THE ROCKS OF THE NEIGHBOURHOOD OF PLYMOUTH AND THEIR STRATIGRAPHICAL RELATIONS.

BY R. N. WORTH, F.G.S.

(Read at Exmouth, August, 1883.)

IN a paper read by me at the Totnes meeting of the Devonshire Association* I announced the discovery of the gneissic character of the Shovel Rock, in Plymouth Sound, in the following terms:

"Some twelve years since . . . an isolated fort was erected immediately within the Plymouth Breakwater on the Shovel Rock, and in the course of the work portions of that rock were removed. Some of them were preserved, and a few months since passed into my possession, when I was astonished to find that they were as distinctly gneissic in character as the most gneissic of the Eddystone examples."

In May, 1882, I had the pleasure of replying to certain enquiries made by Mr. Pengelly, F.R.S., concerning the history of these specimens, and my answers were embodied in a paper read by him before the Association last year at Crediton—"Notes on Notices of the Geology and Palæontology of Devonshire," part ix., as follows:

"Mr. Worth did not personally detach the specimens of gneiss from the Shovel Reef, nor was he present when they were detached; but two of the officers of the Royal Engineers engaged in superintending the construction of the iron-cased Fort built upon the Shovel Reef, immediately within the Plymouth Breakwater, gave them to Mr. Haldane, Librarian of the Public Library at Plymouth, as part of the rock that had been removed in clearing away a portion of the reef for the foundation of the Fort. The Plymouth Library having no museum, Mr. Haldane deposited the specimens in

* *Trans. Devon. Assoc.* xii. 362.

a cupboard, whence they were never moved until some years after, when he took them out himself to show to Mr. Worth, who had expressed a wish to see them, and to whom he at once gave them."*

Specimens of the gneiss were given by me to Mr. A. R. Hunt, F.G.S., and to two or three other gentlemen, and I had no reason to question the accuracy of the assignment of locality until Mr. Hunt, early in the present year, kindly wrote me that attempts which he had made to obtain other specimens in connection with his important enquiry into the submarine geology of the Channel area, had led to his being informed that the Shovel Reef was not gneissic at all. Portions were variously stated to consist of slate, of limestone, and of dunstone; but the evidence, so far as it went, distinctly negatived the occurrence of gneiss in connection with the foundations of the Fort.

I need hardly say that this courteous but unwelcome intimation carried with it a plain duty, and that I at once commenced to re-examine and test the evidence for the existence of gneiss in the Shovel Reef, and to make such further investigation as was possible.

Three things were clear—(1) The rock fragments were gneiss; (2) from the organisms upon them they had come not merely from a marine, but from a submarine source; (3) they had unquestionably been received by Mr. Haldane (whose kind interest I cannot too heartily acknowledge) as from the Shovel Reef, the only point open to doubt being whether the two gentlemen from whom he received them were *civil* engineers or *royal* engineers, as they were dressed in plain clothes. Mistake on his part, or deception on theirs, as to the specimens being alike out of the question, the historical proof seemed incontestible.

I looked therefore for material corroboration. Enquiry at once proved that there was no chance of investigating the actual foundations of the Breakwater Fort. It was equally clear that no part of the Shovel Reef beyond the limits of that foundation could be examined without a diver. The reef itself is nearly three-quarters of a mile long, striking east and west; at its widest part is some half a mile broad; and the least depth of water upon any part at low-water springs is eighteen feet, ranging up to thirty.

It then occurred to me that some clue might be obtained by a careful examination of the rocks on either shore of the

* *Trans. Devon. Assoc.* xiv. 646.

Sound on the horizon of the Reef and Breakwater. This too proved hopeless. At no point within the Plymouth area is there so much contortion and displacement as at Bovisand, and I soon found that if the shore beds kept their apparent direction across the Sound,* the reef in whole or in part might either be clay-slate, or grey or red grit, or limestone, or shale of different kinds, or the "dunstone" which Mr. Prideaux noted fifty years since as heaving the sandstone and slate of Staddon Point "saddlewise." Investigation at Mount Edgcumbe revealed a similar state of things there, with the possible, though not probable, addition of the extension of the Triassic trap at Cawsand, or even of a reappearance of the accompanying Triassic conglomerate. It was thus impossible to predicate from the shore of what rock any particular portion of the Reef was composed, while it was quite certain that unless the conditions below water were wholly different to those above, the Reef did not consist of one rock, but of many, including patches of very limited area.

At this stage in the enquiry, and just as I was thinking of working a vein of collateral evidence that my shore searches had indicated, a friend kindly enabled me to put myself in communication with Mr. Darnton Hutton, C.E., the gentleman under whose superintendence the foundation works of the Breakwater Fort were executed, and who is therefore qualified to speak with the most absolute authority.† He most kindly replied to my letters, and has thus completely dispelled any idea that the portion of the Reef on which the Fort stands is gneissic. He writes:

"The rock on which the centre and south portion of the Fort are founded consists of clay-slate, dipping towards the south-west at an angle of 52 degrees. It was believed when the contract was entered into that the whole of the foundation was of a similar character; but on a closer examination, after the removal of the mud, it turned out that the bottom on the north side consists of a crust of rock from 1′ 0″ to 2′ 6″ thick, overlying a bed of drift sand and pebbles, interspersed with layers of loose rock and some clay."

