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GEOLOGY.—*Stratigraphy of the Virgin Islands of the United States and of Culebra and Vieques Islands, and notes on eastern Porto Rico.*[1]

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INTRODUCTION

The present paper briefly summarizes some of the results obtained from a geologic reconnaissance I made of the islands of St. Croix, Saint John, Saint Thomas, Culebra, and Vieques and of the eastern

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end of Porto Rico in compliance with a request made by the Navy Department for special geologic information on the territory examined. The field work was done between May 21 and June 24, 1919. The collections made were examined by the following of my official colleagues: Mr. C. P. Ross examined the igneous rocks; Dr. T. W. Stanton identified the Cretaceous mollusks; Dr. J. A. Cushman identified the Tertiary Foraminifera; Dr. R. S. Bassler, the Bryozoa; and Dr. C. W. Cooke, the Tertiary Mollusca. The corals were identified by me.

LOCATION AND GENERAL FEATURES

The Virgin Islands, except Saint Croix and its outlying islets, rise above a shallow bank that extends northeastward from Porto Rico to Anegada Passage. The number of the islands is about 100. They are separated from one another and from eastern Porto Rico by water having a maximum depth of 16 to 18 fathoms. Except Anegada which rises only about 30 feet above sea level, the larger islands attain altitudes ranging from about 650 feet (Culebra) to 1800 feet (Tortola) in altitude. The highest point in Saint John is 1,277 feet; in Saint Thomas, 1,550 feet; in Culebra, 650 feet; in Vieques, 981 feet. The islands are well dissected and as a rule have gradual slopes, except along the shores where there may be high sea-cliffs. The absence of inland bluffs is one of the striking features of the topography of these islands. The shore line is indented by bays, which indicate geologically Recent submergence.

The Virgin Bank is about 90 sea miles long and from 24 to 30 sea miles wide. The depth of water on it is as much as about 40 fathoms around its edges where there are steep descents to deep water, to over 3,000 fathoms between Saint Thomas and Saint Croix, to about 1,200 fathoms in Anegada Passage, and to 400 fathoms on the north side, where there is an apparently gradual slope to depths of about 3,600 fathoms at a distance of about 55 sea miles north of the bank. Along a line about 25 sea miles long through the Virgin Passage the depth ranges from 12 fathoms in the shallowest part to about 40 fathoms on the northern edge—the range in relief on the flat being only about 132 feet in about 25 miles. The surface of the bank exhibits submarine terraces both off the shores of Saint John and Saint Thomas and in the Virgin Passage. The living coral reefs have grown up on the terraced surface of the bank after an episode of submergence, a relation which I have described in several papers.

Between the Virgin Bank and Saint Croix there is a deep of 3,400 fathoms which is continuous eastward into Anegada Passage, whose

depth is over 1,000 fathoms. The maximum altitude in Saint Croix is 1,164 feet, the top of Mount Eagle. The higher land is dissected and has gradual slopes similar to those mentioned for the islands on the Virgin Bank, but Saint Croix is peculiar in that in its southwestern part there is an extensive, gently sloping limestone plain. The shore line features are indicative of submergence as in the case of the other islands.

STRATIGRAPHY

In the Virgin Islands three major sets of rocks may be recognized as follows: (1) Upper Cretaceous sediments and interbedded volcanic tuffs, breccias, and lava flows; (2) Post-Cretaceous, probably early Tertiary, intrusive gabbro, dolerite, diorite, and quartz-diorite, and perhaps also volcanic extrusions; (3) Oligocene and Miocene marls and limestones.

Upper Cretaceous Rocks

Saint Croix

The older rocks of Saint Croix are exposed in the northwestern part of the island and they occupy the entire area east of Christiansted. They comprise sandstone, shale, and limestone, with interbedded volcanic tuffs. A very instructive exposure may be studied at Waiter's Point. On the east side of this point there are thinly bedded sandstone and shale, west of which is limestone interbedded with volcanic tuff. Quin published notes on the exposure at this place and collected Cretaceous fossils there, but he did not know the biologic affinities of the fossils or their geologic significance. The Misses Quin presented to me, for transfer to the United States National Museum, all of their father's collection and I collected an additional species. Dr. T. W. Stanton supplies the following list of species from Saint Croix:

Inoceramus sp., related to *I. proximus* Tuomey.
Barrettia monilifera Woodward.
Barrettia sparcilirata Whitfield?
Radiolites nicholasi Whitfield.
Caprinula gigantea Whitfield?
Caprinella occidentalis Whitfield.

