50. Notes *on the* Metamorphic Rocks *of* South Devon.

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(Communicated by Prof. T. G. Bonney, D.Sc., LL.D., F.R.S., F.G.S.)

Contents.

There are scanty notices, by De la Beche and other earlier writers, of this southernmost part of Devonshire; but later it has been very fully described by Professor Bonney*; and taking his paper as a guide, I was able during two visits to obtain some knowledge of the district. I have ventured to think that a few supplementary details might be of some slight interest.

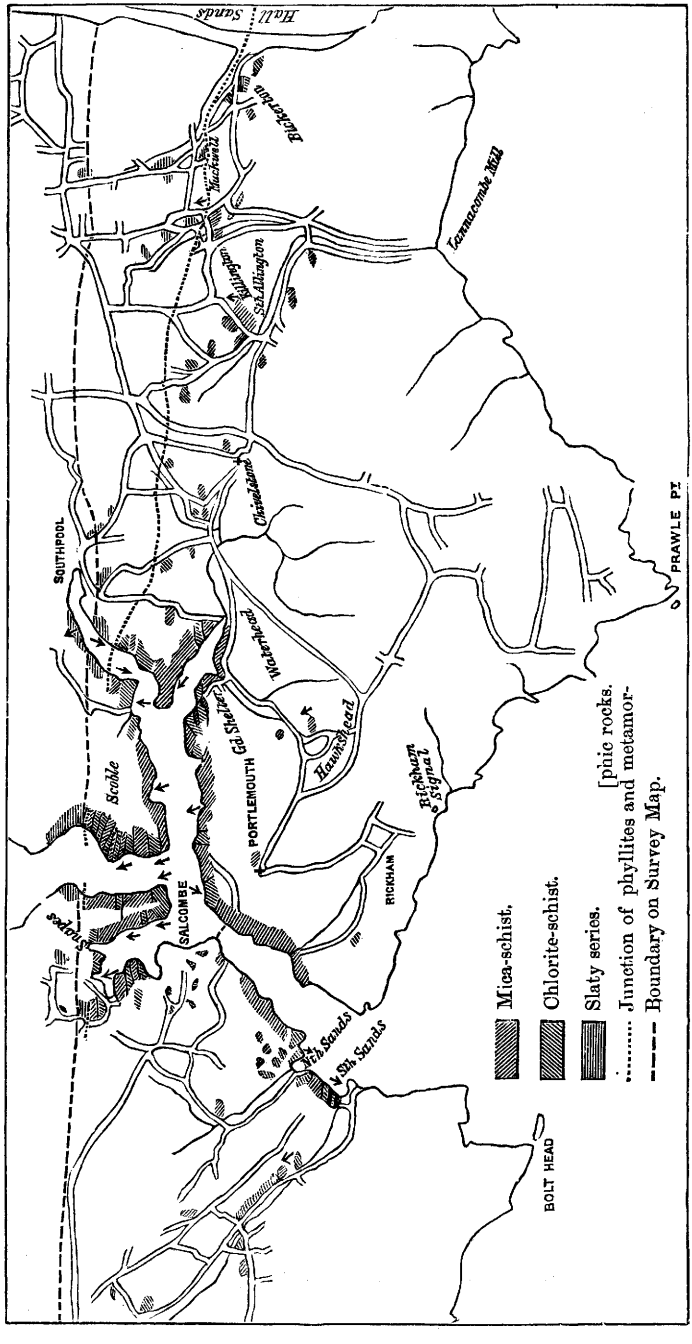
I. Boundary of Slaty and Metamorphic Series.

As I had not time to visit thoroughly all parts of the district, I tried primarily to make an examination of the exposures in the vicinity of the junction of the slaty and the metamorphic series. Here I was anxious to arrive independently at a conclusion on the question whether metamorphism had affected a continuous series of beds, or whether the southern rocks had the character of a separate and probably much older formation. Hence, before visiting any of the sections already described, I made expeditions to two localities on the shores of the estuary north of Portlemouth, where I found exposures, in one place quite, in the other nearly, continuous from Devonian to metamorphic rocks. I had no real difficulty in deciding when I had passed from one formation to the other, and the opinion then formed as to the complete distinctness of the two series was confirmed by further examination in the field and by the microscope.

Along the southern boundary of the slaty rocks, I visited the cliff exposures of the eastern and western coasts, those bordering the estuary, and I also zigzagged across parts of the intervening country.

1. *Hope Cove.*—The western limit of the boundary line at Hope village is marked on the Survey map, and has been described by

* Quart. Journ. Geol. Soc. vol. xl. p. 1.



For district to the south, see Prof. Bonney's Map, Q. J. G. S. vol. xl. p. 2.

Prof. Bonney, as running out to sea in the cove just north of a small rocky headland. I was able, owing to a more favourable tide, to skirt this headland for a short distance, and found clear evidence that its northern face, as suggested, "has been determined by the fault." While the mass of the headland is of mica-schist, fragments of what are evidently beds of the slaty series are found coating its northernmost portion. They agree with that series in direction and amount of dip; and, lithologically, are very like beds occurring at a junction near South Pool, to be described immediately. They consist chiefly of impure limestone, very much indurated and crystalline in character, and of brittle bands of blackish material having a very crushed and slickensided look. At a higher level, where the scour of the waves between high and low tide would be stronger, the neck of the headland has been worn away rather more deeply, and exposes down its cliff signs of what I believe is the faulted junction.

2. *West of Salcombe Estuary.*—On the western shore of Salcombe estuary, as Prof. Bonney has described, the actual junction is not seen; but we can easily recognize when, from smooth satiny slates dipping evenly to the west of north at about 55°, we have passed, over a very short interval, on to mica-schist. To the west of this exposure, I noted, in a lane north of Batson, the occurrence of phyllites* followed by mica- and chlorite-schists, the junction being rather to the south of the line given on the map, thus agreeing with the position on the estuary suggested by Prof. Bonney.