In reply to further enquiries, Mr. Hutton stated that the Reef was examined by him only as far as the site extended; but he "found nothing of a gneissic character there, nor anything to lead me to believe that the Reef changed to gneiss

* Captain Walker, in 1841, showed that there was evidence of continuity for the grits at the bottom of the Sound, more to the north.

† As part of the system of Plymouth Fortifications, the whole was under the general control of Colonel Cunliffe Owen, R.E.

further on, the strata under our observation being (with the exception of the loose crust on the north side) regular and homogeneous." To explain the nature of the "crust of clay-slate on the north," Mr. Hutton enclosed a copy of a boring, which is of a very interesting character, and which carries us back to the time when the Reef was an island bar, and the now submerged forests flourished on the adjoining shore.

BEDS.	THICKNESS.	DESCRIPTION.
1	1 ft. 5 in.	Crust of loose rock.
2	2 ft. 9 in.	Sand and gravel.
3	1 ft. 2 in.	Hard crust.
4	1 ft. 6½ in.	Very soft; bar went down almost with its own weight.
5	9½ in.	Hard crust.
6	8 in.	Apparently sand.
7	3 in.	Coarse sand and pebbles.
8	2 ft. 5 in.	Soft rock; 30 blows from a heavy hammer drove the bar in, on an average, 8 inches.
9	.....	Hard rock; 36 blows from a heavy hammer drove the bar in, on an average, 3 inches.

There is variety enough here in a total depth of less than twelve feet.

Mr. Hutton is "much disposed to believe that some error had been made in the locality from which it [the gneiss] was supposed to have come."

To this I have only to add, before I pass on to my positive branch of evidence, that I have heard of other specimens of the "Shovel Rock" being in existence, preserved, like those in question, on account of their unusual character, but that I have been unable to trace them. "Rock" and "Reef" are used interchangeably in common parlance when speaking of the "Shovel."

It is now clear that the specimens could not have come from that portion of the Reef on which the Fort is built. I think, however, that no geologist who is acquainted with the locality will hold that this fact conclusively proves that they did not come from some other part of the Reef.

Gneiss is a metamorphic rock. Are there any traces of metamorphism in the vicinity of the Reef?* Metamorphism is frequently associated with upheaval. Is there any evidence of disturbance in the same locality?

I. *Is there any evidence of metamorphism on the shores of Plymouth Sound on the parallel of the Shovel Reef?* Mr. Hunt, arguing "that the Shovel and Eddystone and their corresponding granites are of pre-Devonian age," speaks of the Devonian rocks of Plymouth Sound as "quite unaltered, and exhibiting no trace of the immediate neighbourhood of such a large area of granites and gneisses."† Mr. Pengelly, commenting upon the evidence in support of the metamorphosis of the Shovel Reef in pre-Devonian times as "utterly inadequate,"‡ has pointed out that the existence of metamorphic rocks in the Shovel Reef by no means encourages the "expectation of detecting any traces of metamorphosis of the rocks forming any part of the coast of the Sound," on the score of the distance between it and them.§

In this opinion Mr. Pengelly of course by no means excludes the idea that traces of metamorphic action may not be visible, and as a fact I believe they are. It is quite true that, with regard to the western shore of the Sound, the alterations traceable in some of the beds of grit, the silicification of some of the thin layers of slate, and the occurrence of talcose schist, are somewhat doubtful, and may be due to the action of the intrusive Triassic felspar-porphyry of Cawsand, which has clearly thrown the grit beds to the north.

* If the Eddystone and Shovel gneisses, as such should be proven older than the Devonian era, they could of course have no connection with the metamorphosis of Devonian rocks; and we should then have two causes and periods of metamorphosis to deal with instead of one. The probability that the metamorphosed rocks that now constitute this Channel gneiss were older than the Devonian epoch does not affect the argument, since one cause of metamorphosis may operate upon rocks of widely different dates; and in any case we have to deal with disturbances of later than Devonian times. Nor does there seem adequate reason for assigning to our ordinary submarine granitic and granitoid rocks a date which would dissociate them from the granites of the mainland. As will be seen, the evidence indeed points quite the other way.

† *Trans. Devon. Assoc.* xiii. 169.

‡ *Trans. Devon. Assoc.* xiv. 648-9.

§ On this see *post*—the St. Budeaux granitoid rocks.

We cannot, however, account thus for the highly quartzose and fissured character of certain of the grit beds of the Staddon series, some of which, moreover, are not only very micaceous throughout their structure, but have a hard micaceous glaze. The evidence may not be very pronounced, but it is quite as pronounced as is probable under the circumstances, and so pronounced as to give the grit series on the east of the Sound a very different aspect from that which it assumes on the west.

