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ORDINARY GENERAL MEETING.*

GENERAL HALLIDAY IN THE CHAIR.

The Minutes of the last Meeting were read and confirmed.

The following election was announced :—

MEMBER :—Rev. W. P. Schuster, M.A., Vicar of West Lulworth.

The following papers were read :—

ON THE GEOLOGICAL RELATIONSHIP OF THE VOLCANOES OF THE WEST INDIES. By J. W. SPENCER, M.A., Ph.D., F.G.S. (No. I.) (With Map of the West Indian Islands.)

ST. VINCENT has been one of the danger-places of the earth, with its volcanic forces devastating the island, nearly two hundred years ago, and again a century later; hurricanes sweeping off the magnificent tropical vegetation, only three or four years since, and lately the revival of volcanic eruptions carrying destruction to the existing order of things, and building up new physical features. The general interest in such great changes has been concentrated upon Martinique, on account of the volcanic activity being on a more limited area and annihilating a whole city. It is this feature which has awakened the popular interest and drawn to the scene various scientific observers and adventurers, who have described the pathetic side of the devastation and the new conditions in the island. But working quietly at the problem of the late changes of level of land and sea, the writer, after having spent much time in the West Indies and Central America, has studied especially the phenomena which bear upon the question of the age of the volcanoes, and of their place in geological history. It is this aspect of the question which is here brought forward.

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* Monday, April 20th, 1903.

While the Virgin group and the adjacent small islands on the same submerged plateau with Puerto Rico, the Lesser Antilles, or Windward Islands may be considered as commencing with St. Croix* (on the south-eastern side of the great trough across the submarine plateau), and following the form of a crescent for a distance of 750 miles to the coast of South America, this physical barrier between the Caribbean Sea and the Atlantic Ocean, having a breadth of scarcely more than 100 miles, or reduced again to a width of 25 miles, is a submerged plateau dismembered into the various drowned table-lands, more or less surmounted by mountain ridges and volcanoes, now forming the Windward Islands. Everywhere we find wonderful valley-like land forms indenting the submerged plateau connecting North and South America together. The depressions in the plateau between the islands do not exceed depths of more than 2,000 or 3,500 feet below sea level. In one place only is this amount exceeded between the two continents where it is dissected to a depth of 6,000 feet, namely, in the trough between St. Croix and the Virgin Islands, between which and the continent, by way of Puerto Rico and some of the Bahama Islands, an emergence of 2,100 feet would make a continuous land connection. Among the island masses, we find submarine canyons or gorges with a corresponding depth of 6,000 feet, a broad depression between the Grenadines and Barbados reaching to from 6,000 to 9,000 feet, and elsewhere among the Bahamas there are other submarine valleys of depths of more than 12,000 feet. All these are reproductions of land features of plateau regions, such as those of Mexico and Central America, so much so that they may be regarded as evidence of the former elevation of the region, forming a bridge between North and South America, across which we now know some animals migrated in the early Pleistocene period.

The primary foundation of this barrier between the Caribbean and Atlantic basins has never been discovered, but it is probable that no geological formation or physical feature older than some part of the Cretaceous period will ever be found. Except possibly some of the volcanic formations, there is only very little information concerning any rocks as old as this period. In St. Croix and St. Thomas, Cleve found some evidence of the existence of the Cretaceous formation in that region. Possibly the "Scotland Sands" of Barbados, apparently older than the Tertiary era, may also be Cretaceous. Elsewhere

* St. Croix (Fr.), Sta. Cruz (Span.)

throughout the whole chain of islands, there is nothing excepting the volcanic basement that can be assigned to greater antiquity than that of the early Tertiary days.

The Windward Islands are practically divided into two parallel chains. The inner one commencing with Saba, continues through St. Eustatius, St. Kitts, Nevis, and Montserrat; the western of the twin islands of Guadeloupe, Dominica, Martinique, St. Lucia, St. Vincent, Grenada and the Grenadines, is characterized by complex volcanic formations surmounted by volcanic cones and ridges. The outer chain from St. Croix, St. Martin, Anguilla, Antigua, Barbuda, Grand Terre of Guadeloupe, Marie Galante, to Barbados, with probably some sunken islands between the two last mentioned, is characterized by more or less calcareous formations resting upon the denuded surfaces of an old volcanic foundation. Some of these islands are in part mountainous, but of no great elevation, showing the erosion features of considerable antiquity. They are also marked by the rolling outlines of coastal plains, which extend beyond their present shores, and form the summit of the adjacent portions of the submerged plateaus. While the coastal plains, traversed by erosion features, do not prevail upon the western chain of the islands, yet in the large Saba banks, just south-west of the volcanic island of the name, we find the same features repeated at a depth of only 100 feet, or a little more, below the surface of the sea. All these calcareous formations show themselves to be only remnants of such, extending over an immense land area now dismembered and sunken beneath the sea level; and the apparent gap in their succession between the Guadeloupe Archipelago and Barbados, is represented by three banks of similar form where, it is reasonable to suppose, they are of the same character, and that they are the slightly drowned remnants of the submerged Antillean plateau.