3. *East of Salcombe Estuary.*—On the opposite shore of the estuary I landed at Halwell Wood, and walked southwards by a low cliff, where the phyllites were well exposed, varying somewhat in character, but all clearly of the unmetamorphosed series, having a dip of about 55° to the west of north. Some bands were fairly good slate, others true phyllite; while here and there the sheen surface, developed along veined or coarser and more gritty parts, gave an irregular schistose look to the beds, which, however, was easily distinguished as a merely superficial likeness. South of the phyllites, a tiny streamlet comes down to the beach, and the mouth of its slight valley extends about 50 yards with no exposures; then mica-schist, at first very brown and decomposed, forms the low cliff.

4. *Southward of South Pool.*—Along the arm of the estuary which comes down from South Pool, we can again note where the junction of the two series occurs, and we find it some 200 yards south of the line drawn on the Ordnance map. The west shore gives us a continuous section, and, in spite of the ferruginous rotting which has attacked some 75 feet of the rocks, I identified, I believe, both the original phyllites, with hard calcareous bands similar to those which I found at Hope Cove, and also the much altered, but more massive, rhomboidally-jointed chlorite-schist, which is here the first of the metamorphic rocks to be met with as we go south. On the east shore there is a blank of about 100 yards (partly occupied by a cliff of recent deposit) which separates the phyllites on the north from

* I use the term phyllite to denote a slate in which a large amount of microlithic mica is developed.

chlorite-schist to the south; and over this space several very small springs flow out. The more recent series consists chiefly of satiny slates, greenish or greyish, splitting with the characteristic crisp brittle fracture, here and there with hardened bands of impure limestone, and cut at places by thick white quartz veins; they are occasionally contorted and irregular, but for the most part lie smoothly and evenly. The phyllites of the western shore show a steady dip to the west of north; while the chlorite beds, including micaceous bands, after some variation, set in dipping towards the south. On the eastern bank, the slaty beds dip with some exceptions in a southerly direction; but the cliffs are so low, and, in cuttings into the phyllite, I so often noted a tendency for the upper part, even to a depth of four, five or six feet, to be bent over in an opposite direction to the true dip, that I should hesitate to trust the southerly inclination, if there were not a constant, though interrupted, suggestion of it over a space of nearly half a mile.

5. *Eastward of South Pool Estuary.*—At Hall Sands there is at first sight some little difficulty in fixing the boundary of the two series; but on more careful examination, we see that the rocks south of the stream all show schist-like fracturing, and are of very micaceous character, only with something of the look of phyllites, due, I doubt not, to subsequent slickensiding or crushing. To the north of the valley the slaty beds have, it is true, a very thorough development of micaceous surface, and, at places, a wavy lamination, which gives a superficially schistose character, especially when accompanied by corrugations and irregular veinings of quartz; but these beds are soon interrupted by evenly cleaved true slaty bands. My note made on the spot, after re-examination, was, that "any simulations of phyllite, south of Hall Sands, and any simulations of schist, north of Hall Sands, are in each case local and very inextensive; a small flake of the southern cliffs might be mistaken for phyllite, and a veined fragment of the northern rocks might be thought approximating to schist, but any larger examination, even in the field, would show the distinctness." This conclusion, on referring to Prof. Bonney's paper, I found to be in complete agreement with his own summary of the difficulty.

I walked through most of the lanes lying between South Pool and Hall Sands, and found no difficulty in deciding whether an outcrop was of slaty or of metamorphic rock. Over much of the country the rocks are hidden, but deep cuttings by roadsides and occasional quarries enabled me to decide that the line of fault, traced eastwards, bends rather to the south, running out to the sea at Hall Sands, as marked on Prof. Bonney's map. The boundary runs between the South Pool and Chivelstone valleys, along the summit, or the northern slope, of the rising country; its line is not exactly defined, but I rather incline to mark it somewhere along the more southerly of its possible positions. Eastwards, to the south of Ford, I found some indications, which suggest the continuation of the fault south of the main road. Very good exposures mark its position as passing through Killington, to the south of Muckwell, and as having determined the lower part of the course of the Hall-Sands streamlet.

South of this valley, the most northerly of the metamorphic rocks are of chlorite-schist, including micaceous bands. This chlorite rock forms the foundation of some of the Bickerton cottages; it has been worked at one small quarry south of the Bickerton lane, and at another on the hillside overlooking Hall Sands, and is of an ordinary, but very well-banded character.

We have thus roughly traced the southern boundary of the phyllites, and this boundary cuts obliquely across the general strike of the metamorphic beds, so that different members of this series are thrust against the phyllites as we go eastwards. There is, at places, marked variation of dip and strike, and the beds, as I shall describe later, are often disturbed, and dip, in some cases, at a very high angle. Wherever an actual junction is exposed, it emphasizes itself by decomposition of the rocks into a brown iron-stained material. More often the beds thus affected have been completely denuded, and their former place is marked by a small valley or streamlet.

II. Microscope Slides and Lithological Characters of the Metamorphic Rocks.

A. *Microscope Slides.*

I examined slides from various parts of the district, and I may perhaps be allowed to add to the full descriptions, given by Professor Bonney, a few notes on specimens which seem to me not quite of the normal type. The metamorphic rocks, as he has stated, may be grouped into two series, essentially characterized by the abundant presence of mica and of chlorite respectively. I found, however, some specimens containing such an amount of both minerals that I have ventured to speak of them as micaceo-chloritic; but if this term is objected to, they can be placed as exceptional forms, partly of chlorite-schist, mainly of mica-schist. These rocks occur at places where there are alternating beds of chlorite- and of mica-schists, and especially along an extensive tract in the north of the area. It is true that chlorite is present in some of the typical mica-schists; but these differ from the "micaceo-chloritic," even in hand-specimens, and markedly under the microscope; while in the true chlorite-schists, if the colourless mica is found, it occurs generally in only an occasional flake.