It must be admitted that there has hitherto been little if any distinct recognition of metamorphism here, so that Mr. Hunt had very good reason for the conclusion he drew. True, the Rev. D. Williams, in a paper read at the first Plymouth meeting of the British Association, stated of the western shore that the coast from "Redding Point to the great mass of porphyry near the fishing-houses, was one uninterrupted series of varieties of volcanic ash, oftentimes passing into clay-clate, interstratified among the thick red sandstone beds seen on the east and west cliffs of the Sound;" and that he had observed the lower beds of this sandstone "to be traversed by four north-and-south dykes, which cut the beds at right angles, and filled with the same rejectamenta that he had observed to constitute the partings between the sandstone beds. These, he supposed, may have been the vomitories."* But the Rev. D. Williams regarded killas or clay-slate as a volcanic product. And Dr. Boase, writing of the same series, says:

"The most perfect layers of the compact rock [of Mount Edgcumbe] are of an iron-grey colour, of a fine granular texture, crystalline, and very hard: the rock is composed apparently of silica, with a portion of an argillaceous mineral, which is probably a kind of granular felspar, and contains a black mineral, in the form of minute crystalline *spiculæ*, sparingly scattered here and there, which looks like hornblende; but whatever it may be, it is without doubt the colouring ingredient of this rock. Some of the layers are much softer than the last, and are partially decomposed, owing, perhaps, to the felspar being in a larger proportion: they are of a deep red, speckled with white spots, and these coloured parts are sometimes arranged in distinct stripes. The red portion of these strata may be seen in the various stages of cohesion, from that of a hard rock to a state so soft that it will crumble under the pressure of the hand. These rocks may therefore be composed of felspar, quartz, and

* *Trans. Brit. Assoc.* 1841, 62.

hornblende, or an analogous mineral, differing only from the greenstone that occurs further north (nearer the granite) at Saltash and St. Germans, as abounding more in quartz than hornblende. These layers assume various characters, according to the proportion in which the constituents are blended together: thus, those that are quartzose are but slightly affected by the elements." These remarks apply to the rocks on the north of Redding Point; only red sandstone is noted between Redding Point and Cawsand; but "From Cawsand to Rame Head the cliffs are composed of alternate layers of slate, and of compact quartzose rock, the same as those of Mount Edgcumbe." Elsewhere these quartzose rocks are compared with those of Veryan [Lower Silurian], from which they "differ . . . in being more compact and containing less hornblende; the latter being granular, and resembling sandstone."*

Professor Sedgwick and Sir R. Murchison, in their description of the rocks on the east of the Sound, say nothing directly about metamorphism, but note the micaceous character of portions of the sandstone, the frequent occurrence of quartz veins, and the development beyond Crownall Bay to Yealm Mouth of "reddish, greyish, and greenish-grey chloritic slates, with hard quartzose bands and quartz veins,"† all possible but not certain features of *commencing* or rather perhaps *bordering* metamorphism.

Professor Phillips makes no reference that can be at all pressed into the service, save his note of the occurrence of "undulated quartz laminæ between the beds" in part of the Staddon grit series,‡ which affords some evidence at least of *alteration*.

Neither Mr. Pengelly,§ Mr. Jukes‖ (unless we call in his testimony to the existence at Bovisand of silicious grits), nor Dr. Harvey Holl¶ give any evidence of their belief in the existence of metamorphism on the east of the Sound. Nor does Mr. Ussher, the latest writer on the geology of its western shores, note its occurrence there.

It does not, however, follow that, on their attention being called to the point, the existence of traces of what might be

* "Contributions towards a Knowledge of the Geology of Cornwall." By HENRY S. BOASE, M.D. *Trans. Roy. Corn. Geo. Soc.* iv. 215-6, 270.

† *Proc. Geol. Soc.* ii.

‡ *Palæozoic Fossils of Cornwall, Devon, and West Somerset*, 281.

§ "Observations on the Geology of the South Coast of Devonshire." *Trans. Roy. Corn. Geol. Soc.* 1856, 291-297.

‖ *Notes on Parts of South Devon and Cornwall.*

¶ "Older Rocks of South Devon and East Cornwall." *Proc. Geol. Soc.* 1868, 400-454.

metamorphism would have been denied by these authorities, especially if they were asked to account for the enormous difference in composition and general structure between the rocks of the same series east and west of the Sound, and to explain, on any other theory than that of metamorphism, the highly quartzose character of the lower grit beds at Jennycliff and Staddon.

There is, however, a remarkable passage in a paper written more than half a century since by Mr. John Prideaux, which does put on record the belief of at least one geologist in the existence of metamorphic action within the area under consideration, and which seems to have been most unaccountably overlooked. Mr. Prideaux says:

"Flakes of sandstone on the eastern [Staddon] side, eight inches thick and some yards long, copiously veined with white quartz, having slipped off, and lying rolled together for one hundred or two hundred yards along the coast. These rolls look, from innumerable cracks on the convex side, as if they had fallen in a tough state from igneous semifusion."*

While I have carefully examined the coast, and have failed, as was natural, to detect the exact locality—after a lapse of more than fifty years—to which Mr. Prideaux referred, and though I cannot say that any of the numerous flakes of fallen sandstone which I examined presented this appearance, I did find examples *in situ* of what I have no doubt is the same phenomenon, the upper faces of some of the more quartziferous grit beds being broken up by cracks into a kind of rude tesselation, in which an approach to such a rough correspondence of structural outline may be observed as one would not be surprised to associate with rocks of a basaltic character, verging on a sub-columnar state. The appearance is so remarkable that, but for the difficulty of scrambling over the rocks at low tide, and the probability that it would escape such a hurried search of the coast as most of our visiting geologists have made, I cannot account for it having been unnoticed.

