SMITHSONIAN INSTITUTION
UNITED STATES NATIONAL MUSEUM
Bulletin 103

CONTRIBUTIONS TO THE GEOLOGY AND PALEONTOLOGY OF THE CANAL ZONE, PANAMA, AND GEOLOGICALLY RELATED AREAS IN CENTRAL AMERICA AND THE WEST INDIES

FOSSIL CORALS FROM CENTRAL AMERICA, CUBA, AND PORTO RICO, WITH AN ACCOUNT OF THE AMERICAN TERTIARY, PLEISTOCENE, AND RECENT CORAL REEFS

By THOMAS WAYLAND VAUGHAN
Custodian of Madreporaria, United States National Museum, and Geologist in charge of Coastal Plain Investigations, United States Geological Survey

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Extract from Bulletin 103, pages 189–524, with Plates 68–152

WASHINGTON
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CONTENTS.

Geologic history of the upper Eocene, etc.—Continued. Page.

Conditions under which the West Indian, Central American, and Floridian coral reefs have formed—Continued.

Systematic account of the faunas—Continued.

Class Anthozoa—Continued.

FOSSIL CORALS FROM CENTRAL AMERICA, CUBA, AND PORTO RICO, WITH AN ACCOUNT OF THE AMERICAN TERTIARY, PLEISTOCENE, AND RECENT CORAL REEFS.

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INTRODUCTION.

The object of the present memoir is to contribute information that may aid in deciphering the geologic history of the perimeters of the Gulf of Mexico and the Caribbean Sea. Therefore, problems of correlation, the physical conditions under which the different formations were deposited, and the distribution of land and sea during the successive geologic epochs have been particularly in mind.

The material on which this paper is based is extensive. It includes collections made in Panama by Dr. D. F. MacDonald and me, working jointly, and by Doctor MacDonald while alone; and Dr. Ralph Arnold obtained a small but valuable lot of specimens at Empire in the Canal Zone. The collections from Cuba were made by Dr. Arthur C. Spencer, Mr. O. E. Meinzer, and myself; the one from Porto Rico was made by Mr. R. T. Hill, who also obtained a small but valuable lot of specimens in Antigua; the principal collections from Antigua and Anguilla are the results of my individual efforts, and I obtained considerable material in St. Bartholomew, but not so much as Cleve got in 1869. There are numbers of small lots, as follows: One from Nicaragua, obtained by Dr. C. W. Hayes; one from Colombia, collected by Mr. G. C. Matson; specimens from Limon, Costa Rica, procured by Doctor Wailes and Mr. H. Pittier; and specimens from eastern Mexico, obtained by Mr. E. T. Dumble. All of the collections mentioned are the property of the United States National Museum, having been made in connection with official work of some kind, or the material, if privately collected, has been presented to the Museum. Messrs. Matson, Wailes, Pittier, and Dumble have presented specimens. My own collecting in Antigua, St. Bartholomew, and Anguilla was made possible by a minor grant from the Carnegie Institution of Washington, and as a result I brought some thousands of specimens to Washington.

These were presented to the United States National Museum by the Carnegie Institution.

Besides having studied the material indicated, I have twice been able to examine all of Duncan's types preserved in the Museum of the Geological Society of London and in the British Museum (Natural History), and I heartily thank the officers of those institutions for the privileges accorded me. In 1904 Prof. A. G. Högbom and Prof. C. Wiman most generously permitted the Cleve collection from St. Bartholomew and Anguilla to be sent to me in Washington. This collection contained all of Duncan's types from St. Bartholomew; and I thank Messrs. Högbom and Wiman for the excellent opportunity they gave me. Some duplicates from the Cleve collection, identified by direct comparison with Duncan's types, were procured for the United States National Museum by exchange.

Opportunities to study the Gabb collection from Santo Domingo, divided between the Philadelphia Academy of Natural Sciences and the Museum of Comparative Zoology, and the specimen obtained by Miss Carlotta J. Maury in Santo Domingo, have been very valuable. In fact, as a result of Miss Maury's careful stratigraphic studies in that Republic, the stratigraphic relations of the Santo Domingan faunas became known. Except retaining a few duplicates, she has generously presented to the United States National Museum the material obtained by her.

I wish to thank my associates in the United States National Museum and in the United States Geological Survey for their helpfulness during the prosecution of this study. Mr. W. O. Hazard, of the Survey photographic laboratory, made most of the photographs used for illustrations, and Miss Frances Wiesser retouched some of them.

There is almost no literature on the Tertiary fossil corals of Central America, Cuba, or Porto Rico. I listed a few Pleistocene species obtained by Mr. R. T. Hill at a place 1½ miles west of Port Limon, Costa Rica;[1] and Felix has recorded from Colombia[2] three species, as follows:

Orbicella theresiana Felix, probably a synonym of *Solenastrea bournoni* M. Edward and Haime.

Isastraea turbinata Duncan.

Stephanocoenia cf. *S. fairbanksi* Vaughan.

None of these records is further considered in the present paper.

Toula has described *Oculina gatunensis* from Gatun (see footnote, page 352 of this paper).

GEOLOGIC CORRELATION BY MEANS OF FOSSIL CORALS.

That vegetative variation in corals is great and that without large suites of specimens the limits of variation can not be ascertained are

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[1] Mus. Comp. Zool. Bull., vol. 28, p. 275, 1898.

[2] Felix, J., Ueber einige fossile Korallen aus Columbien, K. Bayer. Akad. Wiss., math.-phys. Kl., Sitzungsber., vol. 35, pp. 85-93, 1905.

two facts so well known to students of Madreporaria that they need only to be mentioned. I can not be sure that all of the supposed species recorded in this paper as valid are really valid; and perhaps in identifying specimens from one locality with species from other localities I may not always have discriminated closely enough. I am discussing close resemblances and minute differences, for these are the basis of correlation within such regional limits as the borders of the Gulf of Mexico and the Carribbean Sea, and the recognition and proper evaluation of this kind of resemblances and differences affect the reliability of the deductions as to age equivalence. I have been as careful as I well could be, but I should not like to insist that I am always right in these very refined matters of observation and of inferences based on such refined observation. In order to minimize error inherent in such work, I have tried not to rely on one species, but on groups of species—for instance the species of *Orbicella* and of *Goniopora* in both the Emperador limestone and the Anguilla formation—and I have utilized the testimony of other groups of organisms.

Comparisons of faunas according to the percentages of species in common may be very misleading. Faunas now living only a short distance from each other may have nothing or almost nothing in common. In order to illustrate this I am introducing a table of the corals obtained in the Cocos-Keeling Islands by Dr. F. Wood Jones.[1] Although the list has been published elsewhere, it is not very long and strikingly illustrates faunal phenomena that are of great geologic importance.

List of corals obtained by Dr. Wood Jones in Cocos-Keeling Islands and their habitat.

br.=branching; frag.=fragile; msv.=massive; pl.=plate; incrust.=incrusting.

Name of species and growth-form.	Habitat.		
	Lagoon.	Barrier pools and barrier flat.	Exposed barrier.
Seriatopora angulata Klunzinger, delicately branched	×		
Pocillopora bulbosa Ehrenberg, br., form depends on environment	×		
damicornis (Esper), br., rather strong	×	×	
verrucosa (Ellis and Solander), stout br			
elegans Dana, strong br., aborted ou surf	×		×
eydouxi M. Edwards and Haime, br., rather strong	×		
woodjonesi Vaughan, br., rather strong		×	
Orbicella versipora (Lamarck), msv			×
Cyphastrea microphthalma (Lamarck), msv		×	
Echinopora lamellosa (Esper), thin folia	×		
Leptastrea purpurea (Dana), msv		×	
bottae (M. Edwards and Haime), msv	×	×	
immersa Klunzinger, msv		×	
Favia stelligera (Dana), msv	×	×	×
speciosa (Dana), msv. (dead specimen)			
Favites abdita (Ellis and Solander), msv	×		
melicerum (Ehrenberg), msv. (dead specimen)			
Leptoria phrygia (Ellis and Solander), msv	×		
Hydnophora microconos (Lamarck), msv. (dead specimen)			
exesa (Pallas), lobate			

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[1] Vaughan, T. W., Some shoal-water corals from Murray Island (Australia), Cocos-Keeling Islands, and Fanning Island, Carnegie Inst. Washington, Pub. 213, pp. 70-72, 1918.

List of corals obtained by Dr. Wood Jones in Cocos-Keeling Islands and their habitat—Continued.

Name of species and growth-form.	Habitat.		
	Lagoon.	Barrier pools and barrier flat.	Exposed barrier.
Fungia fungites (Linnaeus), free disk	×	×	
scutaria Lamarck, free disk		×	
Herpetolitha crassa Dana, free coral	×		
Pavona danai (M. Edwards and Haime), strong folia	×		
maldivensis (Gardiner), msv		Lagoon edge of barrier.	
varians Verrill, msv		×	
Psammocora haimiana M. Edwards and Haime, msv		×	×
sp., incrust	Sand flats.		
Dendrophyllia willeyi (Gardiner), msv			×
diaphana Dana, incrust, base, protub. corallites			×
Astreopora myriophthalma (Lamarck), msv		×	
Montipora levis Quelch, br	×		
tortuosa (Dana), frag., br	×		
ramosa Bernard, frag., br	×	Especially inner margin.	
cocosensis Vaughan, br		Lagoon side.	
spumosa (Lamarck), msv			×
sp., lobate columns		Lagoon side.	
informis Bernard, msv., pl. on lower edges			×
foliosa (Pallas), thin folia	×		
Acropora pulchra (Brook), frag., br	×		
pharaonis (M. Edwards and Haime), br	×	×	
forma *arabica* (M. Edwards and Haime)			
corymbosa (Lamarck), corymbose	Lagoon inlet.		
spicifera (Dana), corymbose		×	
scherzeriana (Brueggemann), msv. base, stout br			×
ocellata (Klunzinger), msv. lob			×
variabilis (Klunzinger), br		×	
palifera (Lamarck), strong br	×		×
Porites solida (Forskål), msv			×
somaliensis Gravier, msv			×
lichen Dana, incrust			×
nigrescens Dana, br	×		
Millepora dichotoma Forskal, br		Inner margin of barrier.	
platyphylla Ehrenberg, strong folia			×
sp., incrust			×
Total number of species according to locality	23	20	16

Of the 23 species found in the lagoon, 3 also occur on the exposed barrier, and one of these is so modified to meet surf conditions that ordinarily the specimens from the two localities would not be recognized as belonging to the same species. Thirteen per cent of the lagoon species occur on the exposed barrier; while 18 per cent of the exposed-barrier species occur in the lagoon. These are the relations within perhaps half a mile. There are 20 species in the barrier pools and on the barrier flat. Of these 6 occur within the lagoon and 2 were obtained on the exposed barrier; or there are 30 per cent in common with the lagoon and 10 per cent in common with the exposed barrier. When such relations as these prevail among the living corals of a small group of small islands, what are the chances that we should among fossil corals get a large percentage of common species?

The collection listed shows that certain species do occur in all three habitats, and, by searching, spots may be found where the faunas of the different habitats mingle. Corals of the same habitat should be compared, or groups of species of the same genera, as I have done for Empire (Canal Zone) and Anguilla, where the habitats are nearly enough alike for the same genus to thrive in both. Unless it can be established that the habitats are ecologically very nearly the same the percentages can not be used safely.

GEOLOGIC HISTORY OF THE UPPER EOCENE AND LATER CORAL FAUNAS OF CENTRAL AMERICA, THE WEST INDIES, AND THE EASTERN UNITED STATES.

Eocene.

BRITO FORMATION, NICARAGUA.[1]

Dr. C. W. Hayes collected on or near the Pacific coast of Nicaragua the following species:

Astrocoenia d'achiardii Duncan.
Syzygophyllia hayesi Vaughan.

ST. BARTHOLOMEW LIMESTONE.[2]

I am introducing the name St. Bartholomew limestone for the upper Eocene limestones of St. Bartholomew. Description of the rock, its stratigraphic relations, and summaries of its faunal characters are given in the papers referred to in the footnotes. Only two species of corals found in the St. Bartholomew limestone are actually described in the present memoir, namely:

Astrocoenia d'achiardii Duncan.
incrustans (Duncan) Vaughan.

The fossil corals from the St. Bartholomew limestone have been specially considered by Duncan[3] and myself. Prof. A. G. Högbom, of the University of Upsala, kindly lent me in 1904 the entire Cleve collection from St. Bartholomew, and in 1914 I spent eight days studying and collecting on the island. I am combining both the Cleve and my collections in the following list, and am adding the names of the Jamaican Eocene species, several of which also

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[1] For an account of the Brito formation, see Hayes, C. W., Physiography and geology of region adjacent to the Nicaragua Canal route, Geol. Soc. Amer. Bull., vol. 10, pp. 285–348, 1910. Description of the Brito formation, pp. 309–313.

[2] For accounts of the geology of St. Bartholomew, see as follows: Cleve, P. T., On the geology of the northeastern West India Islands, K. svenska Vet.-Akad. Handl., vol. 9, No. 12, pp. 24–27, 1872. Vaughan, T. W., Study of the stratigraphic geology * * * of the smaller West Indian Islands, Carnegie Inst. Washington Yearbook No. 13, pp. 358–360, 1915; also Yearbook No. 14, pp. 368–373, 1916; [Present status of geologic correlation of the Tertiary and Cretaceous formations of the Antilles], Washington Acad. Sci. Jour., vol. 5, p. 489, 1915; Reef-coral fauna of Carrizo Creek, Imperial County, California, and its significance, U. S. Geol. Survey Prof. Pap. 98–T, pp. 362, 363, 1917.

[3] Duncan, P. M., On the older Tertiary formations of the West-Indian Islands, Geol. Soc. London Quart. Journ., vol. 29, pp. 548–565, pls. 19–22, 1873.

Vaughan, T. W., Some Cretaceous and Eocene corals from Jamaica, Mus. Comp. Zool. Bull., vol. 34, pp. 227–250, 255–256, pls. 36–41, 1899; A critical review of the literature on the simple genera of the Madreporaria Fungida, with a tentative classification, U. S. Nat. Mus. Proc., vol. 28, pp. 371–324, 1905; Study of the stratigraphic geology * * * of the smaller West Indian Islands, Carnegie Inst. Washington Yearbook No. 13, pp. 358–360, 1915; The reef-coral fauna of Carrizo Creek, Imperial County, California, etc., U. S. Geol. Survey Prof. Pap. 98–T. pp. 362–363, 1917.

occur in St. Bartholomew. Duncan described Eocene species from Jamaica in the papers referred to in the footnotes below.[1]

Eocene corals from St. Bartholomew and Jamaica.

