extent being limited to the difference between the measurement of the portion of the earth's circumference and the Chord of its Arc included in any area referred to. This variation will be found comparatively so slight as to be utterly inadequate to account for the presence of such foldings as occur in many districts; though it is to such a cause they are not infrequently attributed. The impossibility of these contortions being the result of such subsidence may be best illustrated by taking two slips of wood (Fig. 1 *a, b*) of equal length—say 10 feet—fastened together at one end by a hinge (*c*); one (*a*) being fixed so as to remain straight, the other (*b*) bent to represent a curve, the greatest distance (*d*) between the chord (*a*) and the curve (*b*) being six inches; it will be apparent that the distance between the extremities of the slips of wood will be very slightly over three-quarters of an inch (*e*); an amount too insignificant to be

capable by the pressing down of the one upon the other to form foldings such as are frequently met with in geological formations.

(To be continued.)

II.—NOTES ON ALTERED IGNEOUS ROCKS OF TINTAGEL, NORTH CORNWALL.

By W. MAYNARD HUTCHINGS, Esq.

IN the autumn of 1887, during a stay in North Cornwall, I paid a hasty visit to Tintagel, and took away a few specimens of rocks, without, however, having time or opportunity to examine more than very superficially into their field-relationships.

In subsequently studying sections with the microscope I found myself unable to correctly interpret some of them, notably a certain highly schistose rock consisting mainly of calcite and chlorite, with residues of triclinic feldspars. Mr. Teall, who very kindly looked over several sections for me, suggested that this was a highly altered and mechanically metamorphosed igneous rock, which might prove to be derived from a certain epidiorite occurring not far from it; and made other remarks and suggestions which decided me to pay another and longer visit to Tintagel in the following year.

As a result of this visit, and the subsequent examination of a series of rock-specimens then collected, I venture to offer a few notes on the altered igneous rocks of the coast in the immediate vicinity, viz. from a point near Boscastle to the south end of Trebarwith Strand.

The more or less altered "Greenstones" of the coast further south have been studied and described to a considerable extent. A résumé of the work done is given and discussed in Teall's "British Petrography." So far as I am aware, the corresponding rocks of

the more northern part of the coast have not received a similar amount of attention.

Referring to the map of the Geological Survey of the district, we find no occurrences of "Greenstone" marked along the coast, or its immediate vicinity, from the neighbourhood of Port Isaac to that of Tintagel, where several outcrops are indicated, extending along to near Boscastle, where we pass from the Devonian to the Carboniferous rocks. There are, however, other prominent occurrences of greenstone around Tintagel which are not shown on the map, notably the very extensive exposure at Trebarwith Strand which is alluded to by De la Beche in his "Report of the Geology of Cornwall, Devon, and West Somerset" (1839).

In this report there are several references to the igneous rocks of this special strip of the coast. Thus, on pp. 56 and 57, Beche speaks of "schistose beds" which are intermingled with the "slates and grits which emerge from beneath the Carboniferous system," and describes these schistose rocks as "strongly reminding us of the substance of greenstone, finely comminuted and permitted to settle in water in which calcareous matter was occasionally present." He states that "greenstones, some large-grained, occur near Tintagel, and the trappean schistose rock is also discovered mingled with them, particularly towards Bossiney."

He looks on the "schistose trappean rock" as an altered ash, and considers that the two kinds, compact and schistose, have "probably been erupted, one in the state of igneous fusion, and the other in that of ash, during the time that the mud now forming slates was deposited."

This sharp distinction made by Beche between the compact and schistose rocks of this neighbourhood, and the definite inference he draws as to their different conditions of origin, would not now, with modern methods of examination, hold good in all cases. Passages of his "large-grained" or "compact" greenstone into the most highly schistose rock may be observed which leave no doubt that the original material was one and the same for both.

There are other occurrences of schistose rock whose origin we may safely say was igneous, but concerning which, in their present extremely altered condition, we could not arrive at any safe conclusion as to whether they have been derived from massive or fragmental material.

