19. *NOTES on the CONSOLIDATED BEACH at PERNAMBUCO.* By J. CLARKE HAWKSHAW, Esq., M.A., F.G.S. (Read January 8, 1879.)

THE narrow ridge of rock which forms the seaward protection of the harbour of Pernambuco, and which appears to be the remains of a consolidated beach laid bare by the slow upheaval of the coast, has become almost as well worn a subject of discussion as the parallel roads of Glen Roy. A drawing was given of it in a Dutch work* as early as 1624, and many travellers have since described and figured it in their works. It has been called a coral reef, and has been described as consisting probably of cretaceous rocks, and it was not until after Mr. Darwin had visited it in 1836 that its true nature was pointed out by him in a short account printed in the 'London and Edinburgh Philosophical Magazine' for 1841.

The late Prof. Hartt, who has added so much to our knowledge of the coast of Brazil, confirms Mr. Darwin's view as to the nature of the reef, and describes several similar formations at various points along the coast†. At Porto Seguro there is a consolidated beach very similar to that at Pernambuco; there is also one at Santa Cruz. The stone reef shown on the chart at the mouth of the Rio Grande do Norte appears to be a consolidated beach, and patches of beach rock occur at other places; I saw some undermined by the sea along the rocky coast north of Bahia.

In 1874 I examined the beach at Pernambuco; and in the course of some investigations made for Sir John Hawkshaw in the following year for a report to the Brazilian Government on the Port of Pernambuco, a number of borings were made in the neighbourhood of the reef. Some of these passed through the reef itself, and they tend to complete our knowledge as to its extent laterally and beneath the surface.

Section opposite the Marine Arsenal, Pernambuco, at right angles to the "Reef."
(Horizontal scale, 1 inch = 500 feet. Vertical scale, 1 inch = 100 feet.)

Difference between high and low water, ordinary spring-tides, 7·3 feet (2·27 metres).

Briefly described, the consolidated beach (see fig.) consists of a ridge of sandstone from 25 to 75 yards broad, and, as shown by the borings, from 10 to 13 feet thick. The surface of the rock has a gentle slope towards the sea, the higher or landward edge being at the

* 'Reys-boeck van het Rycke Brasiliën' see 'Geology and Physical Geography of Brazil,' by C. F. Hartt p. 434.

† *Ib.* pp. 188, 189, 232.

same level as the high water of ordinary spring-tides opposite the Arsenal quay, falling from 2 to 3 feet below that level towards the lighthouse. Along the outer or sea face lie large blocks of the sandstone which have broken off as the reef has been undermined by the surf. The river flows along the inner or land face with a velocity at the ebb during spring-tides of from five to six knots an hour, and the bottom deepens rapidly from this face, there being a depth of 28 feet at low-water spring-tide at a distance of 60 feet from the rock. The rise of the tide at ordinary springs is 7 feet. Shells still preserving their colour and rounded quartz pebbles are scattered sparingly throughout the rock. The surface is in great part covered by a growth of *Serpulæ*, *Balani*, &c., and a calcareous coating described at length by Mr. Darwin. The rock is very hard, yet the pebbles which project in places unprotected by the organic covering show that it has been worn away by the action of the sea-water charged with sand. The organic covering, although softer than the rock, may be better able to resist this abrading action. A piece of lace when laid on the surface of a piece of glass will effectually protect the glass from the disintegrating action of the sand-blast machine, the result being that the pattern of the lace will be faithfully reproduced on the glass.

The surface of the rock is marked by grooves, which have been described by Mr. Darwin* as follows:—"There are also many sinuous cavities 2 or 3 inches in width and depth, and from 6 inches to 2 feet in length. The upper edges of these furrows sometimes slightly overhang their sides; they end abruptly, but in a rounded form. One of the furrows occasionally branches into two arms, but generally they are nearly parallel to each other, and placed in lines transverse to the beach sandstone ridge. I know not how to account for their origin, without they are formed by the surf, as it daily breaks over the bar, washing to and fro pebbles in depressions originally only slight. Opposed to this notion is the fact that some of them are lined with numerous small living *Actinææ*." I think the explanation suggested above as to the origin of the grooves is the true one, but that they were formed under different conditions of the reef, that is, when the surface was at a lower level than at present, so that the surface of the rock was in one plane with the surface of the foreshore. Under the present condition the pebbles, which are not abundant on the rock, would not remain long on the surface, and the action of the surf broken by the rough edge and fallen blocks on the seaward face would be very irregular. On the foreshore at Dover I have noticed grooves of a similar description in the surface of the chalk which has a regular slope from the base of the cliff to low-water mark. These may be seen below the Castle Cliff to the eastward of the last groyne in that direction. Beyond this groyne, which is a very high one, forming a jetty raised above high-water mark for a great part of its length, the foreshore pre-

