THE GEOLOGY OF PLYMOUTH.*

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(Read November 25th, 1875.)

Introduction.

It is now forty-five years since there appeared in the first volume of the Transactions of this Institution an elaborate survey of the geology of the country near Plymouth, written by our distinguished member, the late Mr. John Prideaux. That paper contained a statement of the petrology of the district as accurate as was then possible, and still remains in this particular of very high value. Written, however, in the very infancy of stratigraphical geology, many of its conclusions are to our modern view erroneous, although it is remarkable how far in several respects Mr. Prideaux went before his time, especially in his identification of the rocks on the eastward of the Sound with the Old Red Sandstone, and his suggestion of an allied origin between certain rocks then called Greywackè and the Greenstones. Furthermore, it was the first attempt to systematize our local geology, and entitled to respect on that ground also.

Mr. Prideaux was not alone in these geological labours. A few years before he wrote there had been published by another eminent member of this society, the Rev. Richard Hennah, "A Succinct Account of the Limerocks of Plymouth," which conclusively established what had been strenuously denied—the existence of organic remains in our Plymouth limestones. This work was the result of years of patient labour, carried on with very few aids, when

* It will be understood that in this paper the aim of the writer was to present a general view of the whole history and conditions of the local geology. Much yet remains to be investigated, especially in the important department of Palæontology, which it is hoped may be treated on a future occasion.

geological science was hardly recognised in the West of England, except by a few scattered observers. Alike in the date and character of his researches, Mr. Hennah is entitled to be regarded as the father of our local geology.

And there is another local investigator of geological phenomena, a third member of this Institution, to whose writings I am likewise bound to refer. Mr. J. C. Bellamy, in his "Natural History of South Devon," published in 1839, recorded a number of important facts connected with the geology of this neighbourhood, very different in value to the crude generalizations and hasty theories which, misled by the imperfect knowledge of the time, he put forth.

If by the aid of the wider investigation, systematized conclusions, and clearer acquaintance with the workings of Nature, of the present day, I am enabled now to present a fuller and more accurate view of the history and conditions of the geology of Plymouth and its neighbourhood, I desire at the outset to express my sense of the value of the labours of those who have gone before, and of the honour they conferred upon this Institution. And if I do not mention the names of others associated with us who have done good work in this direction, it is partly because happily they are yet upon our muster roll, partly because I shall have special cause to express my obligations to them as my work proceeds.

It is my desire to bring the results of the labours of other investigators, with my own, into one connected whole, and to give as complete an account as is here possible of the conditions of our local geology, viewed in the light of modern science.

Devonian Rocks.

Geologists long hesitated in opinion concerning the exact place of the older rocks of Devon in the geological scale—the relative chronological position which they occupy. When stratigraphical geology was in its infancy, the rocks of this locality were frequently assigned a higher antiquity than that which any one would now allow. Playfair, in 1802, said that there were no rocks of a more distinctly primary appearance than those around Plymouth; and thence opinion veered to the view that they were what in those days was called Transition. Sir Henry de la Beche, in his earlier publications, with certain of his predecessors, classed them under one of the most general and indefinite of geological terms—based chiefly on lithological likeness to certain rocks in Germany, so

called by the miners—Greywacké. The local geologists of his day, however, applied that term specially to trappean and altered slaty rocks.

To Professor Sedgwick and Sir R. Murchison we are indebted for that identification of the places of our chief Devonshire rocks which is now generally, though in somewhat modified forms, accepted. The bulk of the rocks of the centre of the county they classed as Carboniferous; those bounding them north and south as of the Old Red Sandstone period, for which they proposed the term Devonian. The idea that the latter rocks were Old Red was not absolutely new. Mr. Prideaux spoke of the sandstones of Bovisand as having that character. Mr. Lonsdale, in 1837, suggested, on palæontological grounds, that the South Devon rocks would be found to occupy an intermediate place between the Carboniferous and Silurian systems. Sedgwick and Murchison were then engaged in their investigations in the district; and as the result in 1839 announced this as their conclusion.

Though the identification of the rocks of North and South Devon as of Old Red age is generally accepted, the acceptance is by no means universal. There is no question that these rocks are intermediate between the Silurian and the upper part of the Carboniferous systems, but there has been much question whether in truth they are really Devonian or Old Red Sandstone at all, and whether they are not lower members of the Carboniferous formation.

I shall not venture into this controversy, but only indicate its leading features.

The first to assail in any formal and set form the conclusions of Sedgwick and Murchison was the late Mr. Jukes, who held that while there were undoubtedly rocks in North Devon of Old Red age, most of those so classed were Lower Carboniferous. This interpretation he based on his intimate knowledge of the geology of the South of Ireland. Subsequently Mr. Jukes advocated the opinion in its complete form, that the Devonian slates and limestones which contain marine fossils (and in these our Plymouth rocks are included) are superior to the Old Red Sandstone.

Mr. Jukes expounded his hypothesis in full detail before the Geological Society of London in 1866; dealing then with the rocks of North Devon. In 1868 he read a paper before the Geological Society of Ireland, in which he set forth the results of his examination of the rocks of South Devon and East Cornwall.

Mr. Etheridge, in reply to Mr. Jukes, contended chiefly, but not exclusively, on palæontological grounds, that the Devonian rocks of North Devon (and therefore from their correspondence those of South Devon) are chronologically equivalent to the whole of the Old Red Sandstone.

And while Mr. Jukes and Mr. Etheridge thus represent the extreme views on either side, there are various shades of opinion held between. I shall only quote one more hypothesis, and that not merely because it is put forward by our most distinguished local geologist, but because it seems to me, so far as I have any pretensions to form a conclusion on the matter, to represent very nearly the exact state of the case. Mr. Pengelly, so far back as 1863, suggested that the acknowledged Old Red beds of Scotland and elsewhere, with the Devonian beds, collectively but not separately, fill up the Siluro-Carboniferous interval, the Lower Devonian beds being on the same horizon as those of the Upper Old Red; and the Middle and Upper Devonian between the Upper Old Red and the Carboniferous.