The occurrence which I will first notice is seen in the cliff at the side of a cove which is not named on the map, and of which I heard no name on the spot. It is the next little inlet south of Bossiney Cove, separated from it only by the neck of land off which lie the rocks called "The Sisters." The exposure in question is at the south side of this nameless cove. There is an outcrop, at the surface above the cliff, of angular craggy blocks, and the continuation may be seen dipping steeply down towards the sea. At the outcrop the rock is coarse-grained and massive, showing no foliation at all. It is very hard and tough, making excellent road-metal, for which purpose it is taken in quantity from a similar outcrop in a field a

little way off. Numerous large irregular grains of hornblende are seen set in a greenish-grey speckled mass. It is doubtless an example of the "large-grained greenstone" alluded to by De la Beche.

A little way down the cliff the rock becomes much foliated, is much altered in general appearance, and is softer; and still further down, near the water, it has become very highly schistose, tolerably soft and easily fissile, differing in appearance in every way from the rock at the outcrop. Foliation is coincident with the dip and with the cleavage of the slates, shales, etc., above and below.

Specimens were taken at three points: No. 1, outcrop; No. 2, a few yards down the cliff; No. 3, near the bottom, a few yards above the level of the sea. Microscopic examination of sections from these specimens shows internal changes corresponding to the outward differences in texture and general appearance.

No. 1 is essentially a hornblende-plagioclase rock. The hornblende is all green, secondary and uralitic. It is mostly pale in colour with very moderate pleochroism, but some portions are of a much deeper colour and powerful pleochroism, the contrast being often seen in contiguous parts of one individual, one portion being nearly colourless, and the other a very deep green, though they extinguish together and give nearly the same colours of polarization.

The felspar is nearly all very turbid, but the columnar form of many of the crystals is still perfect, and they are still fresh enough to show twinning, binary and multiple. The structure of the original rock is shown to have been markedly ophitic by the fact that many of the individuals of hornblende are penetrated by felspar crystals, in some cases being nearly bisected. Crystals of apatite are seen here and there. There is comparatively little chlorite or calcite, but epidote is abundant, both in finely granular form in the hornblende and in crystals and irregular fragments and grains all over the sections. It is all quite colourless and non-dichroic. Leucoxene is plentiful in large plates and patches surrounding varying amounts of residual ilmenite; and some granular sphene may be seen. There are grains and little patches of secondary quartz, and a very few bits of perfectly water-clear, obviously secondary felspar, without any trace of definite form or of twinning, recognized by its optic behaviour.

This rock is a typical epidiorite, of which we may say with tolerable certainty that it was derived from a coarse-grained ophitic dolerite.

Sections of No. 2 show that hornblende is much diminished in quantity, with a corresponding increase in chlorite. All stages may be seen of the passage of the hornblende into chlorite. Calcite is also very much increased in amount.

The felspar is largely in the state of a confused, crushed, turbid mass mixed up with chlorite, without any form or sign of twinning, but with this there are a very large number of bigger grains and patches which are water-clear and contain needles of hornblende in some cases, together with numerous grains of chlorite. But few of these water-clear bits show any twinning. Quartz has increased

also considerably in amount. Leucoxene and epidote remain in about the same proportions as in No. 1.

But it is more the mechanical than the chemical or mineralogical change which is very striking in this part of the rock. It has become very much foliated, and sections cut across the schistosity show in a beautiful manner what a great amount of stress and internal movement it has undergone. The chlorite is drawn out into long, curving parallel bands and streaks, and most of the calcite and leucoxene have been squeezed out into long lenticles, tapering off into thin tails. Hornblende also is crushed into layers, but in a less degree, and much of it is now in the form of detached needles and fibres. Epidote has not been drawn out into streaks, but is more broken up and separated and more or less arranged in lines; and the irregular bits of this mineral lying in among the bands and lenticles of the other constituents which have behaved more plastically, often serve to more distinctly mark the amount of "flow" which has taken place around their angles. It would be difficult, I imagine, to find anywhere a more striking example of the great alteration which may be effected in rock-structure by pressure and shearing-movement than is here given within a space of some thirty yards or less.

Sections of No. 3 show that hornblende has wholly disappeared, chlorite taking its place. Calcite is more abundant than in No. 2, while epidote is nearly wholly absent. It may be stated that over a large number of sections of rocks of this district which I have examined, calcite and epidote very generally appear in inverse proportions. They are, of course, very liable to be *originally* developed in inverse proportions. They both originate from the alteration of the same calcareous silicates, and varying conditions under which this alteration is carried on may give rise to varying amounts of the two minerals in question, even in closely adjoining parts of a rock. But it seems not unlikely that epidote may be altered into calcite under some circumstances. I have seen no mention of this, nor have I detected any epidote actually undergoing the change to calcite. Nevertheless, the frequent oscillation in the relative amounts of the minerals in these rocks has constantly suggested such a change, which is likely enough from a chemical point of view, as a possible explanation.