There is no room for doubt as to the geologic age of the deposits from which these fossils come—it is Upper Cretaceous.

The interbedding of volcanic tuff with the limestone has been mentioned.

Saint Thomas

The presence of sediments of Upper Cretaceous age in Saint Thomas was first recognized by Cleve in 1869, when he collected a moderate number of fossils and recognized the affinities of the fauna with that of Gosau, Austria. Some years ago Professor A. G. Högbom of the University of Upsala lent me the Cleve collection and Doctor Stanton listed for me the genera of the fossils. They are as follows:

Glycymeris
Limopsis
Astarte, several species
Opis
Cyprina?
Corbula
Cerithium, two or more species
Nerinea, several species
Actaeonella
Phylloceras?, immature, septa not well shown.

It seems that I did not rediscover the precise spot at which Cleve obtained his specimens; however, I collected at Coki Point, one of the localities mentioned by Cleve, poorly preserved fossils that seem to represent the genera *Astarte*, *Glauconia*, *Cerithium*, and *Actaeonella*. The fauna is clearly the one discovered by Cleve. The fossils occur in very hard, blue, metamorphosed limestone. At a locality near Coki Point, limestone belonging to the same formation contains some volcanic material and is associated with, probably interbedded with, shaly rocks that have been metamorphosed into schists.

The principal country rock of Saint Thomas comprises andesitic breccia and latite, which in places shows rude bedding. I did not actually observe the relations of these rocks to the Cretaceous limestone, but the older volcanic rocks have been considerably metamorphosed. It is to rocks of this kind that the local name "blue-beach" is applied. Cleve says that he found north of Bucks Bay "blue-beache, black and sometimes metamorphosed clay slate, and flagstone, alternating;" and he says that near Coki Point the blue beach contains "calcareous nodules and marble of a white or gray color." The older volcanic rocks, therefore, seem to be of Upper Cretaceous age.

Saint John

Except large rounded, apparently water-worn boulders about half a mile east of Government House, Little Cruz Bay, the only rocks I saw on Saint John are clearly of igneous origin. The rocks at Coral Bay are chlorite and sericite schists and are inferred to be of Cretaceous or more ancient age, because of the metamorphism they have undergone. Cleve mentions greatly metamorphosed limestone at

Anna Bay (probably meaning Anna Berg). Although paleontologic evidence is not available for Saint John, the lithologic characters are such as to leave no reasonable doubt of the presence on it of both Cretaceous sedimentary and volcanic rocks as on Saint Thomas, which is only about one and a half miles from the west end of Saint John, and there may be rocks of pre-Cretaceous age.

Culebra

Metamorphosed sedimentary rocks composed of reworked volcanic constituents were seen in the valley north of San Ildefonso; southwest of Swell Bay at altitudes below 200 ft.; on the point of land on both the east and west sides of Surf Bay; west and north of Great Harbor; and at Playa Sardinos. On the basis of their lithologic characters it seems safe to refer these rocks to the Upper Cretaceous.

Vieques

The oldest rocks observed on Vieques comprise a trachytic lava flow, overlain by limestone conglomerate, over which is an altered basalt, which in turn is overlain by hard blue limestone. This exposure is at Punta Diablo. The dip of the limestone is as high as 60°. Bedded rock of shaly or sandy appearance, which is probably water-laid tuff, was seen at many places. Because of its lithologic characters, its deformation, and its metamorphism, this group of rocks is considered of Upper Cretaceous age.

Eastern Porto Rico

Examination was made of bedded sandstones and shales, which are composed of water-laid volcanic material, in the vicinity of Fajardo and of a folded basalt flow at Cape San Juan. These sediments and their associated igneous rocks, which are cut by great dikes of dolorite, would be referred to the Upper Cretaceous according to the criteria I have applied in Culebra and Vieques. They evidently represent what Hill described as "black or other dark-colored basic igneous rocks, occurring as tuffs, conglomerates, and sills of hornblende-andesite, cut by dikes of diorite."[2] Hill found associated with these rocks limestone in which he collected fossils that Dr. T. W. Stanton identifies as belonging to the Capriniidae and considers representative of the Upper Cretaceous. Berkey's[3] descriptions of the rocks exposed

[2] Hill, R. T., Notes on the forest conditions of Porto Rico: U. S. Dept. of Agriculture, Division of Forestry Bull. 25: 14–15. 1899.