I believe then that there is some evidence of metamorphism —such metamorphism as the near approach of an intrusive granitoid mass might produce.

II. *Is there any evidence of upheaval in the vicinity of the Shovel Reef*, such as we should expect to find if a granitic boss had converted any of its rocks into gneiss?

The "contortions and displacements" of the rocks on each

* *Trans. Plym. Inst.* i. 78.

side of the Sound have been commented upon by every geologist who has written on the district. Professor Phillips called the contortions at Staddon and Bovisand "amazing."* Sir H. de la Beche suggested that they were "probably due to the causes which produced the intrusion of" the "porphyritic rock that occurs in mass on the north of Cawsand."†

Now while it is quite true that the intrusion of the Cawsand porphyry has disturbed the beds in its vicinity, two facts have to be noted—first, that it acted on beds that had been already displaced; second, that the displacements on the west of the Sound are no way comparable in magnitude to those on the east. We cannot conceive of greater energy being exerted by a cause at two miles distance from its centre of force than in its immediate locality.

Dealing with this subject in 1880, I remarked of the contortions on the east of the Sound, "We can hardly, I think, now fail to recognize it as at least highly probable that these inversions and contortions are due to the upheaval of the rocks of the Shovel Reef."‡ I reasoned then from gneiss to contortion. I now suggest the possibility, as a link, and a link only, in the chain of evidence, of arguing from contortion to gneiss. Whoever attempts to work out the stratigraphical relations of the rocks of the Plymouth district has to account for an increasing amount of complexity southward; he has also to deal with a special complexity in this particular locality, the special cause of which must be close at hand.

In my paper on "The Geology of Plymouth"§ I observed, attempting to explain the extraordinary contortions of the Plymouth rocks, "When, at the end of the Carboniferous period the granite of Dartmoor was upheaved, bearing on its flanks the rocks around, the effects of that upheaval must have cumulated here, especially if the Silurian belt to the south was upheaved in a contrary way—perhaps, as Dr. Hall suggests, by deeper-seated granite—or, little affected itself, acted as a buttress against which the Devonian rocks were thrust." It is immaterial to this argument whether we assume—as I did then, following the lead of Sir Henry de la Beche‖—that the Eddystone Reef is a connecting-link between the undoubted Silurian rocks of Veryan, and the presumed Silurian of the Bolt Head district, and that a Silurian belt formed the buttress; or whether the counter-force was applied by a metamorphosing granite boss direct.

* *Palæozoic Fossils*, 201, 202.
† *Rep. Dev. Corn. and W. Som.* 65.
‡ *Trans. Devon. Assoc.* xii. 363.
§ *Trans. Plym. Inst.* v. 466.
‖ *Rep. Corn. Devon. and W. Som.* 31, 32.

Something more is needed, however, than the bare hypothesis of a Channel buttress against the Dartmoor thrust—Silurian or granitic—to explain the excessive disturbances at Staddon and Bovisand. Equal causes operating on equal subjects produce equal effects. The existence of gneiss, even of granite, at the Eddystone affords no aid. The contortions at Staddon must have been caused by a crushing and upheaving counterpoise in immediate operation. Is it not reasonable to find this in the nearer approach of the Channel granite to the Dartmoor granite at this particular point—such an approach as would explain the existence of gneiss in the Shovel Reef, and as must be assumed if the Shovel gneiss is admitted?

It adds great weight to this hypothesis that I should now be prepared to offer evidence in favour of the existence of a subterranean granitic ridge, extending southward from the central granitic axis of Devon and Cornwall, roughly parallel with the east bank of the Tamar.

In all probability the statement that granitoid rocks occur within the same radius to the north-west of Plymouth as the Shovel Reef lies to the south will be received with some surprise, and I can very well understand their existence being overlooked by a visiting geologist; so that I seem the first to recognize their scientific value, though not the first to note their existence. In the paper to which reference has already been made, by Mr. John Prideaux, on "The Geology of the Country near Plymouth," there is a reference* to two "insular rocks" accompanying the slate at St. Budeaux, which "looks like a hill of primitive slate protruding through the transition rocks." One of these is described as "a felspar or porphyry, with a decayed appearance, full of cracks, and pervaded by *spiculæ* of schorl, sometimes an inch long." The other is noted as exhibiting "rounded masses, looking not unlike granite bowlders," and as being composed of "a very fusible mica, brown or semi-metallic in appearance; and granules of white felspar: whence the granitic appearance above noticed." They are described in the catalogue of specimens collected by Mr. Prideaux as "Rude porphyry" and "Micaceous greywacke (?)," and the locality is coloured in his map as "micaceous greywacke."

The indications given by Mr. Prideaux are so clear and precise, that, although the aspect of the locality has no doubt greatly changed in the past half-century, I had no difficulty in finding the rocks, which appear to form part of one area of

* *Trans. Plym. Inst.* i. 34–5.

small extent. I was much surprised, however, to find how very granitoid they were, and not merely granite-like in aspect. It is probable that the lapse of years had given me the benefit of other exposures.

