30. *On the GEOLOGICAL and PHYSICAL DEVELOPMENT of ANTIGUA.*
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F.G.S. (Read April 24th, 1901.)

[PLATE XV—Map.]

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I. INTRODUCTION AND EARLY OBSERVATIONS.

THE island of Antigua may be taken as a starting-point for the study of the Windward Islands, as within its area of 100 square miles almost all of the geological and geographical features of the region, except the later volcanic phenomena, are developed in such a way as to be easily understood. The only other island comparable for a base of study is Guadeloupe, which furthermore includes all the recent volcanic features on a grand scale, but some other features less easily distinguishable than in Antigua.

On November 5th, 1819, Dr. Nicholas Nugent, a physician of Antigua, communicated to the Geological Society of London 'A Sketch of the Geology of the Island of Antigua'¹; but a 'Memorandum' of this had been sent to Benjamin Silliman on April 10th, 1818, and was published two years earlier in America² than the fuller London paper. Nugent also sent to the Geological Society large collections of the rocks and fossils, carefully labelled as to their horizons. These remained almost unstudied for over forty years, when P. Martin Duncan made an elaborate study of the corals contained in them,³ which appeared in 1863-64.

Nugent had a companion in his studies of the island in the

¹ Trans. Geol. Soc. ser. 1, vol. v (1821) pp. 459-75.

² Am. Journ. Sci. ser. 1, vol. i (1819) pp. 140-42. The petrified wood of Antigua had even before this attracted attention; and a notice of a collection made by Pelatiah Perit (of New York) is found a little earlier than Nugent's 'Memorandum,' on p. 56 of the same volume of the Am. Journ. Sci.

³ 'On the Fossil Corals of the West Indian Is.' Quart. Journ. Geol. Soc. vol. xix (1863) pp. 406-58, & vol. xx (1864) pp. 20-44, 358-74.

person of Dr. Thomas Nicholson, who wrote a short account of the geology of the island in the 'Antigua Almanac & Register,'¹ a work forgotten or lost. Prof. S. Hovey² visited the island, with Nugent as his guide, and published a sketch of the 'Geology of Antigua' in 1839 (as he says) on account of the inaccessibility of Nugent's paper in America. In this publication there was little marked advance. Nugent had described the igneous belt of the western portion of the island; the 'clay' and 'conglomerate'-zone in the centre, with the chert-deposits containing silicified wood, freshwater shells, etc.; and the fossiliferous white marl and limestones occupying the eastern or larger belt; as also the recent coral-fringes. Even in 1818, Nugent had recognized the Tertiary character of the marls, and said (*Am. Journ. Sci.* vol. i, p. 142) that in the West India Islands there was

'proof of an extensive formation, more recent than those to which naturalists have heretofore principally confined their attention.'

Nugent's paper showed a remarkable degree of perspicuity, and remained the only classic on the geology of the island for over sixty years, until the appearance of the studies of M. J. C. Purves, published at Brussels in 1885.³

At the time of my visit, I had not seen the work of M. Purves (Curator of the Royal Natural History Museum in Brussels), which will be referred to in succeeding pages, and I am not aware that any geologist had visited the island for the purposes of investigation subsequent to M. Purves, until my own visit in 1896-97. But I met there, interested in the geology of their island, two gentlemen, whose assistance and kindness I wish to acknowledge, Mr. Frank Watt, the Island Chemist, and Mr. W. R. Forrest. The Rev. Mr. Branch is also keenly interested in the natural history of the island.

None of the previous writers had made a study of the two formations more recent than the marls, or of the evolution of the physical features since the Oligocene Period (age of the limestones); all of which phenomena were the special objects of my visit, for the purpose of correlating them with the later life-history of the Greater Antilles and the adjacent continent, especially the evidence of great changes of level of land and sea. My theoretical expectations were realized.

II. SITUATION AND PHYSICAL CHARACTERISTICS.

Antigua and Barbuda rise from the same bank, which occupies the north-eastern portion of the chain of the Lesser Antilles.⁴

¹ A copy was seen by Prof. Hovey in 1839.

² At one time Professor in Yale and Amherst Colleges. See *Am. Journ. Sci.* ser. 1, vol. xxxv (1839) pp. 75-85.

³ 'Esquisse géologique de l'Île d'Antigua' *Bull. Mus. Roy. Hist. Nat. Belg.* vol. iii (1884-85) pp. 273-318.

⁴ See U.S. Hydrographic Chart No. 40, or the corresponding British Admiralty Chart.

Section across Antigua from Five Island Point to Hodge's Hill; distance about 9 miles.

This bank is about 55 miles long and from 18 to 28 miles wide, with an area of 1400 miles. It is only slightly submerged, to a very uniform depth of about 100 feet. But even from the nearest islands — Guadeloupe, Montserrat, and Nevis, which are situated on the same great submarine plateau or ridge — this island bank is separated by somewhat broad depressions reaching to a depth of 1800 feet, or in a few places the narrower channels have depths from 2000 to 2500 feet. Thus the bank presents a striking physical unit, as of an extensive plain interrupted by low hills, with the remains of mountains occurring on the southern side of what is now the island of Antigua. The margins of the bank are everywhere abrupt and precipitous, and they are somewhat indented by deep valleys extending to the more profound depressions.

