.

² *Op. cit.* p. 480.

³ *Op. cit.* p. 479.

⁴ Quart. Journ. Geol. Soc. vol. xlix. (1893) p. 199.

accuracy of my observations that under ordinary circumstances I should have deemed it needless to revisit the district; but when two such critics, the one so keen an observer, the other so skilled a petrologist, both entered the lists against me, though in the most friendly contest, I felt compelled to take the first opportunity of revising my work. This was done in the summer of 1894. Other engagements unfortunately prevented Gen. McMahon from giving me the pleasure and the benefit of his company, but I had the great advantage of the society and co-operation of the Rev. E. Hill, with whom I have so often worked in this and other regions, and to whom I tender my best thanks for constant aid. [He has kindly read a proof of this paper, and requests me to say (as I do most gladly) that he can confirm all the statements as to what was seen in the field.]

Going first to St. Keverne, we succeeded, as we hope, in clearing up a minor difficulty, which our former visit had failed to solve, and we reviewed the hornblende-schists of this neighbourhood. Then, in a fortnight's hard work, from Lizard Town as a centre, we carefully studied all the sections, as far as Mullion Cove on the west and Kennack Cove on the east, which seemed likely to throw light on the problems specially before us: namely, the genesis of the hornblende-schists and of the so-called 'granulitic group,' and the relations of these rocks to the serpentine and to certain other rocks of igneous origin, but less altered than it. The former problem need not be discussed at any great length, though we accumulated a large number of observations, bearing upon it. The latter one in reality involves the whole question of the relations of the crystalline rocks in the Lizard district, and so demands a rather full treatment.

II. THE GENESIS OF THE HORNBLLENDE-SCHISTS.

It will suffice to refer to former papers for descriptions of the petrography of this interesting group. As to the facts, I believe that Messrs. Fox and Teall, Gen. McMahon, and myself are practically in accord.¹ From the neighbourhood of the lighthouses near Lizard Town to Pollurian Cove on the west (a distance in a straight line of about 5 miles) and to Porthallow Cove² on the east (9½ miles), this group, whenever it appears, exhibits substantially the same characteristics. It varies from a dark rock, more or less speckled with white, sometimes so little foliated as to be barely distinguishable from a diorite, occasionally even retaining slight indications of an ophitic or of a porphyritic structure, to one which is clearly foliated and sometimes well banded: dark hornblendic layers alternating with those of a whitish or of a yellow-green colour, the former being rich in feldspar, the latter in epidote. The more banded varieties occasionally exhibit a structure which curiously resembles

¹ Quart. Journ. Geol. Soc. vol. xxxix. (1883) p. 1, vol. xlv. (1888) p. 309, vol. xlv. (1889) p. 519, vol. xlvii. (1891) p. 464.

² I adopt the spelling of the 6-inch Ordnance map; formerly it was Porthalla, as in previous papers.

false or current-bedding.¹ This, as stated in our paper of 1891, was difficult to explain on any other hypothesis than that of an original stratification, which also accorded very well with the aspect of the banded rock. Doubts, however, as mentioned in the paper on Sark by Mr. Hill and myself,² had arisen as to the validity of these difficulties, and proof had been obtained that distinct mineral banding might occur in a true igneous rock of like composition,³ so that the whole question was investigated *de novo*. Three localities appeared to supply evidence of special importance, which I shall endeavour to describe.

(a) Inclusions in the Hornblende-schist at Porthoustock Cove.

The hornblende-schist on the northern side of this cove is sometimes very dark in colour, sometimes rather conspicuously streaked or banded with felspar: the more homogeneous and the more banded rock alternating twice or thrice, in a vertical space of about as many yards. Sometimes fairly well-formed crystals of white felspar occur porphyritically in the dark rock, up to about $\frac{1}{2}$ inch long, sometimes the rock becomes coarser and recalls the structure of a hornblende gabbro. Now and then⁴ the latter rock forms a kind of 'eye' in the normal banded schists and presents a structure resembling current-bedding (fig. 1). But rather towards the western

Fig. 1.—One of four 'eyes,' consisting of a coarse, gabbro-like material in the normal hornblende-schist. (North of Porthoustock Cove.)

end of the Cove we found an inclusion of nearly pure, rather coarsely crystallized hornblende. It is about 6 or 7 inches thick in the part drawn (fig. 2, p. 20): the ordinary hornblende-schist bending round it, as indicated, but it 'trails out' to the right and, interruptedly (there are two layers), to the left. In this direction, at about the same level, are two or three similar but smaller inclusions. A slice from the largest inclusion⁵ shows it to consist almost entirely

¹ Quart. Journ. Geol. Soc. vol. xxxix. (1883) p. 4; see pl. i. fig. 2.

² *Ibid.* vol. xlviii. (1892) p. 122.

³ *Op. cit.* pp. 134-138, cf. p. 124.

⁴ I saw about four instances—varieties of linear streaking were countless.

⁵ The specific gravity of the specimen, as determined with a Walker's balance, is 3.124; the mean of two specimens of fairly normal hornblende-schist is 2.748. I am indebted to Miss Raisin for these and other determinations in this paper. To ensure accuracy, each of us read the balance.

of a dull green, rather strongly pleochroic hornblende, in somewhat irregularly-formed crystals, commonly much speckled with minute and elongated specks of iron oxide. Some larger granules of the latter mineral occur, with a little rutile and possibly pseudobrookite. Besides, there are a few isolated grains or granular patches of a clear

Fig. 2.—*Eye of hornblendite, included in banded hornblende-schist.*
(Northern side of Porthoustock Cove.)

a = banded hornblende-schist.
b = coarsely crystallized hornblende.

mineral: this has rather a high refractive index and low polarization-tints for a felspar, an extinction, I think, oblique (it is difficult to get any line from which to measure), and it may perhaps be a colourless epidote. These inclusions, though on a much smaller scale, recall to mind those which we found so common in Sark.¹

(b) Inclusions in the Hornblende-schist south of Kilcobben Cove.

Here also the rock is frequently streaked, and instances of resemblances to current-bedding are by no means rare. Near to the northern side of the promontory we found long lenticular masses of rather coarse hornblendic rock, such as is described above, lying with their flat sides roughly parallel with the dominant banded structure. They are seldom more than 2 or 3 inches thick, but are sometimes 2 or 3 feet long and almost as wide.² From this size they may be found down to little patches, almost streaks.

(c) Quarry on the descent to Mullion Cove.

This quarry, noticed in the paper of 1891,³ was in a better condition for study at the time of our visit in 1894. The rock here is generally coarser in structure than any other mass known to us in the Lizard peninsula. Most of it shows a banded structure, which,

¹ Quart. Journ. Geol. Soc. vol. xlviii. (1892), p. 128, etc.; see also vol. xliii. (1887) p. 324.

² In a slice from one of these I find nothing but hornblende, like that described above, and a little iron oxide. But the rock was very difficult to cut, and the slice is a rather thick one.

³ *Op. jam cit.*, p. 479.

however, here and there disappears, for it passes into a 'spotty' one. But the general condition of comparatively coarse crystallization is replaced, locally and rapidly, by a finer one; the latter exactly resembling the normal hornblende-schist, whether banded or 'dioritic,' which occurs elsewhere at the Lizard. Fine-banded and coarse-banded portions may be seen, one within a foot of the other. Of the latter variety, bands, quite $\frac{1}{4}$ inch thick, consisting almost wholly of felspar, can be traced frequently for more than a foot in length; bands also, both light and dark, sometimes quite $\frac{1}{2}$ inch thick and occasionally more, run continuously for 8 or 9 inches at least. One part of the rock presented a curious resemblance to false bedding, but a closer examination showed that this might be equally well produced by a shearing movement in the mass. In another place the bands were overfolded, and appeared to have become displaced by a 'strain-slip' movement. The latter, no doubt, might be produced after the solidification of the rock, but the general appearance of the former structure and the absence of divisional planes suggested that it was due to a sliding movement, while the mass was still more or less viscid, so that the ruptured surfaces had become cemented during the last stage of crystallization. The irregular and sporadic passage from the banded to the spotty condition also seemed difficult to explain if the former were due to an original stratification of clastic materials, but seemed easily explicable on the hypothesis that movements had taken place in a magma, after some constituents had separated, but anterior to the complete crystallization of the mass; this had caused the ordinary 'granitic' structure of a holocrystalline rock to be replaced in many parts by a banded one.

It has, however, been suggested that these linear structures are due to a yielding—more or less local—in a coarse holocrystalline rock when subjected to pressure. Apart from considerations which I have elsewhere noticed,¹ I had this hypothesis always before my mind and found it inapplicable as a general explanation, though I should admit the possibility of its accounting for a certain 'slabbi-ness' occasionally perceptible.² The effects of dynamo-metamorphic processes, in the ordinary sense of that long word, can be studied at the extreme south and in a more limited area at Porthallow, as described in our former paper, and the conclusions then formed were strengthened on the present occasion by tracing, especially in the first-named district, the gradual change from the normal hornblende-schist to the pressure-modified 'green schist.' If then the ordinary banded hornblende-schist of the Lizard owes its structure to 'dynamo-metamorphism,' recrystallization must have subsequently occurred to such an extent as to destroy every characteristic of that process. To concede this, I may observe by the way, would be fatal to every attempt to implicate the schist and the serpentine in an 'igneous complex,' for the latter rock, as a rule, exhibits no sign of

¹ Quart. Journ. Geol. Soc. vol. xlix. (1893) p. 94, and vol. l. (1894) p. 279.

² But, even if this be due to a very slight shearing, its parallelism with the banded structure and consequent low hade (universal features, so far as I know) are by no means easy to explain.

crushing or of recomposition, whether as serpentine or as peridotite. The breadth and persistency of the bands in this hornblende-schist, as I have more than once pointed out in similar cases, are further difficulties in the dynamo-metamorphic hypothesis. In order to obtain by crushing bands such as those described above, the original rock would have had to be almost incredibly coarse; yet such bands are not infrequent both at the Lizard and in Sark.