On the geological map of South Devon will be noted a couple of "greenstone" bands, extending from the Tamar opposite Saltash some distance to the eastward inland, and passing to the south of St. Budeaux, and through the village of King's Tamerton. The northernmost of these is worked on for road-metal on the north-east of King's Tamerton; but I am not at all sure of the continuity of either as laid down. Indeed it is quite certain that the northernmost is not continuous; for it is precisely on its line that the "felspar porphyry" occurs, while the "micaceous greywacke," to retain the old terms for distinction sake, apparently forms part of the other.

So far as can be observed, the first-named rock rises in a boss at the intersection of the road leading from King's Tamerton behind Mount Tamar, to the road from St. Budeaux to Saltash Passage. It may be some fifty to sixty yards across from east to west, and appears to continue, if surface indications may be trusted, some three hundred yards in a line a little west of north and east of south, until it ends in a knoll rising on the hillside, immediately above and close to the old turnpike road from Plymouth to Saltash Passage. Both its northern and southern terminations seem to be marked by slight elevations, and to all appearance it joins the micaceous rock going south. Only the former can be distinctly seen *in situ*; but there are numerous boulders of both, and some that appear of an intermediate character. These boulders, moreover, are scattered over a considerable area, many being found beneath the turf to the north-west when the forts were under construction, so that the boss has suffered considerable denudation. The surrounding slates can be followed up so closely that the smallness of the area occupied by the intrusive mass is readily apparent; and yet though there is a certain amount of disturbance, no change of a metamorphic character is apparent *in situ*.* There are, however, fragments of altered rocks about, and the peculiar character of the micaceous rock may be the result of metamorphic action on the mapped band of greenstone. The "primitive slate" of the St. Budeaux hill has been shown by recent operations to be to a large extent of volcanic origin, some massive schistose

* This is an illustration of the danger of arguing against the existence of the Shovel gneiss from the non-metamorphic character of a limited area of the Shovel Reef.

beds having an ashy character, and containing undoubted patches of volcanic rejectamenta. These rocks, however, and the "greenstones" of the locality, are far older than the porphyritic granitoid rock.

Mr. Prideaux described this rock as a decayed felspar pervaded by spiculæ of schorl, and that is precisely its general aspect. The schorlaceous character commonly taken by our granitic rocks on their outskirts will at once be recalled to mind; but the peculiarity here is that this rock is not schorlaceous granite in the ordinary acceptation of that term; still less is it schorl rock. Mica to the eye seems wholly absent, and quartz is of very rare occurrence. The texture as a rule is coarsely granular, and it is slightly porphyritic from the development of crystals of felspar, some of which are traversed by the needles of schorl. A fine, more evenly-textured variety is, like the former, chiefly composed of felspar crystals, with small prisms of schorl, and a little mica.

Of the micaceous rock the more weathered specimens have a roughly spheroidal or ovoid structure, recalling the characters of some undoubted mica traps, and are very friable. The more compact examples present to the naked eye, or under the hand-lens, the ordinary appearance of a somewhat finely-grained schorlaceous granite, but with an absence of quartz, and a varying amount of mica.

It may be well to add here that, apart from the Shovel Reef, the only recognised locality for gneiss in the Plymouth district has been the Eddystone Reef; and that the presumed Shovel Reef specimens are stated by Mr. Tawney, F.G.S., to be very similar in character, which is no more than we might expect. At the same time there are two points of difference, and one of these is important. The Eddystone gneiss contains not only pink but salmon-coloured garnets, visible to the naked eye, whereas the Shovel has pink only; and while the quartz of the Eddystone gneiss has fluid inclosures, these are *absent* from the gneiss of the Shovel.*

Sir Henry de la Beche indeed records the existence of gneiss at Prawle,† where it has not been discovered since, and it has been, as I think too hastily, assumed that he was in error. He was certainly a most competent authority, and gives his reason for distinguishing the gneiss from the mica slate in the presence of felspar. Moreover he likens it to that of the Eddystone. Probably the exposure is small.

* *Trans. Devon. Assoc.* xiii. 172.
† *Rep. Geol. Dev. Corn. and W. Som.* 27, 32.

The foregoing observations, while complete in themselves, are also preliminary to the second branch of my paper, the object of which is simply to throw out a few suggestions that appear to me likely to aid in the solution of some long vexed problems connected with the stratigraphical relations of the Devonian rocks of South Devon. I do not in any way, here also, discuss the position of the Devonian system as a whole, or of any portion of it, in the general geological scale. All I desire is to consider certain internal relationships of the rocks in question, with more or less reference to the typical groupings of North Devon. The questions raised can only be settled by prolonged and minute study in the field, and by close, detailed mapping; but having myself reached the conclusion that the solution of the problem may be found in the rocks of the Plymouth area, it seems but right that I should state that conclusion and give my reasons.

It is generally admitted that the confusion into which the rocks of South Devon have been thrown was largely caused by the upheaval of the Dartmoor granites, originating an enormous vertical and lateral displacement, the extreme thrust of which was taken by a rocky buttress, occupying what is now the Channel area, itself also probably an active and not merely a passive agent. Where the two forces more nearly approached each other, there folding and repetition would be most marked, and the disturbing influence be least affected by counteracting conditions in the rocks themselves. That the widening of the area between the Dartmoor and Channel axes would be accompanied by an expansion of the folds, and lead after denudation to greater irregularity of stratigraphical relationship, seems a self-evident proposition.