[3] Berkey, C. P., Geological reconnaissance of Porto Rico: New York Acad. Sci. Ann. 26: 1–70. 1915.

around Fajardo are correct, but he gives no data of assistance in determining their geologic age.

Summary statement on Cretaceous rocks.—Fossiliferous Upper Cretaceous sediments interbedded with volcanic rocks occur in Saint Croix and Saint Thomas. Sediments with interbedded or associated volcanic rocks similar to those of Saint Croix and Saint Thomas are present in Saint John, Culebra, Vieqeus, and eastern Porto Rico, and because of similar lithology and similar deformational history are considered of Upper Cretaceous age.

Early Tertiary Events

Subsequent to the deposition of the Upper Cretaceous sediments and the extrusions of the associated volcanic rocks, there was intense deformation, which resulted in tight folding in Saint Croix, where dips of 80° or more are common; the dips in Saint John are about the same; in Saint Thomas they are 50° or more; in Culebra I noted some low dips, only 19°; in Vieques the dips are as much as 60°; in eastern Porto Rico the range is from about 13° to almost vertical. Some of the older igneous rocks, which in many instances have been so crushed that they are now chlorite or sericite schists, may be of pre-Cretaceous age. The structure lines cannot be described at this place—only the general statement may be made that in places there are intersecting trends, one approximately east and west and another from northwest to southeast. The two sets of trends are very clearly recognizable in Saint Thomas. There were extensive intrusions of diorite, dolerite, and quartz-diorite, and probably also extrusions of lavas and tuffs. Quartz-diorite is the dominant rock in Vieques. The older series of rocks was subjected to subaerial erosion for so long a time that over considerable areas they were practically base-leveled and the next younger sediments were laid down on a nearly plain surface developed on rocks that dip as steeply as 80°, as in the southwestern part of Saint Croix.

Tertiary Sediments

Sediments of Tertiary age are present in Saint Croix, Vieques, and eastern Porto Rico but appear to be entirely absent on Saint John, Saint Thomas, and Culebra. In fact, except Anegada, there are no known Tertiary sediments on the axial islands of the Virgin group, and in Porto Rico such younger deposits are confined to the northern and southern flanks of the island. Therefore the axial islands of the Virgin Bank and the sierras of Porto Rico appear to have been above water since the close of Cretaceous or since very early Tertiary time.

Saint Croix

In Saint Croix Tertiary limestones and marls cover an area reaching the southern shore south and southeast of the hills in the northwestern part of the island, they extend northward to the north shore just east of the mouth of Salt River, whence the eastern boundary runs southward to the west side of Waiters Point. In general the limestones are soft, rather crumbly, and there are interbedded layers of conglomerate. The dips are in general southward, at angles ranging from 8° to 15°—strongly contrasting with the steep dips, in places 80° or more, of the Cretaceous rocks.

Three horizons seem to be represented in these limestones, viz., (1) middle Oligocene, (2) probably upper Oligocene, (3) lower Miocene.

Middle Oligocene

Station 8649. Two-tenths of a mile southwest of Wheel of Fortune estate house; collection made on northern slope of a low hill.

Foraminifera:

Rotalia sp. Abundant
Amphistegina sp. Compare with station 8648.
Lepidocyclina morgani Lemoine and R. Douvillé. Also Cuba.
Carpenteria americana Cushman. Also Cuba.

Madreporaria:

Astrocoenia decaturensis Vaughan. Also Antigua; Bainbridge, Ga.
Gomiastrea reussi (Duncan). Also Antigua.
Cyathomorpha tenuis (Duncan). Also Antigua; Pepino formation of Porto Rico; and other places.
Goniopora microscopica (Duncan). Also Antigua.