The Devonian rocks, whatever view may be taken of their collective position, are generally divided into three groups—upper, middle, and lower, each of which has representatives on either side of the great culmiferous trough of the centre of the county. Originally the Plymouth rocks were classed as Lower Devonian. They now rank as Middle, with the rocks of Ilfracombe, Bradley Valley, Wolborough, Babbicombe, Dartington, Berry Head, and other limestone districts; those of Lynton, Meadfoot, Mudstone, Looe, Polperro, and Fowey being Lower; and those of Petherwin, Baggy Point, Pilton, Tintagel, &c., Upper. The Devonian rocks of Plymouth may be treated as subdivided by their limestones into upper, middle, and lower likewise.

Let us for a moment recapitulate the conclusions at which we have arrived. The centre of the county is occupied by strata of Carboniferous age, with the granite of Dartmoor on their southern flank. Northward and southward the Carboniferous area is bounded by Devonian rocks. On the east Triassic—New Red Sandstone—rocks extend from Watchet to Torquay, with a singularly irregular outline. Eastward again, in the corner next Dorset, a comparatively small surface is occupied by Liassic and Cretaceous deposits.

With these latter we have little to do; but there is a small patch of Metamorphic rocks between the Start and the Bolt Tail—

coloured in the Geological Survey Maps as altered Devonian, which has considerable local interest. The point cannot be regarded as settled, but to me there seems little doubt, though the conclusion is one rather of inference than evidence, that they are of Lower Silurian age; that they form part of the same series as the rocks of the Dodman and Gorran Haven in Cornwall, which are admittedly Lower Silurian; and that we must associate with them the Eddystone reef, which lies on the line of strike between the two, and the chief rock of which is of a metamorphic character. Mr. Prideaux called it gneiss. If I am right in regarding the Eddystone as the link between those apparently detached Silurian fragments, we must fix the southern limit of the Devonian rocks of Plymouth at or near that point. The northern will be found in the Carboniferous rocks of Tavistock. The granite of Dartmoor occurs somewhat nearer on the east, its closest point being an isolated patch between Newnham and Hemerdon.

And here let me correct a misconception which has been handed down from the infancy of geological science. Granite is commonly spoken of as a primary rock. It is nothing of the kind. There are granites of different ages, as there are slates and limestones. The Dartmoor granites are of three periods. The oldest is of later date than the Carboniferous rocks, through which the whole have been elevated; therefore much inferior in antiquity to our own rocks here. The fact that granite pebbles of all three varieties occur in the Triassic Conglomerates shows that they are of older date than these beds. They may be of Permian age; but all that we can say definitely is that they date somewhere between the Carboniferous and the Triassic periods.* We may, as I have said, treat of the Devonian rocks of Plymouth under three divisions. The underlying slates and associated rocks ranging downwards from the granite; the limestones; and the schistose and arenaceous overlying beds: the whole forming an ascending scale in the order named.

The strata around Dartmoor, in nearly all directions, dip away therefrom. The rocks in this locality have a prevalent southward dip, gradually increasing in extent from the granite, and more frequently varying to the westward of south than to the east. To this there are a few exceptions. Professor Phillips recorded in his "Palæozoic Fossils" the existence between Tamerton and

* This was first shown by Mr. Pengelly, F.R.S.

St. Budeaux of a narrow anticlinal—N. 10° W.; S. 10° E., with a cleavage nearly parallel to the northern dip, and striking N. 80° E. Between Egg Buckland and the Fort on the north, a northerly dip occurs N. 30° E., 60°; whilst, a short distance to the southward, near the church, we find it S. 10° W., 35°. There is another anticlinal at Blackpool, near Lynham; and northerly dips are likewise found near Wolsdon and elsewhere.

The rocks of our northern or lower group are chiefly slates, of a bluish gray or drab. Good roofing slate occurs at Cann Quarry, and a few other points. Near Plymouth there is an abundance of purple and greenish slate, largely variegated. By Saltash there are a few calcareous seams, one of which was worked many years ago, at Moditonham, for lime. Associated with the slate are numerous bands of trap rocks—greenstones and ash beds, some of which graduate into the slates by such fine degrees, that it is hardly possible to distinguish where the one ends and the other begins. The more important trap bands are near Saltash. Others, less pronounced, may be seen between Knackersknowle and Plymouth. There are still more traps at Compton, Swilly, Ford, and Keyham; and immediately to the north of the limestone—forming the hill on which the Devonport Column is built, where it rises at the junction of the limestone and the slate; appearing in an almost identical position at the N.W. angle of St. Andrew's churchyard; and stretching along the top of the hill from Ridgway by Chaddlewood.

This trap-rock, called locally, in conjunction with some of the altered slate, dunstone, occurs in various forms. Near the surface it is generally of a dun or a reddish-brown, often vesicular, and commonly ferruginous, rotten through weathering. In depth it becomes bluish-gray in colour, and very hard. Occasionally it is amygdaloidal, as at Ford and Chaddlewood, where it contains large quantities of carbonate of lime, and may perhaps fairly be termed diabase. The sounder varieties are frequently used for building, and the tougher make excellent road metal. There are few hills in the area under review that do not contain either a trappean nucleus, or are not largely composed of one form of diorite or another. To its superior hardness, as compared with the slates in resisting denudation, no doubt many of these elevations owe something of their present contour.

Great part of these greenstones are undoubtedly the contemporaries of the rocks wherewith they are associated, and therefore of

Devonian age. This contemporaneity is clearly seen in the railway cutting above Weard Quay, not far from Saltash. Here we find a series of layers of trap interstratified with slate, more than a score in number, and varying from an inch to three feet thick. And here, therefore, the lava must have spread itself upon the sea bottom in successive sheets with comparative quietude, and at intervals sufficiently long to allow of the deposition of considerable layers of silt between.

Taking the whole of these phenomena together, they seem to indicate the special local influence of volcanic action, operating over a lengthened period.

I doubt whether the more southerly traps, those next the limestone, are contemporaneous. They seem rather to be intrusive—to have the appearance of being thrust into the positions which they occupy. I have no direct evidence to offer, but it is a fact worth noting, that the greenstone on the north of the Yealmpton limestone is clearly intrusive; nor do I think the fact that they contain large quantities of carbonate of lime without its value. If this suggestion be correct, these rocks may probably be of Carboniferous age; for we know that during this period there was a centre of great volcanic activity so near us as Brent Tor.