The island of Antigua has a maximum length (east and west) of 16 miles and a breadth of 13, with an area stated at 108 square miles. But the coast-line, especially of the eastern half, is very much broken up into lobes by shallow bays. These are occupied by numerous islands, keys, and reefs, among which the extension of the land-valleys can be followed.

The portion of the island south, or south-west, of a line extending from the hills 2 or 3 miles west of St. John's across the island to Falmouth Harbour, forms a zone characterized by the remains of old mountain-ranges (the highest summit, Boggy Peak, reaching to 1330 feet above the sea), and relatively large deep valleys. There are few precipitous cliffs, but the declivity of the mountain-sides is steep, and the

streams in the deep valleys rapidly descend to the lower reaches, which are much broadened out, with flats so low that the deepening processes no longer obtain. The general erosion-features of this zone are those of a mountain-plateau, which has been dissected for

so long a time by atmospheric agencies that only narrow ridges remain between the valleys and ravines.

The central portion of the island, with the mountain-belt, as just described, on one side, and bounded on the other by a line of interrupted hills, extending from Dickenson's Bay (near Wetherell Point) to Willoughby Bay, on the southern coast, is characterized by plains at only a slight elevation above the sea, out of which rise isolated hills, among which Drew's has a height of 356 feet.

The remaining, north-eastern portion of the island forms a third zone, which is marked by undulating plains and hills rising to between 200 and 350 feet above the sea—in one case alone to 450 feet. In this portion of the island the drainage is largely absorbed into the porous strata, and is carried off below the surface, leaving it devoid of permanent streams.

The diverse features of these three belts are dependent upon their geological structure, and their boundaries mark the confines of the principal formations.

III. THE IGNEOUS BASEMENT OF THE ISLAND.

The foundation-rocks of the island appear at the surface, in the mountain-belt described above. Their general character, as then understood, was recognized by Nugent, and has recently been more fully described by M. Purves.¹ He shows that the rocks form a dolerite consisting of triclinc feldspars, with little or no magnesian silicate. The phenocrysts are vitreous feldspar; angular grains of magnetite are associated with them. This is an intermediate eruptive, and if included in Palæozoic rocks would be called a porphyrite, but if in Tertiary rocks an andesite. There is nothing in the character of this rock to establish its age. All that can be said is that it is pre-Tertiary, on account of its underlying the older Tertiary deposits. In places the rock is strongly porphyritic. Among the hard eruptives occur irregularly beds of fragmental materials or breccias and ashes, which have been more or less subjected to alteration, and these dip north-eastward, passing under the newer formations of the island. The compact trappean beds are often found decomposed, forming a residual soil many feet thick.

The eruptive formations suffered great denudation, both before the succeeding deposition of the Tertiary formations and since the close of the early Miocene Period. The long denudation, under varying conditions since that time, has largely given rise to the physical features of the island with which we are concerned. Such old igneous rocks occur in many of the Windward Islands, but in the ordinary accessible literature they are not generally distinguished from the much later volcanic eruptions which have broken through the older formation.

¹ Bull. Mus. Roy. Hist. Nat. Belg. vol. iii (1884-85) p. 279.

IV. THE SEAFORTH LIMESTONES.

At a few points in the valleys of the mountain-zone, as at Seaforth and the adjacent estate of York (which I visited along with Mr. Forrest), there is a very compact dark-grey limestone, in appearance resembling old formations, even of Palæozoic age. The beds dip at considerable angles south-westward. Only fragments of these deposits remain, in protected places, on account of subsequent denudation. This appears to be the oldest formation succeeding the igneous rocks, although this limestone has not been found eastward of the mountain-zone, beneath the stratified rocks which overlie the old trappean deposits. Nothing can be said as to its age, for no fossils were found in it, but it resembles limestones of other islands, and on this account, and because of its very different character from the Tertiary formations, it is possible that it may be as old as the remains of the Cretaceous Period, such as are seen in the island of St. Croix.

V. THE TUFFS AND INCLUDED MARINE AND FRESHWATER CHERTS.

Extending diagonally across the island, in a belt from $2\frac{1}{2}$ to $4\frac{1}{2}$ miles wide, and occupying the central plains and the north-western flank of the mountain-zone (up to an altitude of 695 feet in the case of the isolated hill called Monk's Hill), there is a very thick formation of stratified tuffs. These beds dip from 12° to 20° north-eastward.