Geologic correlation.—The organisms from this locality show clearly that the geologic horizon is the same as that of the Antigua formation of Antigua, for every coral well enough preserved for specific identification also occurs in Antigua, and that it is, therefore, middle Oligocene.

Probably upper Oligocene

Station 8647. One and four-tenths sea miles in a straight line from Christiansted lighthouse, on the south side of North Shore road at Evening Hill.

This is the locality at which Quin[4] says he found large Foraminifera. The rock as exposed in the road is an argillaceous limestone, mostly rather soft but there are indurated lumps and beds. The fossils comprise some well preserved nummulitoid Foraminifera and indetermin-

[4] Quin, John T., The building of an island, p. 17, 1907.

able fragments of corals. The names of the Foraminifera are as follows:

Amphistegina sp.
Heterostegina antillea Cushman. Also Antigua and northeastern Mexico.
Heterosteginoides sp. cf. *H. antillea* Cushman. Also Anguilla.

Station 8648. North Shore road, Montpellier (east).

The rock here exposed is a rather soft, spongy, impure limestone. The contained organic remains include determinable Foraminifera and indeterminable corals and mollusks. The geologic formation seems the same as that exposed at station 8647. The Foraminifera are as follows:

Amphistegina sp. Compare above, station 8647.
Peneroplis sp.
Gypsina globulus (Reuss). Also Anguilla; Recent.

Geologic correlation.—There seems to be no reasonable doubt that the same formation is exposed at both Evening Hill and on the North Shore road at Montpellier (east). The geologic horizon is either middle or upper Oligocene, more probably upper Oligocene.

Station 6850. Montpellier (east), collected by John T. Quin. The specimen referred to by Quin as a volute[5] is a species of *Orthaulax* which seems to be the same as a species of *Orthaulax* I collected at Crocus Bay, Anguilla, now identified as *O. aguadillensis* Maury. The specimen from Saint Croix was presented to me for transfer to the United States National Museum by the Misses Quin, the daughters of the author of "The building of an island," and I had a number of sections cut of the matrix. Foraminifera are abundant and Doctor Cushman furnishes the following list:

Alveolina sp. Also Saint Martin.
Orbitolites duplex Carpenter? Also Saint Martin.
Spiroloculina sp. Also Saint Martin.
Also indeterminable species of *Quinqueloculina*, *Triloculina*, *Globigerina*, and *Amphistegina*.

Geologic correlation.—The presence of the species of *Orthaulax* above noted suggests upper Oligocene, about the horizon of the Anguilla formation, as the age of the bed from which the specimen came. Doctor Cushman says that the Foraminifera are precisely the same as those I collected in the yellowish limestone of Saint Martin. The horizon may be very low Miocene instead of topmost Oligocene.

[5] Quin, John T., The building of an island, plate opposite page 16, 1907.

Miocene

Station 6851. Anna's Hope estate, along the road.

Foraminifera:

Clavulina sp. cf. *C. parisiensis* d'Orbigny. Also Culebra formation.
Clavulina sp. cf. *C. communis* d'Orbigny. " " "
Nodosaria sp. cf. *N. insecta* Schwager. Culebra formation.
Uvigerina sp. (?)
Orbulina sp.
Globigerina sp.
Truncatulina wuellerstorfi Schwager. Culebra formation also Recent.
Siphonina sp. cf. species from Oligocene of the United States.
Pulvinulina sp. cf. species from Oligocene of the United States.
Asterigerina sp. cf. species from Oligocene of the United States.
Amphistegina sp.
Ellipsoidina sp.

Madreporaria:

Obicella sp. cf. a species from the lower Miocene of Trinidad and Vieques Island.
Psammocora sp. cf. a species from the Miocene of Trinidad. Other species of this genus are known from the lower Miocene of Trinidad, Vieques Island, and the Dominican Republic.

Geologic correlation.—The basis for correlating this deposit is not definite, but the horizon seems to be very low Miocene.