The most striking change in No. 3, as compared with No. 2, is that turbid felspar has now almost entirely given way to water-clear. Much of it here shows twinning. It is more or less full of bits of chlorite, and other mineral enclosures which cannot be determined. Quartz has undergone a further very decided increase. Leucoxene is still abundant, but some patches of it are seen to be very much altered to rutile in grains; and small crystals of rutile, some as sphenite, are abundant in some parts of the chlorite. The foliation is seen to be more highly developed, the parallelism of the bands of chlorite, etc., being greater, and their course less curved and wavy, which corresponds with the much greater tendency of this part of the rock to split into flattish pieces.

I may here mention that it was a section of this schist which Mr. Teall saw, together with a piece of the epidiorite, though from another outcrop. His suggestion that they might prove to be directly connected in derivation was made at the time without the slightest knowledge of the actual field-relationships, but has proved to be perfectly correct.

We have here, then, a very interesting case of the passage of a massive epidiorite into a perfect chlorite-schist; and doubtless a further series of specimens, taken at shorter intervals, would prove very instructive.

This sheet is of but moderate thickness—a few feet only. It appears to be separated from a very much thicker sheet, which underlies it, by a bed of shale or slate, the contact with which is well seen at the lower part of the cliff. Concerning the question as to whether this and other sheets of igneous material to which I shall allude are intrusive or contemporaneous, it seems that De la Beche regarded them all as being the latter. So far as my own observation goes, I should incline to hold the same opinion, at least as concerns those exposures where a considerable extent of the upper and lower contacts with the slates, etc., is plainly visible. But I would express this opinion with much diffidence, in view of the great disturbances which have everywhere taken place in this district, and the great amount of alteration the rocks have undergone.

The sheet just considered appears to follow the curve of the coast and to wind round towards Barras Nose and the Castle Cove; but much of the intervening shore is inaccessible and examination could not be made. About two-thirds of the way towards Barras Nose there is another outcrop of chloritic epidiorite, intermediate in nature between No. 1 and No. 2.

In the Castle Cove is exposed a sheet of rock which I am inclined to think is very likely a continuation of the one just described, though it is not possible to trace the connection to the point of proof. The nature of the rock is here different in many respects, but nothing is more striking than the considerable and often rapid changes of character which the igneous rocks of this district show. The sheet I allude to is seen on both sides of the Cove. On the left it is inaccessible in the cliffs of "Tintagel Head," but on the right it may be freely examined. It overlies a bed of black shale, with which its contact is sharply defined;—the same bed of shale which, curving steeply upwards from the Cove, passes right under a portion of the "Mainland," part of the Castle. So that originally this sheet of igneous rock swept up over the country inland, but is now wholly removed by denudation. As seen at the right-hand side of the cove, where the fishing-boat is hung on davits, it is a hard, grey, rather fine-grained, moderately-foliated rock. It is a good deal jointed and cracked, and all these cracks are filled with quartz. This is the only case in the district of an igneous rock being veined with quartz instead of the usual calcite.

The microscope shows it to consist mainly of felspar and chlorite, without any trace of original ferro-magnesian mineral or of secondary

hornblende. The felspar is much the predominant constituent, and part of it is better preserved here than in any other local rock I have examined. Much of it is again in the indefinite and untwinned water-clear condition, but with this there are a great many well-twinned crystals of columnar form. Binary twinning is most prevalent. A series of measurements of maximum extinctions shows that much of the felspar belongs to the labradorite-anorthite group, though more acid felspars seem to be present, most likely of secondary metamorphic origin. Chlorite and calcite are in only moderate amount. Secondary quartz is tolerably plentiful, both in grains of good size and as a mosaic of smaller ones. Leucoxene with residual ilmenite, granular sphene, a little epidote, apatite, small flakes of biotite, and rutile in slender needles, and bunches of needles go to make up this rock. Bent and broken crystals of felspar, and strongly undulous extinctions both of felspar and quartz, bear witness to severe strain. The fact that much of the quartz shows these effects of stress goes to prove that the rock was very much altered before this stress was applied.