* Phil. Mag. vol. xix. 1841, p. 258, and reprinted in Appendix to Darwin's 'Coral Reefs,' 2nd edit.

sents a very remarkable appearance when seen at the time of low water. The whole of the surface between high- and low-water mark is scored by a series of grooves parallel to the direction of the groyne and transverse to the shore-line. The shore is bare of shingle; but pebbles are to be found here and there along the bottom of the grooves, and there is a sprinkling of shingle about a yard in width along the side of the groyne and along the base of the cliff. The grooves on the higher part of the foreshore are from 2 to $2\frac{1}{2}$ feet deep and about a foot wide; but lower down the foreshore they soon diminish in size, and do not vary much over the greater part of it, being from 4 to 5 inches wide, and from 4 to 8 inches deep. They are narrower towards the bottom, which is rounded and hollowed out more in some parts than in others. They branch into one another in places like those at Pernambuco. Though they are generally only a few inches apart, occasionally there is a greater width of chalk between them; and this is generally marked by an incipient groove a foot or two long with rounded ends, as if a piece of chalk had been irregularly scooped out with a gouge. The grooves diminish in number eastward of the groyne; and I have not noticed a similar appearance of the foreshore elsewhere, though grooves occur all along the foreshore, but at rare intervals, and are caused in many cases, I fancy, as much by the flow of land-water from the base of the cliff as by the action of the waves on the shingle. I can only attribute the presence of the grooves in such numbers at the above place to the regular action of the wash of the sea on a small supply of shingle, the groyne acting as a guide to the waves, and also intercepting the west to east drift which prevails along the coast.

It will be seen from the borings made at Pernambuco that there is another layer of rock about 8 or 9 feet vertically below the present ridge (see fig. p. 239). This rock was met with in two of the borings through the reef at depths of 13 and 16 feet below low water of spring-tides. Rock is again met with in the same line, and at a depth of from 16 to 19 feet below low-water spring-tides, at the Barra Grande, about a mile to the north of the lighthouse, which is built on the northern end of the reef. Rock was not met with elsewhere in any of the borings made in the neighbourhood of the reef*. It would therefore appear possible that there is another ridge of rock running at a lower level on the line of the existing reef. Can this be a consolidated beach of older date? The difficulty in the way of such a conclusion is that it would imply a recent depression in the level of the land, of which, I believe, there is no other evidence. On the contrary there are conclusive signs that the coast has recently risen in level, and that the southern part of the continent has been slowly rising for a long period of time. It would be remarkable,

* One other boring, made in deep water near the reef, touched on rock near the surface; but as no rock was met with in another boring made near the same place, the rock met with in the first instance was probably a block detached from the reef.

moreover, that at two periods, separated by the time required to change the level of the coast by the amount recorded in the vertical distance between the layers of rock, the conditions required to produce the consolidated beach should have obtained in the same place.

The cementing material of the Pernambuco rock is carbonate of lime. The rock is very hard, and when freshly broken it has a vitreous look. This is in a measure owing to the grains of quartz which with an occasional grain of magnetic iron ore make up the whole of the residue after the carbonate of lime has been removed by acid, being scarcely rounded, but having the original vitreous surface which they had when first liberated by the decomposition of the felspar in the gneiss from which they were derived.

On many parts of the coast of Brazil long ridges of sand occur, separated from the land by lagoons. The percolation of land-water charged with carbonic acid derived from the decayed vegetable matter in these lagoons through the sand ridges will account for the formation of the beach-rock, the water taking up and again depositing the carbonate of lime of the shells imbedded in the sand. The flood-level of the lagoon-water would determine the level of the upper surface of the beach-rock; and that of the lower surface would be determined by the cessation of the consolidating action at the level at which the sand was saturated by sea-water—that is, almost low-water level. Thus the regularity of the form of these reefs may be explained.