As regards the 'stratification' hypothesis which I formerly accepted, I may mention a difficulty, the gravity of which has increased with my experience. If the rock originally were a basic tuff (and no other materials would give us the appropriate chemical composition), the conditions of deposit must have been very exceptional. Undoubtedly, beds of fine-grained ash occasionally exhibit great regularity of structure, but commonly this is speedily interrupted by the setting in of coarse material, the rock becoming 'knubbly' if not agglomeratic. But these hornblende-schists are singularly free from blotching or irregular spotting¹; the bands of different mineral composition alternate just as the arenaceous and argillaceous layers at Morlaix in Brittany or Port Erin in the Isle of Man. This difficulty might, indeed, be eluded by supposing the materials to have undergone metamorphism so extreme as to dissociate the constituents of the bits of tachylite and the lumps of scoria, and that to have been followed by an orderly process of segregation somewhat analogous to what occurs in the formation of flint, converting ultimately the rather heterogeneous materials into fairly uniform mixtures of minerals not at all minute. This hypothesis, however, though obviously a possible one, obliges us, as I feel more and more strongly, to assume conditions which are so exceptional that they can hardly have prevailed over such large areas. Hence I am forced to adopt the other hypothesis.²

III. THE GENESIS OF THE 'GRANULITIC GROUP.'

On this subject fewer words are needed. I may content myself with saying that the result of this visit has been to strengthen my confidence in the correctness of the explanation adopted in our last paper,³ namely, that these banded rocks have been produced, as probably most banded gneisses have been produced, by fluxional movements in a heterogeneous magma; the cause of heterogeneity in this case being, as in the one described in Sark,⁴ the intrusion of an acid into a more basic rock, by which the latter has been

¹ The nearest approach to this is the case near Mullion Cove, described above, and even here there is nothing resembling the irregularity which is usual in volcanic ashes.

² It also accords better with that which is now generally adopted for the granulitic group. This is supposed to be almost in the condition which it assumed on consolidation; but its darker member is sometimes not very different from corresponding parts of the hornblende-schist, so that one can hardly assume the two rocks to have had totally diverse origins.

³ *Op. cit.* vol. xlvii. (1891) p. 477.

⁴ *Op. cit.* vol. xlviii. (1892) p. 132.

softened, drawn out, and even locally melted down and absorbed by the former. One section, which I found on the southern side of Kennack Cove, so well illustrates this process that it deserves, perhaps, a brief description. A light-greyish granite is intrusive into a dark dioritic rock, which it has shattered into a breccia, but in places one can see that the latter is locally melted by and incorporated with the former, the result being a regular, rather fine-grained, streaked or banded gneiss.¹ I obtained specimens of all three rocks and have examined them under the microscope. The granite consists mainly of quartz and felspar, with a rather small amount of biotite (somewhat bleached).² The structure is granular, only one or two of the larger felspars showing any approach to a crystal-outline, and the grains differ much in size. It exhibits the association of this mineral and the quartz to which I have often called attention as more characteristic of a gneiss than a normal granite,³ with a very slight approach to a linear order in the constituents. The dioritic rock consists of felspar, rather decomposed, apparently plagioclasic, green hornblende, biotite (not much, and rather sporadic), with a little sphene, etc. The structure is granular, with occasionally an approach to ophitic, and felspars, 4 or 5 times the diameter of the rest, occur sparsely. The banded gneiss has a general resemblance in structure to the granite, except that its felspars are even more variable in form and size, the linear ordering of the constituents is more marked, and grains with micropegmatitic structure, which are rare in the other rock, are common here; apatite is more conspicuous and two or three very small garnets occur; there is a considerable amount of a rich brown biotite, but hornblende is absent; at least I do not find a single scrap (there are a few green flakes) that I can identify with certainty. On the significance of this I have already written.⁴

Additional evidence, however, was obtained in regard to one point of interest. I have always believed the granulitic group to overlie the hornblendic, though I felt that the evidence in favour of this was not very strong. The latter rock usually occurs in great continuous masses, the former in more or less interrupted blocks, which, though they may be sometimes traced with but little interruption for considerable distances, are associated (always so far as I remember) with the serpentine, and occur in such a manner as to give the impression that they are fragments of a mass which it has shattered, and in some cases actually transported. In one place, however, in the crags on the south side of Cadgwith Cove, as mentioned in our former paper,⁵ the granulitic rock appeared to be superposed on the hornblendic schist. On the last occasion, favoured

¹ The specific gravity of the granitic rock is 2.611, of the dioritic 2.917, of the banded gneiss 2.628: intermediate, but, as we might expect from its appearance, nearer to the first.

² In these descriptions and throughout the paper, minor details of composition and structure are suppressed, as being without significance for my main purpose.

³ Quart. Journ. Geol. Soc. vol. xxxvi. (1880) p. 97, etc.

⁴ *Ibid.* vol. xlviii. (1892) p. 132.

⁵ *Ibid.* vol. xlvii. (1891) p. 478.

by a calm day, we closely examined, from a boat, the whole line of cliffs from Church Cove to Cadgwith. We found that, after passing the huge mass of hornblende-schist which forms the crags of Carnbarrow and the gloomy portal of Dolor Hugo, the rock, on approaching the archway leading into the 'Frying Pan,' continues, for some distance above the sea-level, to be a true hornblende-schist, but that there are, in the upper part of the cliff, several reddish granitic veins, the direction of which appears to have a rough correspondence with the structure of the former rock, while the cliff above these assumes a more 'granulitic' aspect. On the southern side of the entrance to the 'Frying Pan,' a fault, or group of faults, brings serpentine and typical 'granulite' against hornblende-schist. But, immediately beyond the archway, the headland between it and Cadgwith Cove presents the following section. The upper part of the cliff, beyond all question, consists of the granulitic rock; while the lower part, at the south-eastern corner, for a considerable height above the sea, is no less typical hornblende-schist. The two rocks gently descend in a northerly direction until, near the north-eastern angle, the hornblende-schist gradually disappears beneath the water and the mainland crags consist wholly of typical banded granulite; though even here the hornblende-schist still appears in some skerries very near to the shore. Passing round into the cove, we find that its southern side, as we formerly stated, consists mainly of the 'granulitic group,' but that near the water's edge the rock generally is a hornblende-schist.¹ No sharp line can be drawn between the two groups, but between the well-banded and thoroughly typical representatives of each there is usually a zone from 7 to 10 yards in thickness, rather neutral in character: veins of a reddish granitic rock, breaking, on the whole in a horizontal direction, through a dark rock which now and then resembles the basic member of the granulitic group more closely than the dark part of the hornblende-schist.

Obviously, if both these groups are igneous in origin, this superposition cannot count for much. It may, however, have the significance, that, on the assumption of the hornblendic rock being the earlier extrusion, the upper part of its mass would offer less resistance under ordinary circumstances to the passage of an intruder. Hence the phenomenon may have a bathymetric significance, if it has no other.

IV. RELATIONS OF THE SERPENTINE TO THE 'GRANULITE' AND TO THE HORNBLLENDE-SCHISTS.

Before discussing the group of sections near Ogo-dour and east of the Lion Rock, from which my friends have drawn certain conclusions,² I must make a few remarks upon the general principle, which, as it appears to me, is implied, if not actually enunciated in

¹ It is regularly banded, the white felspar and dark hornblende showing a hypophitic structure, and differs only from the most normal hornblende-schists in becoming here and there slightly micaceous.

² Quart. Journ. Geol. Soc. vol. xlix. (1893) p. 210.

their paper.¹ It amounts to this: that in an extensive district, where the rocks exhibit many difficulties and complications, each section or limited group of sections can be regarded by itself and be made the basis of induction, independently of all the others. But here, unless I mistake, lurks a fallacy, the nature of which will be readily perceived by considering a particular instance as an illustration. Suppose the question to be whether an igneous rock is intrusive into or contemporaneous with a group of sedimentaries. Suppose, further, that in 11 out of 12 sections the evidence is inconclusive, but that the remaining one gives a decisive answer on the one side or the other. Then there would be no room for further doubt. The uncertainties of the eleven would count for nothing against the positive evidence of the one section. Suppose, however, that, of the 12 sections, the evidence of four or five is rather more favourable to one conclusion; that of two makes any other highly improbable, while that of one appears to accord better with the contrary conclusion; and the remainder give no answer at all. We cannot regard the testimony of this one unfavourable witness, as if the others were non-existent. Certainly no judge, probably no jury, would act upon such a principle. The apparent conflict of evidence undoubtedly calls for a careful cross-examination of each witness, but in such a case as we have mentioned it is surely far more probable that the one section should have been misunderstood than that a contradiction should exist. The more specious interpretation does not always turn out to be the true one, and we must proceed in our attempts to learn the secrets of Nature as men who are seeking to decipher inscriptions, where the language is dead and the characters are obsolete.

It may be said, however, that the ordinary laws of inductive reasoning do not apply to this particular case, because we are dealing with an 'igneous complex.' The term undoubtedly is an attractive one; there is a certain mystery about it, but there is also, as in all mysteries, a certain vagueness. 'Complex' means a tangle, and thus is a term which fails to explain anything; to fall back upon it, is a confession of defeat and an admission that when Nature plays the Sphinx we decline to take the part of Œdipus. In the case before us, however, the authors' meaning may be inferred from certain conclusions which they have formulated.² These, briefly stated, amount to this: that in the cliff and on the adjoining shore, east of the Lion Rock, the serpentine is traversed by basic dykes, which pass locally into hornblende-schist, and besides this put on, in the thicker portions, appearances which are characteristic of the 'granulitic group'; also that there is a wedge-shaped mass of this granulitic rock, which exhibits a structure incompatible with the hypothesis that the serpentine was intruded after the mass itself became solid.

In regard to these conclusions, I may venture at the outset to make the old comment *Dolus latet in generalibus*. (a) 'The dykes pass locally into hornblende-schist.' Yes, but into what horn-

Op. cit. p. 200.

² *Ibid.* p. 210.

blende-schist? Is it the same as the rock which forms the great cliffs of Carnbarrow and Hot Point, of Housel Bay, and Predannack Head, not to mention other places? By no means, I should say. True, the dominant minerals are the same in both, and these dykes exhibit locally a trace of foliation. That is also true of other dykes in this region¹; nevertheless, the hornblende-schist proper, as a rule, is a very different rock, even macroscopically. It is commonly more or less banded, almost always distinctly 'linear' in structure; only rarely and only very locally would there be any difficulty in distinguishing the one from the other. I find that the same holds good of the microscopic structure of the two rocks; the differences can hardly be expressed in words, but as a rule they exist. What, then, does this prove? That sometimes, if we take two hand-specimens, carefully selected from two groups of rocks, differing in age and history, we may be unable to distinguish the one from the other, because neither presents characters upon which we can fasten for that purpose. We might as well affirm that the Greek and the Latin uncial alphabets belong to the same language because certain letters in the two are identical. Has any one of these dark pyroxenic dykes in the Lizard region exhibited such a banded structure as that which occurs again and again in the 'hornblendic' group? It would be, in my opinion, just as reasonable to contend that the hornblende-schist was only a modification of the gabbro,² because now and again, though very locally, resemblances can be detected; or that all the basalt dykes of Scotland were of one age, because it is not always easy to say whether a particular one belongs to the Palæozoic or to the Tertiary era. (b) 'The dykes near the Lion Rock, in their thicker parts, sometimes resemble the granulitic group.' To this we may reply in terms similar to those already used. Once or twice a dyke may be found to exhibit some rather irregular felspathic veins or seams. But this, so far as my experience goes, is not a very uncommon feature in districts such as the Lizard. The resemblance between the two rock-masses seems to me hardly closer than the notorious one between Monmouth and Macedon. I have found it difficult in other places to distinguish between veins of infiltration and of intrusion, yet this does not prevent me from believing that each really exists, and can be often identified. So that in this case also, while I grant that certain resemblances may be found, I deny that they are sufficient to warrant the conclusions which have been drawn from them.