Now the whole of these northern rocks, with such exceptions as I have indicated, appear to have a constant southerly dip, at angles which vary from 80° to 10°, but can hardly be averaged at less than 55° or 60°. I say appear, because the cleavage planes are mostly well developed, and it is not easy—nay, at times impossible—to distinguish between the cleavage and the bedding. Still, there can be little doubt that the bedding and cleavage have a general coincidence. Are we, therefore, to infer that this single sub-section of the Devonian system has such an enormous thickness as this regular succession of conformable strata would seem to imply—a thickness that would have to be measured by miles? There is no absolute necessity that we should.

To me these rocks appear to yield evidence of having been thrown into numerous folds with a prevailing southerly dip, so that instead of having a succession of fresh beds southward, we have a frequent repetition. The anticlinals to which I have referred would thus be the remnants of such portions of the actual flexures as have not been denuded off. There is so remarkable a similarity in the slate rocks of this division, that it is by no means

so easy to trace these repetitions as one would desire. Still, there is evidence. The parallelism of the bands of trap near Saltash may be due to this cause. But that to which I would direct especial attention is the grouping of the purple and variegated slates in and near Plymouth. You will find them in the railway cutting at the Friary, at Lipson, in the railway cutting at Rosehill, and again beyond the little tunnel to the west of the Stoke Station. Each group of coloured slates is separated from the next by slates of the ordinary character; and I believe, that instead of having four sets of coloured beds, we have one set four times repeated; so that the total thickness of the strata exposed, instead of being 2,000 yards, is somewhere about 300. Moreover, this hypothesis, if correct, applies more or less to the whole of the rocks of the division.

Before passing on to the limestones, the occurrence of elvans should be noted. Elvans are rocks of granitic character, which fill fissures, and form dykes running across the country. They are thus intrusive. One elvan may be seen at Cann Quarry. There is another, porphyritic, at Roborough Down, which attained considerable local notoriety for building purposes under the name of Roborough Down stone. A third occurs near Jump. They cut through the slate beds, and have a general direction east and west.

Except in the vicinity of Saltash, there are no fossils locally in the rocks of our lower group, which in part are really Lower Devonian. Elsewhere important discoveries have been made; and the Lower Devonian rocks of Looe, Polperro, and Fowey, have yielded fish remains identical in species with some which occur characteristically in the undoubted Old Red. The sea bottom here may have been of greater depth.

We now come to the middle Plymouth group. When, many years ago, it was first stated that the Plymouth limestone contained fossils, the idea was scouted as absurd, though thousands are revealed in the pavements over which we daily tread, and though in the limestone cliffs which bound our shores corals eroded into prominence by the action of the sea and spray constantly occur. It required, however, long-continued labour on the part of Mr. Hennah fully to establish this fact. Now we know that our limestone is in great part made up of organic remains. It is in fact an ancient coral reef. A physical analysis of a fragment of Plymouth limestone by Mr. Sorby gave the following result:

Fragments of coral	12·3
Portions of encrinites	11·5
Organic clay	25·7
Crystallized calc spar	50·5
	100·

After long ages of sedimentation and alternating volcanic action the bed of the ancient sea whereon we now live became tenanted by coral animals, and the formation of a coral reef began. Our limestone has every characteristic of a fringing reef; that is, of a reef following the main outlines of the shore at no very great distance from the land. How the reef-builders were introduced we cannot say. One thing is certain, the temperature of this old-world sea must have been warmer than that of our present waters. It must likewise have been shallow. Reef-building corals do not live in ordinary cases at a greater depth than twenty or thirty fathoms, rarely below fifteen. Hence there is evidence of great changes. Either the palæozoic sea had become shallower, because of the long-continued process of deposition, which is hardly likely to have been an exclusive cause, or its bed had been raised by forces from within. This is most probable, especially as we have so soon to call into play a return movement. The apparent thickness of our limestone, taking its breadth and average dip, is about 600 yards. There may be undulations which would greatly reduce this thickness; but I do not think so.

In any case the thickness is greater than the natural range of the building action of the coral animals; and therefore, to account for its formation, we must call in aid the process now in operation in the Pacific. Only a gradual and steady sinking of the land would enable the coral animals to build a reef of such extent. In a coral reef precisely analogous to those which now exist in the Southern Seas the Plymouth limestones then had their origin. But it may be asked, Whence the bedding, which indicates mechanical and not organic action? The answer is easy. In a coral reef growth and destruction are ever present. No kind of live coral reaches above a few feet in height, and the waves and winds are unceasingly grinding it down. The matter removed is deposited in and around the reef itself, consolidating and extending; and since, while our reef was subject to this double process, the ordinary form of deposition continued in the sea around, we

can at once account for the alternations of slate with calcareous shale observable on each side of the limestone. Whichever form of detritus predominated for the time, governed throughout its sway the character of the current deposit. At intervals silt and sand were cast upon the reef itself. Thus we account for the slates and sandstones (in part) which occur in beds or patches between the layers of limestone. Some of the sand-beds may be of later date, and attributable, as at Torquay, to Triassic sandstone filling up the joints produced by natural forces in a later age.

The depth to which our strata have been proved exceeds 300 feet. This was in the boring for the Victoria Spa, in Bath Street. The section was—

	Feet.
Earthy clay slate	20
Limestone	150
Blue slate	20
Red sandstone	3
Limestone	50
Sandstone	4
Red and blue slate	30
Dunstone	8
Earthy clay slate	20
Red sandstone	12

The slate appeared to come in in wedges. Allowing for dip, the actual thickness of the beds traversed would certainly not exceed two-thirds of these amounts.

There is sandy as well as slaty limestone. Treating a reddish-coloured arenaceous limestone from the Hoe with dilute hydrochloric acid, I found that 25 per cent. of its bulk consisted of a bright-red siliceous sand, exceedingly fine. The stone was of the kind known to the quarrymen as "hard head," which occurs more or less intermixed with the limestone proper throughout its range.