In my paper on the "Geology of Plymouth,"* I pointed out that the grouping of the purple and variegated slates north of the Plymouth limestone afforded evidence of frequent repetition; that the parallelism of the trappean bands near Saltash might be due to the same cause; and that other undulations might reduce also the apparent thickness of the limestone. Further investigation has greatly strengthened this evidence; for I have traced a well-marked parallelism in the trap bands of the Plymouth area immediately to the north of the purple slates. I think it now susceptible of proof that the Middle Devonian rocks of South Devon are in the Plymouth district pinched into their narrowest limits; that the true key to the distribution of the more expanded beds to the east and west is to be found in that locality; and that closer investi-

* *Trans. Plym. Inst.* v. 456.

gation will enable the connections of the various zones to be followed as they sweep round the flanks of the mainland granite, to the varying pressure of which, in conjunction with the rocks of the Channel axis, their complicated structure is due.

Failing the clearer indications supplied by the varying fauna of different strata of richly fossiliferous formations, I have first to suggest that sufficient attention has not been paid of late to lithological peculiarities—doubtful as they may often be—for purposes of identity.

For practical purposes the rocks of Plymouth from the granite to the coast are conveniently divisible in three groups: (A) underlying slates, (B) limestones, and (C) overlying sandstones, with fossiliferous slates. The first and last of these may be again subdivided. With regard to the former, I think we may take a hint from the older geologists, with their half-forgotten nomenclature. De la Beche quotes the Rev. J. Conybeare, as dividing the schistose rocks of Devon and Cornwall into an inferior slate, metalliferous with elvans; and a superior, sparingly metalliferous, but abounding in greenstones.*

I propose so far to adopt this idea as to divide the slates of group A—well developed in the Plymouth area—into three series. 1. The grey and drab slates, which range up to the nearer granite, and are intersected by lodes and elvans. 2. The more varying charactered slates with which interbedded volcanic rocks are abundantly associated.† 3. The purple and green and, generally speaking, more compact slates, which continue close to the base of the limestone. Though these groups pass up into each other, I believe their characteristics will be found quite distinct, and that in all probability they are traceable from the Tamar to the Teign, and across the county of Cornwall. It will serve little purpose therefore to give them local names; but as indicating their most characteristic developments in the Plymouth area, they might be assigned provisional appellations.

Dr. Harvey Holl considers (and in this he is probably correct, though the relations to the North and to the Carboniferous boundary seem doubtful) the rocks of Buckland Monachorum the lowest in the Plymouth district.‡ They belong to the

* *Rep. Dev. Corn. and West Som.* x. 42.

† I am strongly inclined to accept Mr. Rutley's suggestion (*Quar. Jour. Geol. Soc.* xxxvi. 288) that this series may be the same as that of Brent Tor, in which case the Carboniferous "scientific frontier" in the vicinity of Tavistock will have to be "rectified" somewhat considerably.

‡ *On the Older Rocks of South Devon and East Cornwall.*

Rev. J. Conybeare's metalliferous series, and continue southward through the parish of Bickleigh into that of Egg Buckland, metalliferous veins occurring at various points, with occasional elvan dykes, until we reach Cann Quarry. They are wholly slates, and, so far as I am aware, do not contain a single contemporary igneous rock. This, the lowest group of the Plymouth series, I propose therefore to call the Buckland and Bickleigh beds.

Succeeding these comes a band of slates containing an enormous quantity of interbedded volcanic matter—amygdaloidal and slaggy rocks, and ash-beds frequently schistose and graduating at times by imperceptible gradations into the associated shales, some of which contain volcanic rejectamenta. The distinctive peculiarity of this series was clearly noted by the late Mr. John Prideaux, when in his geological sketch-map of the Plymouth district he laid down this area as grauwacke.* As it is most fully developed at Plymouth in the tithings of Weston Peverell and Compton Gifford, I propose to call this the Weston and Compton Group.

Thirdly we have, still further to the south, a great and clearly-marked series of purple and greenish slates, which by frequent repetition are more largely massed here than at any other point in South Devon. These we may term the Mutley beds.

I believe that with a thorough knowledge of the district there will be little difficulty in tracing each of these groups in South Devon, and folding more sharply round and between the granite bosses in East Cornwall. Indeed, Dr. Holl has used the volcanic bands for that purpose; and though to my own knowledge these igneous rocks are at present very imperfectly mapped, and although there is probably no locality in South Devon where by compression the grouping is so distinct as in the Plymouth district, the appearance of the existing skeleton geological map of the county is very suggestive of the conditions of the continuation of group No. 2. So far as No. 3 is concerned, Mr. Champernowne has shown that these purple slates may be traced from Buckfastleigh to the Teign.†

B. The chief limestones of South Devon I believe, in like manner, to be mainly on one horizon—a fact that will appear more clearly when the district is thoroughly worked out. I have recently, for example, noted a limestone patch two miles to the north of the main mass of the Plymouth limestones, in

* *Trans. Plym Inst.* i.