Vieques Island

At Punta Salinas, east of Port Salinas and Salina del Sur, at the east end of the island, and along the south shore from opposite Esperanza to Enseñada de la Chiba, there is soft, light-colored, usually yellowish, bedded, fossiliferous limestone, which although slightly tilted and in places flexed, has been, in comparison with the older hard blue limestone, only slightly disturbed. Between Enseñada Sombe and Port Mosquito, between Port Mosquito and Port Ferro, and on the east side of Port Ferro, steep, northward-facing slopes mark the northern edges of the areas of its outcrop. The following are the paleontologic determinations for Vieques:

Station 8652. Vieques Island, north side, east end, the westernmost of the yellow marl and limestone bluffs at the east end of the island.

Foraminifera:

Gaudryina triangularis Cushman. Also Yumurí River, Cuba, U. S. G. S. 3461, and 6010, Culebra formation, Panama Canal Zone; Recent.
Verneuilina spinulosa Reuss. Also Yumurí River, Cuba, U. S. G. S. 3461; Recent.

Chrysalidina pulchella Cushman? Also U. S. G. S. Station, 6036 Gatun Formation, Panama Canal Zone.

Discorbis bertheloti (d'Orbigny). Also Choctawhatchee marl, one mile south of Red Bay, Fla.; Recent.

Truncatulina americana Cushman. Also Miocene of Coastal Plain, U. S.; upper part of Culebra formation, Panama Canal Zone; and Oligocene of Coastal Plain, U. S.

Truncatulina wuellerstorfi (Schwager) ? Miocene of Coastal Plain, U. S.; Oligocene of Panama Canal Zone; Recent.

Truncatulina lobatula (Walker and Jacob.) Also 3461, Yumurí River, Cuba; Cercado de Mao, Dominican Republic; Recent.

Pulvinulina menardii (d'Orbigny)? Also 6033–35–36, Gatun Formation, Panama Canal Zone; Recent.

Gypsina globulus (Reuss) var. *pilaris* H. B. Brady. Also Bowden, Jamaica; Anguilla?; Recent.

Nonionina scapha (Fichtel and Moll.) Also 6033, Gatun Formation, Panama Canal Zone; Recent.

Quinqueloculina seminulum (Linné). Also Gatun Formation and Culebra Formation, Panama Canal Zone; Recent.

Orbitolites duplex Carpenter? Also Anguilla, St Martin; Recent.

Only 2, 83 per cent, of the species above listed are not reported from the living foraminiferal faunas.

Madreporaria:

Stylophora sp.

Orbicella altissima (Duncan). Also Miocene of Trinidad.

Orbicella sp. Also Miocene of Trinidad.

Orbicella or *Solenastrea* sp.

Siderastrea siderea (Ellis and Solander). Range from lower Miocene to Recent.

Psammocora sp. Also Miocene of Trinidad.

Porites sp.

Mollusca:

Ostrea haitiensis Sowerby.

Teredo sp., like *Kuphus incrassatus* Gabb.

Geologic correlation.—The two species of *Orbicella*, and the species of *Psammocora* and *Ostrea haitiensis*, all indicate an old Miocene age, probably older than that of the Bowden marl of Jamaica. *Siderastrea siderea* is not known from deposits older than Miocene and persists today in Caribbean and Floridian waters.

Station 8654. Vieques Island, sea bluff at Cucuracha Light, south side of the island.

Foraminifera:

Gypsina globulus (Reuss). Also Recent.

Asterigina sp.

Orbiculina sp.

Madreporaria:

Solenastrea bournoni Milne Edwards and Haime. Also Recent.

Porto Rico east of San Juan. As I have given in the final part of Bulletin 103 of the United States National Museum a rather full account of the distribution of marine deposits of these ages, except for the Virgin Islands, Porto Rico, and the island of Haiti, I will not repeat what I published, except in so far as it bears on the problems under discussion.

From corals collected by R. T. Hill in western Porto Rico in 1898 I pointed out in notes published by Hill in 1899 that his Pepino formation is of the same age as the Antigua formation which is now classified as of middle Oligocene (Rupelian) age. In addition to this horizon Miss Maury has recently recognized upper Oligocene and lower Miocene in western Porto Rico. The geologic exploration made for the Military Government during April, May, and June, 1919, in the Dominican Republic has led to the recognition there of upper Eocene, middle Oligocene, upper Oligocene, and six Miocene horizons of which the lowest and the upper three are new—that is, at least seven definable new Tertiary horizons were recognized in the Dominican Republic. South of Santiago, near Baitoa, Condit and Cooke found the basal Miocene resting on the deformed, folded, and eroded surface of middle Oligocene deposits which carry the Antiguan foraminiferal and coral fauna. The specimens of *Lepidocyclina* are equaled in size only by those in Antigua where some are four inches in diameter. The Eocene formations of the Republic of Haiti have been briefly discussed by Woodring in two recent papers.[6] Later the significance of these determinations will be indicated.