1. *Chlorite-Schists.*—When we examine, as our first example, a typical slide of chlorite-schist, we see, without magnifying, irregular bands, greenish in colour, alternating with bands of material apparently quartzose. By the aid of the microscope the separate constituents can be investigated. The green layers consist mainly of a mass of chlorite aggregated in the modes described by Professor Bonney, generally associated with some brown ferruginous deposit, not identifiable, and with epidote. The epidote may appear in numerous small grains, or in larger crystals, some exhibiting cleavage-lines, and showing occasionally a tendency to break up. The chlorite folia are sometimes grouped in a radiate manner; they are generally dichroic, changing from a feeble brownish tint to a deep green colour; by the extinction being parallel to the cleavage-

planes in some examples, the species would seem to be a chlorite of uniaxial character, possibly, in part at least, prochlorite of Dana. The more transparent layers in the chlorite-schist slide are constituted chiefly of grains not usually elongated in form, in some cases adjoining in the manner of quartzite- or schist-grains, but often separated by a pale greenish or dark deposit, composed partly of not clear chlorite, partly of more opaque substance, this intermediate material being often in more or less continuity with the mass of the green chloritic layers. The grains thus defined have an appearance as if they had been forced apart, possibly by local crushing of the rock; and this appearance occurs most markedly in slides from districts where the rocks in the field had a disturbed aspect. Professor Bonney calls attention to a somewhat "clastic look" in specimens examined by him, and suggests its being due to the action of "unequal pressure." The transparent grains themselves are many of them uncleaved and fairly clear, except for minute enclosures, small flakes of chlorite or other belonites; and these grains I suppose to be chiefly quartz. Of others, which show more or less distinct cleavage, some at least, after hesitation, I identified as possibly kyanite, the presence of this mineral being suggested by Professor Bonney in some of the chlorite-schists. In some cases my specimens show, as Rosenbusch describes, an extremely clear appearance, with the occurrence of infiltration-products settled along the very distinct cleavage-planes *. As is stated by Fouqué and Lévy to be the character of thin slices, the grains are colourless and not dichroic †. Felspar seems to be present in certain slides as an occasional grain, and it may occur more markedly in other specimens; but in many cases its appearance is not quite normal, and Professor Bonney has suggested to me the possibility of the crystal consisting of a secondary mineral replacing the original felspar. Such typical characters of chlorite-schist I have noted in slides from rock obtained along the coast northward of Prawle Point, from the cliff near North Sands, and in others to be mentioned immediately.

In a slide cut from the chlorite-schist which is quarried near North Sands, I was interested to find hornblende occurring in portions larger than the belonites described by Professor Bonney. There are in the slide a fair number of specimens varying in size, but all very characteristic; they are green in colour, exhibit dichroism, and have the cleavages parallel to α P well marked. Most of the grains also are partially bounded by prismatic faces. They occur, some of them intercrystallized in nests of quartzose material, others in the greener bands of the rock, where, at parts, they seem to merge into the chlorite, at parts seem as if eaten into by the bordering epidote-grains. In chlorite-schist near Rickham Signal the clastic aspect, previously described, is noticeable, and is emphasized (even more markedly than in my specimen from North-Sands quarry) by the deposition of calcite along cracks in some of the clear mineral. Among the grains may be noted one of a twinned

* Mikr. Phys. der petr. Min. p. 345.
† Min. Micr. p. 460.

crystal, which has evidently been broken and suffered some displacement of its parts with deposition of calcite along the crack. Similar examples of pressure-effects may be found in various slides. Many of the clear grains in this Rickham specimen, even where not exhibiting definite cleavage-lines, contain narrow laths of a richly coloured reddish-brown mineral, possibly hæmatite, which have a uniformity of direction in the grain, as if determined by its cleavage-planes. In another specimen of chlorite-schist, taken from the foundation rocks of the Old Castle near Salcombe, Professor Bonney called my attention to the form and arrangement of the grains in the clear layers. Without magnifying, the folded zigzags of these colourless bands are quite evident across one part of the slide. Under a low power of the microscope their constituent grains show an elongation transverse to the main layer, and with polarizing apparatus an orientation of colours similarly transverse, these characters of form and optical property being therefore due probably to the pressure which bent the layers.

Certain masses of chlorite-schist occurring in the northern part of the district call perhaps for some special notice. Specimens for the microscope were taken from the points on opposite sides of the main estuary north of Salcombe, which I have called for distinction "Snapes" Point and "Scoble" Point. The usual minerals (chlorite, quartz, epidote) are present, and in the Scoble slide occur some grains of the cleaved mineral and some which seem to be felspar; we may note examples of simple twinning, and others of multiple twinning after the manner of plagioclase. One very interesting specimen was pointed out to me by Professor Bonney, where the members of the compound crystal are distorted, waved, and even broken across and displaced—an additional proof of the action of pressure, which had seemed to me marked in this rock even in hand-specimens, and emphasized by the evidence of the microscope-slides. The section of the Scoble rock shows quartz-grains, occurring, for the most part, separated in the chloritic ground-mass, and many of the grains elongated, with their long axes parallel to the lamination. In the Snapes specimen knots of quartz appear frequently as if squeezed out into rather long irregular bands, in which the mineral has assumed the ordinary schist or quartzite characters. Some of the separate grains are of very flattened form. In the mass the rock exhibited, throughout, a close compressed look, but was traversed at places by bands of apparently different mineral constitution. The evenness of these layers and the compressed look, taken in connexion with the micro-structure already noted, seem to suggest that the rock had suffered from a pressure somewhat normal to the bands, and that the lamination may have existed in some form in the rock as a previous stratification-foliation.