The limestone forms a band half a mile in width, and nearly 6½ miles in length. Its main western extremity is in Devonport Dockyard (there are detached beds on the other side of the water further west than Empacombe). It breaks off on the east about Sherford. Its general elevation is much lower than that of the slate hills, averaging about a hundred feet; and whilst its summit line has been truly described as being level as a wall, its continuity

is broken at several points. The Tamar, after rounding its western extremity, passes through it at Cremill; the Plym has a narrow channel at Cattedown; and at Stonehouse Pool, Millbay, and Sutton Pool, the waters of the Sound find access through the barrier to basins worn out of the slate rocks behind.

The limestone varies much in colour, structure, and dip. Its most constant features are its crystalline character, and the regularity of its divisional planes. Both on the north and south it graduates into the slate through calcareous shale. Bedding is frequently indistinct, and in some central parts of the mass apparently non-existent. It abounds in fossils—chiefly coralline in its more massive portions; whilst some of the exterior beds have yielded large quantities of bivalves and univalves; and others, with the adjoining slates, are remarkably fruitful in crinoidal remains. In texture it is generally highly crystalline, and in colour very various, ranging from black, through red, yellow, brown, dove and gray, to white. There is a marked increase of dip from north to south. Whilst on the northern edge the dip varies from 20° to 40°; on the southern it runs from 60° to 75°. At Cattedown there is a shallow synclinal and some undulation, but the prevailing dip is towards the south.

Both the joints and the crystalline structure of the limestone are due to causes subsequent to the formation of the reef. To subsequent causes also must we attribute the fact that portions are dolomitic, containing a large quantity of magnesia, which has been exchanged for the lime. In the Yealmpton limestone dolomite abounds.

And now to return to our reef. At length the building came to an end. There may have been a descent of the ocean bed too rapid for the builders to keep pace with. They may have been overwhelmed by some great discharges of detrital matter; they may have perished in a fresh outbreak of volcanic forces, though recent volcanic action does not in all cases absolutely prevent the growth of coral. But they did not disappear finally without a struggle for existence.

And then we enter the third division of our local system. Its characteristic is sandstone, but this does not immediately appear. The rocks of this group are best studied, though they continue across the Sound, on its eastern side, from Mount Batten southward. They present an interesting but most complicated study.

Slates, limestones, shales, grits, ash beds, and sandstones alternate with each other in very remarkable fashion, while faults and contortions by no means simplify the riddle. Mr. Jukes hints that these rocks—their prevalent southerly dip notwithstanding; for in dip and strike they follow the general rule of the district—may be really under and not over the limestones, brought up by an inverted anticlinal. He seems to have been chiefly led to this by the similarity of the rocks between Batten and Bovisand to some Carboniferous rocks of Ireland. But this is only a suggestion; and while this third division appears to be cut off on the west between Millbrook and Tregantle, on the east its rocks certainly extend to Torbay. Dr. Holl points out the strong family likeness between our own upper rocks and the succession of rocks on the Dart; and I have traced some of the most characteristic of the Staddon beds occupying much the same relative position towards the Yealmpton limestone that they do towards the Plymouth.

I give the descriptions of this group by Sedgwick and Murchison and Professor Phillips with my own notes.

Sedgwick & Murchison.	Phillips.	Remarks.
Brown and yellow earthy slate, with pyritous stains and iron veins, some of which run in the form of strings nearly north and south. This mass alternates three times with beds of impure limestone, and the last bed occurs at Dunstone Point, where it thins out to an edge among the impure earthy slates. This part of the section may be considered as forming a kind of passage from the limestone to the super-incumbent beds.	Near Turnchapel red shales, yellow ochry beds, and purple masses of oxide of iron, form a parting in the limestone, and have a varying dip of about 70° to the south. Laminated schistose beds, irregular beds of trappean rock with irregular and nodular admixtures of limestone, occupy the shore for some distance.	Some of the trap is schistose (? ash), yellow, with ochry spots as if the result of decomposition. One of the ochry beds contains Petraiæ. Some of the beds are largely intersected by quartz veins, which stand out like a network, the rock between being weathered away. About midway a fault is observable, associated with a couple of minor faults. Here the dips and their directions vary from S. 20 E., 35° to E. 25°, and round to S.E. again. The slate which succeeds is dark and hard, less cleaved, and more jointed than usual.

Sedgwick & Murchison.	Phillips.	Remarks.
Dunstone Point to Withy Edge — yellowish-gray and bluish-gray soft slate and quartz veins and coarse arenaceous bands.	Bluish-gray schistose beds, dipping south-east, moderately yielding in gray slaty beds and nodular limestones Encrinites, Brachiopoda, Turbinolopsis, and some unenumerated shells. The limestone nodules contain black (? carbonaceous) spots. Carbonaceous and gritty beds. Argillaceous contorted schists. Calcareous laminæ fossiliferous. Schists. Schists and then grits. Laminated brown and red grits. Schists. Layers of nodular limestone with Crinoidea in argillaceous irony schists; a band of slaty fragments and colour stripes are crossed by cleavage.	The limestone near Dunstone Point dips at low angles. Some is horizontal. There are flints on the beach in Rum Bay.
Extending three-quarters of a mile to Bovisand Bay, bright red and sometimes variegated sandstone, thick bedded and of coarse texture, sub-divided by bands of soft glossy red slate and red micaceous flagstone; overlaid by a reddish slate and flagstone, which gradually passes into next division.	Red grits, hard, coarse. Purple schists and fossils in bands (Spiriferæ, Encrinites, &c.). This series is amazingly contorted, and contains ironstone layers and undulated quartz laminæ between the beds. Red grits, with gray alternations often ripple-marked on the surface, and bearing much resemblance to the beds of Martinhoe in North Devon, appear to lie over the blue or purple fossiliferous beds; but the junc-	Dip of red sandstone above Bovisand Pier, 30° S. 20 E. amount variable, and here decreasing southward. Some of the beds appear almost horizontal. In the road to Fort Staddon, at the back of the hill, easterly dips occur with curvature.