In the centre of the Cove, almost under the waterfall, another exposure of igneous rock is seen, quite at the bottom of the cliff. The extent of it visible is small. It makes the impression of being the upper part of a curve or fold of a sheet. If this is so, and supposing the sheets to be contemporaneous and not intrusive, this rock is older than the last described, considerable thickness of sedimentary material intervening. This rock is very schistose. It is highly altered, very little of its abundant felspar having any definite form as compared with the last. Calcite, chlorite and quartz are in large amount, there is also much ilmenite in various stages of alteration to leucoxene, and many of the large patches of chlorite are full of beautiful sagenitic rutile.

Again, passing from the Castle Cove by the path between the mainland and the so-called "island" of Tintagel Head, and descending to the shore below the steep west cliff of the mainland part of the Castle, we come upon a section of several sheets, or bands, of igneous rocks of various thickness, with intervening black shale. The upper sheet is some feet in thickness, then comes a bed of shale in which are two or three sharply separated bands of igneous rock of a few inches only, and finally a lower sheet of which some four to six feet are seen. They are only exposed for a few yards. It is not possible to make out anything with certainty, but very probably the upper portion of this exposure is connected with the rock seen near the waterfall in the Castle Cove.

I have examined specimens from the upper band of the series. It is again a very schistose rock. Microscopically it is interesting because it contains a good deal of what may undoubtedly be considered to be *original* igneous structure. The felspar, very abundant, is partly turbid and partly water-clear, and all the larger individuals are more or less full of flakes of muscovite. Crystal forms are well retained, and twinning, both binary and multiple, is very little obliterated. Tabular crystals are most numerous, but columnar

shapes are also well represented. Besides the large crystals, however, there are a considerable number of much smaller lath-shaped feldspars. These are all water-clear, well twinned, and quite fresh as to optic qualities. They all extinguish at very small angles. There is no sign of any original ferro-magnesian mineral, which is now only represented by abundant chlorite. There is much leucoxene; but little sphene or rutile. Broken, bent, and optically strained crystals are in plenty here as in the other rocks.

The two rocks of the Castle Cove may have resulted from the alteration of either massive or fragmental igneous materials; the microscopic study of them does not afford sufficient evidence for decision one way or other. But the structure of the rock just described seems plainly to show that it was a massive one, its numerous larger feldspars set in a ground-mass of which the smaller lath-shaped crystals formed part. It was probably a basic rock, though much of its feldspar seems now altered, by dynamic metamorphism, to mere acid forms.

The main occurrence of altered igneous rock in this district, however, is on a very much larger scale than any of those above described, and forms, indeed, one of the principal features of the coast at some parts of the parish of Tintagel.

(To be concluded.)

III.—ON THE BALLANTRAE ROCKS OF SOUTH SCOTLAND AND THEIR PLACE IN THE UPLAND SEQUENCE.

By PROF. CHARLES LAPWORTH, LL.D., F.R.S., F.G.S.

(With Plate III. and a folding Table extra.)

(Concluded from page 24.)

Part II.—The Sequence in the Southern Uplands.

NEXT to the metamorphic region of the Northern Highlands there is perhaps no area in Britain where the strata have been so contorted and convulsed as in the great Lower Palæozoic region of the Southern Uplands of Scotland, and it is only by the zonal method of stratigraphy that these complexities can ever be successfully unravelled. So far as the present results of the application of that method enable us to judge, it appears that, underlying all these stratigraphical complexities, there is, in reality, a broad tectonic structure of great simplicity. For, if we make exception, on the one hand, of the lowest strata (the *Ballantrae* or *Arenig* rocks), which, as we have seen, only rise to the surface within the limits of the Ballantrae district; and on the other hand of the highest formations (*Wenlock-Ludlow*), which merely skirt the Upland plateau upon its north-west and south-west flanks, we find that almost the whole of the Lower Palæozoic strata of the Uplands are naturally grouped in two grand lithological terranes, viz. (I.) a *Lower Terrane* (*Moffat Terrane*), including strata ranging from the Upper Llandeilo to the Upper Llandovery; and (II.) an *Upper Terrane* (*Gala or Queensberry Terrane*), embracing strata generally of Tarannon age.