2. *Micaceo-chloritic Schists.*—An interbanding of some mica- and chlorite-schists in the cliff near Rickham Signal-Station yielded a specimen containing both mica and chlorite, with layers of quartzose and other colourless grains, some cleaved and some exhibiting twinning. Scattered about with epidote are small garnets, abundant

in the mica-chlorite layers, rare elsewhere. The signs of a crushing of the rock are very evident; the grains are of varying sizes, their boundaries shade off in polarized light with an appearance of secondary deposition, and many are dirty and less clear than usual; the micaceo-chloritic layers also are crumpled as in the true mica-schists. Like this last specimen, a mass of rock from the north of "Snapes" Point might be described as a kind of chlorite-schist; but it exhibits, even in the hand-specimen, a large amount of mica. It is dark-greenish in colour, tough, and weathers to a very rough surface, partly ridged from plates and fibres of mica, partly pitted with roundish hollows irregularly weathered out. A slide cut from this rock shows chlorite largely present in aggregated folia, but, inter-crystallized with it, flakes of white mica in much abundance. This mica seems to agree with that in the true mica-schist, and shows the zigzag crumpling of the folia which is so marked in that series. As in chlorite-schists, granular epidote is abundant, and large grains occur with an indication of cleavage-planes and showing a tendency to break into smaller fragments. Within the ground-mass are fairly large isolated grains of other minerals. Some of these seemed at first not easy to distinguish from quartz; but, unless we may infer its secondary deposition, several characteristics of the grains make this identification difficult, as was pointed out by Professor Bonney, who kindly looked at this and other slides for me. Other grains present show twinning or cleavage, and very many of them exhibit characters which seem to me most like those of kyanite, in some cases the mineral appearing in longish forms with lines of pinakoidal cleavage (a P $\breve{a}$ and a P $\breve{a}$) crossed by some of the nearly "perpendicular breaks" of the basal cleavage (O P) described by Fouqué and Lévy * and by Rosenbusch †. In the hand-specimen, I could recognize grains having pearly cleavage-faces and of pinkish or pale brown colour. In the slide all the grains are fairly uniform in size and similar in shape, having a somewhat elongated, elliptical outline (only one showing good suggestion of crystalline form) and the margin at places being fairly even. They contain various enclosures, some of which seem to be epidote, sometimes in rather stumpy crystalline forms; others are clear colourless belonites; and very minute enclosures, such as are common in the quartz of the chlorite-schist, are very abundant. The inclusions, especially the clear belonites, extend, in many cases, in lines parallel to the long axis of the enclosing grain, and often these lines are curved. In some grains, cleavage runs undisturbed obliquely across the lines of enclosures, so that we might perhaps infer the subsequent crystallization of the enclosing mineral around the epidote and belonites. These must in that case have existed previously, and the kyanite, in its present condition, may be posterior to the crumpling and contortion of the rock. It is interesting to note that the longitudinal extension of the kyanite in some examples is roughly in the direction of the

* Minéralogie Micrographique, p. 461.

† Mikroskopische Physiographie der petrographisch wichtigen Mineralien, p. 345.

planes, and that the grains themselves are sometimes outlined approximately parallel to the curving lines within. I tried to observe the optical characters of the belonites, but not always successfully; some indications seemed to agree with characters of sillimanite—the clearness of the mineral, and its absence of colour, its occurrence in long slender prisms with transverse cracks, and occasionally the appearance of bright colours with crossed nicols; the extinction in some examples seemed to occur at an angle of about 20°, but varied in others.

Frequently in the masses of chlorite-schist seen in the field, there occur thin bands of chloritic rock of brighter green colour and with very smoothed surfaces as if slickensided; even in freshly hewn quarries these bands were generally too fragile to yield slides for the microscope. One firmer band, however, having a more silvery micaceous look, occurs in a quarry by the new road near Snapes Point, and may perhaps be representative. This gives a clear, filmy, apple-green chlorite, and very clear large mica-flakes accompanying an exceptionally small quantity of quartz, most of it exhibiting signs of secondary change. There are numerous grains, some of epidote, some of garnet, and others of a mineral rather resembling garnet, but apparently not isometric, giving a dull purple tint on rotating the stage. The layers are crumpled, the mica-flakes lying at intervals obliquely across the general direction, as if bent down in the slipping.

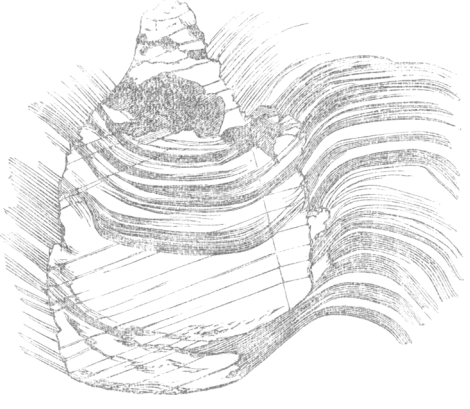
When we turn to the examination of the most general type of micaceo-chloritic schists, we find some of the best specimens near "Snapes" Point, "Scoble" Point, and Westercomb, all places approaching the northern boundary-line. Macroscopically, these rocks differ from the ordinary mica-schists in being duller in appearance, although rather light in colour, greyish, or sometimes with a slightly greenish tint. In the mass they are generally more evenly bedded. Under the microscope these rocks are found to consist chiefly of mica, chlorite, and quartz, with possibly felspar and a mineral, more or less abundant, approximating in its cleavages to kyanite, several grains showing interrupted cleavages meeting at an angle of about 56°, and reminding one of the planes parallel to the base and the brachydome (O P and Pα) shown by Max Bauer *. Grains are fairly abundant in these slides having a marked twinning, some quite simple, others slightly repeated; and in one or more examples the crystal is cracked and its parts displaced. The quartz is dirty from the number of minute enclosures, and has the usual schistose structure, irregularity in the size of the grains and shading of their colours in polarized light suggesting subsequent strain of the rock. In many places, larger clear grains are imbedded in a mosaic of small shaded ones and not uncommonly the large grain is cracked across, and the commencing development of the fine mosaic can be traced along the crack. In some slides occur certain granular aggregations which are partly resolvable under a higher power of the microscope into

* Zeitschrift der Deutschen geologischen Gesellschaft, 1878, Bd. 30, Taf. xiv. fig. 1 *a*.

colourless microliths, somewhat dichroic, if I could trust my not very clear observation; they may possibly be a secondary actinolite. In these micaceo-chloritic slides mica plates at parts form level and continuous layers, at others they constitute bent or wavy laminæ. Occasionally there is an example of a breaking and slipping of the layers at the folds, which I will indicate later, when I speak of similar structures in other schists.