Sedgwick & Murchison.	Phillips.	Remarks.
	tions are complicated by amazing contortions; just as happens when in North Devon the Foreland sandstones touch the Linton gray beds. The red beds form a hill over Staddon Point, and dip to the south-east (45° and 70°), so as to sink below the sea rapidly near the centre of Bovisand Bay, where they are covered by steeply acclined beds of bluish, grayish, and whitish shales. Much contortion prevails here.	
South of Bovisand Bay, earthy slate, passing into shale, with small nodules of ironstone, surmounted by various coloured earthy slates, alternating with reddish arenaceous bands, as seen on the cliffs of Crownall Bay, near the southern end of which is a patch of new red conglomerate, resting unconformably on the edges of the older strata. Beyond Crownall Bay, reddish slate and flagstone and coarse red sandstone, occasionally contorted and penetrated by large quartz veins, passes into reddish, grayish, and greenish-gray chloritic slates, with hard quartzose bands and quartz veins.	Blue and gray shales, and with thin calcareous bands of Bovisand Bay. They are somewhat fossiliferous, containing Turbinolopsis, Crinoidea, Spirifera, and an Alga. Dip, S. 40°.	Going South, micaceous gritty schist, white and reddish, dip S. 50°. Ripple-marked laminations. White and reddish sandstones. Blue shale, with grit seams much contorted. At middle of Bovisand Bay, horizontal strata and beds with northern dip occur. South of Bay, dark slates, dipping north at first, but immediately contorted to the south.

This brings the section so far as Yealm mouth. Beyond Yealm mouth to Stoke Point there are grayish and greenish slates, with quartz veins and occasional gritty beds.

Before I proceed further, it will be advisable that I should again cite the opinions in regard to this section of Mr. Jukes and Dr. Holl.

Mr. Jukes, as already noted, suggests the "possibility of these beds, 'so like the Old Red Sandstone,' which lie to the northward of Bovisand Bay, being brought up by an anticlinal, accompanied by inversion as well as contortion, and that this inversion may even affect the southern borders of the Plymouth limestone themselves." Messrs. Sedgwick and Murchison refer to the rocks of this section as bearing the closest resemblance to the rocks east of Coombe Martin; and upon this Mr. Jukes observes: "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 be over the limestones there really come up from under them, as they certainly do in North Devon." Finally, referring to some of the contortions in Bovisand Bay, Mr. Jukes observes: "If beds could lie horizontally bottom upwards, for 25 yards, that inversion being only to be proved by the discovery of the small locality where the actual curvature of a distinct and recognizable bed happened to be exposed, what was there to forbid the possibility of beds lying in that position for 250 yards, or even 2,500, or more, and yet no direct evidence of that fact being anywhere accessible?"*

Dr. Holl takes the opposite view. "There appears to be on the east shore of Plymouth Sound, south of Mount Batten, and from the limestone of Brixham, along the river Dart, and the coast at Mann Sands, an upward series, though grey, blue, and purple slate, to the red grit, which rocks succeed each other conformably; and the limestones of Berry Pomeroy and Marldon are overlain by variegated argillaceous slates, surmounted at Blagdon Cross by red grits like those of Staddon Point and the banks of the Dart. No similar rocks, however, are seen rising up from below the limestone among the lower rocks north-west of Dartington and Ogwell; nor are any such again brought up to the surface from beneath the limestone in the long downward succession of the beds between Plymouth and the Horrabridge station on the Tavistock railway."†

For my own part I hold that these rocks are really superior to the limestone, though I quite admit, and in fact believe, that here

* "Notes on Parts of South Devon and Cornwall," pp. 18–22.

† "On the Older Rocks of South Devon and East Cornwall." Proc. Geo. Society, April, 1868.

also, as on the north of the limestone, there has been repetition, and that the actual thickness of the series is much less than the apparent.

Perplexing as these rocks are, if we endeavour to indicate the exact relations of the different members of the series, it is not so difficult to recall the causes which issued in their formation. A continuance of that downward movement of the ocean bed which accompanied the building of the reef, combined with changes in the character of the detrital matter brought down by the rivers of the adjacent coast line, and subject to volcanic interference, will supply all the conditions required. The beds of limestone detached from the main body of the reef clearly indicate that whatever the causes which led to the disappearance of the coral animals they were not of instant effect. There was no great cataclysm, no sudden convulsion of nature. The ash and trap beds need no explanation. The grits and sandstones point to a change in the character of the matter brought down by the neighbouring river or rivers. The sandstones of Withy Edge show that the arenaceous influences, although gradual in their appearance, at length long predominated. The ripple-marked beds of Bovisand prove that when they were formed the waters must have been very shallow indeed.

Differences in the character of deposited rocks necessarily imply variations in time or changes in operation. All round the shores of the Sound may be seen the rocks of the future in process of construction—here a mudbank, there a sandy flat; here a layer of shingle, there a beach thickly charged with shells and the remains of other organisms; here again a bare water-worn rock, with sand or pebbles in its hollows. But all these formations that differ so widely are strictly contemporaneous, strictly the effects of the same system of causation. Take another illustration. Go up one of our Devonshire hillside lanes after heavy rain. You will see there a little gully, the bed of a miniature rain torrent. Where the road is steepest the gully will be worn and deep, cut down to the rock. If the road approaches a level the gully will expand, and much of the detritus brought down from above be deposited—the heavier particles first, and then, as the stream loses force, the lighter. And thus one river may have borne into this ancient sea either silt, or sand, or gravel, and shale, or sandstone, or conglomerate result.

All these rocks have undergone great changes since they were first deposited. We have no sedimentary rocks in this locality, setting aside the hypothesis of Mr. Jukes, of Carboniferous date. If there were ever any they have been removed; and although it is by no means improbable that the great culm trough of Central Devon thus far overlapped its borders no evidence remains; unless it be derived from those diorites which seem to be intrusive, and may be of Carboniferous time. When, however, 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. Holl suggests, by deeper seated granite—or, little affected itself, acted as a buttress against which the Devonian rocks were thrust; while the superior rigidity of the limestone over its associates would increase the lateral pressure from the north on the rocks of my third division, lying between. This of itself would account for much of the contortion and faulting that prevails.

Secondary Rocks, &c.

But we do not stop here. There is the clearest evidence in the existence of outliers that the Triassic rocks once occupied a much larger area in Devon than they do now. There is one such outlier in Bigbury Bay, at Thurlstone. And here, at Cawsand, is a felspathic trap identical in character with the trappean rocks of the Trias, and manifestly intrusive, "breaking through the older red deposits." The rock is porphyritic, the base "a somewhat earthy compound of felspar and quarts, containing crystals of mica and (more rarely) felspar."* The intrusion of this rock must have been accompanied by an enormous amount of distortion and dislocation, and in its turn have aided the phenomena at Staddon.