The tuffs are made up of more or less decomposed angular and subangular fragments of trappean rocks, and contain minute crystals of felspar and magnetite. While the tuffs of fine texture predominate, near the mountains they become a conglomerate. In some cases the particles are waterworn. The colour is greenish to brown, and even whitish where kaolinization is more complete. These tuffs appear to have been derived from the denudation of the older volcanic formation, which extended to the nearest islands (30 miles distant). Drew's Hill,¹ situated in the middle of the zone, seems to have been produced by a renewal of volcanic activity, long after the commencement of the epoch of the tuffs, and may have contributed in a measure to the mass of that formation.

Lying conformably within the tufaceous group are lenticular masses of cherty limestone, containing rounded or fragmentary remains of shells and corals. These rocks give rise to isolated prominences. Higher come strata of sands and grits with waterworn volcanic fragments; and still higher are irregular thin layers

¹ The core of this hill is a compact crystalline eruptive, rising vertically through the tuffs to the summit, and is described by M. Purves as a trachydolerite, containing large crystals of triclinic felspar, with a pyroxenic mineral and grains of magnetite. It is the presence of the pyroxenic mineral which distinguishes this rock from the older igneous formation.

of chert containing well-preserved fragments of silicified wood and freshwater shells. In the lower marine limestones the shells were too poorly preserved for identification, but M. Purves obtained five species of corals¹ suggesting Miocene age; and some of the corals described by Duncan² from the Nugent Collection showed that the age is not newer than the older Miocene. But Prof. Rupert Jones observed a fragment in the Nugent Collection containing *Orbitoides Mantelli*,³ which would make the formation from which it came correspond to the Upper Eocene of the American continent.

In the freshwater cherts M. Purves found eight genera⁴ of gasteropods, all in an excellent state of preservation. Five of these genera are not found in more recent beds in the island; and the species of the other three genera cannot be identified with the more modern forms now living on the island. The evidence of the age, derived from these long-extinct forms, supports the antiquity indicated by the corals.

Collections of fossils from the freshwater beds, which Mr. Forrest found intercalated in the tuffs, were kindly given to me by him.

Suffice it here to say that the tufaceous deposits, while older than the succeeding marls resting conformably upon them, had a fauna somewhat different from, though closely related to the latter. For other information concerning the beds of tuff and their enclosed cherts, M. Purves's work should be consulted.

¹ *Prionastræa diversiformis*, Mich. Upper Miocene, Bordeaux and Turin.

Solenastræa turonensis, Mich. Miocene, Turin and Touraine.

Stylocænia lobato-rotundata (Mich.). Miocene, near Turin, etc.

Porites Collegnana, Mich., equivalent of *incrastans*, Ed. & H. Miocene, Turin.

Alveopora Dædalea, Forskål. Recent, Red Sea, Indian and Pacific Oceans.

² *Astræa cellulosa*, var. *curvata*, sp. nov.; *A. megalæxona*, sp. nov.; *Solenastræa turonensis*, Mich.; *Isastræa conferta*, sp. nov.; *I. turbinata*, sp. nov.; *Stephanocænia tenuis*, sp. nov.; *Caloria dens-elephantis*, sp. nov.; *Astroria polygonalis*, sp. nov.; *A. affinis*, sp. nov.; *A. antiquensis*, sp. nov.; *Astroccænia ornata*, Ed. & H.; *Alveopora Dædalea*, Blainv., var. *regularis* & *minor*; and later he added *Stylocænia lobato-rotundata* (Mich.), found also in the lower limestone of Malta.

Thus, three species are like European Miocene, nine peculiarly Antiguan species, and *Alveopora Dædalea* is recent. Duncan added three species as coming from the tuff, namely, *Stephanocænia tenuis*, *Astræa cellulosa*, and *Mæandrina*, sp., but M. Purves points out that these come from a horizon in the tuff above the chert-beds. See Duncan, Quart. Journ. Geol. Soc. vol. xix (1863) p. 411 & Geol. Mag. 1864, p. 97.

³ Geol. Mag. 1864, p. 102. M. Purves thinks, however, that the specimen containing *Orbitoides* came from the higher limestone, which would suggest a somewhat earlier Tertiary date for all the deposits.

⁴ Bull. Mus. Roy. Hist. Nat. Belg. vol. iii (1884-85) p. 294. The five genera confined to the island are *Melania*, *Zonites*, *Nematúra* or *Ammicola*, *Neritina*, and *Pomatias*, and the three genera with species still living are *Planorbis*, *Melampus*, and *Truncatella*. M. Purves says that *Melania* proper does not live in the West Indies, but the subgenus *Hemisinus* occurs in Cuba. *Zonites* does not occur in the West Indies, though a species was found by M. Purves in Demerara. *Neritina* is scattered over the islands, but not in Antigua. *Nematúra* is found in the East Indies and in the Oligocene of the Isle of Wight.