3. *Mica-Schist.*—True mica-schists form the dark massive cliffs which extend towards Bolt Head, with a kind of black-lead sheen, and the paler, more silvery rock of the cliffs near the Start. In the Bolt specimens I identified the constituents described by Professor Bonney, and found one fragment showing good examples of what I believe to be kyanite. The grains are visible without magnifying, and, thus looked at, they are seen to be about $\frac{1}{16}$ inch in diameter, to be blackish in colour, and to have somewhat of a prismatic form. Under the microscope the grains, some of them, show clear kyanite-like cleavages, and in one is a good example of twinning. Where this clear mineral occurs, it abruptly interrupts

Fig. 2.—*Crystal of Kyanite in Mica-Schist near Bolt Head.* (Enlarged 70 diameters.)



The schist consists mainly of chlorite, white mica, and "black mineral," and its layers pass on through the kyanite. The kyanite shows one good cleavage, with interrupted planes, and is twinned.

the micaceous and chloritic layers; but the ferro-carbonaceous material (as I infer it to be from Professor Bonney's description) seems to continue on in its own wavy laminæ through the kyanite (fig. 2). Here, therefore, where the grains are larger, they contain more foreign deposit, some of them being almost full of the black dust; but its arrangement seems only explicable by supposing the growth of the kyanite-grain *in situ* in the rock. The schist from Start Point seems to have in it less of the black mineral, its mica-

folia are clear and well defined, although small and at places irregularly intercrystallized with quartz. The quartz shows minute agglutinated grains, and has the appearance of having suffered from pressure. In all these slides, I was on the look out for evidence of a secondary cleavage-foliation, and I could trace in all the beginnings of such a structure. The thin folia have given way along some of the sharp abrupt folds, as is shown in the figure given in the article before quoted *, and the secondary planes thus here and there arising consist of the black mineral with some mica-folia.

B. *Macroscopic Structures.*

1. *Mica- and Micaceo-chloritic Schists.*—In hand-specimens the mica-schist gives interesting study of various forms of crumpled and contorted beds. In many places examples may be found of a slipping of the zigzagged layers, being an illustration of what might be classed under "strain-slip" (*Ausweichungs-*) cleavage. In the schist of the Bolt Head, Professor Bonney has described how the beds are folded and contorted, and how the rock readily breaks up "into rude prisms." This tendency seems due to the schist being traversed by two sets of divisional planes, one parallel with the original stratification-foliation, the other marking a subsequent cleavage-foliation. The cleavage-surfaces have, on the whole, a smoother, more continuous polish; while the original folia are thinner, closer, but more crumpled, and therefore give rise to surfaces more liable to break with small irregularities.

In certain areas the schists, whether mica- or micaceo-chloritic schist, have a tendency to split along broadly undulating planes, which do not entirely follow the lamination. This is a marked character in much of the rock near Start Headland and at several localities in the northern part of the district. Near Gullet, on the arm of the estuary from South Pool, just before mica-schist sets in, the chlorite rock contains what I should judge to be micaceo-chloritic bands, and these are traversed by undulating planes. Thus these bands have a tendency to split along curving surfaces, dividing the rock into somewhat rounded rhomboids, within which the quartz often thickens at places into little knots or eyes. Here the planes of weakness seem to include in their course part of the slip-planes or planes of cleavage-foliation, and part of what we may consider true bedding-planes. There must in that case have been some modification of the structure, induced by the pressure which the rock has undergone; and I thought that possibly the cause could be connected with the more marked presence of quartzose layers, which might have helped the bending-over of the planes of weakness, by offering a resistance to the cleavage-slipping. Passing now to other examples of like structure, I would note a rock of mica-schist on the beach near Lannacombe, whose surface, polished by the waves, exhibits, with greater clearness and on a more minute scale, similar markings to those of the Gullet specimen. Here, blacker patches in the silvery mica-schist seem, in consequence of the structure

* Quart. Journ. Geol. Soc. vol. xl. 1884, fig. 7, p. 15.

described, to tail off where the cross planes break the lamination. Very similar to this is a micaceo-chloritic rock from the shore opposite Gullet, which I examined with the microscope. In the hand-specimen blacker bands continually tailing off seem to cause an incipient formation of "eyes" of the darker material. These bands, under the microscope, are found to consist of chlorite, mica, and a quantity of a black mineral present in all my slides of micaceo-chloritic rock, which both here and in some others consists markedly of small crystalline masses rather flattened in form, and ranging along the lamination, like the titaniferous iron-ore shown in the Scourie-Dyke schist*, only the ferrite in my slide is more abundant. Here (as well as in one other slide) I thought it accompanied by grains of sphene. Some of the micaceous layers present an appearance as if they were flowing around the larger grains of quartz; and the hand-specimen, like others of the micaceo-chloritic group, has a very squeezed look. The slide has the structure already noted as generally belonging to the group—the small mosaic of quartz granules surrounding larger grains which are sometimes broken across; and the aggregations of microliths are also present. This rock was obtained near Westercomb, from within 60 yards of a junction with the phyllites. In other northern localities of the district the curving fracture-planes, as seen in hand-specimens, are very marked in schists which have what seemed to me a specially slickensided and crushed look; and this occurs where I am inclined, from stratigraphical relations, to suspect that a line of fault occurs, which has very possibly split and followed two directions, as, for example, in the point opposite Westercomb.

On the whole, the characteristic of the mica-schist of South Devon seems to be a tendency to develop cleavage-planes of less or greater force, which become, at places, fairly well marked, although not in an equal degree with the original foliation-planes.