It is evident that from time to time this locality came within the influence of volcanic centres of considerable activity. Nor is it at all improbable that the outlines of the Sound were originally sketched by these mighty forces, qualified in their action by the differing resistile powers of the rocks. The limestone was one of the most rigid; but its resistance after all was limited. If not bent, it would be broken; and fissures were opened therein that,

* De la Beche "On the Formation of Rocks in the South-West and South of England," p. 259.

in the course of untold ages, have been worn into the channels through which pass, or once did pass, the waters of the Tamar and the Plym. Had not these fractures been made, had the waters been set the task of forming their own courses from the beginning, the slates would have been an easier prey; and nature never wastes her strength. The gorge of the Plym at Prince Rock has a depth of eighty feet below high-water mark, before the rock is reached, which there is shale. With slate rocks around, would the limestone have been thus cut, if the passage had not first been opened?

From the era of the Trias onward there is a great gap in our geological history. There is little evidence of the extent to which construction was subsequently exercised over the area under review. Mighty works were doubtless done, of which we have scarcely a trace. Denudation has wiped away countless ages, and brought us face to face with these old Devonian times. We have now but the skeleton of the deposits of that far distant epoch. Of their Secondary and Tertiary successors we have no remains. There is no Lias, no Oolite; Chalk is very doubtful (flints occur on the beaches on the east of the Sound, and on the hill over Staddon, but are too slender a foundation whereon to build with certainty the superstructure of local Cretaceous deposits); no Eocene, no Miocene, no Pliocene.

Quaternary Period.

This brings us to the confines of the Quaternary system, and to the Glacial era. There are in this locality no glacial deposits. I am not aware that there are any traces of glacial action, though certain alluvial deposits have been, as I hold, mistakenly termed drift. There is on the shore of Barnstaple Bay a granite boulder which can only have been deposited where it now lies by ice action. There are boulders of red sandstone at Waddeton Court, on the Dart, which Mr. Pengelly is inclined to believe were transported by ice in some form. There are trap boulders at Englebourne, Harberton, that in his opinion appear to bear the marks of ice transportation. The "Head" on Bovey Heathfield has glacial characteristics.* Mr. C. W. Peach observed what he believed to be traces of glaciation on rocks in the Dodman district. These are the nearest evidences of glacial action to our own locality.

* "Notes on Boulders," &c., W. Pengelly, F.R.S., "Devon Ass. Trans.," vol. vii. pp. 154–161.

The most characteristic of the Post Glacial phenomena of Devon are ossiferous caverns, raised beaches, submarine forests. Plymouth has examples of the first and second.

These submarine forests occur at various points of the coast, as near on the one hand as Blackpool, Dartmouth; on the other, as Pentewan, St. Austell. They consist of beds underlying the present beaches, and extending an unknown distance seaward, partially up valleys landward, and composed of vegetable detritus, mixed with branches and trunks of trees, and occasionally containing stumps *in situ*.

The ancient beaches, precisely similar in their general characteristics to the existing, occur at intervals along the coast at a height of some 30 feet above the present sea level. When they were washed by the waves, the land must have been 30 feet lower than now. When the forests flourished, it was at least 40 feet higher. All the indications prove that these changes of level were gradual and extensive.

Anterior to the beaches are the ossiferous caverns, or rather their contents. Mr. Pengelly argues, from the conditions of the famous Windmill Hill Cavern, Brixham, that its filling preceded the forest era by a period sufficiently long to allow of the excavation of valleys 100 feet in depth. This is quite confirmed by our own local phenomena. I hope to be able to prove that the bone caverns of Oreston received their contents ere the gorge of the Laira was excavated.*

The bone-bearing caverns of Devonshire are among the most interesting of its geological phenomena. The ossiferous caves of this locality are entitled to peculiar distinction. They were the first to direct attention to cavern researches in the county, and among the earliest investigated in England. The first of the series was discovered in 1816, while the famous cave in Kirkdale, to which Dr. Buckland directed so much attention, was not found until five years afterwards. I cannot deal adequately with this important branch of my subject in the space now at my disposal; but a full statement of all that has been written about the Oreston

* Mr. Spence Bate, F.R.S., in his presidential address to the Devonshire Association in 1863, directed attention to evidences of some of the valleys of the lower lands on the south and west of Dartmoor having been filled with *débris* of the Dartmoor rocks to a height of 100 or 150 feet, and then re-excavated.

caverns, compiled by Mr. W. Pengelly, will be found in the Transactions of the Devonshire Association.*

Our limestone rocks abound in caverns. The largest is one at Stonehouse, an entrance to which is indicated by an inscribed stone in the pavement at Emma Place. This cavern contains a large reservoir of water, and it has been utilized for the drainage of certain houses, with what result time will show.

The existence of bone caves in this locality was first ascertained in connection with the works for the construction of the Breakwater. When these commenced, in 1812, Mr. Whidbey, the superintendent, was asked by Sir Joseph Banks to make careful examination of any caverns that might be met with, and preserve their fossil contents, if any. Accordingly, in 1816, a quantity of rhinoceros bones, found in a cavern at Oreston, were sent by Mr. Whidbey to Sir Joseph Banks, and formed the subject of a paper read to the Royal Society by Sir Everard Home in February, 1817. Four years later other bones were found in a cavern 120 yards distant from the first, and described in a letter from Mr. Whidbey read to the Royal Society in February, 1821. In the next year there were still larger finds; and then came a lull. For six and thirty years the bone caverns of Oreston were merely matters of history, until, in 1858, a new series, more important than their predecessors, were discovered.

The bones were found under varied conditions. Some were simply embedded in clay which had been washed into the caverns; some were enclosed in a mass of stalagmitic breccia, traceable in its origin to a similarly acting cause. But from first to last there does not seem to have been any adequate evidence that the caves had been inhabited by the animals whose remains were found therein; in other words, that they were dens. Herein they differ from Kent's Cavern, but agree with the Brixham and one of the Yealmpton Caves. Yealm Bridge Cave was a hyæna den.