† "Age of the Ashburton Limestone," *Geol. Mag.* dec. ii. vol. vii. p. 413.

the valley leading down to Crabtree from Craza Mill, which would correspond to some of the detached limestone beds on the south. At the same time we cannot expect to find evidence of a continuous calcareous zone; for in some cases, at any rate, the reef-origin of our greater limestones has left its mark in abrupt and apparently faulted terminations.

C. There is more difficulty in the subdivision of the upper or arenaceous group, nor do I think we can treat it in the same representative sense in the Plymouth area. While I recognize with Dr. Holl the resemblance between the section on the east of the Sound and that on the Dart,* and while I am convinced that the Staddon grits really overlie the limestone, and are not brought up from beneath, as Mr. Jukes† suggested, I incline to the alternative suggestion of Mr. Ussher, that they may be a "faulted unconformable patch" of superior, if not precisely Upper, Devonian.‡ The accompanying slates and their contained fossils have a striking correspondence with those of South Petherwin, whether these are really Upper Devonian pure and simple, or merely the upper beds of the Middle series. I should be inclined then to correlate the Staddon and Maker grits with the Pickwell Down sandstones. The faulting down of these grits—and of this, it seems to me, there is abundant evidence—would account for the absence of the Pilton beds, of which, so far as I am aware, there is no trace in South Devon. The rocks to the south would, therefore, be to some extent continuations of the Morthoe series, with probably patches of Lower Devonian, as at Torquay, at intervals along the coast; while the lower beds of the Middle Devonian would be brought in occasionally by undulation along the strike—the same cause to which is due the undoubted repetition to the eastward—unaltered—of the Staddon grits.

* *Op. cit.* p. 437.

† Mr. Jukes stated, with reference to the statement by Professor Sedgwick and Sir R. Murchison (*Trans. Geo. Soc.* vol. v.), that the rocks of the Staddon series "bear the closest resemblance to the red arenaceous rocks in the cliffs east of Coombe Martin, in North Devon," that these rocks dip under the Coombe Martin limestones; so that "if the Coombe Martin limestones are on the same horizon as the Plymouth limestones . . . it is a strong argument in favour of inversion occurring at Plymouth, and that the sandstones which seem to lie over the limestones there really come up from under them, as they certainly do in North Devon." Accordingly he suggests "the probability of their real place being considerably under that of the Plymouth Limestones, and not over them, as it appears to be;" while his observation of the contortions and inversions at Bovisand impressed him with "the utter uselessness [in the time at his disposal] of continuing our observations."—J. B. JUKES, F.R.S., "Notes on Parts of South Devon and Cornwall," pp. 18–22.

‡ The Devonian Rocks between Plymouth and East Looe.—W. E. USSHER, F.G.S., *Trans. Roy. Geo. Soc. Corn.* x. 81.

As an illustration of my hypothesis, I would remark that every geologist who has examined the district has observed the marked difference between the rocks on the west and those on the east of the Erme, where by fault the lower beds of the Middle Devonian appear to be brought in. When the dips are so obscured by cleavage as in South Devon, and where fossiliferous bands are comparatively rare, I am sure, as I have already hinted, that something more will yet be made of lithological characters than has for many years been attempted.

While my observations were confined to the immediate neighbourhood of Plymouth, they led me to the conclusion that the limestones formed a natural division of the rocks of the district into two groups, and I was therefore quite prepared so far to accept Dr. Holl's dealing with the series practically upon this basis. Further enquiry compels me to differ from the grouping as recorded in his map. I have never been able to understand his line of demarcation on the Cornish side of the Tamar, between Millbrook and Whitsand Bay, when it was evident to me that it was crossed by the grit beds of Staddon and Maker, which he certainly does appear to regard as upper portions of the Middle Devonian series, whether intercalated or faulted down.

The Looe beds, which are correlated with the Hangman Grits by Dr. Etheridge, are undoubtedly lower than any beds in the Plymouth district. These commence, as it seems to me, with the representatives of the Combmartin metalliferous beds, and end with the Pickwell Down.

The Rev. David Williams treated the Plymouth sandstones (Staddon grits) as the key to his so-called Ocrynian system, and traced them, on the one hand, "by Antony, Sheviock, Bindown, and St. Keyne, into the mountain-looking range of St. Pinnock's Down, Five Barrow Hill, Bodmin, St. Breock's and Denzell Downs, and on to the sea at St. Eval;"* and on the other hand, at intervals up to Torquay. Treating the Plymouth beds as typical, he held strongly to the opinion that they lay folded around the great granitic axes of elevation; and this, with undulations transverse to the line of strike, bringing in and throwing out various beds, to the interruption of the continuity of the members of the series, would account for all the phenomena observed.

But I do not think we can stop here.