VI. THE WHITE LIMESTONES OR ANTIGUA FORMATION.

The north-eastern portion of the island is underlain by a white limestone or marl, which is the 'Marl' formation of Nugent (or the 'Upper Limestones and Marls' of M. Purves). This formation is composed of an earthy marl and beds of compact limestone, often hard and durable enough for building purposes. White is the prevailing colour, but it is sometimes greyish or yellowish in the lower beds. The limestones are distinctly bedded, and dip from 12° to 20° north-eastward; but the bedding in the earthy or marly beds is often obscure. These varieties of rock pass one into the other. This formation is apparently conformable to the underlying tufaceous beds. The thickness of the limestone was not determined, but there still remain of it at least many hundred feet. The limestones are in part capped by a mechanical deposit, which has not been distinguished from the limestones by any previous observer. This series gives rise to the undulating hilly country occupying the north-eastern part of the island, the rolling features of which are the remains after the enormous degradation of the limestone at a comparatively slight altitude above the base-level of erosion. From the dip of the strata it naturally follows that the slopes towards the south-west are somewhat more abrupt than in the opposite direction.

The importance of this formation arises from two facts:—first, that it was the last great accumulation before a very long period of denudation, which removed not only a large proportion of the limestones themselves, but also exposed the older features; and secondly, on account of its containing a fauna by which the age of the beds can be determined. The question is not one of local distribution on the island, but rather one concerning the whole North-eastern Antilles, as showing that the phenomena described did occur in that region, during the geological periods ascertained. These limestones generally form the summits of the higher hills, but at the lower altitudes they have their very much eroded surfaces covered by a thin mantle of mechanical deposits, which have sometimes been removed in artificial cuts and otherwise.

At the north-western end of this belt, the sea has encroached upon the high lands, where at Wetherell Point it has formed a bluff about 100 feet high. Here both the hard and the marly beds occur, each being highly fossiliferous in places. Some of the harder beds appear to be made up of *Ostrea*. There are also other species of molluscs, but they are mostly in a poor state of preservation, and seldom consist of more than casts. The most important fossils found here are the smaller corals which predominate in the softer beds and are often silicified, thus preserving the structure so as to be determinable. I observed fossils at other localities, but nowhere so abundant as at Wetherell Point. The only corals that have hitherto been collected were those sent by Nugent to London in 1819, and studied by Duncan, who enumerates eleven

species (of three genera) and some additional varieties as here named¹ :—

Astræa crassolamellata, sp. nov., with varieties *magnetica*, *pulchella*, *nobilis*, *minor*, *Nugentii*, and *magnifica*; *A. antiguensis*, sp. nov.; *A. endothecata*, sp. nov.; *A. tenuis*, sp. nov.; *A. barbadensis*, sp. nov.; *A. radiata*, Lamarck, var. *intermedia*; *A. costata*, sp. nov.; *Rhodærea irregularis*, sp. nov.; *Alveopora Dædalea*, Blainv., var. *regularis*; *A. microscopica*, sp. nov.; *A. fenestrata*, Dana.

I have seen no determination of the shells collected by Nugent, but with regard to some of them, Duncan says that they were unfortunately determined by some good authorities to be specifically identical with forms now existing in the reefs round the island. I might suggest that these recent types of shells may have come from the lower altitudes above the sea, and belonged to a different horizon not distinguished by the collector from the White Limestone Series, for, as already stated, the earlier observers confounded an overlying accumulation with the great formation now being studied.

My collection of corals has been kindly determined for me by Dr. T. Wayland Vaughan, who found the following species :—

Trochomilia sp. nov.

Stylophora sp.

Stephanocania sp.

Astrocania ornata, Ed. & H.

Brachyphyllia sp.

Orbicella (Astræa) crassolamellata,
Duncan.

Orbicella cellulosa, Duncan.

Orbicella endothecata, Duncan
(= *cavernosa*, Linn.).

Orbicella sp.

Symphyllia sp. nov.

Astroria polygonalis, Duncan.

Oroseris sp. nov.

Alveopora regularis, Duncan.

Porites sp. nov. (?).

Besides these corals a species of *Orbitoides* was also found.

This list includes eight new or undetermined species of other genera, not found by Duncan, and six species common to the two collections. Two of these species are those which Duncan found in collections from the marl-beds; three from those belonging to the chert-beds (that is, midway within the great beds of tuff) or in the tuff itself; and one species common to the marl and the lower beds. Thus while Duncan recognized a difference in the fauna of the lower and upper beds, he found that they were closely allied, and the present collection still further emphasizes this point. Accordingly it would appear that the underlying beds of tuff with the overlying White Limestone form scarcely more than one geological unit, although characterized by great changes in the physical conditions during the accumulation of the system.

This collection of mine contained old types only. Duncan identified some of the species as belonging to the Miocene Period of the Old World. A few he found to be recent, but related to those of other West Indian islands, though the nearest analogies are found in the Indian and Pacific Oceans. The majority of the species are peculiar to Antigua, but none of them have any relationship with the living forms in the adjacent waters, showing a complete gap between them and the coral-fauna of the marls.

¹ Quart. Journ. Geol. Soc. vol. xix (1863) p. 410.

From these considerations Duncan inferred that the formation belonged to the mid-Tertiary or Miocene Period.