Revised name.	St. Bartholomew.	Jamaica.			Notes.
		Catadupa formation.	Richmond formation.	Cambridge formation.	
Placotrochus clevei (Duncan)	×				*Turbinoseris clevei* Duncan.
Asterosmilia pourtalesi Duncan	×				
new species	×				*Flabellum appendiculatum* Duncan, *not* Brogniart.
Trochosmilia new species	×				
hilli Vaughan		×			
Stylophora compressa Duncan	×				
contorta (Leymerie) (fide Duncan)			×		
Astrocoenia duerdeni (Vaughan)	×		×		*Stylocoenia duerdeni* Vaughan.
incrustans (Duncan)	×				*Stephanocoenia incrustans* Duncan.
d'achiardii Duncan	×				
Antillia (?) *compressa* (Duncan)	×				*Circophyllia compressa* Duncan.
(?) *clevei* (Duncan)	×				*Circophyllia clevei* Duncan.
species	×				
Columnastrea eyeri Duncan					"Eocene of Jamaica."
Favia new species 1	×				
new species 2	×				
Goniastrea variabilis Duncan	×				
Maeandra new species 1	×				*Manicina areolata* Duncan, *not* Linnaeus.
new species 2	×				*Ulophyllia macrogyra* Duncan, *not* Reuss.
Leptoria profunda Duncan	×				
conferticosta (Vaughan)		×			*Diploria conferticosta* Vaughan.
conferticosta var. *columnaris* (Vaughan)		×			
Trochoseris catadupensis Vaughan		×			
Antilloseris eocaenica (Duncan)	×				
major (Duncan)	×				These three "species" may be reduced to one.
grandis (Duncan)	×				
jamaicaensis (Vaughan)	×			×	
cantabrigiensis (Vaughan)	×			×	
angulata (Duncan)	×				
cyclolites (Duncan)	×				
Physoseris insignis (Duncan)	×				*Trochosmilia insignis* Duncan + *T. arguta* Duncan, *not* Reuss.
Protethmos (?) new species 1	×				*Trochosmilia subcurvata* Duncan, pl. 19, fig. 1, *not* Reuss.
new species 2	×				*Trochosmilia subcurvata* Duncan, pl. 19, fig. 1*a*, *not* Reuss.
new species 3	×				
new species 4	×				
Metethmos (?) new species	×				
Dendracis cantabrigiensis Vaughan				×	
Actinacis new species	×				*Astraeopora panicea* Duncan, *not* Pictet.
Multicolumnastraea cyathiformis (Duncan)		×			
Goniopora new species 1	×				*Actinacis rollei* Duncan, *not* Reuss.
new species 2	×				*Porites ramosa* Duncan, *not* Catullo.

The following names in Duncan's list of St. Bartholomew corals are dropped, because the specimens on which he based his determinations could not be found:

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[1] Duncan, P. M., and Wall, G. P., A notice of the geology of Jamaica, especially with reference to the district of Clarendon; with descriptions of the Cretaceous, Eocene, and Miocene corals of the island, Geol. Soc. London Quart. Journ., vol. 21, pp. 1–15, pls. 1, 2, 1865 (the descriptions of the corals are by Duncan), Duncan, P. M., On the fossil corals (Madreporaria) of the West Indian Islands, Geol. Soc. London Quart. Journ., vol. 24. pp. 9–33, pls. 1–2, 1867.

Stylophora distans (Leymerie).
    conferta Reuss.
    tuberosa Reuss.
    granulata Duncan.
Stephanocoenia elegans (Leymerie).
Astrocoenia multigranosa Reuss.
    ramosa (Sowerby).
Plocophyllia caliculata (Catullo).
Solenastraea columnaris Reuss.

The revised list of the St. Bartholomew coral-fauna contains 33 species, two of which may be referred to the synonymy, but a few species may be added from the collection I made, the study of which is not quite complete. I have described and have had figures made of all the species in the Cleve collection. I hope soon to add descriptions of the specimens I obtained and then to publish a full account of the fauna.

I seriously doubt the Catadupa corals being Eocene; it seems more probable that they are Cretaceous. The species I described as *Trochosmilia hilli* is probably a fungid coral. The Richmond "beds" of Jamaica contain two species, one of which is found in the St. Bartholomew limestone. The Cambridge "beds" contain three species, two of which also occur in the St. Bartholomew limestone. The correlation of the Richmond and Cambridge formations of Jamaica with the St. Bartholomew limestone, seems to be well founded.

JACKSON FORMATION AND OCALA LIMESTONE.

The corals of the upper Eocene Jackson formation in the Gulf States are described in monograph cited below.[1] The species are as follows:

Flabellum cuneiforme var. *wailesi* Conrad.
Aldrichiella[2] *elegans* (Vaughan).
Turbinolia pharetra Lea.
Trochocyathus lunulitiformis (Conrad).
        var. *montgomeriensis* Vaughan.
Caryophyllia dalli Vaughan.
Parasmilia ludoviciana Vaughan.
Archohelia burnsi (Vaughan).[3]
Astrangia expansa Vaughan.
    ludoviciana Vaughan.
    harrisi Vaughan.[4]
Platycoenia jacksonensis Vaughan.
Balanophyllia irrorata (Conrad).

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[1] Vaughan, T. W., The Eocene and lower Oligocene coral faunas of the United States, U. S. Geol. Survey Mon. 39, pp. 263, 24 pls., 1900. See especially p. 30.

[2] Changed from *Aldrichia*.

[3] Changed from *Astrohelia*.

[4] Name added.

Endopachys maclurii (Lea).
var. *triangulare* Conrad.
shaleri Vaughan.[1]
minutum Vaughan.

A comparison of this list with the one of the St. Bartholomew and Jamaican corals reveals nothing in common; but I believe it can be made clear that the two faunas are of nearly the same age. That the Jackson formation in Mississippi and Louisiana is a shallow-water deposit is indicated by the nature of the sediments, the growth of specimens of *Astrangia* on rounded, somewhat indurated balls of sand, such as are common along some beaches, the presence of oyster shells, etc. The striking difference between the Jackson and St. Bartholomew coral faunas is due neither to great difference in geologic age nor to difference in the depth of water in which the faunas lived, but it is due to difference in the temperature of the water. The St. Bartholomew is a tropical fauna; the Jackson is a temperate fauna.

The correlation of the St. Bartholomew limestone, the Richmond and Cambridge formations of Jamaica, and the Brito formation of Nicaragua with the Jackson formation of the Gulf States has been made possible by the work of C. W. Cooke and J. A. Cushman. Cooke shows in the paper cited in the footnote [2] that the Ocala limestone of southern Georgia and Florida is of Jackson age; and in more recent papers he [3] describes the stratigraphic occurrence, and J. A. Cushman [4] describes the species of the orbitoid genus of foraminifera *Orthophragmina* from the Ocala limestone in southern Georgia and Florida. The following is a list of the species:

Orthophragmina flintensis Cushman.
floridana Cushman.
americana Cushman, *st.*
mariannensis Cushman, *st.*
mariannensis var. *papillata* Cushman, *st.*
georgiana Cushman, *st.*
vaughani Cushman, *st.*

Those species whose names are followed by "*st.*" are stellately marked or are stellate in form. The Ocala limestone is a shoal-water deposit, laid down in a sea having a tropical temperature.[5] One of the results of my collecting in St. Bartholomew was to find in the St. Bartholomew limestone a stellate species of *Orthophragmina*,

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[1] Name added.

[2] Cooke, C. W., The age of the Ocala limestone, U. S. Geol. Survey Prof. Pap. 95-I, pp. 107-117, 1915.

[3] Cooke, C. W., The stratigraphic position and faunal associates of the orbitoid foraminifers of the genus *Orthophragmina* from Georgia and Florida, U. S. Geol. Survey Prof. Pap. 108-G, pp. 109-113, 1917.

[4] Cushman, J. A., Orbitoid foraminifera of the genus *Orthophragmina* from Georgia and Florida, U. S. Geol. Survey Prof. Pap. 108-G, pp. 115-124, pls. 40-44.

[5] Vaughan, T. W., A contribution to the geologic history of the Floridian Plateau, Carnegie Inst. Washington Pub. 133, pp. 150-153, 1910.

nearly related to *O. mariannensis* Cushman, and a second species of *Orthophragmina* that is of lenticular form. I also collected two species of *Nummulites* and one species of *Lepidocyclina* in St. Bartholomew. *Lepidocyclina* occurs in Georgia as far down stratigraphically as a horizon about the middle of the Jackson formation, and apparently as low as the base of the formation. The presence of a species of *Orthophragmina* so similar to *O. mariannensis* seems to warrant the correlation of the St. Bartholomew limestone with the upper part of the Ocala limestone of Florida and Georgia, and therefore with the Jackson formation in Mississippi and in the States farther westward.

Regarding the Brito formation of Nicaragua, it must be recognized that a single poor specimen of coral furnishes slim evidence on which to base a correlation. Doctor Cushman submits the following statement regarding the foraminifera from the Brito formation:

> As to the Brito material, two lots especially are of interest. No. 6411 "coast about 2 m. s. e. of Brito Harbor" marked "Ool. fos. l. s." has abundant orbitoids with a beautifully ornamented exterior which without the confirmatory evidence of sections seem to be clearly *Orthophragmina* of a group not so far represented in the material studied. From No. 6408 two miles n. w. of Brito Harbor, however, there is more evidence. The material is very different and contains specimens which in accidental section show definite chambers of *Orthophragmina* of a different group. This does not however suggest either of the species from St. Bartholomew. Associated with it is a species of the flattened, broadly spiral form of nummulites. In the St. Bartholomew material there is such a form but of a species very much larger.
>
> Now there is on the other hand a closer resemblance, that is to the lowest material of the Flint River collections. The Brito species of *Orthophragmina* is similar so far as I have made out to the one I have called *O. flintensis*. Moreover it is associated at Brito as along the Flint River with this broadly spiral, flattened form of nummulite. The specimens of nummulite from the two localities are very close in form and size and only differ in minute details. They may not be specifically identical in final analysis but are very close.

The statement by Doctor Cushman seems conclusive.

A horizon very nearly the same is recognizable in Colombia as the following quotation from Doctor Cushman shows:

> Now, as to the specimen from one league west of Arroyo Hondo, Bolivar, Republic of Colombia. There is an association of *Nummulites* and stellate orbitoids which very decidedly suggests Eocene. While I can not definitely make out the equatorial chambers, the stellate form is very apparent in several specimens, and I should say specifically different from any of the species of *Orthophragmina* described in my paper from Georgia and Florida; in fact, they represent a very different group, I think, but are undoubtedly *Orthophragmina*.

Eocene deposits of the same or nearly same horizon as the St. Bartholomew limestone are widely distributed in Cuba, as is indicated by species of *Orthophragmina* and a number of echinoid species that also occur in St. Bartholomew.

CONCLUDING REMARKS ON THE EOCENE.

From the foregoing discussion it is clear that marine upper Eocene formations are widely distributed in the southern United States, the West Indies, Central America, and northern South America, and that the Atlantic and Pacific Oceans were connected at that time. One of the areas in which there was such a connection was across the present site of eastern Nicaragua.

Haug, I believe, correctly correlated the Jackson of Mississippi and other Gulf States with the Bartonian-Ludian (Priabonian) of Europe.[1]

Attention should be directed to a statement by Oppenheim [2] in which he suggests that the St. Bartholomew coral-fauna might be the equivalent of the Priabona formation. The sequence I am giving three of the important American horizons precisely parallels Oppenheim's order, as expressed on page 13 of his work cited. It is as follows:

Oligocene:
- Middle (Stampian = Rupelian = Antiguan).
- Lower (Sannoisian = Lattorfian = Vicksburgian).

Eocene:
- Upper (Priabonian = Ludian = Jacksonian = horizon of St. Bartholomew limestone, etc.).

OLIGOCENE.

LOWER OLIGOCENE.

The lower Oligocene corals of the United States have been described by me.[3]

Dr. C. W. Cooke, in a paper recently published, subdivides the Vicksburg group in Mississippi, Alabama, and Florida as follows:

Subdivisions of the Vicksburg group in Mississippi, Alabama, and Florida.

<table>
<tr><th colspan="2">Mississippi.</th><th>Alabama.</th><th>Florida.</th></tr>
<tr><td colspan="4">Bryam calcareous marl.</td></tr>
<tr><td rowspan="2">Marianna limestone.</td><td colspan="2">Glendon limestone member.</td><td rowspan="2">Marianna limestone.</td></tr>
<tr><td>Mint Spring calcareous marl member.</td><td>"Chimney Rock" facies</td></tr>
<tr><td>Forest Hill sand (Western Mississippi).</td><td>Red Bluff clay (Eastern Mississippi).</td><td></td><td></td></tr>
</table>

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[1] Haug, Émile, Traité de géologie, vol. 2, p. 1523, 1911.

[2] Oppenheim, P., Die Priabonaschichten und ihre Fauna, Palaeontographica, vol. 47, pp. 348, 21 pls, 1901.

[3] Vaughan, T. W., The Eocene and lower Oligocene coral faunas of the United States, U. S. Geol. Survey Mon. 39, pp. 263, pls. 24, 1900. See especially p. 30.

The "coral limestone," formerly referred to the top of the Vicksburg group, as will be shown on subsequent pages, is, in my opinion, equivalent to the basal part of the Chattahoochee formation. The following is a list of the species of corals at present known from the Vicksburg group:

Fossil corals from the Vicksburg group.

Name.	Byram calcareous marl.	Marianna limestone.		Red Bluff clay.
		Glendon limestone member.	Mint Spring calcareous marl member	
Flabellum magnocostatum Vaughan				×
rhomboideum Vaughan				×
Turbinolia insignifica Vaughan	?		×	×
Steriphonotrochus pulcher Vaughan				×
Archohelia neglecta (Vaughan)				×
vicksburgensis (Conrad)	×		×	×
mississippiensis (Conrad)	×			
harrisi (Vaughan)				×
aldrichi (Vaughan)				×
Antiguastrea cellulosa (Duncan)	×			
Balanophyllia elongata Vaughan				×
caulifera (Conrad)		×	×	
caulifera var. *multigranosa* Vaughan				×
Dendrophyllia new species	×			

This fauna is different from any now known in the West Indies or Central America. It lived under conditions closely similar to those under which the Jackson fauna of the same area lived. It is important to note that *Antiguastrea cellulosa*, a species very abundant in the middle and sparingly present in the upper Oligocene, occurs in the uppermost beds of the Vicksburg group. The Oligocene coral reef represented by the "coral limestone" at Salt Mountain, Alabama, and at Bainbridge, Georgia, overlies the Vicksburg group, which can with considerable assurance be correlated with the lower Oligocene (Lattorfian) of Veneto and elsewhere in Europe. The greatly-developed Oligocene coral reefs of Antigua are to be correlated with the reefs of Bainbridge. They are therefore stratigraphically higher than the Vicksburg group and are of middle Oligocene (Rupelian = Stampian) age.

MIDDLE OLIGOCENE.

ANTIGUA FORMATION.[1]

The following list of species is based on a revision of Duncan's work on the Antigua corals,[2] after a study of his types in the collec-

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[1] Name proposed by J. W. Spencer in his paper entitled On the geological and physical development of Antigua, Geol. Soc. London Quart. Journ., vol. 57, pp. 496–498, 1901. See also, Brown, Amos P., Notes on the geology of the Island of Antigua, Acad. Nat. Sci. Phila. Proc. for 1913, pp. 584–616, pls. 18–20, 1913. Vaughan, T. W., papers referred to in footnote on page 193; and Memorandum on the geology and groundwaters of Antigua, B. W. I., Imperial Dep't of Agriculture West India Bull., vol. 14, No. 4, 5 pp., 1915.