There is a steady decrease in elevation along the central ridge of Devon and Cornwall, from the north of Dartmoor to

* *Trans. Roy. Geo. Soc. Corn.* vi. 337.

the Land's End, in the same proportion as the promontory narrows; and the present evidence seems to favour the opinion that as we progress westward, and what we may figuratively call the underlying granite sea-bed becomes shallower, older rocks are presented. With the exception of the small patch of Lower Silurian on the south coast, the map of Cornwall remains, however, as Sir Henry de la Beche left it—Devonian. Reasoning simply *a priori*, this should seem very doubtful. If there are any stratified rocks of earlier age than the Devonian era in this district, they would would be the lowest affected by the granitic upheaval, and the last, as a whole, to be removed by denundation. There is very good evidence that West Cornwall generally is underlain by granite at a comparatively small depth, and that many of the overlying rocks in Devon must be wanting there.

That these older rocks exist there now appears abundant proof. In the admirable series of Palæo-Geological and Geographical Maps of Great Britain, for which we are indebted to Professor Hull, F.R.S., Director of the Geological Survey of Ireland, a land surface is shown gradually advancing from the north-west, during the Laurentian and Cambrian period, towards and partially over (Ireland and Scotland) the British Isles; retreating during the Lower Silurian era; but in the Upper Silurian and what he calls the Devono-Silurian periods, closing in upon Great Britain from north and south, so as to bring a land surface within a few miles of our south coast. This in the Devonian period approaches still closer, accounting for our shallow water deposits, although throughout the western promontory remains submerged. It it not indeed until Permian dates that Western England certainly rears its head above the water, though a portion of the Lower Carboniferous epoch may be regarded as doubtful.

In a letter written by the late Sir Roderick Murchison to Sir Charles Lemon, in 1847, and published in the *Transactions of the Royal Geological Society of Cornwall*,* in which Sir Roderick recognized the Lower Silurian character of the rocks of Gorran Haven, he expressed the opinion "that the quartzose rocks and killas" of the coast between Gorran and Falmouth, and probably much further to the south-west, were of Silurian age also, and quoted the Director-General of the Geological Survey (Sir H. de la Beche) as thinking it highly probable that Silurian rocks were to be recognized in other parts of Cornwall, citing especially the quartzose rocks of

* Vol. vi. 317–326.

Pydar Down. It was moreover his own "decided belief, that the slaty rocks constituting the great southern headland of Devonshire, at least all the schists, &c., to the north of the Start Point, will eventually be classed with the Silurian group of South Cornwall."* And I do not think it safe to dismiss this idea even yet.

In 1878 Mr. J. H. Collins, F.G.S., presented a paper to the Royal Geological Society of Cornwall—a "preliminary note" on the stratigraphy of the west of that county—in which he suggested that the west of Cornwall, instead of being Devonian, was either Silurian or pre-Silurian; considerably extending the Lower Silurian area to the south-west from Gorran, precisely—but by means of definite evidence—as Sir Roderick Murchison had suggested; finding beds which in all probability were Upper Silurian in the parish of Ladock, and again stretching across the county from the north, much as Sir H. de la Beche thought likely; and advancing reasons for classing the rocks of the Redruth, Camborne, and Illogan mining districts as Cambrian, or, at least, pre-Silurian.†

Still more recently Professor Bonney has assigned an Archæan age to the metamorphosed rocks of the Lizard district.

The results of my own observations at Plymouth, and my attempt to correlate the local phenomena with the general conditions of Devonian geology, lead me to concur in the views expressed by Mr. H. B. Woodward (not touching the controversy Devonian *v.* Carboniferous), that the structure of South Devon "*may* . . . be much simpler than is generally thought."‡ In fact it seems to me that, given an area of Devonian and Carboniferous rocks, and the three sub-parallel south-west and north-east axes of elevation, suggested long ago by Professor Sedgwick—the one on the strike of the existing granitic highlands, the others in either sea, represented respectively by Lundy Island, and by the granitic area of the English Channel demonstrated by Mr. Hunt—we have all the conditions requisite for the fullest explanation. The elevation of the exterior axes would produce the great culmiferous trough of central Devon, and crop up the lowest rocks of the area, Devonian or *other*, at the extreme verge on either side. The upheaval of the central axis would convert the one great synclinal into two; and the varying conditions

* Vol. vi. p. 323.
† *Trans. Roy. Geol. Soc. Corn.* x. 1–7.
‡ "Notes on the Devonian Rocks," *Geol. Mag.* dec. ii. vol. iv. p. 7.

of activity in connection with the relative masses intruded, would be sufficient to account for the irregularities which when viewed in detail are so perplexing. In all probability there are subterranean connecting ridges between the granitic areas, which would undulate the rocks transversely; and of such a ridge it seems to me we have evidence in the granitoid rocks of St. Budeaux and the metamorphic rocks of Plymouth Sound and the Eddystone, whether we accept or hold in suspense the Shovel gneiss.

My conclusion is then, if we may take the rocks in the vicinity of Plymouth as affording any clue, and if I am right in my interpretation of the appearances which they present, that we have in South Devon (beside portions of Lower Devonian) the whole of the Middle Devonians of North Devon, with the basement of the Upper beds; these folding round to the south and west, and more partially to the east, the great mass of the Dartmoor granite; while still further to the westward we have in descending succession the Lower Devonians brought northward from Looe, the Upper Silurians marked out by Mr. Collins, the Lower Silurians identified so long ago as the result of the labours of Mr. Peach, and the pre-Silurians of the western mining district.