It has been stated before (p. 495) that Prof. Rupert Jones had found an *Orbitoides Mantelli* in the Nugent Collection. I also found a species of *Orbitoides* in the marls of Wetherell Point. This fossil is one of the most important collected, as it affords a correlation with the Tertiary of the South-eastern States, and would suggest that the formation is somewhat older than the mid-Tertiary Period, in a word, that the rocks are older Miocene or Oligocene. Thus it would appear that the time of this formation was a continuation of that of the fossiliferous beds of the tuffaceous deposits (reaching probably to a thickness of several thousand feet)—the whole being one undivided geological unit, referable to the older Tertiary Period (including the Eocene and extending to the later Oligocene days).¹

The shells of the same formation, which, as before stated, are mostly in the form of casts, have not been determined, but Prof. W. H. Dall, having cursorily examined them, formed a general impression confirmatory of the evidence established by the corals.

Prof. Gregory² mentions *Echinanthus* (or *Diplothechanthus* of Duncan) *concavus*, Cott. and *E. Antillarum*, Cott., sent by Mr. Forrest, as the first echinoids recorded as coming from Antigua, thus correlating the beds of this island with those of St. Bartholomew.

The eroded surfaces of these limestones give form to the hills, rising to 200 or 350 feet (one point to 456 feet) above the sea, with the gently sloping depressions between them. The higher portions of the hills appear not to have been subsequently covered by the accumulations about to be described. But the question of the erosion-features produced during the different periods since the early Miocene emergence of the limestones will be considered as a separate topic. I have refrained from comparing the age of the rock-formations and other features with their equivalents in the other West Indian islands, as this subject should form a chapter by itself.

The series has become a type in the Antillean islands, and may thus appropriately be called the Antigua formation.

VII. THE HODGE'S HILL SANDSTONES.

Hodge's Hill is situated at the north-eastern angle of Antigua, rising to a height of 154 feet above the sea. The exposed strata of this hill are composed of a creamy white calcareous sandstone. It is compact and suitable for building-material, hardening and darkening on exposure. The dip is in the normal north-easterly direction, but less than that of the White Limestones—not exceeding 10°. The rounded grains of calcareous sand give the

¹ [Since I sent in the manuscript of this paper, Dr. Vaughan has shown that the Antigua coral-fauna is identical with that of the lower beds of the Upper Oligocene formation in South-western Georgia. See 'Science' n.s. vol. xii (1900) pp. 873-75.]

² Quart. Journ. Geol. Soc. vol. li (1895) p. 295.

rock an entirely different appearance from that of the White Limestones upon which it rests unconformably, as shown along the sea-coast west of the hill. At one point near here, the White Limestones were seen to form a sharp anticline, the eastern arm being much steeper than the western, the axis running north and south. The age of these beds has not been determined; but as they have been involved in the dislocation of the White Limestones, one suspects that the Hodge's Hill Sandstones belong to an epoch not long subsequent to that of the former rocks.

VIII. THE FRIAR'S HILL SERIES.

Lying on the eroded surface of the White Limestones at Friar's Hill is a thin layer of waterworn pebbles (formed out of the harder material of the underlying formation), succeeded by a bed of a homogeneous yellowish-white marl, 12 feet thick. In other artificial cuts in the hilly country, in the northern part of the island, as on the road to Millar's Mill, etc., one may observe the eroded surfaces of the underlying series, covered by a mantle of fragmental deposits of pebbles and marls not exceeding a thickness of 20 feet, except in buried depressions. The marly beds of the series are most frequently seen underlying the pebbles. The marls are in places indistinctly laminated, in others the stratification is shown only by lines of pebbles within the finer material. The bedding appears to be everywhere horizontal, although there are slight undulations (but not tilting). This deposit, whether marly or pebbly, is evidently one of mechanical origin, where the limestone has been more or less pulverized and rounded by the action of the waves. Occasional fragments of the older rocks have been seen included with other pebbles. The White Limestone-pebbles form a very considerable portion of the whole mass. On the gently-sloping hillside, from which the accumulation has not been entirely denuded, the finer marl has been so washed out as to leave the fields covered with a very stony surface—the pebbles being those left from the denudation of the overlying mantle. As the substance of these pebbles is identical with that of the underlying rocks, it is not surprising that they should not have been distinguished from disintegrated fragments of the older surface-rocks, but the intervening unconformity should have been recorded if not explained. Although they are waterworn, the soft materials of which they are composed do not become so well rounded or preserve their forms as do those of harder rocks. Furthermore, in places both the rounded pebbles of the upper series and the more angular surface-fragments of the limestones are intermingled; but where the waterworn pebbles are seen, they can usually be traced to lower altitudes, where their relationship to the typical deposits can be easily ascertained. The Friar's Hill Series is widespread, covering most of the lower slopes of this part of the island, and occurs up to an altitude of 200 feet, above which the hills of the older formation rise from 100 to 250 feet higher. This superficial mantle has been greatly denuded, so as to reduce its

thickness in places to only a few feet, or even to expose the underlying rocks, being, however, unmistakably preserved in the depressions of the older surface.