[2] Duncan, P. M., On the fossil corals of the West Indian Islands, Part 1, Geol. Soc. London Quart. Journ. vol. 19, pp. 408–458, pls. 13–16, 1863; Part 4, Idem., vol. 24, pp. 9–33, pls. 1, 2, 1867.

tions of Geological Society of London and the British Museum (Natural History), and principally the collection made by myself which contains 60 species. It seems that I failed to find 7 of the species reported by Duncan; and apparently Mr. Robert T. Hill and Dr. J. W. Spencer each obtained one species that I did not collect. I feel a little doubtful about two or three of Duncan's types having really come from Antigua. Each species whose name is preceded by an asterisk * is considered in the systematic part of this paper.

Fossil corals from the Antigua formation.

Name.	Distribution outside Antigua.	Nomenclatorial notes.
**Stylophora ponderosa* Vaughan	Salt Mt., Ala	
new species 1		
new species 2		
Pocillopora tenuis Duncan		
new species		
Madrepora new species		
**Stylocoenia pumpellyi* (Vaughan)	Bainbridge, Ga	*Stylocoenia lobato-rotundata* Duncan, *not* M. Edwards and Haime.
new species		
**Astrocoenia guantanamensis* Vaughan	Cuba, Panama	
**decaturensis* Vaughan	Cuba, Bainbridge, Ga	*Astrocoenia ornata* Duncan, *not* M. Edwards and Haime.
**portoricensis* Vaughan	Porto Rico	
new species		
Asterosmilia exarata Duncan var	Santo Domingo	
Genus indet. new species		
Euphyllia new species		
Antillia new species		
Leptomussa new species		
Genus indet. new species		
Cladocora recrescens Lonsdale	Chattahoochee formation, upper part, Ga.	
**Orbicella antillarum* (Duncan)	Montserrat	*Heliastraea antillarum* Duncan.
**costata* (Duncan)	Porto Rico, Canal Zone, Anguilla	*Heliastraea costata* (Duncan) Duncan.
**insignis* (Duncan)	Arube	*Heliastraea insignis* Duncan.
**intermedia* (Duncan)		*Heliastraea radiata* var. *intermedia* (Duncan).
**Antiguastrea cellulosa* (Duncan)	Porto Rico, Cuba, Fla., Ga., Miss., Mex., Anguilla, Arube.	*Heliastraea cellulosa* (Duncan) Duncan + *Isastraea turbinata* Duncan.
*var. *curvata* (Duncan)		
*var. *silecensis* Vaughan	Ga., Fla., Mex	
Diplothecastraea monitor (Duncan) Duncan.		
* *Favia macdonaldi* Vaughan	Panama	
* *Favites polygonalis* (Duncan)	Bainbridge, Ga	
new species		
Lamellastraea smythi Duncan		
Genus indet. new species		
Goniastrea reussi (Duncan)		*Stephanocoenia reussi* Duncan.
* *Maeandra antiguensis* Vaughan	Panama	*Coeloria denselephantis* Duncan.
dens-elephantis (Duncan)		
**Leptoria spenceri* Vaughan.	Cuba	*Maeandrina* species Duncan.
* *Manicina willoughbiensis* Vaughan		*Cocloria labyrinthiformis* Duncan, *not* Linnaeus.
**Pironastraea antiguensis* Vaughan	Cuba	
Pavona new species		
Leptoseris new species 1		
new species 2		
Haloscris new species		
**Siderastrea conferta* (Duncan)	Porto Rico, Canal Zone, Anguilla.	*Isastraea conferta* Duncan.
* *Cyathomorpha hilli* Vaughan		
**browni* Vaughan		
**belli* Vaughan		
**splendens* Vaughan		
**antiguensis* (Duncan)	Porto Rico, Cuba, Mex	*Heliastraea antiguensis* (Duncan) Duncan + *Astroria affinis* Duncan + *Astroria antiguensis* Duncan.
**tenuis* (Duncan)	Porto Rico, Cuba	*Heliastraea tenuis* (Duncan) Duncan.

Fossil corals from the Antigua formation—Continued.

Name.	Distribution outside Antigua.	Nomenclatorial notes.
**Diploastrea crassolamellata* (Duncan)	Porto Rico, Cuba, Ga., Canal Zone.	*Heliastraea crassolamellata* (Duncan) Duncan + vars. *magnetica, pulchella,* and *nobilis.*
*var. *magnifica* (Duncan)	Porto Rico, Cuba, Ga	
*var. *nugenti* (Duncan)		+ var. *minor* Duncan.
Dendrophyllia new species		
**Acropora panamensis* Vaughan	Canal Zone	
new species 1		
**saludensis* Vaughan	Canal Zone	
new species 2		
**Astreopora antiguensis* Vaughan	Canal Zone	
**Actinacis alabamiensis* Vaughan	Salt Mt., Ala.; Bainbridge, Ga.	
new species 1	Bainbridge, Ga	
new species 2		
Goniopora new species 1		
new species 2		
*regularis (Duncan)		*Alveopora daedalaea* var. *regularis* Duncan.
*var. *microscopica* (Duncan)		
new species 3		
**clevei* Vaughan	Anguilla, Canal Zone	
**portoricensis* Vaughan	Porto Rico	
**cascadensis* Vaughan	Anguilla, Canal Zone	
new species 4		
new species 5		
Goniopora (?) *tenuis* (Duncan)		*Stephanocoenia tenuis* (Duncan) + *Rhodaraea irregularis* Duncan.
Alveopora new species 1		
new species 2		

Three of the species recorded by Duncan from Antigua, in my opinion, are incorrectly identified and their names are dropped from the list. They are as follows:

Favoidea junghuhni Reuss, according to Duncan.

Heliastraea barbadensis Duncan.

Solenastraea turonensis (Michelin), according to Duncan.

Another species, *Astraea megalaxona* Duncan, is based on unidentifiable material, and its name is also dropped. The total number of recorded species from Antigua, therefore, is 69, and 5 varieties are recognized. Of the 33 species indicated as new, descriptions of 8 have been written and descriptions of 26 remain to be written at the time of making out the preceding table.

The number of species, 69, recognized is interesting for comparison with the number recorded for areas in which living reefs occur. Von Marenzeller[1] records 71 species from the Red Sea in his report on the *Pola* expedition corals Bedot[2] records a total of 74 species +5 varieties from Amboina—a number that should be reduced by about 4, because of the reference of some names to the synonymy of other species listed, leaving the number of valid species at about 70. In my paper on the shoal-water corals from Murray Island, Australia, I list 63 species from Murray Island and its vicinity in water not exceeding 18 fathoms deep, and report 51 species from Cocos-

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[1] Von Marenzeller, E., Riffkorallen, Exped. S. M. Schiff *Pola* in das Rote Meer, Zool. Ergeb. 26, K. K. Akad. Wiss. Wien, Mat.-Naturwiss Cl., vol. 80, pp. 28-97, pls. 1-29, 1906.

[2] Bedot, M., Madréporaries d' Amboine, Rev. suisse de Zool., vol. 15, pp. 143-292, pls. 5-50, 1907.

Keeling Islands.[1] It is known that at least a few more than 51 species occur in these islands. Outside the main coral-reef zone the number of species is smaller. For instance, there are only 43 supposedly valid species recorded from water between 0 and 25 fathoms deep in the Hawaiian Islands and Laysan.[2] It is not certain that 3 of the species included in the number 43 were obtained in the Hawaiian Islands. The usual number of species obtained in Florida or the West Indies, in water less than 25 fathoms deep, where conditions are favorable for coral growth is about 35. There were on the Antiguan reef as many species of corals as are at present usual for one island or a small group of islands in the Indo-Pacific, and about twice as many species as are usual on a living West Indian reef.

The reason for referring the Antigua reefs to a horizon above the lower (Lattorfian) Oligocene is given on page 199. The following list of middle (Rupelian) Oligocene genera is taken from Fabiani,[3] but it is considerably revised and needs further revision:

Middle Oligocene (Rupelian) genera of corals in Veneto.

*Stylophora.
*Stylocoenia.
*Astrocoenia.
Trochosmilia.
Coelosmilia.
Epismilia?
Phyllosmilia?
Parasmilia.
*Euphyllia.
Dichocoenia.
Stylina?
Grumia.
Montlivaultia?
Leptaxis.
Astrangia.
Holangia.
Gombertangia.
*Orbicella.
Solenastrea.
*Antiguastrea.
Aplophyllia?
Rhabdophyllia.
Calamophyllia
*Goniastrea.
*Hydnophora.
*Leptomussa.
Mycetophyllia.
*Trochoseris.
Cyathoseris.
*Mesomorpha.
Comoseris?
Mycetoseris.
Leptophyllia?
Stephanosmilia.
Thamnasteria?
Dimorphastrea?
Cyathomorpha.
Hydnophyllia.
Astraeomorpha?
Acropora.
Dendracis.
*Astreopora.
*Actinacis.
*Goniopora.
*Porites.
*Alveopora.

* Indicates that the genus is also found in the middle Oligocene of the West Indies or the southeastern United States.

The generic characters of a number of the corals listed by Fabiani can not be ascertained without a restudy of authentically identified specimens in the light of modern systematic technique, which require that besides having an adequate knowledge of the morphology of the coral skeleton, the investigation shall proceed from a critical study of the type-species of the genera to be recognized to a similar critical study of the species to be generically identified, and that due attention shall be paid to the rules of zoologic nomenclature as expressed in the International Code. I will point out in passing that there are in the United States National Museum 10 specimens of the coral to which Reuss applied the name _Cyathophyllia annulata_. It would be too great a diversion to give in this place a discussion of the literature on this species. This is a fungid coral,

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[1] Vaughan, T. W., Some shoal-water corals from Murray Island (Australia), Cocos-Keeling Islands, and Fanning Island, Carnegie Inst. Washington Pub. 213, see especially pp. 67–72, 1918.

[2] Vaughan, T. W., Recent Madreporaria of the Hawaiian Islands and Laysan, U. S. Nat. Mus. Bull. No. 59, pp. 32–34, 1907. [The list referred to has been slightly revised and the number reduced by 2 names.]

[3] Fabiani, R., Il paleogene del Veneto, R. Univ. Padova Inst. Geol. Mem., vol. 3, pp. 229–231. 1915.

with a synapticulate and perforate wall at and just below the calicular margin, the wall at lower levels usually, but not invariably, becoming solid. In Fabiani's list this species, under the generic name *Stephanosmilia* (name proposed by Reuss in 1874, not *Stephanosmilia* De Fromentel, 1862), comes between *Parasmilia* and *Plocophyllia* (a synonym of *Euphyllia*). I do not know what the systematic relations of *Leptaxis* Reuss are. Reuss based the genus and the type-species, *L. elliptica* Reuss, on a single specimen from Monte Grumi and seems not to have obtained another from anywhere. Until additional specimens of *L. elliptica* have been critically studied, *Leptaxis* is not an identifiable genus. Although Duncan considered *Leptaxis* a subgenus of *Antillia*, I think that it may be one of the simple fungid genera. The species referred to 10 genera, whose names are followed by a question mark," ?," should all be critically restudied.

The names of the genera preceded by an asterisk, "*", in the foregoing table are also found in the middle Oligocene of the West Indies or the southeastern United States. The following genera have closely related species:

Stylophora
Stylocoenia
Astrocoenia
Euphyllia
Orbicella
Antiguastrea
Leptomussa
Cyathomorpha
Astreopora
Actinacis
Goniopora
Alveopora

I am not at all sure that some of the American middle Oligocene and the European Rupelian species are not identical.

Dr. Joseph A. Cushman has described the following species of *Lepidocyclina* from the collection I made in Antigua (not yet published):

Lepidocyclina gigas Cushman
undulata Cushman
undosa Cushman
favosa Cushman

L. undulata seems to be the largest known species of *Lepicocyclina*, some specimens attaining a diameter of 100 mm.

The calcareous algae, echinoids, Mollusca, and Bryozoa, as well as the Foraminifera of the Antigua formation will be described in a forthcoming volume to be published by the Carnegie Institution of Washington. The Antigua formation must, in my opinion, be the type of the American middle Oligocene.

PEPINO FORMATION OF PORTO RICO.[1]

The corals here listed were almost all collected by Mr. R. T. Hill. I have added the names of a few additional species collected by members of the New York Academy Porto Rico Survey.

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[1] For accounts of the geologic relations of this formation, see Hill, R. T., Notes on the forest conditions of Porto Rico, U. S. Dept. Agriculture Div. of Forestry Bull. No. 25, pp. 14, 15, 1889. Vaughan, T. W., see references in footnote on pp. 193, 205.

Fossil corals from the Pepino formation.

Astrocoenia portoricensis Vaughan, Antigua, and Canal Zone.
Orbicella costata (Duncan), Antigua, Anguilla, Canal Zone.
Antiguastrea cellulosa (Duncan), Antigua, Florida, Georgia., etc.
Maeandra portoricensis Vaughan.
Leptoseris portoricensis Vaughan.
Pironastraea anguillensis Vaughan, Anguilla.
Siderastrea conferta (Duncan), Antigua, Canal Zone, Anguilla.
Cyathomorpha antiguensis (Duncan), Antigua, Cuba, Mexico.
    tenuis (Duncan), Antigua, Cuba.
Diploastrea crassolamellata (Duncan), Antigua, Cuba, Georgia.
Astreopora portoricensis Vaughan.
Goniopora portoricensis Vaughan, Antigua.

Of the 12 species from the Pepino formation, 8 are known in the Antigua formation of Antigua.

LIMESTONE ABOVE CONGLOMERATE NEAR GUANTÁNAMO, CUBA.

The geologic relations of the corals from the vicinity of Guantanamo will be described by Mr. O. E. Meinzer in a forthcoming report. The following is a list of the species:

Fossil corals from the middle Oligocene, Guantanamo, Cuba.

Pocillopora guantanamensis Vaughan.
Astrocoenia guantanamensis Vaughan, Antigua, Panama.
    decaturensis Vaughan, Antigua, Georgia.
    meinzeri Vaughan.
Antiguastrea cellulosa (Duncan), Antigua, Porto Rico, etc.
Trochoseris meinzeri Vaughan, Panama.
Pironastraea antiguensis Vaughan, Antigua.
Cyathomorpha anguillensis Vaughan, Anguilla.
    antiguensis (Duncan), Antigua, Porto Rico, etc.
    tenuis (Duncan), Antigua, Porto Rico, etc.
Diploastrea crassolamellata (Duncan), Antigua, etc.
Goniopora decaturensis Vaughan, Georgia.

Of the 12 species here listed 7 are also found in Antigua; of the 5 remaining species 2 are at present known from only one locality, 2 occur elsewhere in association with a fauna of the same facies as that of Antigua, while 1 occurs in the base of the Anguilla formation.

Limestone, Rio Canapu, Manasasas trail, Cuba.

The following species were collected by Dr. Arthur C. Spencer:
Leptoria spenceri Vaughan, Antigua.
Cyathomorpha tenuis (Duncan), Antigua.
Diploastrea crassolamellata (Duncan) Antigua.