Consolidated beaches, however, occur in localities where there is little or no vegetation or land-water, as on the shore of the Red Sea, where I have seen beach-rock enclosing recent shells. So also on the Great Barrier reef, on the north-east coast of Australia, consolidated beaches are frequently met with. The sand is there often wholly calcareous, and when consolidated forms a very tough rock, which has been described by the late Prof. Jukes in his account of the voyage of the 'Fly'*. He attributes the formation of the rock on the coral reefs to the action of rain-water dissolving the carbonate of lime in the upper layer of coral sand and redepositing it lower down, the deposition ceasing at the level where the sand became saturated with sea-water. Prof. J. D. Dana, who describes the consolidated beaches which occur on many coral islands in the South Seas, attributes† the consolidation to the alternate wetting and drying of the sand by the rise and fall of the tide, the carbonate of lime being taken up by the sea-water and redeposited as the water evaporates. On some islands he noticed pebbles of basalt on the shore, each of which was coated with a white layer of carbonate of lime. Mr. Darwin saw somewhat similar deposits on the Island of Ascension‡. Prof. Dana also describes some drift-sand rocks on coral islands where hills of blown sand have been more or less consolidated by the agency of infiltrating water, "fresh or salt."

* 'Voyage of H.M.S. Fly,' vol. i. p. 128.

† 'Corals and Coral Islands,' p. 152.

‡ 'Voyage of the Beagle,' p. 588.

Thus it appears that beach-rocks are generally formed by the deposition of carbonate of lime; but this is not always the case. M. A. Papier has described* a rock, formed on the beach near Bona, of which the cementing material is a silicate. At that place he found sand and fragments of shells, and also a shingle of quartz pebbles, consolidated into a hard rock. The sand-rock effervesced slightly with acid, owing to the presence of fragments of shells; but the shingle-rock, which was exceedingly hard, showed no signs of effervescence whatever, and neither the one nor the other was disintegrated by the strongest acids.

The beach-rock at Pernambuco has probably not been exposed for a long period of time, there being unmistakable signs elsewhere of a recent elevation of the coast. Nevertheless it is remarkable that it should have resisted the sea for so long a time as it is known to have done. The port of Pernambuco owes its existence entirely to the presence of this narrow bar of sandstone.

Is it possible that these beaches mark periods of repose in the slow vertical movements which have occurred within recent times in the northern part of South America, as the successive lines of inland cliffs which divide the sloping shingle plains of Patagonia in almost unbroken lines for hundreds of miles have been shown by Mr. Darwin to mark, on a much grander scale, the periods of repose during the slow elevation of the southern part of the continent?

DISCUSSION.

Prof. DUNCAN said that he thought geologists, as a rule, agreed that Prof. Dana's explanation of the formation of coral-rock was correct, though there might be exceptional cases. The amount of carbonate of lime introduced into these beaches was remarkable. The marine vegetation found at the bases of these rocks seemed to show that there was a considerable quantity of carbonate of lime in the sea-water. He thought, from the specimens on the table, that the author was right in assuming an upheaval. With regard to the grooves in the Chalk of the Kentish shore, noticed by the author, he had observed that waves meeting made lines of greater pressure, which seemed to correspond with these grooves. The case of the cementation by a silicate mentioned by the author was very interesting.

Sir JOHN HAWKSHAW had examined the reef, and, from its appearance, had conjectured it to be thin, which on boring proved to be the case. There are along the Brazilian coast, in some places, parallel ridges of sand at much the same distance from the shore as the reef. These did not appear to be yet solidified; but, under favourable circumstances, they might be. Behind some of these ridges were pools of water, in which are found shrimps which are different from those found in the adjoining sea, their antennæ

* Bull. de la Soc. Gol. de France, 3 sr. vol. iii. pp. 46-48.

being enormously long and their eyes much larger than in those found in the sea. The water in these pools was opaque, which might have led to the above singular differences.

The PRESIDENT asked if the author had ascertained the amount of carbonate of lime in the consolidated rocks.

The AUTHOR stated that he could not give the amount; but the cementing material in the specimens examined was wholly calcareous. Liais states that the cementing material in some of the beaches is partly calcareous and partly siliceous.