The earlier discoveries at Oreston were shrouded in a great deal of needless mystery. Mr. Whidbey held that the caverns were entirely enclosed in the solid limestone, and that there were no traces of communication with the surface in any direction. Dr. Buckland, who paid the caverns a visit in 1822, in conjunction with Mr. Warburton, and made a careful examination of all the conditions, held that there had been openings to the surface, but

* Vol. v. part i. p. 249, *et seq.*

that these had become closed since the entombment of the remains; and finding a quantity of detrital matter in the caves—clay, sand, limestone, gravel—concluded that the bones had been washed down therewith, and "lodged wherever there was a ledge or cavity, sufficiently capacious to receive them, or a straight sufficiently narrow to be completely obstructed by them; they were entirely without order and not in entire skeletons, occasionally fractured but not rolled, apparently drifted but to a short distance from the spot on which the animals died." Buckland's final hypothesis was that the animals had fallen during the antediluvian period into open fissures, and there perishing had remained undisturbed until the waters of the deluge drifted their remains to the position in which they were found. With his first suggestion I generally agree; from the latter I dissent. Geologists of the present day do not call a special deluge to their aid. It was far otherwise however once; since a little after Buckland writes, we find Mr. Joseph Cottle declaring, "No one phenomenon presents a fuller attestation of that overwhelming catastrophe [the Deluge] than the innumerable animal remains discovered in the Oreston Caves."

We owe to Mr. Pengelly the most exact account of the recent cave phenomena which we possess. Visiting Oreston in 1859, in consequence of the renewed discoveries of the previous year, he ascertained that the new cave was in the same line as the old ones, which had been long entirely removed, "as if the various caverns had been so many enlarged portions of one and the same original line of fracture." Moreover he found that such portion of the roof of the cavern as remained was a "mass of limestone breccia made up of large angular fragments cemented with carbonate of lime, and easily enough mistaken without careful inspection for ordinary limestone, somewhat rich in coarse veins." This was what some of the older investigators had taken for an unbroken stratum of solid rock. Having thus established the original open character of the fissure, Mr. Pengelly declined to say "whether animals fell or were dragged in, or whether the bones found there were wholly or partially the remains of dead animals washed in. . . . . Some of the bones appear to have been rolled as if they had been washed in, whilst if as Sir Henry De la Beche supposed the loam or clay is really impregnated with animal matter, it seems reasonable to infer that at least in some cases,

something more than mere portions of the osseous system was introduced." Fully agreeing with this view, I hope to be able to carry the matter one step further.

There is another hypothesis concerning the channels by which the remains were introduced, to which perhaps I ought to refer. It is that of Mr. H. C. Hodge, who holds that the caverns were really enclosed by solid stone, and suggests that the original openings are to be sought between the limestone beds at points where they are separated by seams of purple calcareous slate. I do not know a single instance of the occurrence of this slate which I should not pronounce contemporaneous with the limestone itself.

The animals whose remains have been clearly identified as occurring in the Oreston Caverns are—*Ursus priscus*, grizzly bear; *Ursus spelæus*, great cave bear; *Felis spelæa*, cave lion; *Hyæna spelæa*, cave hyena; *Canis lupus*, wolf; *Vulpes vulgaris*, common fox; *Equus fossilis*, fossil horse; *Equus plicidens*, ditto, with plicated tooth; *Asinus fossilis*, fossil ass or zebra; *Bison minor*, lesser bison; *Bos longifrons*, long-fronted ox. These were all identified by Professor Owen, who likewise assigned the rhinoceros remains to *Rhinoceros tichorinus*. Mr. Busk holds that they belong to *Rhinoceros leptorhinus*, which has never been found in cave deposits elsewhere, and is always of much rarer occurrence than its congener.

Mr. J. C. Bellamy states that bones of the mammoth and hippopotamus in his possession were found at Oreston; but he expressly mentions that he did not examine the caverns himself. The Rev. R. Hennah, who did, distinctly avers that in the caverns to which Mr. Bellamy refers no remains of the larger animals were discovered. I do not think therefore that either belong to the Oreston fauna, though Dr. E. Moore states that bones of the mammoth, rhinoceros, and bear were found in fissures on the Hoe; and the bones of the mammoth certainly did occur at Yealm Bridge.

Dr. Buckland concurred with Messrs. Clift and Cottle in believing that the weasel was included in the Oreston fauna. Professor Owen holds that the evidence is insufficient. Mr. Cottle mentions bones of the boar, the hare, and the water-rat as in his collection. Mr. Pengelly has identified the hog; but of the hare and the water-rat we hear no more. Mr. Bellamy mentions (second-hand) the occurrence of ovine bones. Mr. Hodge enumerates the deer,

the camel, the giraffe, and a small rodent of the size of a mouse as contributing to the contents of this ancient charnel. But in this, so far as I am aware, he stands alone.

The fauna of Oreston differs materially from that of Kent's Hole. It does not supply the great sabre-toothed tiger, *Machairodus latidens*, nor the Irish elk. On the other hand, Kent's Hole has neither *Equus plicidens*, *Asinus fossilis*, nor the lesser bison. And there are several lesser variations.

I pass away from the caverns for a while. We have in this locality an interesting series of alluvial deposits of varying age and character. The oldest are those beds of earth, intermixed with fragments of slate lying for the most part horizontally, which occur high up on the slopes of some of our valleys, and are of kindred origin to the ordinary river gravels. The newest occupy the creeks and higher portions of our estuaries, as at Lipson and Chelson Meadow, or at Puslinch on the Yealm, where a boring has been made of over forty feet without finding bottom.

The most interesting series are those which have from time to time been discovered on the Hoe. The highest point of the Hoe, which has a plateau of some width, is 110 feet above mean tide level, and the average height of the plateau is about 100. Midway on the Hoe extensive excavations revealed the existence of the deposits which I desire to describe.

Below the ordinary turfy soil there is a bed of earth more or less clayey in character, through which are scattered numerous pebbles. This varies in depth up to four or five feet, and contains patches of white and red clay appearing to graduate, partially at least, into the less distinctively clayey soil by which they are surrounded. With the clay are small veins of sand tending downwards to larger arenaceous deposits, which have not been bottomed.