The first and second species of the above list were obtained at station No. 3473 of the U. S. N. M. record of localities for Cenozoic invertebrate collections. Specimens of *Orthophragmina* were obtained at the same station and indicate upper Eocene or lower Oligocene as the age of the rock. This matter will be further discussed in the forthcoming report on West Indian paleontology.

BASAL PART OF CHATTAHOOCHEE FORMATION IN GEORGIA.[1]

The localities at which the specimens of fossil corals were obtained are at Blue or Russell Springs on Flint River about 4 miles below Bainbridge, and at other localities along Flint River to Hale's Landing, about 7 miles below Bainbridge. The corals are most embedded in or weathered out of chert which was once a coral-reef limestone that was formed on the subaerially eroded surface of the Eocene Ocala limestone after submergence. Dr. W. H. Dall in a recently published paper[2] appears to correlate this bed with the *Orthaulax pugnax* zone of Tampa, Florida, and states that I concur in that opinion. Although the chert forming the base of the Chattahoochee formation in the vicinity of Bainbridge is faunally nearly related to the "silex" bed of the Tampa formation, in my opinion they are not of the same age, the "silex" bed being geologically younger. The coral faunas are not the same, and there is at least a species of one genus at Tampa of stratigraphically later affinities than any species in the vicinity of Bainbridge.

The following are the species from near Bainbridge mentioned in this paper:

Fossil corals from basal part of Chattahoochee formation near Bainbridge, Georgia.

Stylophora minutissima Vaughan.
Stylocoenia pumpellyi (Vaughan) Vaughan, Antigua.
Astrocoenia decaturensis Vaughan, Antigua, Cuba.
Orbicella bainbridgensis Vaughan, Santo Domingo?, Porto Rico.
Antiguastrea cellulosa (Duncan), Antigua, etc., Tampa.
  var. *silecensis* Vaughan, Antigua, etc.
Favites polygonalis (Duncan) var., Antigua.
Siderastrea silecensis Vaughan, Tampa; Alum Bluff formation.
Diploastrea crassolamellata (Duncan), Antigua, etc.
  var. *magnifica* (Duncan), Antigua, etc.
Astreopora antiguensis Vaughan, Antigua.
Actinacis alabamiensis (Vaughan), Antigua; Salt Mountain, Ala.
Goniopora decaturensis Vaughan, Cuba.

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[1] The more important references to the literature are as follows:

Vaughan, T. W., A Tertiary coral reef near Bainbridge, Georgia, Science, n. s., vol. 12, pp. 873-875, 1900; Bainbridge and vicinity in Preliminary report on the Coastal Plain of Georgia by O. Veatch and L. W. Stephenson, prepared under the direction of T. W. Vaughan, Geol. Survey of Ga. Bull. 26, pp. 328-333, 1911; The reef coral fauna of Carrizo Creek, Imperial County, California, and its significance, U. S. Geol. Survey Prof. Pap. 98-T, pp. 363-364, 1917.

Cooke, C. W., Age of the Ocala limestone, U. S. Geol. Survey Prof. Pap. 95-I, pp. 107-117, 1915.

[2] A contribution to the invertebrate fauna of the Oligocene beds of Flint River, Georgia, Proc. U. S. Nat. Ms., vol. 51, pp. 487-524, plates 83-88, 1916.

Of the 13 species and varieties listed above, 9 are common to Antigua, and *Goniopora decaturensis* occurs in Cuba in association with species of corals abundant in Antigua; of the 3 remaining species, *Stylophora minutissima* has so far been positively identified only at Bainbridge, but it is very near a species common in Antigua; 2 of the 13 forms are known from the "silex" bed of Tampa. The coral fauna near Bainbridge is a moderately rich one. In addition to those listed there are species of *Stylophora*, *Astrocoenia*, *Antillia?*, *Astrangia* or *Rhizangia*, *Mesomorpha*, *Astreopora*, *Actinacis*, *Goniopora*, and *Alveopora*, and of a few genera not yet positively identified. There are between 25 and 30 species, of which only 4 or 5 are common to the Tampa coral fauna.

It should be stated here that casts of a species of *Pecten*, which appears to *P. suwaneensis* Dall, occur at station 3381 in the matrix with *Diploastrea crassolamellata*, which may therefore be of upper Eocene as well as of Oligocene age, or I may not have discriminated closely enough between species.

"CORAL LIMESTONE" OF SALT MOUNTAIN, ALABAMA.[1]

I described in the monograph referred to in the footnote two species, as follows:

Stylophora ponderosa Vaughan, Antigua.

Actinacis alabamiensis (Vaughan), Antigua; Flint River, Georgia.

I long surmised that the "coral limestone" of Salt Mountain really represented the basal part of the Chattahoochee formation, but only recently did I obtain evidence that this limestone is the stratigraphic correlative of the Antigua formation and of the coral reef horizon near Bainbridge.

SAN RAFAEL FORMATION OF EASTERN MEXICO.[2]

The formation from which the fossil corals were obtained was first designated by Mr. Dumble "San Fernando beds," a name long in use for a Tertiary formation in the Island of Trinidad. He has recently changed the name to San Rafael. It is an important formation in eastern Tamaulipas, Mexico. Several of the corals are not well enough preserved for purposes of identification. The following is a list:

Antiguastrea cellulosa (Duncan), Antigua, etc.
 var. *silecensis* Vaughan, Antigua, etc.
Favites mexicana Vaughan.
Maeandra dumblei Vaughan.

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[1] For a description of the geologic relations, see Vaughan, T. W., Eocene and lower Oligocene coral faunas of the United States, U. S. Geological Survey Mon. 39, pp. 30, 31, 1900.

[2] The principal literature is as follows:

Dumble, E. T., Some events in the Eocene history of the present Coastal area of the Gulf of Mexico in Texas and Mexico, Journ. Geol., vol. 23, pp. 481–498, 1915 (see especially pp. 495–497); Tertiary deposits of northeastern Mexico, California Acad. Sci. Proc., ser. 4, vol. 5, pp. 163–193, pls. 16–19, 1915 (see especially pp. 189–192).

Cyathormorpha antiguensis (Duncan), Antigua, etc.

Goniopora species. Similar to Antiguan species.

Although the identifiable species are few, it appears safe to correlate the San Rafael formation with the Antigua formation.

TONOSI, PANAMA.

Doctor MacDonald obtained at this locality, station 6587, the following species of corals:

Astrocoenia guantanamensis Vaughan, Antigua, Cuba.

Favia macdonaldi Vaughan, Antigua.

Maeandra antiguensis Vaughan, Antigua.

Trochoseris meinzeri Vaughan, Cuba.

Diploastrea crassolamellata (Duncan), Antigua, Cuba, etc.

There can be no reasonable doubt that this is the same as the coral fauna found in the Antigua formation. As the locality at which the specimens were obtained is on the Pacific coast of Panama, the evidence is conclusive that there was middle Oligocene connection between the Atlantic and the Pacific in that area.

SERRO COLORADO, ARUBE.

Three species were obtained at this locality,[1] as follows:

Orbicella insignis (Duncan), Antigua.

Antiguastrea cellulosa (Duncan), Antigua.

Goniopora species (the kind of casts to which Duncan applied the name *Alvepora daedalea* var. *regularis*).

This fauna is evidently the same as that of the Antigua formation.

CONCLUDING REMARKS ON THE MIDDLE OLIGOCENE.

The foregoing lists show that Antiguan middle Oligocene coral fauna is known in Porto Rico, Cuba, southern Georgia, southern Alabama, eastern Mexico, Panama, and Arube. That it also occurs in Santo Domingo is known from some of the specimens, *Siderastrea conferta* (Duncan) typical and a peculiar variety of *Asterosmilia exarata* (Duncan), both brought from Santo Domingo by Gabb. It is a key horizon in the American Oligocene. The Byram calcareous marl of Mississippi occurs either at its base or just below its base. It therefore overlies all the Vicksburgian lower Oligocene, with the possible exception of the uppermost member, and is stratigraphically just below the "silex bed" of the Tampa formation. The correlation of the deposits containing this fauna with the Rupelian of Veneto has been made on page 202.

That there was middle Oligocene connection between the Atlantic and the Pacific was pointed out on this page in discussing the species from Tonosi, Panama.

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[1] Vaughan, T. W., Some fossil corals from the elevated reefs of Curaçao, Arube, and Bonaire, Geolog. Reichs-Mus. Leiden Samml., ser. 2, vol. pp. 1-91, 1901 (especially pp. 11, 12).

UPPER OLIGOCENE.

CULEBRA FORMATION.

The Culebra formation and the base of the Emperador limestone in the Canal Zone contain a few species that indicate close relationship with the Antiguan horizon, but on the whole the affinities are rather with the next higher fauna. Fossil corals were obtained in the Culebra formation at three stations, as follows:

Station 5863, west side of Gaillard Cut, at station 1863 of the Canal Commission, between points opposite Curacha and Paraiso.

Station 6020*c*, Las Cascadas, Gaillard Cut, third bed from the bottom of the section.

Station 6026, one and one-half miles south of Monte Lirio, on Panama Railroad (relocated line).

The list of species is as follows:

Species of corals from the Culebra formation.

Name.	Station 5863.	Station 6020*c*.	Station 6026.	Emperador Is.	Antigua.	Anguilla.
Stylophora imperatoris Vaughan	×	....	×	×	....	×
goethalsi Vaughan	....	....	×	×	....	....
Orbicella costata (Duncan)	....	×	....	....	×	×
Siderastrea conferta (Duncan)	....	×	....	....	×	×
Astreopora antiguensis Vaughan	....	....	×	....	×	....
Goniopora cascadensis Vaughan	....	×	....	....	×	×

Of the 6 species in the Culebra formation, 2 also occur in the Emperador limestone; 4 also occur in the Antigua formation; and 4 also occur in the Anguilla formation. There is only one species, *Astreopora antiguensis*, that is elsewhere known only from the Antigua horizon; while 2 species are at present known elsewhere only from the Anguilla horizon. These relations indicate, but do not prove, that the upper part of the Culebra formation, the part of the formation in which the corals were collected, is stratigraphically higher than the Antigua formation, and is, therefore, referable to the upper Oligocene. The foraminiferal fauna, to be discussed on pages 554, 555, 585, supplies stronger evidence in favor of considering the upper part of the Culebra as of upper Oligocene age.

EMPERADOR LIMESTONE.

The principal collections from the Emperador limestone were made by Doctor MacDonald and me at Station 6015 and 6016, in Empire village. Dr. Ralph Arnold subsequently made a small collection in Empire and obtained one species, *Pocillopora arnoldi* Vaughan, not collected by Doctor MacDonald and me. Doctor MacDonald and I also made a small collection at Station 6024*b*, the upper bed at the lower end of the culvert where the Panama Railroad (relocated line) crosses Rio Agua Salud; and he subsequently obtained some very interesting specimens at station 6256, which is 1½ miles south of Miraflores. The following is a list of the species:

Species of corals from the Emperador limestone.

	Empire quarries.	Station 6024*b*.	Station 6256.	Anguilla.	Antigua.
Stylophora imperatoris Vaughan	×	×	....	×	....
panamensis Vaughan	×	....	....	....	....
goethalsi Vaughan	×	....	....	....	....
macdonaldi Vaughan	×	×	....	....	....
canalis Vaughan	×	....	....	....	....
Pocillopora arnoldi Vaughan	×	....	....	....	....
Astrocoenia portoricensis Vaughan	....	×	....	....	×
Orbicella imperatoris Vaughan	×	....	×	×	....
canalis Vaughan	×	....	....	×	....
Stylangia panamensis Vaughan	×	....	....	....	....
Goniastrea canalis Vaughan	×	....	....	....	....
Pavona panamensis Vaughan	×	....	....	....	....
Acropora panamensis Vaughan	....	×	....	....	×
saludensis Vaughan	×	×	....	....	×
Astreopora goethalsi Vaughan	×	....	....	....	....
Goniopora hilli Vaughan	×	....	....	....	....
panamensis Vaughan	×	....	....	×	....
imperatoris Vaughan	×	....	....	×	....
canalis Vaughan	×	....	....	×	....
clevei Vaughan	×	....	....	×	×
Porites douvillei Vaughan	×	....	....	....	....
toulai Vaughan	×	....	....	....	....
panamensis Vaughan	×	....	×	....	....
anguillensis Vaughan	×	....	....	×	×
(*Synaraea*) *howei* Vaughan	×	....	....	....	....
macdonaldi Vaughan	×	....	....	×	×

Of 26 species from the Emperador limestone, 6 have been identified in the Antigua formation and 9 in the Anguilla formation, but it is probable that the number of species common to the Emperador limestone and the Anguilla formation will be somewhat increased. The Emperador limestone is of nearly the same horizon as the Anguilla formation. Additional evidence favoring this opinion will be adduced on subsequent pages.

ANGUILLA FORMATION.[1]

This name is proposed for the coralliferous limestone and argillaceous marls of Anguilla. The type-locality is on the south and west sides of Crocus Bay, where it is exposed to a thickness of about 200 feet. The fauna has been monographically described, and the account of it will be published in a forthcoming volume of the Carnegie Institution of Washington. The following species of corals from it are considered in the present paper:

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[1] The principal literature is as follows:

Cleve, P. T., On the geology of the northeastern West India Islands, K. svenska Vet.-Akad. Handl., vol. 9, No. 12, p. 22, 1872.

Vaughan, T. W., see references in footnote, p. 193.

Species of corals from the Anguilla formation.

Name.	Culebra formation.	Emperador limestone.	Antigua.	Other localities.
Stylophora imperatoris Vaughan	×	×		
Orbicella imperatoris Vaughan		×		Cuba.
costata (Duncan)	×		×	
canalis Vaughan		×		
Antiguastrea cellulosa (Duncan)			×	P. R.; Cuba; etc.
Agaricia anguillensis Vaughan				
Pironastraea anguillensis Vaughan				P. R.
Siderastrea conferta (Duncan)	×		×	P. R.
Cyathomorpha anguillensis Vaughan				
roxboroughi Vaughan				
Goniopora panamensis Vaughan		×		
imperatoris Vaughan		×		
canalis Vaughan		×		
clevei Vaughan		×		
cascadensis Vaughan	×			
Porites anguillensis Vaughan		×		
(*Synaraea*) *macdonaldi* Vaughan		×		

P. R.=Porto Rico.

Of the 17 species listed above, 4 are also found in the Culebra formation, 9 in the Emperador limestone, and 12 of the 17 in the combined Culebra and Emperador of the Canal Zone. In addition to the species here considered there are other species of *Stylophora*, *Stylocoenia*, *Antillia*, *Cladocora*, *Maeandra*, *Goniopora*, and *Porites*. There are 9 or 10 species of *Goniopora*. The total coral fauna in the collections available to me comprises about 28 species.

The Anguilla formation is correlated with the Emperador limestone for the following reasons: *Heterosteginoides*, a new genus of orbitoidal foraminifera described by Doctor Cushman, is represented in the Anguilla formation by a species, also found in Antigua, but very near a species that occurs in the Emperador limestone. Although *Heterosteginoides* occurs in both Antigua and Anguilla, *Lepidocyclina*, which is so abundant in Antigua, was not collected by me in Anguilla and is only sparingly present in the Emperador limestone. The identity of certain species of corals in the two formations has been shown. *Echinolampas semiorbis* Guppy is abundant in Anguilla (on the west side of Crocus Bay between 25 and 70 feet above sea level) and in the base of the Emperador limestone, Canal Zone. *Orthaulax pugnax* (Heilprin) was collected in the base of the Crocus Bay exposures.