Pleistocene deposits

Although I did not land on the Cordilleras reefs, I could see from the subchaser on which I travelled that they are composed of limestone. A specimen of soft limestone from Icacos Key, given me by Mr. Jorge Byrd-Arias, is a very fine-grained oolite. I suppose that this rock is of Pleistocene age from analogy with Florida and the Bahamas.

SUMMARY OF GEOLOGIC HISTORY

(1) The presence of shoal water deposits of Upper Cretaceous age, in Saint Croix and in the islands on the Virgin Bank from Saint John to Porto Rico and in Porto Rico shows that the major tectonic axis of this part of the West Indies antedates Upper Cretaceous time,

[6] Woodring, W. P., Middle Eocene foraminifera of the genus *Dictyoconus* from the Republic of Haiti: this Journal 12: 244–247. 1922; and An outline of the results of a geological reconnaissance of the Republic of Haiti: Ibid. 13: 117–129. 1923.

because there was an antecedent basement on which these deposits were laid down. I have suggested that these major trends may be even as old as late Paleozoic.

(2) During Upper Cretaceous time it is probable that most of, perhaps all of, the areas now occupied by land were under water; and that there was considerable volcanic activity is proved by the water-laid tuffs and lava flows which are interbedded with the shoal-water calcareous sediments.

(3) In early Tertiary, probably Eocene, time there was mountain making by folding which in places was so intense that the stratified rocks were left in an almost vertical position and both the sediments and the older igneous rocks were metamorphosed. There were also intrusions of diorite, dolerite, and quartz diorite, and probably the extrusion of some volcanic rocks. West of the Virgin Islands, there was during later Eocene time extensive submergence in the Dominican Republic, Haiti, and Cuba, as is attested by the Eocene formations now above sea-level in those areas.

(4) The episode of mountain making was followed in the Virgin Islands by one of prolonged subaerial erosion, and the production of the Virgin Bank apparently may in large part be assigned to this period of the history of the region. It seems that the axial islands on the Virgin Bank and the Central Sierras of Porto Rico, from its east to its west end, have continuously stood above the water since the close of Cretaceous deposition. In Saint Croix by middle Oligocene time erosion had proceeded far enough to reduce almost to base level the tightly, steeply folded strata of the mountains.

(5) In middle Oligocene time a large part of Saint Croix wes submerged and, with slight fluctuations, remained under water until sometime during the Miocene. Although both the northern and southern, but not the axial, parts of western Porto Rico were submerged in middle Oligocene, and probably in lower Oligocene time, the eastern end of Porto Rico and the axial islands of the Virgin Bank west of Anegada Island were not submerged. The age of the limestone on Anegada Island is not known. These facts mean that there was differential movement, the movement being greater toward the west than in the central part of the bank. In lower Miocene time the northern shore of Porto Rico east of San Juan was submerged as were also the southern shore and eastern end of Vieques Island—both the northern and the southern edges of the bank were submerged probably by marginal down flexing. Although there are corals in the exposed sediments of Oligocene and Miocene age, and corals were therefore constructional agents during those epochs, their work as compared with

that of other agents was of minor importance. If the work of these organisms in forming deposits concealed under water can be evaluated by their work in deposits exposed to view, the conclusion would be drawn that they played only a minor rôle in the formation of the Virgin Bank. There is as yet no evidence showing intense deformation during later Oligocene time in the Virgin Islands and Porto Rico such as is known to have taken place in the Dominican Republic.

(6) Subsequent to early Miocene time there has been uplift, greater along the axis of Porto Rico and the Virgin Bank than on the flanks, bringing Miocene and older Tertiary sediments, in places where they are present, above sea level. The Tertiary sediments are tilted and gently flexed but they have not been so much deformed as the Upper Cretaceous deposits. It is about this time that the land connections permitting migration of land animals from Anguilla to Porto Rico, Haiti, and Cuba seem to have existed. Saint Croix seems to have been connected with Anguilla, Saint Martin, and Saint Bartholomew.