In the outer chain of islands, we find that the volcanic basement is covered by formations of the older Tertiary era, the upper portions belonging to the Oligocene system, while the lower beds may perhaps reach down to the base of the Eocene. This gives us the clue to the age of the older volcanic formations. These rocks, without describing them accurately, are a sort of dolerite consisting of triclinic felspars with but little magnesium silicate. It is a kind of intermediate eruptive rock, which if found in Paleozoic strata would be called porphorite, and if in the Tertiary, andecite. There is nothing to establish the age of these old rocks beyond the fact that they are below the old Tertiary formation. Such volcanic deposits dissected by

the rains and streams, form the low mountains of the outer chain of islands and the foundation of the inner chain of volcanic islands, where they may be seen at many points, and on the smaller islands away from the recent volcanic cones. Typically they may be best observed in that little continent, which we call the island of Antigua, for there the erosion features of their surface have not been buried beneath the late volcanic accumulation. And here we also find the formations passing under tuffs which are themselves succeeded by the lower Tertiary limestones. In St. Kitts the south-eastern end of the island is composed of these old igneous rocks with their surface features characteristically modified by atmospheric agents, but in the centre of the island they are surmounted by more recent volcanic cones. The same is true with regard to the southern end of Martinique; but in other islands like Nevis, the mountain part of Guadeloupe, Dominica, Montserrat, St. Lucia, and St. Vincent, the old igneous foundation has been more or less buried by the later volcanic accumulations. While more detailed studies may lead to some modification of opinion, the writer is inclined to regard these rocks as the remains, left after atmospheric denudation, of a widespread igneous system, forming the apparent foundation of the modern submerged Antillean plateau.

From the evidence left in the outer chain of islands, there was little or no volcanic activity throughout the region during the greater part of the Tertiary era, though further investigations may show that eruptions occurred, in the inner chain, extravasating part of the material out of which the various stratified beds of tuffs were apparently formed in the older Tertiary days. Throughout the middle and later Tertiary periods all the region of the islands was a great land surface which was moulded by the erosion agents into features with broad rounded outlines, the higher parts of which now form the foundations of the islands. But about the close of the Pleiocene the West Indian Bridge was submerged so as to leave only small islets, and marine beds containing modern forms of life were accumulated about them. These, in several of the islands, occur resting upon volcanic sands containing recent skulls of animals, showing that the volcanic forces had again commenced to be operative before or by the beginning of the Pleiocene period, after a more or less general rest of long duration.

The renewal of volcanic activity thus appears to have been coincident with the changes which marked the advent of the Pleistocene period, but it has been confined to very much more

restricted areas than the old pre-Tertiary igneous eruptions, as we find late volcanic accumulations in the first place restricted to the inner chain of islands, and even there not covering their whole surface, without even building up connections between what are now the adjacent islands. From observations especially in St. Kitts, Guadeloupe and Dominica, and the resemblance of the igneous formations in the other islands to those first mentioned, it is apparent that the volcanic ridges and cones built upon the surfaces of the old igneous formations, owe their size and great height, reaching to 4,000 or 5,000 feet, to the volcanic eruptions accompanying the great changes of level of land and sea which have occurred since the beginning of the Pleistocene or Glacial period. The building up of the ridges of these inner islands has been due entirely to volcanic forces which have scarcely affected the portions of the island beyond the ridges themselves; but within this limit we find that the stratified beds, some of which are mechanical formations derived from the ancient rocks and stratified beneath the sea, had been everywhere tilted outward from the centre of the volcanic cones which rest upon their surfaces. These sloping volcanic beds have not been confounded with the tufaceous deposits which have been accumulated upon the slopes of the cones of which they make up almost the entire mass, as lava is found at only occasional points. While the volcanic activity at the present time is startling from the disasters that the eruptions have produced, yet it is insignificant compared with the whole amount of material which has been erupted to build up the cones.