The materials of the Friar's Hill Series have not been transported to any considerable distance. For this reason, and on account of the fragmental character of the tuffs, as well as perhaps on account of the subsequent denudation, the evidence of the submergence to 200 feet, during this short epoch of rapid deposition, was not observed in the central portion of the island—unless it be in some of the cherty fragments (containing shells and petrified wood) scattered over the surface—where, however, the remains of a still newer deposit occur.

No fossils belonging to this formation ¹ *per se* have been discovered as yet, but a few waterworn corals of the older beds occasionally are found among the pebbles. While the age cannot be determined from the included fossils, yet from physical considerations and from analogous accumulations with similar relationship—namely: the Matanzas formation of Cuba, the Layton of Jamaica, and the Lafayette of the American continent—the Friar's Hill Series is thought to belong to the close of the Pliocene or the early part of the Pleistocene Period.

IX. THE CASSADA-GARDEN GRAVELS.

Cassada Garden Estate is situated about 2 miles east of St. John's, on the eastern margin of the tuffs, and very near the south-western chain of hills of the White Limestone Series. Consequently, it is somewhat distantly removed from even the newer volcanic rocks of Drew's Hill. At the mill on Cassada Garden Estate is a low eminence rising only about 20 feet above the plain. A chain of similar mounds extends south-eastward. These are composed of somewhat coarse, perfectly waterworn pebbles of igneous rocks, with fresh, compact, undecomposed surfaces. In section, at the pond of Cassada Garden, the gravels are seen to be interstratified horizontally with loam. Mr. Watt, who kindly took me to this locality, had examined the section shown in the well, sunk through the deposit, and found that it did not exceed 20 feet in thickness, or precisely the height of the knolls above the plain. The gravel-knolls do not attain an elevation of more than 60 to 75 feet above the sea. These deposits, transported from considerable distances, and accumulated by currents, have also suffered denudation. The whole series resembles sections of the Columbia formation of America, the Zapata of Cuba, and the Liguanea of Jamaica, which belong to the early part of the Pleistocene Period.

X. RECENT DEPOSITS.

Many portions of the island adjacent to the sea-shore, as at St. George's Church, directly east of St. John's, have their surface

¹ [Some of the corals studied by Duncan may have come from these marls, or else from a still more recent formation not yet distinguished on this island, equivalent to the Usine Beds of Guadeloupe.]

covered with a thin layer of marly earth, containing a considerable number of marine shells, such as are now living in the adjacent sea. I observed the deposit, which is horizontally stratified, only to an elevation of 10 feet above sea-level. This surface was defined by M. Purves as a terrace of 'Horizontal Marls,' a feature of which, noticed by him, should not be passed over. In the upper portion of the accumulation he found a considerable number of land-shells, which had been washed down into the basins where the marls were formed. Among these shells he found *Helix formosa*, Férussac, to be the most abundant, but the shell no longer lives in this portion of the island, although it still survives in the mountain district of the south-western part of the island. He also found *Helicina Crosbyi*, Nob. now extinct, and known nowhere in the West Indies; and *Succinea Boonii*, Nob., a species no longer living. On account of these wholly or locally extinct species, although commingled with a number of living forms, he concluded that a considerable time has elapsed since the deposition of the beds containing them.

XI. CORAL-REEFS.

Coral-reefs are extensively developed round both the islands of Antigua and Barbuda, rising to the surface of the sea, but they do not appear to form elevated reefs, characterizing the margin of the island. Even the low peninsulas and islands separating the bays on the north-eastern coast are composed of older formations, but the reefs in part obstruct the entrances of the bays or form 'keys' in them.

XII. NOTES ON BARBUDA.

Before considering the erosion-features of Antigua, a word may be said with reference to Barbuda, which was involved in the denudation of the region. This island, nearly as large as Antigua, is a low undulating plain, passing into lagoons on its western side. The greatest elevation is only 115 feet. While I did not visit the island, Mr. Watt informed me that it was everywhere composed of a limestone, poorly covered with soil, and he kindly gave me fragments of the rock containing casts of old fossil shells, the whole apparently identical with the White Limestones of Antigua. This resemblance was also noticed by M. Purves. The collection of Nugent contained specimens from Barbuda, among which was *Cyphastrea costata*, Duncan, a form of coral occurring in the older Tertiary beds of Santo Domingo and Jamaica. Although the evidence of the identity of the rocks in the two islands is incomplete, yet there can hardly be any doubt of it, especially as they are not distantly separated, and the beds of the one island lie almost along the continuation of the strike of the strata in the other, but they may represent higher beds of the same series preserved from erosion. The recent formations, at most forming thin mantles, have not been studied. M. Purves states that the land-shells are identical with those of Antigua, except one variety of *Helicina*, thus indicating a late connection of the two islands.