(7) The period of high stand of land was followed by faulting, such as I have several times described recently; but, as pointed out by Woodring, the faulting was concomitant with folding. By these processess Anegada Passage between the Virgin Bank and Anguilla was produced and the islands assumed very nearly the outlines and arrangements of today.

(8) Subsequent to the episode of faulting there was emergence of the land, and terracing of the margins of the Virgin Bank, followed by submergence. In places in Porto Rico and along the Cordilleras reef, which extends eastward from the northeast corner of Porto Rico, there has been local emergence due to differential crustal movement.

(9) The living coral reefs on the Virgin Banks are growing on an extensive flat in a period of geologically Recent submergence. This flat is geologically an old feature. Its origin in large part at least may reasonably be attributed to the long period of erosion following early Tertiary mountain-making.

List of Publications on the Geology of the Virgin Islands

Cleve, P. T., On the geology of the northeastern West India Islands: Vetensk. Akad. Handl. 9: No. 12, 48. 1871, 2 maps.

Cooke, C. Wythe, *Orthaulax*, a Tertiary guide fossil: U. S. Geol. Survey Prof. Paper 129: 23–37, pls. 2–5. 1921.

Lobeck, A. K., The physiography of Porto Rico: New York Acad. Sci. Scientific Survey of Porto Rico and the Virgin Islands, 1[4]: 301–379. 1922. 1 map. This work contains information on Vieques and Culebra.

Quin, John T., The building of an island, being a sketch of the geological structure of the Danish West Indian Island of Saint Croix, or Santa Cruz, pp. 106, 1 map, 32 text figs. Published by the author, Christiansted, Saint Croix, 1917.

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———, Some littoral and sublittoral physiographic features of the Virgin and northern Leeward Islands and their bearing on the coral reef problem: Journ. Wash. Acad. Sci. 6: 53–66. 1916.

———, Fossil corals from Central America, Cuba, and Porto Rico, with an account of the American Tertiary, Pleistocene, and Recent coral reefs: U. S. Nat. Mus. Bull. 103: 180–524, pls. 68–152, text figs. 4–25. 1919.

———, The biologic character and geologic correlation of the sedimentary formations of Panama in their relation to the geologic history of Central America and the West Indies: *Ibid.* 547–612. 1919.

———, Corals and the formation of coral reefs: Smithsonian Inst. Ann. Rept. for 1917: 189–276, 37 pls., 1919.

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———, Stratigraphy of the Virgin Islands of the United States and of Culebra and Vieques Islands (abstract): Geol. Soc. Amer. Bull. 31: 216–217. 1920.

———, Correlation of the Tertiary formations of Central America and the West Indies: Bernice P. Bishop Mus. (Honolulu) Spec. Pub. No. 7: 819–844. 1921.

———, and others: A geological reconnaissance of the Dominican Republic: Dominican Repub. Geol. Survey mem. 1: 95. 1921. (Spanish edition, p. 106. 1922).

SPECTROSCOPY—*Regularities in the arc spectrum of vanadium.*[1]

W. F. MEGGERS, Bureau of Standards.

Kossel and Sommerfeld, in 1919, proposed the spectroscopic displacement law[2] (Verschiebungssatz) which states that the spark spectrum of any chemical element resembles in structure the arc spectrum of the element preceding it in the periodic system. This led to the alternation law[2] (Wechselsatz); that is, the even and odd structures of both arc and spark spectra alternate between adjacent columns of the periodic classification. Until recently, the validity of these laws could be tested only in the first three columns since scarcely any spectral regularities were known except for the relatively simple spectra of elements in these groups. The incomplete and inaccurate description of the more complex spectra has been responsible, in part, for the delay in finding significant regularities among them. In recent years many of these spectra have been more accurately measured in international Angstrom units, and the majority of them have had their wave-length tables extended into the red and infra-red regions, chiefly as the result of investigations by the Spec-

[1] Received July 16, 1923. Published by permission of the Director, Bureau of Standards.

[2] Sommerfeld, Atombau und Spektrallinien 3rd Ed; 456. 1922.