Interesting examples of the localized effects of the eruptions in lifting and disturbing the strata, may be seen in St. Eustatius and in St. Kitts. In the latter island there is a prominence rising to a height of 700 feet with a diameter of much less than half a mile, called Brimstone Hill, which is veneered to a height of 450 feet by a bed of limestone, having a thickness of about 30 feet, dipping outward in all directions at high angles, which was the former sea bottom. This prominence was elevated by the volcanic forces pushing up a cone, which, however, was not surmounted by a crater. This elevation took place as far back as the mid-Pleistocene epoch; and as it occurs on the flank of the main volcanic ridge of St. Kitts, it suggests that the volcanic activity had greatly diminished in that island long before the present day, although more recent eruptions had built up the summit of the cone where we now find the crater. Twelve miles distant across the

sea, in St. Eustatius, a similar phenomenon was repeated; but there the sea bottom was raised to a height of 900 feet, and the prominence became surmounted by a crater now rising about 2,000 feet above the sea. No eruptions in these islands have been observed within the historic period. But this locality is situated near the north-western end of the volcanic chain.

However, in the not distant island of Guadeloupe, several eruptions occurred in the eighteenth and earlier part of the nineteenth centuries, and in Dominica, a small disturbance took place about 1880. While a small manifestation was observed in Martinique some fifty years ago, yet the volcanic forces had come to be considered inactive, and the only dangerous volcanic island was thought to be St. Vincent, where the eruptions of 1718 and of 1812 sent its *débris* as far as Barbados, more than 100 miles away.

The relationship of the volcanic activity to the physical changes in the Antillean region should be somewhat more fully explained, even though partial repetition may be unavoidable.

In pre-Tertiary times the whole Caribbean plateau was subjected to wide-spread volcanic eruptions which, however, do not appear to have been entirely beneath the surface of the sea, and later the plateau seems to have been a land surface, which was greatly modified by atmospheric denudation sweeping away any craters or cones that existed, and leaving only modified hill surfaces such as now occur between the Tertiary formations, or lie buried beneath the later volcanic ridges. Even the origin of the plateau may have been mostly volcanic, but that was antecedent to the early Tertiary period.

While the old igneous basement is found beneath the surface rocks of nearly all of the islands, yet we cannot certainly say that the pre-Tertiary eruptions covered the whole breadth of the submerged plateau between the Atlantic and Caribbean basins; for in Barbados upon its outer edge, there is a series of sand deposits, probably as old as the later Cretaceous or early Eocene days, which forms the oldest foundation in that region of which we know anything. After the completion of the now buried features carved out of these ancient eruptive rocks, and after the deposition of the sandy shore deposits just mentioned, the whole region sunk to depths unknown. In Barbados this depression, perhaps referable to the same general epoch, reached to the abysmal depth of perhaps two miles, as pointed out by Professor Harrison and Mr. Jukes-Browne, the evidence of which is shown by the oozes containing oceanic radiolaria,

etc., which were accumulated in the district now elevated to form the island. As these deposits lie beneath old Tertiary formations, their origin cannot have been later than the early part of the Tertiary period.

Passing by the minor changes, the general condition of the region in the earlier Tertiary period was one covered by the sea, at first with the accumulation of clastic strata derived from the remains of the older volcanic rocks. These were succeeded by white limestones and marls containing fossils which show their age not to have been later than the Oligocene period, by the close of which time the general construction of the Antillean plateau was formed; to be greatly denuded and carved into its present broader outlines during the long Miocene-Pleiocene period. During the earlier part of the land history, its elevation appears to have been considerable, but the altitude was gradually reduced so that about the end of the Pleiocene days its surface was reduced in area so as to leave only the present chain of islands somewhat smaller than now. During this long period of land surface, North and South America were bridged by a now sunken plateau. Throughout this long era we are not certain that volcanic activity was energetic throughout the region, and the differentiation of the many tufaceous formations of the more western islands needs further elucidation.

After the subsidence about the close of the Pleiocene period, the whole region rose to form a very high table-land, whose elevations as shown among the Windward Islands themselves, must have been from 3,000 to 6,000 feet, but from the evidence among the Bahamas and off the coast of the North American continent, it must have exceeded two miles, at a time which corresponded to the earlier Pleistocene days. This elevation seems to have been a sufficient cause of the Glacial period. Then the rapidly descending streams carved out the canyons which became great deep river-like valleys now submerged beneath the sea.