2. *Chlorite-Schists.*—Certain structures in the chlorite-schist, when it is studied in the field, seem to require some notice; but I am very diffident about making any suggestions as to their relations. Apart from any ferruginous decomposition, the chlorite in weathering acquires often a paler shade, sometimes almost whitish, and sometimes a delicate pale sea-green. This last colour I generally found occurred in parts protected from rain-wash, and I have never seen a more beautiful study in rocks than that in some of these chlorite-masses where, receding slightly beneath a projecting ledge, they expose a surface coated with the soft pale sea-green dust. The picturesque appearance is increased by the tendency to pitted weathering here, as elsewhere, exhibited, which has already been described by Professor Bonney. In other exposures, I noted a tendency to rather regular rhomboidal divisions. These two structures I should suppose nearly related; but the rhomboids at all events seem to be due to the development of two obliquely crossing sets of planes, the one set being in the direction of bedding, the cause of the other set being more difficult to prove. It might perhaps be a kind of jointing; but there is some

* Teall, 'British Petrography,' pl. xx. fig. 2.

slight evidence which would rather connect it with the effects of pressure. One example, which had some weight with me, was a case of chlorite-schist interbanded with a 15-inch mica-band. The mica-schist showed puckerings, which I can best describe as giving an outline roughly duplico-dentate, and the transverse planes of the chlorite ran up into the sharp teeth of the puckerings. It seemed as if the force which crumpled the mica-band had developed the oblique planes in the chlorite. At other localities also, the divisions seemed to be suggestive of pressure-planes, as in exposures near Rickham Signal-station, on the shore east of Portlemouth Parsonage and elsewhere. For comparison with these examples I searched on the shore south of Portlemouth for an occurrence in chlorite-schist, referred to by Professor Bonney *, and described as a cleavage-structure, and I think the cases I have quoted will bear a similar explanation. To such pressure-planes crossing those of bedding, modified by the not very plastic material of the rock in which they are developed, I am inclined to attribute the irregularly worn surfaces of the chlorite-schist; since the hollows which weather out at places can be found in all gradations from regular angular rhombus-shapes to rounded and irregular pits. The rounded depressions, like the angular ones already described, follow planes of bedding; in one example I traced them along the contortions of a corrugated mass of chlorite-schist. Where the pitting was most irregular in its arrangement, the beds had often suffered such foldings and dislocations that it was difficult, or even impossible, to track the bedding-planes.

The angular markings I have alluded to were generally rather local in their occurrence; but over large masses of chlorite-schist there was a development of a second set of planes, presumably joint planes, along which the rock continually broke up and slipped. This often gave erroneous impressions as to the dip of beds seen from a distance.

III. Stratigraphical Relations of some of the Metamorphic Rocks.

In this part of the paper I shall restrict myself mainly to the small northern area beyond Portlemouth, which was not specially examined by Professor Bonney. The best exposures are along the main Salcombe estuary, whose shores, extending roughly from north to south, cut across successive beds. The eastern cliff is perhaps rather less disturbed, and from it chiefly we may describe a typical succession.

1. (*a*) *Interbanded Series of Main Estuary and Batson.*—South of the fault, near Halwell Wood, we come to a mass of mica-schist, partly brown from decomposition, which dips northerly and extends about 100 yards; beyond this, chlorite-schist is exposed. Hence, nearly to the beginning of "Scoble Point," we have beds, at first and at places, with variable or southerly dip, but, on the whole,

* Quart. Journ. Geol. Soc. 1884, vol. xl. p. 9.

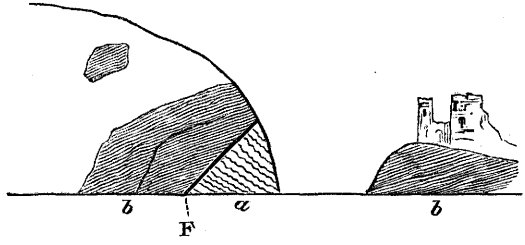
dipping to the west of north. These are chlorite-, mica-, and micaceo-chloritic schists alternating one with another. Bands only a few feet thick or even less occur; but the average thickness may be taken as about 50 feet, though there are two masses of mica-schist nearly 200 feet in thickness. With few exceptions the beds quietly overlie, and after looking out carefully for evidences of repetition or overfolding, I came to the conclusion that these rocks probably represented a true stratigraphical succession. This series is not quite so well shown along the western shore; here a westward thinning-out of the chlorite bands is suggested, unless they come in partly where exposures are wanting or beds disturbed. Further west, the rocks are exposed in roadside cuttings, one at Lower Batson, and one to the north of it close to a phyllite outcrop, and also along the shores of Batson Inlet. Here the eastern cliff has an extensive development of mica-schist, but part of it, much gnarled and contorted and with a changed dip, may possibly have cut out, by faulting, the chlorite-band, which would otherwise have continued to this place from the western shore and from the lane by the cemetery. The general dip is northerly or to the west of north, varying from 35° to 80°, but often at about 60° to 70°.

1. (*b*) *Chlorite-Schist of Scoble and of Snapes.*—To the south of the interbanded series, on both sides of the main estuary, a thick bed of chlorite-schist has resisted the action of the water and still projects in the opposite headlands of "Scoble" and of "Snapes." This chlorite-schist is closely and evenly laminated, very firm, at places so compact as to be almost flinty in appearance, and has altogether a squeezed look, which is confirmed by the microscope slides that I have already described.