CUBAN LOCALITIES.

Orbicella imperatoris Vaughan has been collected at the following localities in Cuba: Station 3450, 4 miles north of Pinar del Rio; station 3451, one-half mile west of Ciénaga railroad station, near Habana; station 3566, Bejucal; station 7544, Rio Yateras, near Guantanamo. That the Anguilla horizon is widely extended in Cuba is shown by the distribution of the echinoids which will be considered in another place.

TAMPA FORMATION OF FLORIDA.

The corals from the "silex" bed of the Tampa formation considered in this paper are as follows:

Orbicella tampäensis Vaughan.
var. *silecensis* Vaughan.
Antiguastrea cellulosa (Duncan).
Siderastrea silecensis Vaughan.

Siderastrea hillsboroensis Vaughan occurs at about the same horizon as the "silex" bed.

The Tampa coral fauna has not been described in print, but I furnished Doctor Dall a list of my manuscript names of the species and it appeared in his monograph of the molluscan fauna of the *Orthaulax pugnax* zone of the Oligocene of Tampa, Florida.[1] I have pointed out that *Orbicella tampaensis* var. *silecensis* (see p. 391 of this paper) closely resembles some of the variants of *O. costata* from Anguilla and that the specimens identified as *Siderastrea silecensis* in which there are over 60 septa perhaps should be referred to *S. conferta* (see p. 449). Besides the species mentioned, there are species representing the following genera: *Stylophora*, *Antillia*?, *Galaxea*, *Solenastrea*, *Maeandra*, *Syzygophyllia*?, *Endopachys*, *Acropora*, *Goniopora*, *Porites*, *and Alveopora*.

Two and perhaps three of the "silex" bed species of corals also occur at Bainbridge, but the faunas otherwise are not the same. Two of the species from Tampa are near living West Indian and Floridian species. These are *Solenastrea tampäensis* Vaughan, *nomen nudum*, which is near *S. hyades* (Dana); and *Porites willcoxi* Vaughan, *nomen nudum*, which has the septal arrangement of *Porites astreoides*. The presence of such species with modern affinities seems to me to indicate a considerably younger age than that of the reefs near Bainbridge. Furthermore *Lepidocyclina* is abundant in the reefs near Bainbridge, but has not yet been found at Tampa. *Orthaulax pugnax* occurs in the "silex" bed at Tampa, but it has not been found in the overlying limestone; the same species occurs in the base of the Anguilla formation, but I did not find it at higher levels. Dr. C. W. Cooke, who has monographically described the mollusca of the Anguilla formation, correlates it with the Tampa formation on the basis of similarity in their molluscan faunas. The correlation of the Tampa formation is further discussed on pages 570, 571.

CONCLUDING REMARKS ON THE UPPER OLIGOCENE.

That there was connection between the Atlantic and Pacific oceans during upper Oligocene time is shown by the continuity of both the Culebra formation and the Emperador limestone from the Atlantic to the Pacific slopes of the Isthmus. On the geologic map, plate 153,

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[1] U. S. Nat. Mus. Bull. 90, p. 18, 1915.

the Emperador limestone is represented as dipping below the Gatun formation on the north side of the Isthmus, and it is exposed almost down to the sea level on the south side. The Culebra formation underlies the Emperador limestone on both slopes, but it is not indicated on the map on the north slope of the Isthmus.

MIOCENE.

BOWDEN MARL.[1]

The point of departure in the consideration of the Miocene is the fauna of the Bowden marl of Jamaica. The following is a revised list of the species:

Placotrochus costatus Duncan.
Sphenotrochus new species.
Placocyathus barretti Duncan.
alveolus (Duncan.)
Stylophora granulata Duncan.
Asterosmilia profunda (Duncan).
hilli Vaughan.
Stephanocoenia intersepta (Esper), also living.
Antillia walli Duncan.
Thysanus excentricus Duncan.
elegans Duncan.
new species.
Syzygophyllia gregorii (Vaughan).
Siderastrea siderea (Ellis and Solander), also living.
Goniopora new species.
Porites baracoäensis Vaughan.
Acropora new species.

This fauna indicates somewhat deeper water than that in which the species mentioned on preceding pages lived; but the presence of *Stephanocoenia intersepta*, *Siderastrea siderea*, *Acropora* new species, a massive species of *Goniopora*, and *Porites baracoäensis*, furnish evidence in favor of the conclusion that the depth probably was not so much as 20 fathoms. The most striking feature of this list is that it contains the names of two species still living in the Caribbean region, in this respect differing from all the other faunas previously considered in this paper. The Bowden not only marks the introduction of species that persist in the West Indian region, but as neither in Jamaica, Santo Domingo, nor Cuba, have species of *Astrocoenia*, *Stylocoenia*, *Leptomussa*, *Antiguastrea*, *Favites*, *Leptoria*, *Trochoseris*, *Leptoseris*, *Haloseris*, *Pironastraea*, *Mesomorpha*, *Cyathomorpha*, *Diploastrea*, *Astreopora*, *Actinacis*, or *Porites* (*Synaraea*) been found in beds of the same age as or younger than the Bowden, these

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[1] For an account of the stratigraphic relations of the Bowden marl, see Hill, R. T., The geology and physical geography of Jamaica, Mus. Comp. Zool. Bull., vol. 34, No. 1, pp. 226, with 35 plates, 1899 (especially pp. 82–86, 145–152).

15 genera and one subgenus of middle and upper Oligocene corals apparently had become extinct in this region. The genus *Thysanus* is present in the Pliocene Caloosahatchee marl of Florida; and in Santo Domingo *Placocyathus*, *Stylophora*, *Antillia*, and *Syzygophyllia* occur at horizons above that of the Bowden marl, while the number of species now living increases. The Bowden marl marks an important change in the character of the coral faunas, a change from an older to a more recent facies. It therefore seems to me that the Bowden marl can not be considered of Oligocene age, and that it must be referred to the lower Miocene.

SANTO DOMINGO.

With regard to the species reported by Duncan from Santo Domingo, it will be said that Duncan does not describe the stratigraphy of Santo Domingo, but refers the specimens to the Nivajè shale, the superficial or tufaceous limestone, Posterero shale, Cerro Gordo shales, Esperanza shale, and "the silt of the sandstone plain." The following is a list of the species recorded by him, the gèologic formation in which they were reported to be found, and the revised names with annotations:

Fossil corals reported by Duncan from Santo Domingo.

Name used by Duncan.	Nivajè shale.	Superf. and tufaceous limestone.	Postrero shale.	Esperanza shale.	Silt of the sandstone plain.	Revised names and annotations.
Flabellum exaratum Duncan	......	......	......	......	......	Described from Vere, Jamaica; genus doubtful; identification doubtful.
Flabellum new species	(?)	......	......	......	......	Not determinable.
Placotrochus lonsdalei Duncan	+	......	......	......	......	*Placotrochus lonsdalei* Duncan.
Ceratotrochus duodecim-costatus M. Edwards and Haime.	......	......	......	......	......	From yellow shale of Angostina, Santo Domingo; specimen not determinable.
Trochocyathus latero-spinosus M. Edwards and Haime.	+	......	......	......	......	*Placocyathus* new species.
Paracyathus heneckeni (Duncan) Duncan.	+	......	......	......	......	*Paracyathus henckeni* (Duncan).
Placocyathus barretti Duncan	......	......	+	......	......	*Placocyathus barretti* Duncan; originally described from Bowden, Jamaica.
variabilis Duncan	+	......	......	......	+	*Placocyathus variabilis* Duncan.
costatus Duncan	+	......	......	......	......	*Placocyathus costatus* Duncan.
Pocillopora crassoramosa Duncan	+	......	......	......	......	*Pocillopora crassoramosa* Duncan.
Stylophoro affinis Duncan	+	......	......	......	......	*Stylophora affinis* Duncan.
var. *minor* Duncan	+	......	......	......	......	*Stylophora minor* Duncan.
Stylophora affinis Duncan var. 2	+	......	......	......	......	*Stylophora* new species; also from Cerro Gordo shales.
raristella M. Edwards and Haime.	......	......	......	......	+	Name discarded for Santo Domingan species.
Trochocyathus abnormalis Duncan	+	......	......	......	......	*Asterosmilia abnormalis* (Duncan).
Asterosmilia anomala Duncan	+	......	......	......	......	
cornuta Duncan	+	......	......	......	......	
exarata Duncan	......	......	......	......	......	*Asterosmilia exarata* Duncan; also in Antigua formation, Antigua.
Stephanocoenia intersepta M. Edwards and Haime.	......	......	......	......	+	*Stephanocoenia intersepta* (Esper).
Antillastraea spongiformis (Duncan) Duncan.	......	......	......	......	+	
Dichocoenia tuberosa Duncan	+	+	......	......	......	*Dichocoenia tuberosa* Duncan.
Barysmilia intermedia Duncan	......	......	......	+	......	

Fossil corals reported by Duncan from Santo Domingo—Continued.

Name used by Duncan.	Nivajè shale.	Superf. and tufaceous limestone.	Postrero shale.	Esperanza shale.	Silt of the sandstone plain.	Revised names and annotations.
Flabellum dubium Duncan	+	......	......	......	......	*Antillia dubia* (Duncan).
Antillia lonsdaleia Duncan	+	......	......	......	......	
bilobata Duncan	+	......	......	......	......	*Antillia bilobata* Duncan.
Cyphastraea costata Duncan	+	......	......	......	......	The type of this is from Barbuda and is a precise synonym of *Orbicella annularis* (Ellis and Solander); but the Santo Domingan specimen is a species of *Solenastrea*.
Phyllocoenia sculpta M. Edwards and Haime var. *tegula* Duncan.	+	......	......	......	......	*Orbicella limbata* (Duncan); also reported from "yellow shale."
Phyllocoenia limbata Duncan	......	......	......	......	......	
Plesiastraea ramea Duncan	......	......	......	......	+	
Heliastraea cylindrica (Duncan) Duncan.	......	+	......	......	......	Varietal forms of *Orbicella cavernosa* (Linnaeus).
endothecata (Duncan) Duncan	+	......	......	......	......	
brevis (Duncan) Duncan	+	......	......	......	......	*Orbicella brevis* (Duncan).
Plesiastraea distans Duncan	......	......	......	......	+	Varietal forms of *Solenastrea bournoni* M. Edwards and Haime.
globosa Duncan	......	......	......	......	+	
Solenastraea verhelsti M. Edwards and Haime.	......	+	......	......	......	A highly fossilized specimen; name discarded for the Santo Domingan coral.
Stephanocoenia dendroidea M. Edwards and Haime.	......	......	......	......	......	Locality not given; probably a species of *Astrocoenia*.
Thysanus corbicula Duncan	+	......	......	......	......	*Thysanus corbicula* Duncan.
Teleiophyllia grandis Duncan	+	......	......	......	......	*Thysanus grandis* (Duncan).
navicula Duncan	+	......	......	......	......	*Thysanus navicula* (Duncan).
Manicina areolata (Linnaeus)	+	......	......	......	......	*Maeandra areolata* (Linnaeus).
Maeandrina filograna Lamarck	......	......	......	......	......	"Shale," no other data on geologic relations; name dropped from list.
sinuosissima M. Edwards and Haime.	......	......	......	......	+	The name proposed by Milne Edwards and Haime is a synonym of *Maeandra strigosa* (Dana); name dropped from list.
Lithophyllia affinis (Duncan) Duncan	......	+	......	......	......	*Mussa affinis* (Duncan); may be the young of *Mussa angulosa* (Pallas).
Antillia ponderosa (M. Edwards and Haime) Duncan.	+	......	......	......	......	*Syzygophyllia gregorii* (Vaughan) type from Bowden, Jamaica.
dentata Duncan	+	......	......	......	......	*Syzygophyllia dentata* (Duncan).
Agaricia agaricites Lamarck	+	......	......	......	......	Material poor; names dropped from list.
undata Lamarck var	+	......	......	......	......	
Siderastraea grandis Duncan	......	......	......	......	+	Type from Jamaica is *Siderastrea siderea* (Ellis and Solander).
crenulata Blainville var. *antillarum* Duncan.	+	......	......	......	......	This seems to be a synonym of *S. siderea* (Ellis and Solander).
Porites collegniana Michelin	+	......	......	......	......	Name dropped from list.
Alveopora fenestrata Dana	+	......	......	......	......	Name dropped from list.

It has appeared that perhaps two distinct geologic horizons were represented by these collections, one of which is the Nivajè shale and another which is represented by the superficial and tufaceous limestones and the silt of the sandstone plain. The revised list for the Nivajè shale is as follows:

Revised list of species reported by Duncan from the Nivajè shale.

Placotrochus lonsdalei Duncan.
Paracyathus henekeni (Duncan).
Placocyathus variabilis Duncan.

Placocyathus costatus Duncan.
new species.
Pocillopora crassoramosa Duncan.
Stylophora affinis Duncan.
minor Duncan.
new species.
Asterosmilia abnormalis (Duncan).
exarata Duncan.
Dichocoenia tuberosa Duncan.
Antillia dubia (Duncan).
bilobata Duncan.
Orbicella limbata (Duncan).
brevis (Duncan).
cavernosa (Linnaeus).
Thysanus corbicula Duncan.
grandis Duncan.
navicula Duncan.
Maeandra areolata (Linnaeus).
Syzygophyllia gregorii (Vaughan).
dentata (Duncan).

A total of 23 species.

The species from the superficial and tufaceous limestones and the silt of the sandstone plain are as follows:

Revised list of species reported by Duncan from the superficial and tufaceous limestones and the silt of the sandstone plain.

**Placocyathus variabilis* Duncan.
Stephanocoenia intersepta (Esper).
**Dichocoenia tuberosa* Duncan.
Orbicella limbata (Duncan).
**Orbicella cavernosa* (Linnaeus).
Solenastrea bournoni M. Edwards and Haime.
Mussa affinis (Duncan).
Siderastrea siderea (Ellis and Solander).

A total of 8 species, of which 3, those preceded by an asterisk *, are also reported from the Nivajè shale; 6 of these species are either at present living in the West Indies or the fossil specimens are so similar to those of living species that specific discrimination is uncertain (see table on pp. 213, 214 for notes). One species, *Orbicella limbata*, is very similar to one of the growth forms of *Orbicella annularis*. This leaves only one species, *Placocyathus variabilis*, that seems clearly to indicate an older Tertiary age. But it should be added that the species of *Stylophora*, to which Duncan attached the name *raristella*, also incicates a rather old Tertiary formation. Might these two species have been mixed with specimens from a younger formation? Having in mind the information above stated, I published the suggestion that some of the Santo Domingan fossil corals are perhaps of Pliocene age.[1]

Recently Miss Carlotta J. Maury has submitted to me for study the fossil corals she collected during an expedition to Santo Domingo. She informs me that the zones on Rio Gurabo are lettered in stratigraphically descending series, "A" being at the top and "G" at the base of the section; zone H on Rio Cana is considered to be the same as zone G on Rio Gurabo. Bluff 1 on Cercado de Mao is correlated by Miss Maury with a part of the Rio Gurabo section above zone G, and bluff 3 on Cercado de Mao is correlated with that part of the Rio Gurabo section below zone F.