(a) Relations of the Serpentine to the Granulitic Rock.

But I pass from generalities to particulars, and first to 'the wedge-shaped mass of typical granulitic rock.' There can be no question that this—like the great masses which crop up on the

¹ Quart. Journ. Geol. Soc. vol. xxxix. (1883) p. 6 (reference).

² If so, there should be no 'complex,' for the gabbro cuts the serpentine again and again.

shore some little distance to the south, belongs to the granulitic group. The drawing which my friends have given is substantially accurate¹; the inference also which they draw is correct, but only in an extremely limited sense—in other words, everything turns upon the exact meaning attached to the phrase ‘solid granulitic rock.’ Taking that mass as a whole, its darker bands indicate firstly, the formation of a banded or rather a streaky structure, and secondly the contortion of the same²; but, so far as I could see, no connexion exists between these structures as a whole and the external shape of the mass, and there is nothing to difference this block from those which occur, as I have said, to the south and so often on the eastern coast. The rock is only rather curiously contorted, but this structure is not

very uncommon in the granulitic group, and I was unable to see that any relation existed between either it or the shape of the mass and the serpentine, or to find evidence either that the granulitic rock was intrusive in the serpentine or that the two had been folded together, as the result of earth-movements while both were in a plastic condition. As is stated above, there are two large masses of the granulitic rock on the shore towards the south. These, however, are not wedge-shaped intrusions, but huge blocks; yet in places they exhibit contortions, which are hardly less pronounced than those in the other mass.³ The serpentine in their neighbourhood exhibits a slight foliation, which dips at a high angle to a point a little W. of W.N.W., but this neither makes the rock fissile, nor produces any marked effect on its microscopic structure, nor stands in any relation to that of the granulitic masses.

I accordingly claim a verdict of ‘not proven’ here, and pass on to other localities to see how far their evidence is ‘incompatible with the theory that the serpentine was intruded into solid granulitic rock.’ At the first glance it seems possible to explain the

Fig. 3.—*Projection from the granulitic mass included in serpentine. (East of the Lion Rock.)*

In all these diagrams the serpentine is dotted, and the fine lines indicate the more micaceous bands in the granulitic rock.

¹ *Op. cit.* p. 209, fig. 4. I venture to suggest two trifling emendations. At B the obtuse angle should be replaced by a blunt thumb-like projection (see fig. 3, above), and at D the serpentine occupies the wider, but not the narrower part of the inlet in the granulitic mass: the latter rock being practically continuous at a depth of 3 or 4 inches, as I could see in one place and feel with my fingers all along. To this point I shall return.

² These might be either successive stages in one process or separated by some considerable interval of time (as I incline to think).

³ In these, however, the ‘dioritic’ rock predominates, so that it is granitic (lighter-coloured) bands that wriggle about.

relation of these two rocks by one of four hypotheses: (a) that the two rocks have been brought together by faults; (b) that the two have been folded together; (c) that the two have flowed together; (d) that the serpentine is intrusive in the granulitic rock.¹

As the relations of the two rocks have been described in former papers, I shall not repeat what is already in print, but content myself with remarking that though I have again examined all these cases, I find no reason for altering my statements, and with describing very briefly a few other instances. As a preliminary, I venture to remind the reader that the granulitic rock commonly occurs as blocks, which sometimes appear to be completely included in the serpentine, but at others may be either projecting ridges or crags attached to much larger masses below or behind the visible surface. Where these exhibit a definite structure, this seems more or less to determine their outline, so that well-banded varieties are often fairly rectangular in shape; but as such a structure is not always present, considerable variety of form is possible. Though small slips and displacements are common in the serpentine, the faces of these blocks do not appear, as a rule, to correspond with faults; moreover, the two rocks occasionally, though not commonly, are welded together—in other words, the relations of the granulitic rock and the serpentine appear to me, as a rule, incompatible with the first or the second hypothesis. As for the third, it may be understood to mean either that the two rocks have been simultaneously emitted as parts of a magma already separated in accordance with Soret's or some other principle, or that the one material has been injected into the other, and has so completely softened it, if it were already solid, that the two have subsequently flowed on together. Now, the granulitic mass itself exhibits irregularities in structure and variations between the extremes of mineral composition, which accord well enough with the one or the other of these interpretations; but between it and the serpentine no transitional condition can be found, neither does it occur in lenticular or streak-like bands, such as the third hypothesis would lead us to expect, but in blocks; while the fourth hypothesis, as I trust will be perceived from the evidence which I am about to quote, accords better with the facts.

Time, however, may be saved by noticing at the outset a general objection which might not unreasonably be raised, namely that, if the serpentine be intrusive in the granulite, its relations to the latter are rather unusual. It has formed neither dykes nor branching veins in the 'granulite,' nor has it shattered that rock and caught up numerous small fragments. Yet all these are done by granite, diorite, gabbro, and other deep-seated rocks, as well as by their more compact representatives. The serpentine adopts the form, as those holocrystalline rocks often do, of irregularly-rounded bosses or somewhat elongated tongues, but it is not connected, as they very commonly are, with peripheral dykes and veins. This, however, appears to be the usual habit of peridotites and serpentines.

¹ I exclude that already mentioned, namely, that the granulite is the intruder, because, in the cases which I am about to mention, I cannot conceive the possibility of its being seriously entertained

I have probably examined in the field more of these rocks—especially the latter—than most geologists, yet I have never seen a branching vein, and only two or three dykes.¹ The mode in which this rock occurs generally suggests that it was extruded in a rather ‘pasty’ condition; sometimes also that the temperature was not very high.²

But though the serpentine does not send veins into the ‘granulite,’ its relations to that rock appear to me generally to suggest and sometimes to prove intrusion. Take, for example, this instance from Polbarrow Cove (fig. 4), where a fragment of serpentine about 14 inches long, 3 to 5 inches wide, and seemingly about 3 inches thick, still adheres to the granulite, which is particularly evenly-bedded (reddish grey with dark-coloured) for about half a yard above and a yard below. Some two or three yards behind the top of the craglet is another and longer mass of serpentine which appears to occur in a similar fashion. Or this

Fig. 4.—*Serpentine adhering to a ‘step’ of granulite, in Polbarrow Cove.*

case from the same cove (fig. 5), where the junction-surface is irregular, the granulite for a short distance is disturbed, and two or three small fragments of it occur in the serpentine. Or this one from Enys Head, where the serpentine seems to have forced open the granulite along the lines of banding, rumpling those in its immediate neighbourhood (fig. 6, p. 30). Or this other one from the same locality, where the junction-surface is

Fig. 5.—*Banded granulite (with fragments in serpentine), south of Poltesco Cove.*

puckered and squeezed up, while in one case (as shown in fig. 7, p. 30) the bands of the granulite are cut off by the serpentine. We found another, and a very marked instance of the same kind,

¹ I do not forget the case in Forfarshire described by Sir Charles Lyell, but I have not been in that part of Scotland.

² I may add that in districts where the rocks have undergone much mechanical disturbance, the junctions, as a rule, are spoiled. Serpentine is a brittle rock, and commonly yields to strains before its neighbours, so that a line of junction is generally a line of fracture, and often of complete ‘smash.’ This rule is almost universal in the Alps.

near the White Rock, a little above sea-level, and the projection with bent bands (fig. 8) occurred, like those above, in Polbarrow Cove.¹ I have, indeed, sketches and notes of not a few similar cases in my journal, but forbear to multiply like figures and statements. I must, however, once more refer² to the remarkable mass in the quarry at Kildown Point, which again has been most carefully studied. Before the excavation was made, it must have been wholly or almost wholly enclosed in the serpentine. That rock still rests in places on the top; it forms one or two small tongues between the bands of granulite, and a blunt lobe at the base of the southern side, where some of these bands are bent and intercepted. Yet in the immediate neighbourhood of this mass the serpentine does not show the slightest sign of crushing; it is in a perfectly normal condition, while that in the lobe, though rotten, exhibits a slightly streaked or foliated structure, which, however, makes a high angle with the horizon, though the bands in the granulite are inclined at a low angle to the same. But this is not all the evidence. Masses of granulite appear to crop out from the serpentine on the almost precipitous slope below the quarry. The descent of this would be so hazardous that I have never made the attempt; but this year I managed to land from a boat in a little cove at the base of the cliff. Here we find granulite

Fig. 6.—*Serpentine and banded granulite, Enys Head.*

Fig. 7.—*Serpentine and banded granulite, Enys Head.*

Fig. 8.—*Serpentine and banded granulite, Polbarrow Cove.*

¹ Compare also the projecting mass of granulite in the included mass east of the Lion Rock (fig. 3, p. 27), and note the outlines of the granulitic part and of the micaceous bands.

² Quart. Journ. Geol. Soc. vol. xlvii. (1891) p. 469; see also vol. xxxiii. (1877) p. 899.

forming the southern, and serpentine the northern side of the cove, and in the middle part a mass of granulite through which in more than one place serpentine 'breaks irregularly, exactly as it would break through a rather hard sedimentary rock, in places forcing back and crumpling up some of the bands.'¹ One mass of serpentine, of which I made rough sketches, was about 4 yards long and 2 wide. That also showed a slight foliation or fluxional structure, and this too was nearly at right angles to the bands in the granulite. All the way up the crags above this place we see outcrops both of the one rock and of the other.

I submit then, that these instances (and it would be easy to go on multiplying them) show that the serpentine is really intrusive in the 'granulite.' The former rock, however, must have been at this time only in a semi-fluid condition—viscid and tough—so that it was not able to do more than force its way occasionally along planes of weakness in the 'granulite' (blocks of which it often included and perhaps tore away), softening the latter rock locally and squeezing it about, though the effect which it produced generally extended only for a few inches away from the actual junction-surface.

(b) Relations of the Serpentine to the Hornblende-schists.