Salcombe and Southwards.—This chlorite-schist seems to strike to the northern part of the large mass on which Salcombe is built, and of this there are exposures, as Professor Bonney has described, as far south as an alley beyond the Ferry. Southward from this alley, at an exceptionally low tide, I was able to scramble along the shore, and found the cliffs, nearly to the Old Castle, to consist of mica-schist, folded and contorted and nearly vertical, but striking boldly out to the north of east. As the road on the top of the hill, after leaving Salcombe, cuts most of its way through mica-schist, of which rock there is one quarry by the road and two on the southern slope overlooking North-Sands valley, it would seem probable that to the south of Salcombe the hill mainly consists of the mica-formation until we come to the chlorite-schist forming the foundation of the Old Castle ruin and worked in the quarries near North Sands. Here I would suggest the possibility of a faulted junction, and of a southerly pressure overturning the chlorite and some interbanded beds, and thrusting them against the mica-schist. There seemed some grounds for the idea in the aspect of the cliffs between the Old Castle and North Sands—the beds are disturbed, contorted and broken, and form a wild scene of rugged points of cliff, worn into caves, and weathered irregularly to yellows and reds, the brighter colours of decomposition; the beach is a piled-up mass of

huge fallen blocks. The dip of these beds varies, but on the whole seems to incline southerly at one spot, being to W. of S. at quite a low angle, about 30°, while the mica-schist to the north, as I have said, seems nearly vertical, or with a high dip towards the north. Moreover, opposite the Old Castle is a good junction, which may mark, if not the main fault, a minor break connected with it, where the chlorite rock with a dip to W. of S., much jointed and marked by cross planes, overlies mica-schist with a dip to E. of S.; the true nature of the latter is almost concealed by the uniform deep red tint which it has assumed in decomposition (fig. 3). If this chlorite-

Fig. 3.—*Cliff opposite the Old Castle near Salcombe.*



a. Mica-schist, massive, of deep red colour.
b. Chlorite-schist.
F. Line of fault (?).

schist and these interbandings have been thrust northward, the chlorite-rock, which occurs in a lane from north of South Mill to north of Combe, might possibly represent the same mass, whose outcrop had been carried further north out of its proper line of strike; but the beds in this inland exposure seem less disturbed and retain their northerly dip where I had opportunity of testing it.

I was able, during the same favourable tide, to traverse hastily the shore from North to South Sands, passing from the southerly dipping chloritic rock, over the beds marked by Prof. Bonney as showing much disturbance. They consist of a rather thick mass of mica-schist, agreeing in strike to N. of E., but with an almost vertical dip and much folded, possibly bounded on the south by a small fault, where there follow, first, chlorite-beds nearly vertical and with variations of dip, and then, as far as South Sands, interbandings of chlorite- and of mica-schists, exhibiting a southerly dip. The mica-schist in these cliffs beneath Molt agrees in its appearance with the larger masses occurring to north and to south; but the greatly diminished thickness would be difficult to explain on this hypothesis, and I incline to consider it a lower band appearing beneath a fold of the chlorite-schist.

2. *Mica-Schist, with* (?) *Interbandings.*—Turning back to the district beyond Scoble Point, we find, south of its chlorite-schist, mica-schist rising and extending very continuously along the northern

shore of the side estuary, being possibly part of an interbanded series, the remains of which to the south still occur along the opposite shore. The mica-schist strikes in the common direction of N. of E., and has often a high northerly dip; it is mostly nearly vertical and much folded. At places the dip varies, and the beds have a squeezed look, rather like those in the mica-schist point up the estuary. From the uniform direction of strike, the mica-schist is cut very obliquely by the shore, which trends eastwards from Scoble; but, bounding a small inlet in this shore, a cliff occurs, which cuts across the beds; although much weathered and overgrown, we can see that they consist of similar mica-schist. In this side estuary, the southern shore, passing Portlemouth Parsonage, exposes interbandings, some of only a few feet, some thicker. The rather massive chlorite-schist, which is quarried near the old limekiln, is of such small extent that I place it and also the chlorite-schist of the cliff north of Portlemouth Ferry as a subordinate part of this series. The dips of the latter mass of chlorite-schist rather vary, but the rocks of this series have a general dip to the W. of N.

3. *Mica-Schist (of Portlemouth Ferry).*—They would thus probably overlie the large mass of mica-schist found along the shore to Portlemouth Ferry and beyond, which has previously been described. Similarly, this interbanded series, dipping northerly, seems along the estuary shores to overlie mica-schist, about a quarter of a mile north-west of Good Shelter. The schist, with one rolling over, dips northerly, although towards Waterhead it seems to change, but is not well exposed. The mica-schist is also traceable inland near Portlemouth church, and at places along the lanes south of Waterhead estuary, notably near Hawkshead. The strike here is well marked, still to about 10° N. of E., and the dip is about 70° to W. of N.

Estuary shores southward of South Pool.—Passing now to exposures further eastward, we have rather more difficulty in deciding their relations. First, in completing our survey of the estuary shores, we find along the arm descending from South Pool, south of the phyllites already noted there, exposures of chlorite- or interbanded schists; these extend southwards, and form the point east of Westercomb, and also the cliffs of the opposite shore north and south of Gullet. The beds are partly normal chlorite-schist, such as those quarried opposite Gullet, partly mica- and micaceo-chloritic bands, resembling those obtained from the main estuary.

Parts of these beds are rather out of the direction of the strike of chlorite-schist from the westward; but this, I think, might be from a faulting of the district. The slickensided look in the mica-schist of the point opposite Westercomb, the changed, variable and high dips of the Gullet beds and those opposite, all seem to support the idea of faults having broken the country near. Such faults may have partly determined the lines of the estuary. If we suppose these chloritic beds to be equivalents of the Scoble-Point rocks, and to have been partly displaced to the southward, then there is some difficulty in accounting for the mica-schist, which forms the cliffs nearly all the way from a little south of Gullet around the projecting

point and up the estuary branch to Waterhead. It seemed possible, however, that the rocks had been thrust northward and that the mica-schist might belong to the mass occurring at Good Shelter, stretching westward, and probably, as we shall describe, eastward also.

The Point, which projects where the two branches of the estuary join, is occupied by mica-schist much folded, varying in dip, often nearly vertical, and so crushed and slickensided that small fragments have quite a phyllite look; indeed they split up into thin folia, so as to be almost describable as "papery." About one third the distance from the point to Waterhead along the northern shore, these schists pass into mica-schist of more usual character, folded and gnarled, but dipping steadily to the W. of N., with one interbanding of chloritic beds.