As regards the corals, the definite stratigraphic tie-point is found in zone H on Rio Cana, where three species which also occur in the Bowden marl of Jamaica were collected. It has been stated on pp. 212, 213 of this paper that the Bowden coral fauna is stratigraphically above the Oligocene faunas of Antigua, Bainbridge (Georgia), Lares (Porto Rico), Empire (Panama), and Tampa (Florida). These Santo Domingan corals, except those from zone G–H, therefore belong stratigraphically above the horizon of the Bowden marl. In a manuscript now almost ready for press I am describing as new six additional species of *Placocyathus* from Miss Maury's collection. These are not entered in the table following.

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[1] Washington Acad. Sci. Jour., vol. 5, p. 489, 1915.

Table of species of Santo Domingan corals and their zonal distribution.

	Rio Gurabo—Zones.							Rio Cana Zone.	Cercado de Mao—Bluff.		Samba Hills 540+ ft.	The Morro.	Los Quemados limestone.	Notes.
	A and B	B	C	D	E	F	G	H	1	3				
Placocyathus new species					?									
barretti Duncan											+			
variabilis Duncan						+	+				+		+	
costatus Duncan			+											
Stylophora granulata Duncan								+						
new species					?									
affinis Duncan				+										
Madracis decactis (Lyman)	+			+	+									
Asterosmilia abnormalis (Duncan)									+					
Pocillopora crassoramosa Duncan				+										Rio Gurabo, zone not stated.
Stephanocoenia intersepta (Esper)				+	+								+	
Dichocoenia tuberosa Duncan						+								
Antillia dubia (Duncan)						+			+	+				
bilobata Duncan								+						
Orbicella limbata (Duncan)				+				+						Do.
bainbridgensis Vaughan?								+						
cavernosa var. *cylindrica* (Duncan)				+										
Solenastrea bournoni (M. Edwards and Haime)								+						
Thysanus grandis Duncan														Do.
Syzygophyllia dentata (Duncan)				+	+						+	+		Do.
gregorii (Vaughan)								+						
Agaricia dominicensis Vaughan							+							
Pavona new species					+									
new species	+	+												
Siderastrea siderea (Ellis and Solander)								+						
Porites new species		+												
new species										+				

An inspection of the foregoing table shows that at zone H *Orbicella cavernosa* and *Solenastrea bournoni,* both now living, were collected, bringing the total of living species from the Bowden horizon up to four.

The following are my conclusions on the geologic age of the coralliferous beds of Santo Domingo:

1. The oldest fauna represented by Miss Maury's collection, zone H on Rio Cana, is that of the Bowden marl. It is somewhat younger than the Chipola marl of Florida and is of Burdigalian age according to European nomenclature.
2. Zone F is closely related to G and H. It is also probably of Burdigalian age, and corresponds to a part of the Alum Bluff formation of Florida lying above the Chipola marl member.
3. Zone E and D are faunally near the underlying beds and are probably of uppermost Burdigalian or Helvetian age.
4. Zones C to A, inclusive, are probably of Helvetian age.
5. The Santo Domingan coral faunas are younger than the extensively developed Oligocene coral reefs of Georgia, Florida, Cuba, Porto Rico, Anguilla, Antigua, and Central America.
6. The presence in Santo Domingo of *Asterosmilia exarata* variety, which is also found in the Antigua formation, of a species of *Leptomussa,* and of *Siderastrea conferta* (Duncan) typical, indicates that there are deposits of middle and upper Oligocene age in Santo Domingo, but Miss Maury did not make collections of corals from those horizons.

CUBA.

BARACAO AND MATANZAS.

Fossil corals of Bowden age were collected at two localities—namely, station 3476, in a yellow marl at Baracao; and station 3461, also in a yellow marl in the gorge of Yumuri River, Matanzas. The species are as follows:

Fossil corals from Baracoa and Matanzas, Cuba.

Name.	Baracoa.	Matanzas	Bowden.
Stylophora granulata Duncan	×	×	×
Pocillopora baracoäensis Vaughan	×	....	....
Madracis mirabilis (Duchassaing and Michelotti)	....	×	....
Thysanus haycsi Vaughan	....	×	....
Porites baracoäensis Vaughan	×	....	×
var. *matanzasensis* Vaughan	....	×	....

LA CRUZ MARL.

This name is proposed for the bedded, yellow, argillaceous, and calcareous marl particularly well exposed on the east side of Santiago Harbor between Santiago and the Morro. The type exposures are along the railroad eastward from the La Cruz to the crossing of the highway from Santiago to the Morro. The corals collected in this formation are listed below. Descriptions of the mollusca by C. W. Cooke will appear in a forthcoming publication of the Carnegie Institution of Washington. The corals are as follows:

Fossil corals from the La Cruz marl, Cuba.

Name.	Santo Domingo above zone H.	Santo Domingo zone H	Bowden.	Recent.
Stylophora affinis Duncan	×			
Pocillopora species				
Stephanocoenia intersepta (Esper)	×		×	×
Orbicella limbata (Duncan)	×	×		
Solenastrea hyades (Dana)				
bournoni M. Edwards and Haime		×		×
Thysanus aff. *T. excentricus* Duncan			×	
Siderastrea siderea (Ellis and Solander)		×	×	×
Goniopora jacobiana Vaughan				
Porites porites (Pallas)				×
astreoides (Lamuck)				×

Of 11 species listed above, 5 are now living in the Antillean region; but of the 8 genera represented, 4, *i. e.* 50 per cent, are now unknown in the Atlantic Ocean. The horizon appears to be above that of the Bowden marl, and to be near zones D and E of the table on page 217. I obtained numbers of poor prints and casts of corals near or at the base of the formation in the vicinity of Santiago. Although they are too poor for determination, they resemble in form the species of *Placocyathus*, *Asterosmilia*, *Antillia*, *Thysanus*, and *Syzygophyllia*, of the Santo Domingan deposits. Similar poor casts and imprints suggest that this is a widely distributed formation in Cuba.

FLORIDA.

ALUM BLUFF FORMATION.

The coral fauna of the Chipola marl, member of Alum Bluff formation is small, comprising four species representing as many genera, namely, *Stylophora*, *Antillia*, a new genus that resembles a *Thysanus* with a commensal sipunculid worm in its base, and *Goniopora*.

The coral fauna of the Alum Bluff formation is meager. Excluding the Chipola marl member it comprises the following species:

Fossil corals from the Alum Bluff formation.

Name.	Oak Grove.	White Springs.[1]	Tampa brick-yard.
Astrhelia new species	×		
Siderastrea hillsboroensis Vaughan		×	×
silecensis Vaughan			×
Goniopora jacobiana Vaughan		×	

[1] For description of the stratigraphic relations of beds at White Springs see Vaughan, T. W., and Cooke, C. W., Correlation of the Hawthorne formation, Washington Acad. Sci. Journ., vol. 4, pp. 250-253, 1914.

Although, in my opinion, the formation in which these corals occur should be referred to the Miocene, I believe it is very low Miocene, below the Bowden horizon. A recent discovery by Sellards is of importance in determining the age of the Alum Bluff formation.[1] The following is a list of the vertebrates:

Parahippus leonensis Sellards.
Merychippus species.
Mesocyon? leonensis Sellards.
Oxydactylus?
Leptomeryx?

Sellards says:

> It would seem, therefore, as a whole, that the vertebrate fossils indicate that the Alum Bluff formation is to be referred to the Miocene. The presence of protohippine horses in particular would seem to be decisive as to the age of the formation, excluding its reference to the Oligocene.

The opinion of Prof. J. C. Merriam on the age indicated by the *Merychippus* is quoted. He says that he would judge the horizon to near the lower portion of the middle Miocene. Later Professor Merriam informed me that he considers the *Merychippus* as of lower Miocene (Burdigalian) age.

The evidence in favor of considering the Alum Bluff as of lower Miocene age might be greatly multiplied. The presence at Oak Grove, Yellow River, Florida, of a species of *Astrhelia* closely related to *A. palmata* (Goldfuss) of the Maryland Choptank and Calvert formations suggests Miocene. *Pecten sayanus* Dall indicates Miocene. Canu and Bassler are positive that the Bryozoa are of Miocene age. Berry's opinion based on his study of the fossil flora [2] is not incompatible with this interpretation.

MIDDLE AND SOUTH ATLANTIC STATES.

The following is a list of the Miocene species, as far as at present known:[3]

Miocene corals from the Middle and South Atlantic States.

Name.	Geologic formation.					
	Calvert.	Choptank.	St. Marys.	Yorktown.	Duplin.	Choctawhatchee.
Paracyathus vaughani Gane			×	×	×	
Astrhelia palmata (Goldfuss)	×	×				
Astrangia lineata (Conrad)			×	×		
conradi Vaughan			×			
Septastrea marylandica (Conrad)			×	×		×
crassa (Tuomey and Holmes)					×	
Favites vaughani (Gregory)						

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[1] Sellards, E. H., Fossil vertebrates from Florida, A new Miocene fauna, Florida Geol. Surv., 8th Ann. Rept., pp. 83-92, 1916.

[2] Berry, E. W., The physical conditions and age indicated by the flora of the Alum Bluff formation, U. S. Geol. Survey Prof. Pap. 98-E, pp. 41-59, pls. 7-10, 1916.

[3] Vaughan, T. W., Anthozoa: Maryland Geol. Survey Miocene, pp. 438-448, pls. 122-129, 1904; The reef coral fauna of Carrizo Creek, Imperial County, California, and its significance, U. S. Geol. Survey Prof. Pap. 98-T., p. 366, 1917.

Berry has recently reviewed the Miocene Calvert flora of Maryland and Virginia, and expressed the following opinion:[1]

> Seven of the Calvert plants, or 26.9 per cent, are common to the Tortonian of Europe, and 10 others, or 38 per cent, are represented in the Tortonian by very similar forms. In view of the fact that these floras spread into both regions from a common and equally accessible source, as I have just stated, the evidence that the Calvert flora indicates a Tortonian age is as conclusive as intercontinental correlations can ever be. Compared with other American floras of Miocene age, that of the Calvert has little in common with the described Miocene floras from Colorado, Idaho, Oregon, or California, which are all lake or river valley floras of moist upland forest types.

Should Berry be correct in his correlation of the Calvert with the European Tortonian, there is at present no definitely recognized Helvetian Miocene in the Coastal Plain of the United States; and consequently no Helvetian coral-fauna.

COSTA RICA.

Corals representing the Bowden horizon or one very near it were obtained in Costa Rica at two localities, viz:

"Limon, Colline en démolition," No. 618 of the H. Pittier collection; and at station 6249, Hospital Point, Bocas del Toro. The species from the former of these localities are as follows:

Asterosmilia hilli Vaughan.
Stephanocoenia intersepta (Esper).
Dichocoenia tuberosa Duncan.
Balanophyllia pittieri Vaughan.

Balanophyllia pittieri was obtained at Hospital Point as well as at Port Limon.

PANAMA.

The type of *Stylophora portobellensis* Vaughan, from Portobello, was probably collected in the Gatun formation.

COLOMBIA.

Mr. George C. Matson collected at a locality 0.5 kilometer east of Usiacuri in association with a fauna representing the Gatun formation specimens of *Septastrea matsoni* Vaughan, which is very nearly related to *Septastrea marylandica* (Conrad)—a species common in the St. Marys and Yorktown Miocene of Virginia. The available evidence leads to the opinion that the Gatun formation is of Miocene age, and that part of it is of upper Miocene age.

CONCLUDING REMARKS ON THE MIOCENE.

The Gatun formation, the formation next above the Emperador limestone, according to the geologic map, plate 153, occurs only on the north flank of the Isthmus and does not extend from ocean to ocean. There is in the Canal Zone no evidence to indicate inter-

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[1] U. S. Geol. Survey Prof. Pap. 98-F., p. 66, 1916.

oceanic connection during Miocene time, although there was such connection in other areas not far away, in Nicaragua for instance. During the Miocene there was a very weak development of reef-corals in Central America, the Antilles, and the southeastern United States, as the foregoing lists show. The Miocene is characterized by the disappearance of many genera of corals that were abundant in the middle and upper Oligocene and by the introduction of the modern coral-fauna. However, a number of genera at present known living only in the Indo-Pacific persisted. These genera are as follows:

Placotrochus.
Placocyathus.
Stylophora.
Pocillopora.
Antillia.
Favites.
Syzygophyllia.
Pavona.
Goniopora.

Of the Miocene genera, *Asirhelia, Septastrea,* and *Thysanus* are not known living.

Pliocene.

CALOOSAHATCHEE MARL, FLORIDA.

The following species of corals have been recognized in the Caloosahatchee marl:

*_Archohelia limonensis_ Vaughan.
Dichocoenia new species 1.
new species 2.
Meandrina maeandrites (Linnaeus).
Cladocora johnsoni Gane.
Phyllangia floridana Gane.
*_Solenastrea hyades_ (Dana).
*_bournoni_ M. Edwards and Haime.
Septastrea crassa (Tuomey and Holmes).
Thysanus species.
Maeandra pliocenica (Gane).
aff. *M. strigosa* (Dana).
aff. *M. clivosa* (Ellis and Solander).
*_Siderastrea pliocenica_ Vaughan.
*_dalli_ Vaughan.
*_Porites porites_ (Pallas).
*_furcata_ Lamarck.
divaricata Le Sueur.

Those species whose names are preceded by an asterisk are considered in the descriptive part of this paper.

The foregoing list is complete for the Caloosahatchee corals from Caloosahatchee River and Shell Creek, Florida, except one species of whose genus I am not sure. There are in the United States National Museum 19 species from the Caloosahatchee marl. Of these 19 species, 6 and perhaps 8 are also living in the Floridian region, while the other species, except those belonging to *Septastrea* and *Thysanus,* have close relatives in the present Floridian fauna. I have previously pointed out[1] that this fauna contains no genera at present confined to the Indo-Pacific, such as *Placotrochus, Placocyathus, Stylophora, Pocillopora, Antillia, Syzygophyllia,* and *Goniopora,* all of which occur in the West Indian Miocene, and all except the first two also occur in the West Indian Oligocene or Eocene.

LIMON, COSTA RICA.

Certain corals collected in the vicinity of Limon are reputed to come from a bed of Pliocene age. They are as follows:

Madracis mirabilis (Duchassaing and Michelotti).
Archohelia limonensis Vaughan.
Orbicella annularis (Ellis and Solander) var.
cavernosa var. *endothecata* (Duncan).
var. *cylindrica* (Duncan).

Except *Archohelia limonensis,* it appears that these corals might represent the Santo Domingan Miocene above the Bowden horizon. The material is not adequate for a positive opinion.

CARRIZO CREEK, CALIFORNIA.

Recently I have described in detail an interesting small reef-coral fauna from Carrizo Creek, Imperial County, California.[2]

The following table, taken from the paper mentioned, contains the names of the species composing this fauna and of the most nearly related species in Florida and the West Indies.

Corals from Carrizo Creek, Cal.