The best sections for studying these relations, so far as I know, are at 'Potstone Point,' on the cliffs north of Ogo-dour, and at Henscath, on the west coast; at Carnbarrow and in Porthallow Cove on the east. Except the first, these were well known to me, and of it I had a general knowledge. All, however, have been carefully examined. First, with regard to the Potstone Point sections, of which Messrs. Fox and Teall have given so admirable an account.² These lead, in their opinion, to sundry conclusions, of which I quote three,³ as the rest need no further discussion:—

'(1) The hornblende-schist and serpentine of the Ogo-dour district form together a banded complex of crystalline foliated rocks.

'(2) The relative ages of hornblende-schist and serpentine cannot be satisfactorily determined, but the occurrence of lenticles of serpentine in hornblende-schist points to the conclusion that, if there be any difference in age, the serpentine is the earlier.

'(3) The complex of schist and serpentine has been folded after the banding was produced, and before the dykes were intruded. Some, if not all, of this folding probably took place when the complex was formed.'

Of these the second and third alone are important, because without them the first, so far as I understand the word 'complex,' commits us to very little.

In this locality also the question between us is one of interpretation rather than of facts. I gladly avail myself of the opportunity

¹ Quoted from notes written on the spot.

² Quart. Journ. Geol. Soc. vol. xlix. (1893) p. 200.

³ *Ibid.* p. 210.

of expressing my admiration of the map published in Messrs. Fox and Teall's paper.¹ The making of it must have been no easy task, for the slope is very irregular, broken, and sometimes not the place for an unpractised climber. So accurate are both it and their description that I had no difficulty in following them step by step in going over the ground. This, then, is how I interpret the sections.

Nowhere in the serpentine can I find any of those symptoms, so familiar to me, which indicate that after solidification it has been subjected to severe mechanical disturbances (dynamo-metamorphism. The two cases, figured by my friends² (and the number of such is small), appeared to me due to a different cause. The intrusion of a hot viscid mass into one already solid suffices sometimes to bend either the latter locally or pieces of it which have been torn off.³ Here there is no sign of the two rocks being folded as solids.

Furthermore, here and there, the serpentine includes slabs of hornblende-schist of normal aspect, or the junction of the two rocks may be often seen (as will be presently described), to be perfectly welded and yet distinct. In one case (fig. 9) the serpentine runs up to the broken edges of a wedge-like projection of the hornblende-schist. In the latter rock the banding is regular, only a little rumpling and flexure being perceptible at two places, which are respectively 2 feet and 4 feet in a line from the point of the former rock, while the mass as a whole is not affected. The disturbance, in short, reminds one of the crumpling which might be produced by thrusting the thicker end of a flat paper-knife between the pages of a tightly-closed book. The serpentine in parts of this 'complex' appears to be sometimes impure and harder than it ought to be; often it is streaked like a brownish slag, while here and there a thin band can be discovered, which resembles hornblende-

Fig. 9.—*Banded hornblende-schist in serpentine, Potstone Point.*

The dotted rock represents serpentine, the lines indicate diagrammatically the banding of the hornblende-schist.

¹ Quart. Journ. Geol. Soc. vol. xlix. (1893) p. 203 (I had it with me as I worked). Once or twice I felt doubtful about the small faults, and should have made a slight change as to a dyke; but these are insignificant details, and I, not they, may be wrong.

² *Op. cit.* p. 212.

³ Which explains figs. 1 and 2, *op. cit.* p. 202. Under these circumstances the junction-surface of the two rocks might be 'wavy,' and 'for every tongue of serpentine into schist [there would be] . . . a corresponding tongue of schist into serpentine.' In such cases also the two rocks would probably exhibit a parallel foliation. This does not appear to have occurred to my friends, and I find no evidence that they minutely investigated the structure of the serpentine, in which, however, the key of the position is to be found.

schist, and seems to pass rapidly into the adjoining serpentine.¹ In the field I came to the conclusion that the latter rock had intruded into the former, occasionally breaking off pieces of it and even locally melting them, wholly or in part. Let us then see how far this conclusion is supported by study with the microscope. Taking first a slice cut from a specimen which showed (as I supposed) a junction of the serpentine and hornblende-schist, I find that the greater part consists of a serpentine (mineral) of a brownish or greenish-orange colour, exhibiting a structure which, if this were an acid rock, I should not hesitate to claim as fluxional. In this groundmass are scattered clear grains of a mineral without definite external form or any well-marked cleavage, which, however, I think may be identified as a hornblende, together with one crystal of a serpentinized bastite, including rods of a monoclinic pyroxene. Besides these are numerous granules, often aggregated, of a fairly translucent brown mineral; some, doubtless, are picotite, but others, which exhibit double refraction, are probably hæmatite. This part is succeeded by a streak rich in pyroxenic grains, many of them light brown in colour; and the latter rock (sometimes after an intervening film of the former one) changes to a band (slightly irregular in outline) consisting of felspar, in a very decomposed condition,² of hornblende, warm brown in colour, and of a moderate number of grains, which probably are a white augite, though the mineral is rather 'dirty' and sometimes serpentinized. This band is about $\frac{1}{2}$ inch wide, and the slice then is ended by a serpentine like that already described. But on examining the hand-specimen, this serpentine appears to be little more than a film, for in not more than one-fifth of an inch we find fairly normal hornblende-schist. Next let us take two specimens from a part of my friends' section³ near the porphyritic dyke. It is thus described in my notes:—'A curiously banded and streaked rock, exhibiting fine compact bands and coarser-looking brown bands, in parts much wrinkled and once or twice slightly brecciated, somewhat resembling serpentine, but rather harder than is usual with that rock. I have a strong suspicion that this is a mixture of serpentine and hornblende-schist, the latter being partly melted down by and carried along with the former.' Of one specimen, cut where the streaky structure is much curved, one would claim part, without hesitation, for hornblende-schist. It exhibits (Pl. I. fig. 5) the usual rather granular structure, and consists mainly of a felspar, somewhat decomposed, and hornblende, which, however, is brown instead of the ordinary strong green colour. In other parts (streaks) we find the grains of brown hornblende in a 'matrix' of composite microgranular

¹ I suppose, of course, that the serpentine was a peridotite at the time of the intrusion. This must be understood throughout.

² It is whitish by reflected light, earthy brown by transmitted, and shows specks of brightest colour with crossed nicols.

³ *Op. cit.* p. 203 (map). I think it is from the part *S* and *Sc* below the patch marked *e*. Whether this be the top of a 'dome' or not, I believe it to be an included mass, or, at any rate, to indicate intrusion on the part of the serpentine.

minerals; in others this 'matrix' is the orange-coloured serpentine already mentioned. Other streaks consist of this serpentine with rather small pyroxenic grains. All these varieties are associated in a slag-like fashion (Pl. I. fig. 6). A slice from another specimen, rather more serpentinous in aspect, exhibits a junction of two kinds of rock. One presents the general structure of a hornblende-schist, but the grains of that mineral are brown, while the others, instead of being felspar, are commonly a brownish-orange or greenish serpentinous mineral, which in some cases, when examined with crossed nicols, resembles a bastite, in others prove to be a granular aggregate. The other kind of rock exhibits a very marked fluxional structure in a matrix (if one may so call it) which seems to be composed of minute doubly-refracting minerals, and its bands are darkest when parallel with the vibration-planes of the crossed nicols. This is spotted with a brown hornblende, which occurs both in granules and in grains of the usual size, and the above-named structure is almost at right angles to a very slight parallel ordering of the grains in the other part (Pl. I. figs. 3 and 4).

This, however, is not all. Let us examine a piece of hornblende-schist which was included in the porphyritic dyke.¹ It is a fairly well-banded variety, thoroughly typical, except that it is a little duller or of a more 'greasy' aspect than is usual.² Under the microscope we find a rather marked difference between the bands. Those which are lighter coloured in the hand-specimen, and are spotted with white in reflected light, consist of a very decomposed felspathic mineral, and of pyroxenic minerals, some (the less numerous) brown hornblende, others a pale green rather fibrous hornblende, and yet others consisting of aggregates of minute minerals. In certain bands the brown hornblende dominates, and some felspar still remains, while in yet another band the granular structure has wholly disappeared, and the rock consists of numerous colourless flakes or prisms (about .02 inch long), which have the extinction of actinolite, and are set in a mass of smaller flakes, probably, in part at least, a white chlorite. Here then a specimen of hornblende-schist, once normal, which has been affected by 'contact-metamorphism,' unites the characteristics to which I have just called attention and those mentioned in our last paper,³ as belonging to supposed

¹ A specimen of this dyke, taken from close to the included hornblende-schist, has been examined with the microscope. In one part of the slide there are indications of mechanical disturbance. This, however, is almost certainly due to some accidental cause, such as a slight faulting, which escaped notice in the field; for the porphyritic felspars are uninjured, and the other parts exhibit a hypophitic structure. The felspar is generally decomposed, and the augite has been replaced by a dirty-looking secondary product, which shows a composite structure with crossed nicols. The rock is readily distinguishable from the hornblende-schist.

² Its specific gravity is 2.917, that of a speckled variety from S. of Kilcobben Cove 2.986, that of a banded (epidotic) variety from Church Cove 3.074. The specific gravity of the serpentine in this district is 2.730 (pit between Mullion and Lower Predannack) and 2.766. The specific gravity of two of the specimens of the streaky rock described above is 2.935 and 2.954. This is significant.

³ Quart. Journ. Geol. Soc. vol. xlvii. (1891) pp. 472-73.

cases of contact-metamorphism produced in hornblende-schist by serpentine.

But before quitting this subject I must again refer to the locality near Parc Bean Cove, north of Ogo-dour,¹ where I have already asserted the serpentine to exhibit true intrusive junctions. Again, perhaps for the fifth time, I studied this rocky slope with scrupulous care. Here the serpentine has forced itself in a rather irregular fashion through hornblende-schist, though it conforms on the whole to the banded structure in the latter rock, slabs of which appear occasionally to be broken off by and caught up in the serpentine.² In this part the serpentine, which is sometimes streaked, and in which the bands occasionally present some resemblance to hornblende-schist, is very rotten, but at a short distance the rock is in better condition. A few yards to the west of this complicated area,³ a gully exhibits the junction of the principal masses of serpentine and of hornblende-schist. Here, as shown in the annexed figure (10), a slab of hornblende-schist is separated from the main mass by a 'sill' of serpentine. This slab, where it was drawn, was about $3\frac{1}{2}$ inches thick, and it tapers away in a yard or so to less than $1\frac{1}{2}$ inch. That the hornblende-schist about here is the ordinary rock cannot be doubted; it exhibits both the 'dioritic' and the 'banded' varieties. The serpentine, generally more or less decomposed, is a little 'platy' in the direction of and parallel with the junction-surfaces, but this structure is in no way suggestive of crushing. The serpentine also is occasionally harder than is usual and looks impure. It is locally streaked, alternately warm brown and brown-black in colour. When the included hornblende-schist becomes very thin—say not more than an inch in thickness,—it is sometimes difficult to fix upon the exact line of junction, but where it is thicker, this is generally sharply defined, and the weld between the two rocks is perfect.