XIII. EROSION-FEATURES OF THE ANTIGUA-BARBUDA REGION.

As before stated, these two islands and connecting banks form a geographical unit, although the greater part is slightly submerged. Whatever erosion had affected the mountain-districts of Antigua, prior to the elevation of the White Limestones, it left but little effect upon the later topography. The physical features of the north-western part of the island are such as show the former uniform thickness of the White Limestones from one end of the belt to the other. The surface gently descends in the same direction as the beds are inclined. At an elevation of about 100 feet is a peneplain sloping towards the eastern coast, but out of it rise isolated ridges. Following the trend of the belt, the country is characterized by a succession of hills, from 200 to 350 feet above the sea (which in one case only rise to 450 feet), separated by broad undulating depressions reduced to 150 feet above the sea. Thus we find that the atmospheric agents had not merely removed a great thickness of the White Limestones, but dissected the whole region and transformed the incisions into gently-sloping depressions, leaving only the higher points as isolated hills, occupying a subordinate portion of the country. One cannot even guess to how enormous an extent these rocks have been removed by degradation. They must have also covered to a greater or less extent the tuffs to the south-west. Such topography indicates the denudation of a region rising only gently above the base-level of erosion (that is, the level of the sea, the margin of which was then located at least beyond the banks); for the peninsulas of the eastern coast are the remains, in part, of the White Limestones separated by the excavation of the intervening valleys now submerged.

The configuration of Barbuda conforms to that of the north-eastern portion of Antigua; and the banks between the islands represent a coastal plain now submerged to 100 or 120 feet, which does not appear to have been subsequently modified by the growth of corals, as in the shallower water immediately about the islands.

The tufaceous deposits have evidently suffered a greater amount of erosion than the limestones, as the incoherent materials have been removed so as to form the low broad plains of the middle belt of the island, out of which some of the harder rocks, such as the remains of Drew's Hill, rise to elevations similar to that of the limestone-hills to the eastward; and indeed one eminence at the southern end of the belt (Monk's Hill) shows the remains of this deposit to an altitude of about 700 feet, indicating a differential denudation of nearly this amount.

The broad valleys of the lower reaches of the streams, with their low gradients, deeply indenting the mountain-zone, appear to belong to the same long period of denudation, but the deeper valleys of the interior of the island have quite different features, suggesting that during the long Miocene-Pliocene Period it was a plateau or mountain-area only partly dissected by the rapidly-

descending waters. As a broad feature of this old erosion, it may be mentioned that the wide shallow harbours, such as Willoughby Bay, Falmouth Bay, and Five Island Harbour, are only sunken portions of the land-valleys. But between these, which were once surrounded by high hills in the form of amphitheatres, and the low interior country, the elevated lands at their heads have been so reduced in height as to form low passes, leaving the sides of the valleys characterized by prominent elevations.

The broad undulating or rounded features were formed by atmospheric agents prior to the deposition of the Friar's Hill Series, which at most covers the old surface by only a thin mantle. Consequently, the island was continuously a land-surface from the early Miocene to about the close of the Pliocene Period, when it was again partly submerged during the Friar's Hill epoch. Throughout this long era, the topography of the region was a mountain-district, bordered by foot-hills of considerable elevation, among which was the adventitious volcano of Drew's Hill, and perhaps later a volcanic outburst at Crosbie's,¹ beyond which the coastal plains extended to the edge of the banks north of Barbuda.

After the Friar's Hill epoch, subsequent erosion produced other characteristics throughout the region. The broad depressions indenting the margins of Antigua were greatly deepened and extended farther into the highlands. These valleys, on the coast, are now drowned to a depth of 40 or 50, and in one case to 80 feet. On the southern coast the channels of Willoughby Bay and English Harbour are distinctly traceable to a depth of 100 feet, and that of Falmouth to 140 feet, within the limits of the less submerged banks. Similar trenches can be traced upon the submarine plains between the two islands, having a depth of 25 or 40 feet, and in a locality west of Barbuda there is one of 100 feet below the surface of the banks, which are themselves submerged only 80 feet. Where the margins of the submarine plateau have dropped to 150 feet and more below the surface of the sea, they show valley-like indentations trending to those of the land. One of the most conspicuous occurs west of Five Island Harbour. It reaches a depth of 1290 feet within the line where the banks are covered by less than 150 feet of water. This deep amphitheatre opens out into the broad submarine valley, where the soundings reach over 1900 feet. Broad embayments encroach upon both sides of the plateau between Antigua and Barbuda, thus considerably reducing its breadth.

I have just mentioned comparatively narrow channels upon the surface of the submarine plateau, and deep indentations into its margin. The former feature may be produced either where the land has no great altitude above the drainage-level, or upon the surface of a high plateau, sufficiently far within its margin for the streams not to be affected by the deep declivity of its edge.

¹ This is a dolerite containing far more pyroxenic elements than that of Drew's Hill, one of the facts which led M. Purves to infer its more recent origin.