Name.	Most nearly related species in Florida or West Indies.
Eusmilia carrizensis Vaughan	*Eusmilia fastigiata* (Pallas), Pl, R.
Dichocoenia merriami (Vaughan)	*Dichocoenia* species, P; *D. stokesi* Milne Edwards and Haime, Pl, R.
var. *crassisepta* Vaughan	
Solenastrea fairbanksi (Vaughan), typical	
var. *columnaris* (Vaughan)	*Solenastrea hyades* (Dana) and *S. bournoni* Milne Edwards and Haime, P, Pl, R.
var. *normalis* Vaughan	
var. *minor* Vaughan	
Maeandra bowersi Vaughan	*Maeandra labyrinthiformis* (Linnaeus), Pl, R.
Siderastrea mendenhalli Vaughan	*Siderastrea dalli* Vaughan, P.
var. *minor* Vaughan	
Siderastrea californica Vaughan	*Siderastrea pliocenica* Vaughan, P.
Porites carrizensis Vaughan	*Porites astreoides* Lamarck, Pl, R.

P, Pliocene; Pl, Pleistocene; R, Recent.

Regarding the geologic age of this fauna, it was said:

> The specific affinities of the Carrizo Creek corals are discussed in detail after the descriptions in the systematic part of this paper. The Carrizo Creek species are so near species belonging to the same genera in the Pliocene Caloosahatchee marl of Florida and in the Pleistocene and living reefs of Florida and West Indies that it seems to me they can scarcely be so old as Miocene; lower Pliocene appears to be the maximum age which may be assigned to the fauna.

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[1] The reef-coral fauna of Carrizo Creek, Imperial County, California, Prof. Pap. 98-T. p. 366, 1917.

[2] U. S. Geol. Survey Prof. Pap. 98-T, pp. 355-386, pls. 92-102, 1917.

The following is said as to the bearing of this fauna on a possible post-Oligocene interoceanic connection:

> That there was interoceanic connection across parts of Central America during upper Oligocene time and that this connection was terminated in Miocene time is generally admitted. The extinction of Pacific faunal elements in the Gulf of Mexico, the Caribbean Sea, and the Western Atlantic Ocean has been discussed and summarized on page 366. Was there interoceanic connection during upper Miocene or Pliocene time after the sharp differentiation of the Caribbean and Mexican Gulf faunas from the Indo-Pacific faunas, thereby permitting interoceanic faunal migration? The discovery of a reef-coral fauna of purely Floridian and Caribbean facies at the head of the Gulf of California strongly suggests, if it is not positive proof, that the western Atlantic fauna extended from the Atlantic into the Pacific after the faunal differentiation had taken place. It is well known that the living reef-coral fauna on the Pacific side of Central America is depauperate in comparison with that on the Atlantic side. Greater vigor may account for the dominance of the migrant fauna over the Pacific fauna, which was finally suppressed, or geologic or other ecologic conditions that are not yet understood may have excluded the Pacific fauna from the head of the Gulf of California, while they permitted the migration of the Atlantic fauna into that area.
>
> That the suggested interoceanic connection existed can scarcely be doubted. To locate it, in the present state of meager knowledge of the areal and stratigraphic geology of Central America, is not possible. Perhaps it was across the Isthmus of Tehuantepec. The problem awaits future investigation.

This fauna differs from the Miocene fauna of the La Cruz marl of Cuba in the absence of genera at present living in the Indo-Pacific, for instance, *Stylophora*, *Pocillopora*, and *Goniopora*. As none of the Indo-Pacific genera occurs in the Carrizo Creek fauna, and as only genera of Atlantic affinities have been found there, it seems necessary to infer that the fauna migrated from the Atlantic to the head of the Gulf of California after the Indo-Pacific genera had become extinct in the Atlantic. This would mean connection between the Atlantic and the Gulf of California in very late Miocene or Pliocene time.

Attention should here be called to a statement for which I am responsible. It is said in the report referred to below [1] that some fossils obtained by Mr. William Palmer in a quarry in Calle Infanta, Habana, may be of Pliocene age, although it is probable that they are Pleistocene and that other limestone near Habana is perhaps of Pliocene age. The material obtained by Mr. Palmer is very poor, but some specimens are casts of the inside of the calice and the interseptal loculi of a large bilobate species of *Antillia*. The species more probably is *A. walli* Duncan of the Bowden marl, but it might be *A. bilobata* Duncan; another cast seems to represent a species of *Thysanus*; while another is a species of *Syzygophyllia*, probably *S. dentata* (Duncan). One specimen of *Stephanocoenia intersepta* (Ellis and Solander) is identifiable. The material seems quite clearly to represent either the Bowden or a somewhat higher horizon

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[1] Hayes, C. W., Vaughan, T. W., and Spencer, A. C., A geological reconnaissance of Cuba, p. 23, 1902.

in the Miocene. It is not Pliocene, according to our present knowledge of Pliocene coral faunas.

PLEISTOCENE.

Only the names of the Pleistocene species considered in this paper are given in the following lists:

Pleistocene corals from Mount Hope and Colon, Canal Zone.

Oculina diffusa Lamarck.
varicosa Le Sueur.
Eusmilia fastigiata (Pallas).
Astrangia (Phyllangia) americana M. Edwards and Haime.[1]
Cladocora arbuscula Le Sueur.
Solenastrea bournoni Milne Edwards and Haime.
Favia fragum (Esper).
Maeandra areolata (Linnaeus).
Manicina gyrosa (Ellis and Solander).
Agaricia agaricites (Linnaeus).
var. *purpurea* Le Sueur.
pusilla Verrill.
Siderastrea radians (Pallas).
siderea (Ellis and Solander).
Acropora muricata (Linnaeus)[1]
palmata (Lamarck) at Colon.
Porites furcata Lamarck.
astreoides Lamarck.
Millepora alcicornis Linnaeus.

It will be remarked in passing that the coral fauna at Mount Hope is a typical inner-flat coral fauna.

Pleistocene specimens were obtained at Monkey Point and Limon, Costa Rica. The list is as follows:

Pleistocene corals from Monkey Point and Limon, Costa Rica.

Name.	Monkey Point.	Limon Moin Hill
Eusmilia fastigiata (Pallas)	×	
Maeandra clivosa (Ellis and Solander)	×	
strigosa (Dana)	×	
Manicina gyrosa (Ellis and Solander)		×
Agaricia agaricites var. *crassa* Verrill		×
Siderastrea siderea (Ellis and Solander)	×	
Acropora muricata (Linnaeus)	×	
palmata Lamarck	×	
Porites furcata Lamarck		×

The corals from Monkey Point represent a seaward-facing reef; while those from Moin Hill are more characteristic of inner-flat conditions.

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[1] Names added in the proof and not entered in the table of species, pp. 228-237., or the systematic account of the faunas.

Summary of the stratigraphic and geographic distribution of the Tertiary and Pleistocene coral-faunas of Central America and the West Indies.

1. The upper Eocene coral-fauna of the St. Bartholomew limestone is known in St. Bartholomew, in Jamaica, and on the Pacific side of Nicaragua.

2. No lower Oligocene coral-fauna is at present known in the West Indies or Central America.

3. Rich middle Oligocene coral-faunas are known in Antigua, Porto Rico, Cuba, Georgia (near Bainbridge), Alabama (Salt Mountain), eastern Mexico, Panama, and the Island of Arube. The same fauna is known to be present in Santo Domingo.

4. Upper Oligocene coral-faunas are present in Anguilla, the Canal Zone, Florida (Tampa formation), and there are some reef-corals representing the same fauna in Cuba. There seems to be a distinct break between this and the succeeding Miocene faunas.

5. The Bowden, Jamaica, lower Miocene fauna is represented in Santo Domingo, Cuba, and Costa Rica. This fauna is probably younger than the coral-fauna of the Alum Bluff formation in Florida.

6. A closely related but higher Miocene fauna is present in Santo Domingo and Cuba. It seems probable that this fauna is geologically older than the coral fauna of the Maryland and Virginia Miocene.

7. The presence at Usiacuri, Colombia, of a species of *Septastrea*, very closely related to *S. marylandica* of the St. Marys and Yorktown Miocene of Virginia, suggests the presence in northern South America of a middle or an upper Miocene coral fauna.

8. There is a moderately rich Pliocene fauna in the Caloosahatchee marl of Florida, and this fauna appears to be represented at Limon, Costa Rica.

9. Pleistocene reefs are extensively developed in Central America, the West Indies, and Florida.

10. Living reefs exist in the same areas in which there are Pleistocene reefs.

11. The periods of reef-coral development are as follows:

(*a*) Upper Eocene St. Bartholomew limestone, weak development.

(*b*) Middle Oligocene, the greatest known development of American coral-reefs.

(*c*) Upper Oligocene, considerable development of reefs.

(*d*) Miocene, weak development of reefs.

(*e*) Pliocene, weak development of reef-corals in Florida.

(*f*) Pleistocene, extensive development of reefs.

(*g*) Recent, extensive development of reefs.

12. Periods of connection between the Atlantic and Pacific oceans are as follows:

(*a*) Upper Eocene.

(*b*) Middle and upper Oligocene and lower Miocene.

(*c*) A connection, probably narrow, in very late Miocene or in Pliocene time.

TABLE OF STRATIGRAPHIC AND

Name of species.	Eocene—Brito formation, Nicaragua.	Oligocene.		
		Horizon of Antigua formation.	Culebra formation, Canal Zone.	Horizon of Anguilla formation.
Stylophora imperatoris Vaughan			Gaillard Cut; 1½ mi. S. Monte Lirio.	Anguilla
panamensis Vaughan				
affinis Duncan				
portobellensis Vaughan				
goethalsi Vaughan			1½ mi. S. of Monte Lirio.	
macdonaldi Vaughan				
granulata Duncan				
canalis Vaughan				
ponderosa Vaughan		Alabama; Antigua.		
Pocillopora arnoldi Vaughan				
baracoaensis Vaughan				
guantanamensis Vaughan		Near Guantanamo, Cuba.		
Madracis mirabilis (Duchassaing and Michelotti).				
Astrocoenia d'achiardii Duncan	Also St. Bartholomew.			
guantanamensis Vaughan		Antigua; near Guantanamo, Cuba; Tonosi, Panama.		
incrustans (Duncan)				
decaturensis Vaughan		Bainbridge, Ga.; Antigua; near Guantanamo, Cuba.		
meinzeri Vaughan		Near Guantanamo, Cuba.		
portoricensis Vaughan		Antigua; Lares P. R.		
Stylocoenia pumpellyi (Vaughan)		Bainbridge, Ga.; Antigua.		
Oculina diffusa Lamarck				
varicosa Le Sueur				
Archohelia limonensis Vaughan				
Asterosmilia hilli Vaughan				
Stephanocoenia intersepta (Esper)				
Dichocoenia tuberosa Duncan				
Eusmilia fastigiata (Pallas)				
Cladocora arbuscula (Le Sueur)				
Orbicella annularis (Ellis and Solander).				
limbata (Duncan)				

Geographic Distribution of Species.

Oligocene—Continued. Emperador limestone, Canal Zone.	Miocene—Horizon of Bowden marl, etc.	Pliocene.	Pleistocene.	Recent.	Remarks.
Empire: Rio Agua Salud.	...	...	...	...	
Empire ...	...	...	...	...	
...	Santo Domingo; Santiago, Cuba.	...	...	...	
...	(?)	...	...	...	Porto Bello; probably Gatun formation.
Empire ...	...	...	...	...	
Empire; Rio Agua Salud.	...	...	...	...	
...	Matanzas and Baracoa, Cuba; Rio Gurabo, St. Domingo, etc.	...		...	
Empire ...	...	...	...	...	
...	...	...	...	...	
Empire ...	...	...	...	...	
...	Baracoa, Cuba	...	...	...	
...	...	...	...	...	
...	Matanzas, Cuba.	Colon, Costa Rica.	...	Caribbean region.	
...		...	...	...	
...	...	...	...	...	
...	...	...	...	...	Upper Eocene of St. Bartholomew.
...	...	...	...	...	
...	...	...	...	...	
Rio Agua Salud.	...	...	...	...	
...	...	...	...	...	
...	...	...	Mt. Hope, C. Z.	Florida; West Indies, etc.	
...	...	...	Mt. Hope, C. Z.	...do...	
...	...	Limon, C. R.; Caloosahatchee marl, Florida.	...	...	
...	Limon, C. R.; Bowden, Jamaica.	...	...	...	
...	Bowden, Jamaica; Limon, C. R.; Santo Domingo; Santiago, Cuba.	...	West Indian region.	West Indies, Bermuda, etc.	
...	Limon, C. R.; Santo Domingo.	...	...	...	Very near the Pleistocene and living *D. stokesi* M. Edwards and Haime of the West Indies, Florida, etc.
...	...	...	Mt. Hope, C. Z.; Monkey Pt., C. R.; W. I.	West Indies; Florida, etc.	
...	...	...	Mt. Hope, C. Z.	...do...	
...	...	Limon, C. R. ...	W. I.; Fla.; etc.	...do...	
...	Santo Domingo, Cuba.	...	...	...	

TABLE OF STRATIGRAPHIC AND GEOGRAPHIC

Name of species.	Eocene—Brito formation, Nicaragua.	Oligocene.		
		Horizon of Antigua formation.	Culebra formation, Canal Zone.	Horizon of Anguilla formation.
Orbicella imperatoris Vaughan				Anguilla, Cuba.
antillarum (Duncan)				
altissima (Duncan)				
cavernosa (Linnaeus)				
var. *endothecata* (Duncan)				
var. *cylindrica* (Duncan)				
aperta (Verrill)				
bainbridgensis Vaughan		Bainbridge, Ga.		
costata (Duncan)		Antigua; Lares, P. R.	Las Cascadas	Anguilla
canalis Vaughan				Anguilla
tampäensis Vaughan				
var. *silecensis* Vaughan				
brevis (Duncan)				
insignis (Duncan)		Antigua; Arube.		
intermedia (Duncan)		Antigua		
gabbi Vaughan				
irradians (M. Edwards and Haime).				
Solenastrea hyades (Dana)				
bournoni M. Edwards and Haime.				
Septastrea matsoni Vaughan				
Antiguastrea cellulosa (Duncan)		Antigua; P. R.; Cuba; Ga.; eastern Mex.; Arube.		Anguilla; Tampa, Florida.
var. *curvata* (Duncan)		Antigua		
var. *silecensis* Vaughan.		Bainbridge, Ga.; Antigua.		
elegans (Reuss)				
alveolaris (Catullo)				
Stylangia panamensis Vaughan				
Favia fragum (Esper)				
macdonaldi Vaughan		Tonosi, Panama; Antigua.		
Favites mexicana Vaughan		Eastern Mexico.		
polygonalis (Duncan)		Antigua; Bainbridge, Ga.		
Goniastrea canalis Vaughan				
Maeandra antiguensis Vaughan		Antigua; Tonosi, Panama.		
portoricensis Vaughan		Lares, Porto Rico.		
dumblei Vaughan		Eastern Mex		
areolata (Linnaeus)				

Distribution of Species—Continued.