Inland, eastward of South Pool.—Eastward of South-Pool estuary, we can trace the beds which are successively cut out by the faulted junction, and which probably form a downward succession. With the exception of the chlorite-schist which occurs first, whose disturbance we may possibly correlate with that of the beds near Gullet, these inland exposures show a general dip to the N. or W. of N. Near Wilton and eastward of it, chlorite-schist occurs exposed by roadsides and in several quarries; the dip is not altogether uniform, especially at places approaching the boundary line, but is partly in the general northerly direction. Next, underlying, is a mass of mica-schist cropping out around Chivelstone, at and northward of South Allington, and cut by the main fault at Killington, having a uniform strike and northerly dip. There is evidence of chlorite-bands occurring at places in the mica-schist. I would venture to suggest that, possibly, this mass may be a continuation of the Portlemouth-Ferry schist. Underlying the mica-schist, chlorite-schist again occurs (including some mica-bands) at Bickerton, and is quarried on the south of the valley to the eastward.

Summing up the succession in this northern area we seem to have, in descending order, as shown in the annexed section (fig. 4), which is only diagrammatic :—

1. (*a*) Interbanded series, found south of Halwell Wood, and on the opposite shore, also near Lower Batson.

(*b*) A thick band of chlorite-schist, at Scoble and at Snapes Point, west of Batson inlet and extending beneath Salcombe. On the coast this might be represented by the Westercomb-Point and Gullet rocks and by those near Wilton and eastwards, but I rather prefer to place these with the interbanded series, 2 (*b*).

2. (*a*) Mica-schist north of the side estuary.

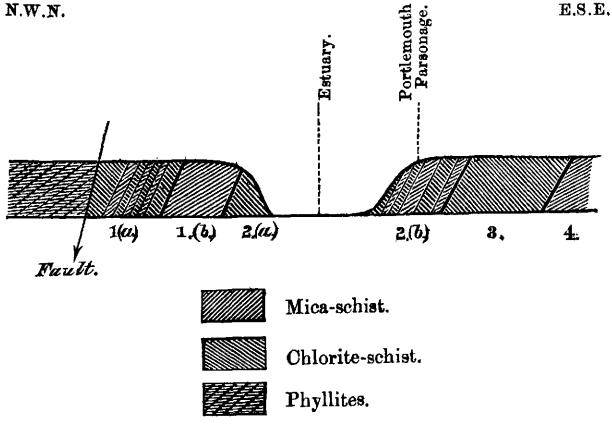
(*b*) Interbanded series (including one or more marked masses of chlorite-schist) remaining on the southern shore of the side estuary, doubtfully including the Westercomb, Gullet, and Wilton rocks.

3. Mica-schist of Portlemouth Ferry and of inland exposures occurring near Good Shelter and Waterhead, possibly including the rocks of the point south of Gullet, and probably continued in the Chivelstone, South Allington, and Killington exposures.

4. Chlorite-schist of Bickerton, which I have not attempted to

trace westwards, so that its presence in the line of the annexed section is inferential.

Fig. 4.—*Generalized Section across the Eastern Arm of the Estuary.*



IV. Summary.

I. As to the relation of the South-Devon schists to the adjacent rocks, all observations which I have been able to make support Prof. Bonney's statement that the slaty beds are markedly distinct from the true metamorphic rocks to the south, and that there is no evidence of progressive metamorphism in this district.

II. I have indicated some additional illustrations in these metamorphic rocks of the results following from the action of secondary forces. That both the chlorite- and the mica-schists, however originally formed, had been later affected by lateral pressure is shown in Prof. Bonney's paper, where he several times alludes to the crushing of the one series and the crumpling of the other. The indications of a folding of layers in chlorite-schist are but rarely exhibited with clearness; but such structures as the transverse planes locally occurring, the pitted weathering, and the "arenaceous aspect" alluded to by De la Beche, seem partially due to the effects of lateral pressure. In other examples there is a compressed look, evidencing apparently similar force differing in direction. The microscope has given additional evidence of the crushing of the chlorite-rock, shown in the breaking up of quartzose layers, the fracture of individual crystals, and the appearance of much secondary mineralization; while a squeezing of the beds is indicated by the pressed-out form of the layers and the elongation of their constituent grains. In mica- and micaceo-chloritic schists the pressure to which they have been subjected has resulted in a crumpling of the layers, often in the formation of strain-slip cleavage-planes exhibited in hand-specimens and under the microscope, and at places has given rise to slickensided, crushed and even papery schists. The larger

effects of pressure are seen in the general folding of the beds with a dominant strike from east to west, and in the high dip of the strata, sometimes even vertical, thus indicative of a great thrust along a S. to N. line, no doubt in connexion with that which caused the folding of strata in the long axial region, stretching from Devonshire away to the Hercynian range.

III. In tracing stratigraphical relations among the northern metamorphic rocks, I have pointed out extensive examples of interbandings there occurring. Mica- and chlorite-schists alternate in thin layers or thicker beds over a fairly large area in the north, as they do also, perhaps more locally, in other parts, reminding one of the descriptions given by Prof. Bonney, in his Presidential Address *, of rocks in more than one locality, where he asserts the necessity of some material distinctions in the original beds. The mineral bands in these South-Devon rocks may be of an inch or a few inches in width, but often they are to be measured by feet, and, as I have shown, the alternating and generally even-bedded series south of Halwell Wood consist of masses, on an average, some 50 feet thick. The limit of each bed is often abrupt and distinctly marked off from the next in succession, although many gradations can be obtained by collecting from particular and often separated areas. If it should be that we have here an example of a stratification-foliation, this will lead us back to an anterior epoch when the great Channel mountains were not, and will suggest to us the wide problem of the origin of these rocks and the question of a primary metamorphism.

I cannot conclude without expressing my indebtedness to Prof. Bonney, not only for the help his paper afforded me, but also for valuable suggestions and kind encouragement in this endeavour to carry on his work in the south of Devonshire.

* Quart. Journ. Geol. Soc. (1886), p. 46.