Upon the changes of level which carried down the land of the later Tertiary days below sea-level, volcanic activity after the long rest was renewed as we have already seen, and the volcanic ridges were in part upheaved and further built up by the eruptions mostly before the mid-Pleistocene period, which reduced the area of the islands to sizes smaller than now. In short, the great chain of volcanoes belongs to the late Tertiary and post-Tertiary days, being coincident with the great changes of level of land and sea.

Since the mid-Tertiary epoch there have been terrestrial oscillations causing the islands to be enlarged somewhat beyond their present size, only to again be depressed to near their present altitude. In several islands at least a slight comparatively recent elevation is noticeable, as seen by geological evidence, though we have no satisfactory records from an historical standpoint.

Thus it appears that the volcanic phenomena were closely connected with those of earth movements, which in proportion have declined as also has the volcanic activity.

While the volcanic forces have built up ridges and cones, by the accumulation of the *débris* of eruption, yet in part their elevation has been due to upper thrusts of the ridges themselves, fringed with fragments of the sea bottom; but the great changes of the whole now submerged plateau may in part have been tectonic, but if so they have been modified by what in America is called epeirogenic or slow continental movements; for everywhere the surfaces of the submarine plateau are dissected by systems of valley-like indentations which have not obscured the movements due to volcanic or other forces.

The vibrations in the rocks during the recent eruptions were sufficient to break the submarine cables, often overhanging the walls of the submerged canyons. It has also been reported that the sea bottom had collapsed in places. Such sinkings in the crust have been contradicted with the general statement that there have been no apparent changes. If such a collapse of the submarine crust had really occurred, then there might be some doubt as to the origin of part of the valley-like features, made known by the dredgings. Although the district is volcanic with caldrons and *cul de sacs* of valleys, in part originated by the destructive forces of exploding volcanoes, yet the general features are those of denudation; so that the idea that the valley forms in the submarine plateau have been due to past atmospheric action, does not seem to be affected. Accordingly, from the records of these drowned valleys, we obtain our knowledge of great changes of level of land and sea in recent geological times.

The terrestrial movements, as also the volcanic, have been mostly along the line represented by the chain of islands—the margin of the Atlantic Ocean—which has been marked as a zone of terrestrial weakness favourable to both tectonic movements and volcanic action, and suggestive of renewed volcanic activity along this course. But the recent eruptions in Martinique and St. Vincent, those in Central America and

Mexico, others reported in the region of the Azores, in Japan, and the great earthquakes of Guatemala, Chinese Turkestan, etc., all belonging to parallel zones, yet they seem to point to some terrestrial disturbance of a general common origin acting parallel with the line of the equator, as if the movements are readjusting the terrestrial crust in a transverse as well as a normal direction. In fact, we know but little about volcanicity, and it seems strange how little has been added to our knowledge by the recent eruptions almost at our own doors.

The effects of the eruptions have been made known to us in a popular way through very many media of communication, so that the writer has deemed it desirable only to respond to the courteous request for a contribution, by telling something of the relation of the igneous formations to their place in geological history, as based upon travel among the islands; and some of his data for the opinions here expressed, have already been published, and to them the reader is referred, and for this reason, fuller detail here becomes unnecessary.

References.

"On the Geology of the North-eastern West India Islands," by P. T. Cleve, *Trans. Roy. Swedish Acad. Soc.*, ix, No. 12 (1870).

"Geology of Barbados," by Messrs. J. B. Harrison and A. J. Jukes-Browne, *Quart. Jour. Geol. Soc.*, vol. xlvii (1891), and vol. xlviii (1892).

"Reconstruction of the Antillean Continent," by J. W. Spencer, *Bull. Geol. Soc. Ann.*, vol. vi (1894).

"On the Geological and Physical Development of Antigua"; "of Guadeloupe"; "of Anguilla, St. Martin," etc.; "of the St. Christopher Chain," etc.; "of Dominica, with notes on Martinique, St. Lucia, St. Vincent, &c."; "of Barbados, with notes on Trinidad." Six papers by the present writer in *Quart. Jour. Geol. Soc.*, volumes lvii and lviii, 1901 and 1902.

Note.—The Council is indebted to Dr. Tempest Anderson for the loan of lantern slides from photos taken by himself and Dr. J. S. Flett when investigating the recent eruptions in St. Vincent and Martinique at the instance of the Royal Society. The Report was presented to the Royal Society on November 20th, 1902, and since then Dr. Anderson has contributed a paper on the eruptions to the Royal Geographical Society, which is published in the *Geographical Journal*, March, 1903.—E. H.

Map of the West Indian Islands.