I have examined a specimen of this streaky serpentine (obtained from near a weld) under the microscope (Pl. I. fig. 1). The darker

Fig. 10.—*Gully north of Ogo-dour.*
Intercalation of serpentine and
hornblende-schist.

- I = Hornblende-schist (more or less
banded, as at x).
2 = Bottom of gully.
Serpentine dotted.

¹ Quart. Journ. Geol. Soc. vol. xxxix. (1883) p. 22, and vol. xlvii. (1891) p. 470 (with General M'Mahon).

² The bands occasionally are cut across by the serpentine.

³ It could only be accurately mapped on a very large scale-map, and the trouble of doing it would not be repaid by the result.

bands consist of a very pale green serpentine thickly speckled with opacite or streaked with clusters of the same substance; the lighter of the orange-coloured serpentinous mineral, mentioned above, of a colourless, but rather 'dirty' pyroxene,¹ and of barely translucent brown granules, in part at least iron oxides, more or less hydrous. In short, this rock in parts closely resembles the serpentinous portions of the Potstone Point specimen.² I have also examined a specimen of the hornblende-schist in contact with the serpentine. The fragment—from the face of the mass on the left hand of the figure—is about an inch thick. Beginning with the part farthest from the other rock, we find a band from $\frac{1}{4}$ to $\frac{3}{8}$ inch broad, which exhibits a granular structure like that of an ordinary hornblende-schist, the hornblende being roundish in outline and brown in colour, and the other grains composed of an 'earthy' material, no doubt replacing felspar, which, indeed, here and there can be recognized. A thin lighter-coloured band succeeds, still containing grains of brown hornblende, but with a more fibrous structure in the intervening material. This is followed by a generally similar layer, in which, however, the hornblende-grains are paler in colour, though, with the polarizer, they exhibit a brown pleochroism. In the remaining part of the slide (about $\frac{1}{2}$ inch) the brown colour of the hornblende-grains is less conspicuous, and they are sometimes embedded in a pale-green fibrous mineral. The interval, in short, between the grains everywhere appears to be a variable mixture of minute minerals, of a more or less fibrous habit, among which I think actinolite and serpentine may be recognized, and near the very edge, where the grains of hornblende become less frequent, are dull orange-coloured patches, perhaps only staining, and the rock becomes more definitely fibrous. Granules of iron oxide, as might be expected, occur here and there in the slice.

Another specimen, from a part of the adjacent hillside, where the serpentine appears to have forced its way between two slabs of hornblende-schist and to include a little streak of the latter, is very interesting. This streak is about an inch thick, and the slice has been cut through it (Pl. I. fig. 2). Beginning on one side we find a greenish, orange-coloured serpentinous mineral, in which are scattered more or less acicular microliths of a colourless hornblende. As these microliths increase in number, the former mineral is replaced by a more or less distinctly fibrous one, though the transition between the two kinds of rock is rather abrupt, as in the case of fluxional streaking; then comes a brownish hornblende, rather more granular in habit, associated with a colourless mica-like mineral, probably a chlorite. Lastly, the hornblende-grains, still generally composite in structure, but becoming larger and more definite, are parted by earthy spots like the residue of felspar, and from this

¹ Probably white hornblende, for the mineral occurs in all the serpentine of this neighbourhood.

² The specific gravity is 2.539, that of the Predannack serpentine, as already stated, being 2.766, but the difference is probably due to decomposition.

condition, as we approach the other edge of the slice, we pass back, speaking in general terms, through the conditions already described.

I have again examined the sections at Henscath, Carnbarrow, and in Porthallow Cove. As regards the first and second, I could fill a page with minute descriptions, but may content myself with saying that I found it impossible to explain what I saw, either by displacements due to earth-movements, or by the flowing together of differentiated magmas, or by anything else than the intrusive action of the serpentine on the hornblende-schist, after the latter had become solid. As for the Porthallow sections, it may suffice (except in regard to one interesting detail) to refer to what has been already published, and to copy the words which I wrote on the last occasion in my journal:—"Some of the cases here are inexplicable to me on any hypothesis other than that of an intrusion of the serpentine into the schist. It may be said that 'the two have flowed together,' but the serpentine sometimes cuts across the edges of bands in the other rock in a way which suggests direct fracture and not the result of a strain-slip. The serpentine may indeed sometimes bend with the bands, but that proves no more than that the schist (like the included fragments of gabbro near Manacle Point) has been somewhat softened and made flexible. The bending cannot be attributed to subsequent earth-movements, because the serpentine does not show the slightest sign of crushing, and the weld between the two rocks is often perfect."

But an examination of the specimens collected on this occasion has enabled me, as the result of the whole work, to clear up a difficulty which this Porthallow serpentine hitherto had presented. We find here and there in it, close to junctions with the hornblende-schist, grey bands, which are intermediate in aspect and hardness. Is this a less pure variety of serpentine, a streak of picrite, which, as indicated by the analysis, is present in the rock? and, if so, how can we explain its presence? I had hitherto vaguely referred it to some differentiation in the magma, but can now offer a more precise explanation, in accordance with the cases already described. I brought away a few specimens for further investigation. One of these, about $4\frac{1}{2}$ inches long, consists mostly of the ordinary Porthallow serpentine (a little redder in colour than usual); the remainder, a band about an inch thick, is of a greenish-grey colour, and this was in contact with, though here not welded to, a dark-grey, minutely speckled rock, which in hardness and general aspect agreed with a hornblende-schist. The latter, on examination with the microscope, exhibits traces of a banded structure; in some bands are residual grains of felspar, and with them grains of brown hornblende, but the greater part of the rock consists of flakes or longish prisms of actinolite in a felted mass of the same or of a colourless chlorite. The red part of the other specimen is a fairly normal serpentine (Porthallow type). It consists chiefly of the peculiar orange-coloured granular serpentine (mineral), often much stained with hæmatite, the latter also occurring in minute rods,

¹ See paper by Gen. M^cMahon and myself, *op. cit.* pp. 471-475, and table of analyses (facing p. 466).

and of small elongated prisms of colourless hornblende. It contains, however, a number of small 'inclusions,' consisting almost wholly of clustered ferrite, surrounded by a clear zone, not quite so broad as they, of actinolite; and two larger inclusions (?), much ferrite-stained, recall the structure of a fluxion-breccia. This part of the slice is separated from the grey band by a rather sharply defined border. The latter affords indications of a banded structure in the presence of ill-defined lines of brown hornblende-grains (not numerous), of felspar(?) grains, and (chiefly) of a felted mass of flaky or acicular actinolite, with which probably a colourless chlorite is also associated. These specimens, with that from Parc Bean Cove described above, lead me to the conclusion that their adjacent faces indicate the junction-surface of the two rocks, but that here also the outer part of the serpentine has been rendered impure by some superficial melting of the hornblende-schist.¹

The facts cited above, it may be worth while to repeat, seem to indicate that the brownness of the hornblende² is one indication of contact-metamorphism, while a more extreme result of the latter is the production of a rather fibrous, somewhat minute actinolitic hornblende and of sundry flaky minerals (representing the aluminous constituents of the rock), probably light-coloured chlorite or mica.

Here I may refer to a section which has been mentioned more than once in former papers,³ namely, that exhibited in a low crag at the foot of the main cliffs, north of Kynance Cove. On each visit I have spent some time in studying it, without, however, feeling much more certain as to its exact interpretation. As described on the first occasion, serpentine occurs on either side, and in the cliff above, the craglet in question, which exhibits, apparently in vertical bands, "(2) a mass of grey, rather sandy, 'hornblende-schist,' about 8 feet thick, with apparently many thin laminae of red serpentine; (3) red serpentine, rather fissile in structure, 2½ feet; (4) a dark brownish-grey rock with crystals rather resembling diallage, 2 feet; (5) red serpentine, 4½ feet, divided by a thin [rather wedge-shaped] band of the schist, then bedded schist like (2), with the apparent layers of serpentine, for about 6 feet."⁴

¹ It may be well to remark that the serpentine of the Lizard is generally very uniform in structure, and only departs from this rule (and that by no means always) in the immediate neighbourhood of a junction with hornblende-schist.

² I have more than once called attention to the fact that in hornblende a brown colour often precedes the green; the latter may indicate an early stage in the process of hydration, affecting the ultra-microscopic grains of iron oxide or some constituent to which the colour is due.

³ Quart. Journ. Geol. Soc. vol. xxxiii. (1877) pp. 888, 920; vol. xxxix. (1883) p. 23.

⁴ 'Rather more than 7 feet' was my note in 1894; the measurements then were a little more precise than on former occasions, but the differences are so slight that I leave the passage as it stands. Between the last-named 'schist' and the serpentine (5) is a thin darkish dyke, which I had supposed to be part of the schist, and there may be another in the latter.

Afterwards I described the microscopic structure of the rocks, pointing out that the serpentine is an unusually compact variety, and stating that I regarded the mass as representing a block of hornblende-schist, caught up by the serpentine, altered thereby, and probably since then further changed by the action of water. In the 18 years which have elapsed since I wrote these descriptions, my experience has been considerably enlarged, yet I still find the rock numbered (4) a very perplexing affair. I note that it is sporadically porphyritic, that the larger crystals under the microscope appear to exhibit traces of 'lustre-mottling,' that the wedge-shaped piece included in the serpentine (5) is almost certainly a more compact variety of the same rock, and that this may have been a picrite; also that the serpentine is probably the intruder. But I can now throw a little light on the banded structures, which are among the perplexities of the section. On examining the dyke-like serpentine (3) I found that towards the edges it gradually became banded. This structure on the right-hand side began to be indicated about 2 inches from the exterior, but only became very marked in the outer inch, where a grey tint predominated. The red part, on microscopic examination, is found to owe its colour to hæmatite-staining, and to consist of a serpentine (mineral) thickly crowded with minute flakes of a clear mineral, many of which give oblique extinction, and resemble actinolite, but others give straight extinction, being probably a chlorite. The last inch, however, is practically colourless (only spotted with a few grains of iron oxide), consisting of matted flakes, quite double the length of those in the other part, but the same minerals. The edge of the serpentine (5), where it is in contact with the small dyke, exhibits a band about $\frac{1}{4}$ inch wide. The red part resembles that described above, except that it seems to be a rather purer serpentine, and it contains one or two ill-preserved grains of bastite, while the band itself consists of a streak of fairly clear orange-coloured serpentine, followed by the matted minerals just mentioned, in which a kind of bandlet is formed by some small grains of brown hornblende, with a little streaking of serpentine. I have also examined a piece of the dyke, which is in contact with this face of the serpentine. Probably it was once a basalt; it has consisted mainly of two minerals, each of which has been replaced by secondary microliths: the clearer patches probably representing a felspar, the others almost certainly a pyroxene. But attached to this is a zone, which in the field I thought might represent a junction. This bears a considerable resemblance to part of the border in the other specimen, for it consists of a matted mass of acicular minerals, some being considerably larger than the rest and distinctly actinolitic, in which one or two grains suggest the possibility of having been bastite. Besides these I have examined a piece of the striped red-and-grey rock (the supposed schist) in the left-hand part of the crag, where the bands locally are sharply folded. The red rock is a serpentine, like that already described; the grey one is a mass of microliths, generally too minute for iden-

tification, but here and there in it are zones of larger flakes, in part at least actinolitic, spotted with grains of hæmatite and of a pyroxene, in some cases certainly hornblende.