The second condition is the result of atmospheric denudation and rapidly-descending streams, producing deep valleys, headed by amphitheatres, which are constantly receding into the highlands, and cause the shallow channels upon the surface to become eventually transformed into cañons and valleys dissecting the plateau.

The difference between the erosion-features of the Miocene-Pliocene and the early Pleistocene Periods (separated by the Friar's Hill submergence) lies in the low undulating topographic forms of the first-mentioned, requiring a long period of development at a low elevation; and the deep valleys and sharp outlines of the latter, produced rapidly at considerable heights above the drainage-level of the region. But it should not be forgotten that the valleys on the high tablelands, well within their borders and not affected by the declivity of their margins, may still preserve the flattened features of a lower level of erosion.

The erosion-features of the higher parts of the mountains of Antigua—highlands dissected into narrow ridges and deep valleys of great declivity—are the result of the older degradation continued to the present time without interruption by submergence. This complete dissection of the mountain-districts is an illustration of the effects which would have been produced upon the Antigua-Barbuda plateau had the secondary period of denudation under conditions of great elevation been continued sufficiently long.

A considerable portion of the Friar's Hill Series was removed during the early Pleistocene elevation. Again there has been a certain amount of denudation since the epoch of the Cassada-Garden Gravels, and also since the accumulation of the low marls on the eastern coast, this latter extending below sea-level.

The relative amount of work during the last episode is not so well defined in Antigua as in other islands, and deserves further study in the field.

XIV. SUMMARY AND CONCLUSIONS AS TO CHANGES OF LEVEL OF LAND AND SEA.

As has already been shown, this region was an extensive land-surface during the Miocene-Pliocene Period, which was eventually reduced to a comparatively low elevation above sea-level before the close of that time. This is the conclusion arrived at from the evidence within the boundaries of the submerged plateau, surrounded by the islands of Antigua and Barbuda. But outside the limit of this paper there is evidence that leads me to think that during the earlier part of the period the whole region was at least 2000 feet higher than now, when the broad valleys between the Antiguan mass and the neighbouring islands on the submarine Antillean plateau were being fashioned out of a higher tableland: of this a remnant remains in the Antigua-Barbuda plateau, the surface of which was reduced to its present form in the latter part of the period. I have not observed in Antigua the evidence of an insular elevation, as seen in the islands where late volcanic

activity has prevailed, but this is a question for consideration when studying the general changes of level of the Antillean plateau.

The Miocene-Pliocene elevation in Antigua was followed by a submergence (the Friar's Hill) to a depth of 200 feet below the present altitude. On this account it is possible that the mechanical accumulations of Antigua are represented in Barbuda by calcareous beds containing a recent type of organic remains.

Following this submergence about the close of the Pliocene Period, the land rose to a great altitude. The evidence from the dissection of the banks shows the elevation to have reached 2000 feet. But the submarine plateau between Antigua and Guadeloupe is further incised by channels, indicating the elevation to have exceeded 3000 feet. This is not the extreme height to which the region rose, but the evidence lies beyond the province of this paper. These conditions did not continue sufficiently long to complete the dissection of the tablelands, and consequently the Antigua-Barbuda mass remains intact. This elevation (subsequent to the deposition of the Friar's Hill Series) was in the early part of the Pleistocene Period, fuller evidence of which occurs elsewhere.¹

Then followed a subsidence, which culminated in a submergence to a depth of 75 feet when the Cassada-Garden Gravels were deposited, to be succeeded by a re-elevation—not merely to this amount, but to 100 feet or more—when the shallow channels on the submarine bank were formed. This feature would be in harmony with the later movements observed in other islands. Sufficient study has not been given to the subject to determine whether the recent marls on the eastern coast were laid down during the post-Cassada Garden emergence—in which case they were once considerably higher before sinking to the present level—or whether they belonged to a later episode indicating another subsidence and re-emergence to a height of 10 feet. However, a doubt is cast upon a very recent re-emergence, on account of the considerable age of the shells in the marls, and also because recent corals do not occur in the raised reefs.

EXPLANATION OF PLATE XV.

Geological sketch-map of the Island of Antigua, on the scale of about 2½ miles to the inch.

A south-western mountain-zone composed of old igneous formations; a central rolling valley-belt with undulating hills, formed of tufaceous deposits; a north-eastern hilly or rolling country underlain by early Tertiary (Eocene-Oligocene) White Limestones, whose eroded surfaces are often succeeded by a denuded mantle of the Friar's Hill Series of marls. There are also isolated patches of a later formation of gravel, as at Cassada Garden.

¹ See 'Reconstruction of the Antillean Continent,' Bull. Geol. Soc. Am. vol. vi (1895) pp. 103-40; 'Geographical Evolution of Cuba,' *ibid.* vol. vii (1896) pp. 67-94; and 'Late Formations & Great Changes of Level in Jamaica,' Trans. Canad. Inst. vol. v (1898) pp. 325-58.