The matrix of the pebbles differs in no respect from the ordinary alluvium of an ordinary river valley; unless in the occurrence of the patches of clay.

The pebbles scattered through it range from a very small size up to boulders a dozen pounds or more in weight. They are chiefly quartzose, some apparently a mixture of quartz and schorl, others granitoid in character, though rather resembling an elvan than a true granite; with a few of a dark hard slate. There are likewise fragments of limestone more or less waterworn; but the pebbles are unquestionably travelled.

The clay occurs in patches rather than beds, occasionally lenticular. The white clay in exterior character exactly resembles the ordinary clays of the Bovey Heathfield, and at once suggests a similar origin in the decomposed felspar of the Dartmoor granite. This clay contains very few pebbles. The red clay, as a rule, is not so free from them. It may have been derived from the decomposition of a granite with a reddish felspar; but the probability is that it owes its colour to the direct action of iron. Fragments of iron ore have been found in association. The white and red clays occur in close juxtaposition on the same level. Probably therefore the origin of both is the same, and the difference in colour due to local causes of an accidental character.

The sand is the chief peculiarity of the series of deposits. It varies in colour from white, to drab, cream-colour, and red; is very fine and unmistakeably siliceous—precisely such a sand as would be produced by the degradation of a granitic or a quartzite rock—such a rock, in short, as that from which the quartz pebbles already spoken of came. In mass it occupies a position distinctly subordinate to the clays, and evidently fills a large fissure in the rock, as yet of unknown depth.

These deposits are by no means isolated phenomena in connection with the Hoe. Sand was found in digging the foundations of Elliot Terrace adjoining; but that was largely mixed with pebbles. At the south-eastern corner of the Hoe, near the little cavern which is used as a tool house, the fissures in the rock contain pebbles precisely similar in character to those above. In such fissures we have the authority of Dr. Moore for saying that bones were found representing with tolerable closeness the Oreston fauna, including remains of the elephant, rhinoceros, and bear. Then again in 1808, a deposit of sand was found on the Western Hoe, fifty feet above high water mark, which contained the jaw of an animal with teeth two inches long, and a large vertebra $9\frac{1}{4}$ inches by $4\frac{1}{2}$. Nor are such deposits confined to the Hoe. They occur elsewhere on the shores of the Sound. We are indebted to Mr. Spence Bate for the account of certain beds of freshwater sand at Bovisand, unquestionably of kindred and probably of contemporaneous origin. And at Deadman's Bay may be seen the remains of a large "pocket" in the limestone—one side having been worked away, which was at least sixty feet in depth, and probably much more, and which was filled with clay and pebbles precisely similar to the

white clay and pebbles of the Hoe. We have the right to infer that wherever the conditions were favourable, the whole range of the limestone within the area of the Sound, and the streams flowing thereinto, received these deposits.*

I hold it to be capable of demonstration that the level wall-like character of our limestone—and this is no mere local phenomena, but may be observed in Torbay—is due to the action of water; that our limestone ridge is, in short, a platform of denudation, formed by a great river which probably followed in the main the course of the present Tamar, though it is quite possible that ice may have aided in producing this result. The range of limestone must have been exposed to the denuding action for a period of great duration, ere the platform could have been levelled as we now find it. While this process was onward, either no deposits were thrown down, or they were only harboured in sheltered spots. At length there commenced a period of upheaval —slow and long continued; and then the formation of new deposits set in. I am inclined to think that the deposition did not commence until the crest of the Hoe had been raised nearly to the level of the waters. Such fine sand could not have been deposited by either a rapid or a deep stream, at any rate at the actual site of deposition; and so with the clay. We see deposits of precisely analogous character formed in the present day by the streams which flow from china clay works. In the ordinary alluvium, and the pebbles intermixed, we have evidently the work of a still later period, when the Hoe had begun to peer above the waters, and was only liable to occasional overflow, the river meanwhile busily eroding the present channels by which it passes the rocky barrier, probably in the track of pre-existing fractures and fissures.†

And now, to return to the bone caverns. Their contents must have been carried into them by waters which flowed at a much higher level than those of the Tamar and the Plym, or by waters which flowed when the land was at a much lower level. Here, then, is my hypothesis. The similarity in character and method of occurrence of the two classes of deposits, lead me to hold that the caverns are in the main contemporaneous with the surface

* This view of mine has been confirmed, since the lecture was delivered, by my attention being called to similar phenomena at Billacombe. One of the Yealm Bridge caves was also filled in this way.

† "Trans. Devon Ass," vol. i.

formations which I have described, and date back to a time when the limestone rocks which enclose the fissures were but slightly raised above the waters, and when therefore nothing was easier than the introduction into the caverns of bodies of animals swept down the stream, probably in time of flood; just as they are commonly swept down the rivers of tropical countries in the present day. This view has the double advantage of reconciling difficulties, and of agreeing with the generally-observed facts.

Finally, as to the raised beaches. Mr. Bellamy, in his "Natural History," states that the height of the ancient beach on the Hoe was generally about thirty feet above high-water mark; and describes a patch as it then existed (1839), twenty feet in depth, and fifty feet above high water. It rested on a shelf of smoothened rock, which sloped gently seawards, and consisted of regularly "superposed or stratified" layers, varying from extremely fine sand to moderately-sized pebbles. As traces of pholades were discovered in the rock on which these deposits rested, there can, I think, be no doubt that they were what they were taken to be—a raised beach.

I may add that pholas borings are said to occur in the limestone of Hooe, nearly 100 feet above the present tide level; but that doubt has been cast upon their origin.

This brings our narrative of the geological history of Plymouth down to (geologically) recent times; and here, then, I close the record.

SOME REMARKS ON RECENT SPECULATIONS ON THE ORIGIN AND SPECIFIC CHARACTER OF MAN.

ABSTRACT OF REV. J. ERSKINE RISK'S PAPER.

(Read December 9th, 1875.)

Darwin's theory of the origin of man stated. Arguments in support of his conclusion that "man is descended from a hairy quadruped, furnished with a tail and pointed ears, probably arboreal in its habits, and an inhabitant of the old world." Argument