Whether the whole of these two masses, which I formerly supposed to be mainly altered and decomposing hornblende-schists, consists of serpentine streaked with bands, which are more nearly picrites in composition, it would be impossible to say without another and yet more minute examination, and this, perhaps, after all would hardly repay one for the trouble; for it is now clear that this section affords a conspicuous instance of a banding in the serpentine itself. As to the two larger, apparently included, masses of 'brownish-grey' rock, I incline to regard them as pieces of a picrite, rather than as exceptionally altered fragments of the hornblende-schist, but in the present state of my knowledge cannot venture to speak more positively.

V. CONCLUSIONS.

I submit, then, that the facts described in this paper justify the following conclusions:—

(a) Mechanical forces, due to earth-movements, have only rather locally produced important effects on the crystalline rocks of the Lizard: namely, in a very limited area at Porthallow, near the great boundary-fault, and over a larger one in the south, approximately bounded by a line drawn from a little east of Polpeor to rather south of Caerthillian Cove.¹

(b) Elsewhere the results of such forces are of very secondary importance, being restricted to the neighbourhood of faults, and even there producing commonly very limited effects.

(c) The slightly foliated or linear structure rather common in the serpentine, its occasional distinct banding, together with rather similar structures in the gabbro and a faint approach to them in certain basic dykes, as has been more fully shown in the paper by General M^cMahon and myself, have nothing to do with 'dynamometamorphism,' but have been produced by fluxion-movements anterior to the complete consolidation of the rock.

(d) The serpentine is intrusive in the 'granulitic group,' which, however (though it may have torn off large blocks), it has only locally softened and indented. It is also intrusive in the hornblende-schist, but this it has sometimes riven, and occasionally melted down, in certain cases partially, in others perhaps wholly, thus producing the streaks of a less pure character, with some resemblance to the former rock: these phenomena, as might be expected, being restricted to the exterior of the mass, the rest of it generally exhibiting an uniform character for considerable distances.

In short, though the effect of twelve years' work in the field and with the microscope has caused me to change my views as to the

¹ An area very nearly correspondent with that assigned to the 'mica-slate series' of Sir H. De la Beche. The line, if it runs straight (I have not attempted to trace it), would be roughly from N.W. to S.E.

genesis of the 'granulitic group' and the hornblende-schists, I adhere (except in regard to a few matters of detail) to the conclusions which were expressed in my paper published in 1877, and more emphatically than ever to those expressed in the first three of the above paragraphs—namely, that I can find no ground for attributing the foliated or banded structures, whether in the granulitic and the hornblendic groups or in the serpentine, gabbro, and a few basic dykes, to dynamo-metamorphism. As regards the banding of the granulitic and hornblendic rocks, I can only say that if it be due to any kind of shearing in solid heterogeneous materials—it is not easy to follow mentally the steps of the process—recrystallization has been so complete that the usual indications of such action have vanished. Hence the structure must have been produced anterior to the incoming of the serpentine and the gabbro. Yet, if the serpentine were folded together with the granulitic rock so as to distort its bands, traces of crushing and shearing should be found in the latter. Even if we assume these to have disappeared (which I could not admit) and claim the foliated and banded structure occasionally exhibited by the gabbro as a result of dynamo-metamorphism, what is the testimony of the serpentine? It is sometimes welded to the granulite, often to the hornblende-schist; it is constantly cut intrusively (everybody, I believe, grants this) by dykes or veins of gabbro. But the serpentine almost invariably shows no signs of crushing. Strain and pressure might destroy a weld, but I never knew them produce one between rocks of this kind; hence the foliation and banding of the serpentine cannot be due to any such cause.¹

But serpentine is a much more brittle rock than granite, hornblende-schist, or gabbro; the last, as one quickly learns in the Alps, being a very obdurate material. Hence earth-movements, which would affect these rocks, would leave their marks distinctly enough on the serpentine. This is a brief summary of my observations in regard to it. Under strain, perhaps under moderate pressure, serpentine simply brecciates²; when the pressure becomes more severe the rock breaks into pieces, which are generally rather lenticular in shape, with a 'glaze' on the outside,³ and, as a final stage of the 'peine forte et dure,' the serpentine becomes so slaty that it might be sometimes used for roofing purposes.⁴ The Alps afford many

¹ On this point I am not afraid of being accused of speaking dogmatically. My first visit to the Lizard was in the autumn of 1873, and I speedily fell a victim to the fascinations of serpentine, probably because I found it to be a subject where *quot homines tot sententiae* held good. I have never felt strongly attracted to beaten paths. Since then I have studied serpentine (including peridotite) in the field on an average once in a year. I have returned five times to the Lizard, I have been thrice to Anglesey, I have examined the rock in three districts in Scotland, in at least a dozen separate localities in the Alps (in some cases not only as a passing traveller), in two districts of the Apennines, and in the Pyrenees, besides studying with the microscope specimens collected expressly by myself, with many others acquired by gift or by purchase. The effects of earth-movements also are not novel to me, since for more than a dozen years I have been studying these in the Alps and elsewhere.

² Geol. Mag. 1879, p. 365.

³ *Ibid.* 1880, p. 538, and elsewhere.

⁴ *Ibid.* 1890, p. 533.

opportunities of studying these changes. Towards the outside of a large mass, in a region which has undergone severe pressure, one may find the 'lenticular' structure, and it is vain to hope for a decent specimen, but as we pass inward the rock often becomes less brecciated, so that at last fairly normal specimens may be obtained. Even the slaty structure may not affect the whole of a large mass; now and again portions of it escape comparatively uninjured. Of this, however, we may be sure, that if a force had acted sufficient to produce a marked effect on either the granulite, the hornblende-schist, or the gabbro, the serpentine would have been almost invariably torn apart from the weld, and would have been crushed, perhaps to a slate, for at least a considerable distance from the junction.¹ If, then, the relations of the serpentine with the granulites and the hornblende-schists indicate an 'igneous complex,' if its structures and those of the gabbro are the results of dynamo-metamorphic action on the rocks when they were solid, the Lizard district flatly contradicts everything which I have learnt about rock-structures during more than twenty years of work in the field and of studying under the microscope specimens collected with my own hands.

VI. APPENDIX.

(a) Miscellaneous Notes.

It would be a very long task to examine every rock in such a district as the Lizard, so that even in going over ground comparatively familiar one picks up 'crumbs' of information, some of which may be worth a brief record.

Dykes.—A porphyritic diabase, as described by Messrs. Fox and Teall, and by Gen. M'Mahon and myself, is occasionally found, usually in rather thin dykes. Those hitherto recorded, if not actually confined to the hornblende-schist, are closely associated with it, as near Potstone Point,² but we came upon one cutting through serpentine (the variety with small crystals of colourless hornblende) near the path³ leading from Mullion Village to Predannack Wartha. The hornblende-schist, near the western end of the cliffs on the northern side of Porthoustock Cove, is cut obliquely by a yellowish rock, generally rather decomposed, which, though only a few inches thick, is more like a dyke than an infiltration-vein. I find this on microscopic examination to exhibit a finely granular structure not resembling any of those usual in veins, and to consist of epidote. This mineral no doubt readily forms as a secondary product in rocks of suitable composition, but the uniformity in composition is a little strange. Such an epidote would come most readily from a rock composed of a lime-felspar with some minutely

¹ The effects of pressure are never more conspicuous than in the weaker of two rocks near the junction-surface.

² P. 33.

³ It is about 350 yards, in a line drawn rather N. of E., from Oreggian Mill; in the same direction are two other shallow pits in serpentine.

disseminated iron oxide. Two or three dykes of coarse gabbro, very poor in the ferro-magnesian silicates, have indeed been observed on the coast farther south; can this epidosite have been a very compact variety of the same rock?

Manacle Point and Porthoustock Cove.—We can add a few notes to the description given by Gen. McMahon and myself.¹ The ordinary gabbro (which forms the Crousa Down *massif*) when followed along the shore towards Manacle Point, passes occasionally into a very coarse variety, in which the constituent crystals sometimes even exceed 2 inches in length. This forms patches in the ordinary rock, with ill-defined boundaries, suggestive of an imperfect mixture of heterogeneous materials in different stages of consolidation. Other parts of the gabbro are foliated, and these occur in like manner, so as to suggest local movements anterior to complete consolidation. The 'warm grey' or brownish rock intrusive in the gabbro,² especially as Manacle Point is approached, would repay a closer study than our arrangements allowed us to give it. It pierces and rips up the ordinary gabbro in a very curious fashion, and pieces of the latter sometimes assume singular shapes, as if they had been slightly softened and bent (fig. 11). Frequently, also, it

Fig. 11.—*Strip of moderately coarse gabbro included in granular dolerite (or gabbro), south of Porthoustock Point.*

The unmarked part indicates the latter rock. The sketch is diagrammatic.
The inclusion represented measures nearly 2 feet from end to end.

includes flake-like fragments of the foliated variety.³ Besides this, it rather often exhibits a porphyritic structure, the mineral being commonly felspar, but sometimes a variety of pyroxene, which forms green spots. The felspar-crystals are a dead-white colour, like that in the gabbro, ranging up to about half-an-inch in length. They are 'sporadic' in habit, occurring in small 'swarms,' sometimes more or less scattered. Sometimes, also, they are actually in contact, and it becomes difficult to distinguish them from the smaller rock-fragments. Occasionally a felspar, as it appears at first, proves on examination to contain a speck of diallage. In short, the

¹ Quart. Journ. Geol. Soc. vol. xlvii. (1891) p. 491.

² It is noticed on pp. 491 and 494 in the paper by Gen. McMahon and myself. As there stated, it is a kind of dolerite or fine-grained gabbro.

³ The bearing of these observations on some of the reasoning in the earlier part of this paper will, I presume, be obvious.

intrusive finer-grained rock seems to have softened, bent or drawn out some fragments of the coarser gabbro, and even to have partly melted down others, destroying the pyroxenic rather than the felspathic constituents, so that the latter are scattered sporadically in the newer rock.¹ Prof. Sollas, it will be remembered, has described a somewhat similar occurrence in the Carlingford district.² This intrusive rock is less abundant than the ordinary gabbro, but more so than the 'greenstone' ³ dykes, which cut them both, and usually do not exceed 4 or 5 feet in thickness.

A low spring tide enabled us to make a more complete examination of the southern side of Porthoustock Cove. As mentioned in our paper (p. 491), General M^cMahon and myself felt uncertain as to the nature of the rocks forming the shore and adjacent cliffs. They presented, as we remarked, some resemblance to the more dioritic members of the 'granulitic group,' and were cut by 'greenstone' dykes, like those mentioned above, the gabbro being near at hand; for we traced it on the slopes above the cliff almost to the head of the cove.⁴ This time we managed to get along the shore eastward, to a point where the ordinary gabbro was exposed in the face of the cliff. Here the rocks on which we stood consisted beyond question of the fine-grained gabbro or dolerite, becoming, as usual, sporadically porphyritic in the neighbourhood of the coarser rock, and from this point we succeeded in following it westward, and convincing ourselves that, though somewhat disguised by the effects of faulting and weathering, it is the dominant rock on this side of the cove. It is cut, as has been said, by 'greenstone' dykes, and traversed not unfrequently by reddish veins. Some of these appeared due to infiltration, but others resembled a rather felspathic gabbro, by no means identical with that forming the principal *massif*. Thus Porthoustock Cove marks the position of a fault or group of faults,⁵ which brings together the Crousa Down gabbro, with its associated intrusives, and the hornblende-schist.

Serpentine.—We examined the mass at Porthkerris ⁶ more carefully than on former occasions. It is represented in the geological

¹ Microscopic examination confirms the statements made above, and discloses one or two other facts of general interest. In the granular ground-mass the feldspars are generally fairly well preserved; the pyroxenic constituent was originally an augite, very pale brown in thin sections, which now, without change of external form, is replaced by a brown, strongly pleochroic hornblende (brownish straw-colour to rich brown). The feldspar of the included fragments is almost wholly replaced by secondary and mostly earthy material; the augite by fibrous, often felted, aggregates of a greenish actinolitic hornblende. Here and there the included fragments are so minute that one can hardly identify them with certainty.

² Trans. Roy. Irish Acad. vol. xxx. (1894) p. 477. The changes, however, in this instance are different—probably owing to local circumstances—from those observed by him.

³ I use this vague term designedly, for they may be anything from a fine-grained dolerite or basalt to a hornblende diabase.

⁴ Still cut by the fine-grained gabbro or dolerite and by the 'greenstone.'

⁵ The coves in the Lizard almost invariably correspond with one or more dislocations.

⁶ Polkerris in earlier papers. In this I have followed the nomenclature of the 6-inch Ordnance map.

map as coming down to the shore on the northern side of the cove; but if there be an outcrop here, it was concealed on this occasion. At any rate, I think it must be isolated from the main mass of the serpentine; this crops out in many places on the moorland which rises on the northern side of the little valley, being seen over an area measuring about 200 yards from east to west, and not more than this in a transverse direction, hornblende-schist cropping out south, east, and north of it. Whether this mass of serpentine is continuous with the one at Porthallow we could not determine, the two being separated by rather more than a furlong of covered ground. Macroscopically it agrees fairly well with one variety of that rock, but it is perhaps a little smoother in aspect and brighter in colour. It has been much cracked and then cemented by yellowish steatite, so that it is apt to break up under the hammer. The two rocks agree fairly well in microscopic structure, each resulting from the alteration of a fine-grained peridotite, which appears to have consisted simply of olivine and iron oxide (*i. e.* a kind of dunite).¹ We ascertained that at Porthallow the serpentine not only runs up the cliff in a dyke-like fashion, but also does this at each end, so that the shape of the mass might be compared—very roughly—to a flattish crescent with its back to the water.² The quarry afforded better sections than it had done for some years. I can understand doubts arising about the interpretation of particular sections, but not as to the general fact that the serpentine is intrusive in the hornblende-schist.

We again paid much attention to the structure in the serpentine resembling a foliation, which may be observed in many places, more distinctly on the western than on the eastern coast, though on the latter also, as from Kildown Point to Kennack Cove, it is often to be found. Frequently it is barely perceptible on a perfectly fresh face of the rock, becomes visible on wave-worn surfaces, and is quite distinct on weathered crags. It obviously proceeds from a slight alignment of the constituents in the original peridotite, and in the case of bastite-serpentine seems more especially determined by that mineral. While it is not seldom fairly persistent in orientation over considerable areas, marked changes in direction may be observed; and while in the neighbourhood of included masses of granulite it is sometimes parallel with the junction-surfaces, cases not unfrequently occur where it makes a high angle with them. In other words, we have failed to discover any necessary relation between the structures in the two rocks. The serpentines in which this 'foliation' exists do not exhibit, macroscopically or microscopically, any indications of strain or crushing, and I adhere to the opinion expressed by Gen. M^cMahon and myself,³ that the structure was produced while the original peridotite was consolidating.

¹ I refer to the ordinary serpentine of Porthallow, regarding the banded variety as exceptional.

² The slopes here are steep, rough, and much overgrown with brambles and coarse herbage, so that it is not easy to map the outcrops, and we have not attempted to do this very precisely.

³ Quart. Journ. Geol. Soc. vol. xlvii. (1891) pp. 447, 476.

We have already pointed out¹ that the Lizard affords two fairly distinct types of serpentine — one, that more generally known, containing distinct grains of bastite (*e. g.* Kennack Cove), and sometimes augite in addition (*e. g.* Coverack Cove); the other, in which the bastite, if present, is inconspicuous, while small crystals of white hornblende are abundant (*e. g.* south of Mullion Cove); the former being most abundant on the eastern, the latter on the western coast.² But we find the bastite-serpentine on the west coast to the south of Kynance Cove,³ and again on the actual headland of the Rill. Here, also, within a short distance, the peculiar variety of serpentine occurs which has been said to contain felspar,⁴ but I could not discover how they were related. From north of Kynance to Gue Graze the dominant serpentine is a rather compact, slightly streaked rock, which on the whole seems more nearly related to the hornblendic than to the bastite-serpentine. The hornblendic serpentine also occurs, though not abundantly, on the east coast; that at Porthallow⁵ on the whole more nearly agrees with it than with the other; we find it on the shore for some little distance south of Poltesco Cove and from Cadgwith to Carnbarrow. But the most curious instance is at Kildown Point. In the quarry at the top we find the bastite-serpentine, while the mass at the foot of the cliff⁶ is a very typical hornblende-serpentine. I regret that I have not from the first recorded the variety of serpentine in each quarry or outcrop examined; but, so far as I remember or have noticed, the serpentine, at places within a curved line drawn from Coverack to Kynance Cove, roughly symmetrical with the eastern coast, is generally the bastite variety, and that outside this line is the hornblendic variety, including with it the dull compact type already mentioned.

Green Schists of the Southern Coast.—We paid special attention to the relations of these schists with the normal hornblende-schists, and are more than ever satisfied that, as stated by Gen. M^cMahon and myself, they are only the latter rocks modified by extreme pressure.⁷ In more than one place we were able to trace a gradual

¹ Quart. Journ. Geol. Soc. vol. xxxix. (1883) p. 23, and vol. xlvii. (1891) pp. 466-468.

² Sp. gr. (mean) of four specimens of the former (two determined for this paper) 2.62. Sp. gr. of three specimens of the latter (two determined for this paper) 2.755.

³ As in the sections near the Lion Rock, described by Messrs. Fox and Teall.

⁴ I remain sceptical as to the identification of this mineral with felspar, though I believe it to be an aluminous silicate.

⁵ Its sp. gr. ranges from 2.545 to 2.644 (J. H. Collins); that of the Rill is heavier, 2.74; that of Gue Graze heaviest of all, 2.85 (M. W. Travers).

⁶ See p. 30. The sp. gr. of a serpentine such as that at the top is 2.653, of that at the bottom is 2.698, which is very nearly that of the west coast serpentine.

⁷ In regard to this my work in the Alps during the last few years has been very helpful; see Quart. Journ. Geol. Soc. vol. xlix. (1893) p. 94, and vol. l. (1894) p. 279. [As this admission was quoted by a speaker in the debate to justify the extension of 'dynamo-metamorphism' to the whole region; I must point out that, by admitting a certain cause to have produced marked modifications in two very limited parts of a district, we, in effect, exclude it from the

change from the normal to the abnormal type. Still, the mass as a whole exhibits a little more variety in composition than is usual in the hornblende-schists. Gneissoid rocks occur in it, as near Old Lizard Head and on the south side of Holseer Cove, and masses of a brownish mica-schist at Polledan Cove (discovered by Mr. Fox), Polpeor Cove, and in the headland south of Holseer Cove. This last I had not before observed. It is seen, under the microscope, to consist of quartz and mica, mostly biotite, which, as in the similar rock in Polpeor Cove, has evidently suffered from pressure, and it contains grains, not very regular in shape, of a water-clear mineral, evidently of secondary origin. This may be felspar, but the refraction-index seems a little high for that mineral, and one or two grains show a slight pleochroism (reddish), so I think it more probably andalusite.

On the northern side also of Holseer Cove are two rather peculiar rocks. One is a slaty, purplish-coloured rock, which is found, on microscopic examination, to consist of grains of a clear mineral, much of which is isotropic (? opal) with a greenish mineral, extinguishing obliquely (probably a chlorite), ferrite, and opacite. The mode of occurrence in the field suggested the possibility of an intrusive origin, but I cannot say that the microscopic examination throws any light on this question. Nor does it help us with a purplish, slightly-streaked rock at the head of the Cove, which still more resembles an intrusive mass. It consists of grains of the above-named clear mineral, flakes of biotite, more or less altered, a little white mica, grains of iron oxide, and a few very small garnets. Both these rocks, whatever may have been their origin, are now schists, and with that group we must leave them.

(b) Age of the Lizard Rocks.

Though I now think it more probable that the hornblende as well as the granulitic groups are not altered sedimentaries, but peculiar forms of igneous rocks, I am more than ever convinced that they are older, perhaps very much older, than the serpentine and the other rocks intrusive in it—that is, I still consider them to be Archæan. It is needless to recapitulate arguments which have been more than once stated in print, but I may say that the resemblance of some of the gneissoid rocks of Sark and Brittany to those at the Lizard, and the practical identity of the hornblende-schists in the first and last localities, make it highly probable that they do not differ materially in age. Now, the gneissoid rocks of Brittany are older than the Cambrian, older even than the ‘Schistes de St. Lô’; while it is almost certain that the hornblende-

remainder. This, I may add, is not the only instance in which a like incorrect appeal has been made to the evidence of ‘dynamo-metamorphism’ at the northern and the southern boundary of the district.—January, 1896.]

schists of Sark, with many of the larger masses of crystalline rock in the Channel Islands, are pre-Cambrian, so that my estimate of the age of these rocks at the Lizard is not affected by any change of opinion as to their origin. But what is the age of the serpentine? It is older than the troctolite, the two varieties of gabbro, the granite, and the various 'greenstone' dykes. The last-named, indeed, may be very much younger than it; for some of them must have cooled quickly, and occasionally seem to be very fresh. Rather similar rocks, and the granite, elsewhere in Cornwall are certainly, at least in many cases, post-Carboniferous.¹ So possibly may be the 'dyke-rocks' at the Lizard. I think that the serpentine, the troctolite, and at any rate the coarse gabbro, must have followed one another rather quickly; the finer gabbro, however, which sometimes seems to become rather more compact near a junction, may be separated from the others by a longer interval, for reasons which I presume will be sufficiently obvious. But what is the date of the others? The picrite at Menheniot, which presents resemblances to some varieties of the Lizard serpentine, is intrusive in Devonian sedimentaries. This question, however, may be ultimately solved by a careful study of the rocks at the Nare Head between Gerran and Veryan Bays. I am indebted to Mr. Fox for my first sight of this most interesting district, of which, however, owing to unfavourable weather, I could only examine a very small part (at Pennare Wallas). Here, going southward up the slope of a hill, we found, first a slaty rock, then serpentine, then outcrops of gabbro. The serpentine, in which a shallow pit has been opened, is much crushed, so that it is difficult to obtain good specimens. It is, however, a dark bastite-serpentine,² very like that in Kildown and Kennack Coves, allowing for the effects of pressure. But on the northern side of this pit we find some of the sedimentary rock, which, though much crushed, is evidently a slaty mudstone with coarser bands, formed of materials which seem to have been derived from crystalline schists. The gabbro is identical with that of the Lizard, when the one constituent has become a kind of saussurite, and the other hornblende. The sedimentary rock is doubtless Palæozoic, although its exact age cannot be determined. The junction here very probably is a faulted one, but so far as I can learn, the crystalline schists do not appear in this district. Thus it looks as if the serpentine had broken through the Palæozoic sedimentaries. If this, on further examination, prove to be true, then it will be highly probable that the Lizard serpentine also is post-Archæan in age.

¹ Or at any rate later than any Carboniferous rocks in that region. But they are older than the rocks now generally regarded as Permian.

² Its specific gravity is 2.579; that of a specimen from the above-named locality is 2.647.

EXPLANATION OF PLATE I.

- Fig. 1. Intrusive serpentine, streaked brownish and blackish, from near Parc Bean Cove (see fig. 10 and description in text, p. 35). *a* is a band of the orange-coloured serpentinous mineral; the other bands (*b*) are lighter in colour, but often speckled with a light puce-brown and with opacite. The large dark grain is of a deep brown tint. ($\times 8$.)
2. From a band of serpentine, intrusive in hornblende-schist, and including a thin 'streak' of the same, from the section described near Parc Bean Cove (see description, p. 36). The part drawn represents the junction of the serpentine with the included streak of schist. *a*, film of true serpentine, forming outer part of specimen; *b*, fibrous minerals—brownish hornblende, chlorite (?), etc.; *c*, more granular brown hornblende, and dark 'earthy' spots (decomposed felspar). ($\times 8$.)
- 3, 4. Junction of serpentine and hornblende-schist near 'Potstone Point.' The two rocks, as described in the text, are 'fused' together. In order to represent this better, 4 is in part a repetition of 3, the lower portion of the former corresponding with the upper portion of the latter. *a* represents the serpentine with a fluxional structure. It contains grains of brown hornblende, which are more conspicuous near the junction *b*; *c* is hornblende-schist (with brown hornblende), between which is a greenish mineral, often serpentinous in aspect, as described in the text (p. 33). ($\times 12$.)
5. Serpentine interstreaked with hornblende-schist, which it has partly fused, from Potstone Point (see p. 33). *a*, mostly a rather fawn- or orange-coloured serpentine, including brownish hornblende, etc.; *b*, hornblende-schist with brown hornblende and earthy material (the part dark in the drawing) representing the felspar. ($\times 9$.)
6. Another specimen from the same locality, showing a more complete interstreaking of serpentinous (*a*) and hornblende (*b*) layers, as if the two rocks had flowed together like a slag. ($\times 9$.)

DISCUSSION.

Mr. TEALL said that, although he had visited the Lizard several times, he had been unable to form any general theory as to the structure of the district. He was glad to find that, so far as the facts were concerned, there was no serious difference of opinion. The question of the relation of the granulitic series to the serpentine was complicated by the occurrence of veins and dykes of both acid and basic rocks cutting serpentine and gabbro. He could not, in all cases, separate these from the corresponding rocks of the granulitic series. He called attention to photographs and clay models illustrating his theory that the granulitic rocks were of igneous origin, and that many of the peculiar structures were the result of deformation. The Author had accepted the igneous origin of the granulitic rocks, and considered that the deformation took place when the acid rock was intruded.

The main object of the joint paper by himself and Mr. Fox, so far as it related to the section near Ogo-dour, was to call attention to the interbanding of the serpentine and schist, and to the folding which had affected the banded series. He thought that infolds had sometimes been mistaken for intrusive tongues, and he pointed out that transgressive junctions might be produced in connexion with folding. He preferred the interpretation which he and Mr. Fox had arrived at to that proposed by the Author.

1. $\times 8$.

3. $\times 12$.

2. $\times 8$.

4. $\times 12$.

5. $\times 9$.

6. $\times 9$.

F.H. Michael. del. et lith.

Mintern Bros. imp.

BANDED SERPENTINE AND PARTIALLY MELTED
HORNBLende-SCHIST.

Speaking as to the origin of hornblende-schists, he reaffirmed his belief in the theory that both gabbros and basic dykes had been converted into rocks of this character by dynamic metamorphism. He pointed out that in 1887 he had called attention to the existence of a zone of intense mechanical disturbance in the south-western portion of the Lizard, and to the fact that this had been accepted by the Author. The main mass of hornblende-schist lay to the east of this zone: in the same position relative to a zone of disturbance as the Moine Schists of Sutherland. There was a close resemblance in structural features between the main mass of hornblende-schist and the Moine Schist, and he thought it highly probable that this resemblance would be found to be due to dynamic metamorphism.

The Rev. EDWIN HILL said that Messrs. Fox and Teall seemed to imply that granulite had been thrust into serpentine at the Lion Rock, but it appeared to him that the opposite was the case. At Potstone Point he saw no such folding as they seemed to speak of. As for the fact that the bands of included masses of granulite usually follow the external boundaries of the masses, it was most natural to expect that the masses when ripped should yield along the banding as lines of least resistance.

Gen. McMAHON said that, if he understood the Author aright, the latter now believed that no part of the hornblende-schists had originally been ash-beds; if so, he reserved his judgment on that point. In all other respects he was in cordial agreement with the Author. He had not visited the whole area covered by Messrs. Teall and Fox's paper alluded to, and could only speak to the parts of the Lizard actually visited by him. He thought that there had been granitic eruptions at different periods in the Lizard area, and that the intrusion of the granite which had been injected into what is known as the granulitic series was of earlier date than the granite which had invaded the serpentine. As regards the question of the intrusion of the serpentine into the schists, and the granulitic series, his mind was at rest. He had seen several sections which had convinced him as to the correctness of Prof. Bonney's original discovery of the relations of these rocks; and he mentioned, in particular, the section to be seen in the Flagstaff Quarry, Cadgwith, which could not be explained on the hypothesis of the serpentine being caught up in the folds of the granulitic beds.

Sir ARCHIBALD GEIKIE said that he had had the advantage of being conducted over part of the Lizard district by Mr. Fox and Mr. Teall, and though he would not venture to offer an opinion upon most of the disputed questions in the geological structure of that area, he had seen evidence sufficient to convince him that in the Potstone Point part of the coast the serpentine and hornblende-schist formed, as Mr. Teall maintained, a great complex which presented a marked coincidence of banding and had been plicated by one common series of movements. He could see no indication of the serpentine being intrusive in the schists. Without expressing any judgment as to their relative date or mode of origin, he could not doubt that both groups of rock had been simultaneously exposed

to the pressure which had resulted in the marked plication which they both now exhibited.

Mr. J. H. COLLINS said that he had not visited the district referred to by the Author for a dozen years or more, so that his recollection of the facts upon which his opinion was based was rather hazy. He had, of course, read the able papers which had been presented to the Society by several eminent geologists in that period, but had not felt called upon to alter in any important particulars the opinions which he had expressed in 1885 in the 'Geological Magazine.' It was remarkable that so small an area should afford grounds for so great a diversity of opinion: there were almost as many opinions as parties of observers. There were, indeed, some indications of approximation of divergent views; but the approximation was so small during the eighteen years which had elapsed since the reading of Prof. Bonney's first paper, that he feared no one then present would live to witness the general acceptance of the one and only right view which would embrace all the facts.

The AUTHOR said in reply to Mr. Teall that, from the remarks of the latter, it appeared that he still adhered too much to the principle which he (the speaker) thought likely to mislead—namely, restricting the attention to single sections, and dwelling on the minor difficulties presented by them, without regard to the evidence in other parts of the district. Of this the speaker pointed out instances. He thought that Mr. Teall had overstated the amount of banding visible in the serpentines of the Mullion—Ogo-dour district; as a rule (except in the cases mentioned by the Author—what he considered to form a mixture of the two rocks), it was only foliation. As for the Norway peridotites, certain things had been asserted of them, but not proved. Such bending as there was of the rocks about Potstone Point could not be the result of flexure by ordinary mechanical forces; nor could this cause the 'flaser' structure in the gabbros of the east coast. In the former case the weld of the serpentine and hornblende-schist would have been destroyed; in both the serpentine would have been much broken, in the latter crushed, for gabbro is one of the toughest of rocks. On this point his experience in the Alps enabled him to speak with confidence.