Oligocene—Continued.	Miocene—Horizon of Bowden marl, etc.	Pliocene.	Pleistocene.	Recent.	Remarks.
Emperador limestone, Canal Zone.					
Empire and near Miraflores.	...	...	...	...	
...	...	...	...	...	Montserrat, geologic horizon unknown.
...	...	...	...	...	St. Croix, Trinidad; probably about the horizon of the Antigua formation.
...	...	...	West Indies; Florida.	West Indies; Florida; Brazil.	
...	Santo Domingo.	Limon, C. R.	...	...	
...	do	do	...	...	
...	...	...	...	Brazil.	
...	? Santo Domingo.	...	...	...	
...	...	...	...	...	
Empire	...	...	...	...	
...	...	...	...	...	Tampa, Fla.; about the horizon of the Anguilla formation.
...	...	...	...	...	Do.
...	...	...	...	...	Santo Domingo, Nivajè shale. Horizon unknown.
...	...	...	...	...	
...	...	...	...	...	
...	...	...	...	...	Santo Domingo; horizon unknown.
...	...	...	...	...	Lutetian (Eocene); Rupelian (Oligocene) of Veneto, Italy.
...	Santiago and Ciénaga, Cuba.	Caloohatchee marl, Fla.	West Indies; Florida.	West Indies; Florida.	
...	Santiago, Cuba; Santo Domingo.	do	...	do	
...	Usiacuri, Colombia.	...	...	...	Formation in part the same as the Gatun formation, C. Z.
...	...	...	...	...	Byram marl, Miss.
...	...	...	...	...	
...	...	...	...	...	
...	...	...	...	...	Rupelian (Oligocene), Venetio, Italy.
...	...	...	...	...	Rupelian (Oligocene), Venetio, Italy.
Empire, C. Z.	...	...	...	...	
...	...	...	Mt.Hope,C.Z.; W.I.; Fla.	W. I.; Fla.; Bermudas; Azores; St. Vincent.	
...	...	...	...	...	
...	...	...	...	...	
...	...	...	...	...	
Empire, C. Z.	...	...	...	...	
...	...	...	...	...	
...	...	...	...	...	
...	...	...	...	...	
...	...	...	Mt.Hope,C.Z.; W. I.; Fla., etc.	W. I.; Fla.; etc.	

TABLE OF STRATIGRAPHIC AND GEOGRAPHIC

Name of species.	Eocene—Brito formation, Nicaragua.	Oligocene.		
		Horizon of Antigua formation.	Culebra formation, Canal Zone.	Horizon of Anguilla formation.
Maeandra clivosa (Ellis and Solander)				
strigosa (Dana)				
Leptoria spenceri Vaughan		Rio Canapu, Cuba; Antigua?.		
Manicina gyrosa (Ellis and Solander)				
willoughbiensis Vaughan		Antigua		
Thysanus excentricus Duncan				
hayesi Vaughan				
Syzygophyllia hayesi Vaughan	Brito			
Trochoseris meinzeri Vaughan		Guantanamo; Tonosi, Panama.		
Agaricia agaricites (Linnaeus)				
var. *purpurea* Le Sueur				
var. *crassa* Verrill				
var. *pusilla* Verrill				
anguillensis Vaughan				Anguilla
dominicensis Vaughan				
Pavona panamensis Vaughan				
Leptoseris portoricensis Vaughan		Lares, P. R.		
Pironastraea anguillensis Vaughan		Lares road, Zone C, P. R.		Anguilla
antiguensis Vaughan		Antigua; Guantanamo, Cuba.		
Siderastrea pariana (Duncan)				
radians (Pallas)				
stellata Verrill				
confusa (Duncan)				
pourtalesi Vaughan				
pliocenica Vaughan				
hillsboroensis Vaughan				
siderea (Ellis and Solander)				
var. *dominicensis* Vaughan				
silecensis Vaughan				Anguilla
dalli Vaughan				

Distribution of Species—Continued.

Oligocene—Continued.	Miocene—Horizon of Bowden marl, etc.	Pliocene.	Pleistocene.	Recent.	Remarks.
Emperador limestone, Canal Zone.					
			Monkey Pt., C. R.; W. I.; Fla.	do	
			do	do	
			Mt.Hope, C.Z.; Moin Hill, C. R.; W. I.; etc.	Fla.; W.I.; etc.	
	Santiago, Cuba; Bowden, Jamaica.				
	Matanzas, Cuba.				
			Mt.Hope, C.Z.; W. I.; Fla.; etc.	W. I.; Fla.; etc.	
			Mt.Hope, C.Z.	do	
			Moin Hill, C. R.	Especially abundant east side of Andros Is., Bahamas.	
			Mt.Hope, C.Z.	Colon, C. Z.	
	Santo Domingo; Matanzas, Cuba.				
Empire					
					St. Croix, Trinidad; probably nearly the same as the Antigua horizon.
			Mt.Hope, C.Z.; W. I.; Fla.; etc.	W. I.; Fla.; Bermudas.	
				Brazilian reefs.	
					Do.
					Santo Domingo; horizon unknown.
		Caloosahatchee marl, Fla.			
					Chattahoochee, Tampa, and Alum Bluff formations, Florida and Georgia.
	Bowden, Jamaica; Santo Domingo; Santiago, Cuba.		Mt.Hope, C.Z.; Monkey Pt., C. R.; W. I.; Fla.	W. I.; Fla.; etc.	
				Haiti	
					Do.
		Caloosahatchee marl, Fla.			

TABLE OF STRATIGRAPHIC AND GEOGRAPHIC

Name of species.	Eocene—Brito formation, Nicaragua.	Oligocene.		
		Horizon of Antigua formation.	Culebra formation, Canal Zone.	Horizon of Anguilla formation.
Siderastrea conferta (Duncan)		Antigua; Lares, P. R.	Las Cascadas	Anguilla
Cyathomorpha rochettina (Michelin)				
hilli Vaughan		Antigua		
browni Vaughan		do.		
belli Vaughan		do.		
splendens Vaughan		do.		
anguillensis Vaughan				Anguilla
roxboroughi Vaughan				do.
antiguensis (Duncan)		Antigua; Lares, P. R.; Guantanamo, Cuba; eastern Mexico.		
tenuis (Duncan)		Antigua; Lares, P. R.; Rio Canapu and Guantanamo.		
Diploastrea heliopora (Lamarck)				
crassolamellata (Duncan)		Antigua; Lares, P. R. (Zone C); Cuba; Bainbridge, Ga.; Tonosi, Panama.		
var. *magnifica* (Duncan)		Antigua Lares, P. R.; Guantanamo, Cuba; Bainbridge, Ga.		
var. *nugenti* (Duncan)		Antigua		
Blanophyllia pittieri Vaughan				
Acropora panamensis Vaughan		Antigua		
saludensis Vaughan		do.		
muricata (Linnieus)				
palmata (Lamarck)				
Astreopora goethalsi Vaughan				
antiguensis Vaughan		Antigua; Bainbridge, Ga.	1½ mi. S. of Monte Lirio.	
portoricensis Vaughan		Lares, P. R.		
Actinacis alabamiensis Vaughan		Ala.; Bainbridge, Ga.; Antigua.		
Goniopora hilli Vaughan				
panamensis Vaughan				Anguilla
decaturensis Vaughan		Bainbridge, Ga.; Guantanamo, Cuba.		
regularis (Duncan)		Antigua; P. R.; Arube.		
var. *microscopica* (Duncan)		Antigua		
jacobiana Vaughan				
imperatoris Vaughan				Anguilla
canalis Vaughan				do.
portoricensis Vaughan		Lares, P. R.; Antigua.		

Distribution of Species—Continued.

Oligocene—Continued.	Miocene—Horizon of Bowden marl, etc.	Pliocene.	Pleistocene.	Recent.	Remarks.
Emperador limestone, Canal Zone.					
....	....	....	....	....	
....	....	....	....	....	Lattorfian and Rupelian (Oligocene) of Veneto, Italy.
....	....	....	....	....	
....	....	....	....	....	
....	....	....	....	....	
....	....	....	....	....	
....	....	....	....	....	
....	....	....	....	....	
....	....	....	....	....	
....	....	....	....	....	
....	....	....	....	East coast of Africa to Fiji Islands.	
....	....	....	....	....	
....	....	....	....	....	
....	....	....	....	....	
....	Limon and Hospital Pt., C. R.	....	....	....	
Rio Agua Salud, C. Z.	....	....	....	....	
Rio Agua Saud and Empire, C.Z.	....	....	....	....	
....	....	....	Monkey Pt. and Moin Hill, C. R.; W. I.; Fla.; etc.	W.I.; Fla.;etc.	
....	....	....	Monkey Pt., C. R.; Colon, C. Z.	W.I.; Fla.; etc.	
Empire........	....	....	....	....	
....	....	....	....	....	
....	....	....	....	....	
....	....	....	....	....	
Empire........	....	....	....	....	
.....do........	....	....	....	....	
....	....	....	....	....	
....	....	....	....	....	
....	....	....	....	....	
....	Santiago, Cuba; White Springs, Fla.	....	....	....	
Empire........	....	....	....	....	
.....do........	....	....	....	....	
....	....	....	....	....	

TABLE OF STRATIGRAPHIC AND GEOGRAPHIC

Name of species.	Eocene—Brito formation, Nicaragua.	Oligocene.		
		Horizon of Antigua formation.	Culebra formation, Canal Zone.	Horizon of Anguilla formatian.
Goniopora clevei Vaughan		Antigua		Anguilla
cascadensis Vaughan		do	Las Cascadas	do
Porites porites (Pallas)				
furcata Lamarck				
baracoäensis Vaughan				
var. *matanzasensis* Vaughan				
douvillei Vaughan				
toulai Vaughan				
astreoides Lamarck				
panamensis Vaughan				
anguillensis Vaughan				Anguilla
(*Synaræa*) *howei* Vaughan				
macdonaldi Vaughan				Anguilla
Millepora alcicornis Linnaeus				

Distribution of Species—Continued.

Oligocene—Continued.	Miocene—Horizon of Bowden marl, etc.	Pliocene.	Pleistocene.	Recent.	Remarks.
Emperador limestone, Canal Zone.					
Empire...	...	...	...	...	
...	...	...	...	...	
...	Santiago, Cuba.	...	W. I...	W.I.; Fla.; etc.	
...	...	...	Mt. Hope, C. Z.; Moin Hill, C. R.	...do...	
...	Baracoa, Cuba; Bowden, Jamaica.	...	...	...	
...	Matanzas, Cuba	...	...	...	
Empire...	...	...	...	...	
...do...	...	...	...	...	
...	Santiago, Cuba.	...	Mt. Hope, C. Z.; W. I.; Fla.	W. I.; Fla.; Bermudas; Brazil, etc.	
Empire...	...	...	...	...	
...do...	...	...	...	...	
...do...	...	...	...	...	
...do...	...	...	...	...	
...	...	...	Mt. Hope, C. Z.	W. I.; Fla.; etc.	

CONDITIONS UNDER WHICH THE WEST INDIAN, CENTRAL AMERICAN, AND FLORIDIAN CORAL REEFS HAVE FORMED, AND THEIR BEARING ON THEORIES OF CORAL-REEF FORMATION.

A brief review of the results obtained from a study of American Tertiary and post-Tertiary corals in their relation to the larger problem of coral-reef formation in general will now be given. In a paper recently published[1] I stated that in my opinion coral reefs should be studied from at least the following standpoints:

1. The corals themselves, to ascertain the ecologic conditions under which they live or lived, and to distinguish the calcium carbonate secreted by corals from that contributed through other agencies.
2. A complex of geologic processes operating in the area must be studied, analyzed, and evaluated—among these are the agencies other than corals whereby calcium carbonate may be taken from the sea water, the probability of the solvent action of sea water on calcium carbonate, the effects of winds, currents, and waves in building, shaping, and destroying banks, and in submarine planation.
3. The stratigraphic and structural geology of the area, including a careful study of the origin of the sedimentary rocks with which corals are associated.
4. The physiography, especially that of the shore line, that of the land area adjacent to the shore, and that of the sea bottom from the shore to abyssal depths.

In the subsequent discussion, after defining coral reef, brief attention will be given to the following topics: (1) The general ecology of reef-forming corals; (2) the more striking hypotheses of the formation of coral-reefs; (3) the conditions under which the American Tertiary and Pleistocene reefs have formed and their importance as constructional geologic agents; (4) the conditions under which the living reefs of the same area formed and their importance as constructional agents; (5) coral reefs of the Pacific Ocean and comparison of them with the American fossil and living reefs; (6) summary of conclusions.

It is needless to say that, as an elaborate discussion of the subjects mentioned would require a large volume, it is possible in the present connection to give only summary statements.

Definition of the Term "Coral Reef."

As definitions are essential in this as in other discussions, the expression "coral reef" will be defined as follows:

> A coral reef is a ridge or mound of limestone, the upper surface of which lies, or lay at the time of its formation, near the level of the sea, and is predominantly composed of calcium carbonate secreted by organisms, of which the most important are corals.[2]

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[1] Some shoal-water corals from Murray Island (Australia), Cocos-Keeling Islands, and Fanning Island, Carnegie Inst. Washington Pub. 213, p. 54, 1918.

[2] Vaughan, T. W., Physical conditions under which Paleozoic coral reefs were formed, Bull. Geol. Soc. America, vol. 22, p. 238, 1911.

Frequently it is difficult to decide whether or no to apply the designation "coral reef" to richly coralliferous deposits that are obviously bedded. However, I am applying it wherever corals of reef facies seem sufficiently abundant to have formed appreciable rugosities on the sea bottom, although the deposits are bedded.

Reefs predominatly formed by calcareous algae should be designated "nullipore" or "Lithothamnium reefs." However, where the proportion of these organisms to corals is so nearly the same that only exact computation will decide between the two, such a reef may be designated "coral." The expression "reef coral" will be applied to corals of the facies usual in reefs; and "coralliferous limestone" or "coralliferous beds" will be applied where corals are present, although they may be rare. Rock predominantly composed of the shells of mollusks, of the tests of foraminifera and Bryozoa, and of chemically precipitated calcium carbonate are excluded from the category "coral reefs."

The restricted use of the term "coral reef" in this paper will probably be disapproved by a considerable number of investigators, but in my opinion it is essential to clear thinking. Limestones are initially formed by one of two processes, namely, (1) through chemical precipitation either by inorganic or organic agencies that lead to supersaturation of water with reference to calcium carbonate ($CaCO_3$), (2) through the activity of organisms that cause the precipitation of calcium carbonate ($CaCO_3$) in contact with their soft tissues. Corals belong to a group of organisms that secrete calcium carbonate ($CaCO_3$), that is, cause the precipitation of calcium carbonate ($CaCO_3$) in contact with their soft tissues. Every kind of shoal-water calcium-carbonate deposit has been called "coral rock": the molluscan-shell sands of the Bermudas, the chemically precipitated calcium carbonate of the oolites of Florida and the Bahamas, and limestones composed of the remains of Foraminifera and Bryozoa. The terms coral sand and coral mud have been applied to bottom-deposits in which there is no coral. To apply the term "coral rock" or "coral-reef rock" to all the kinds of limestones indicated would at the present time, in my opinion, be willful mental obfuscation. The study of the origin of limestones and the classification of limestones according to the source of their ingredients constitute a scientific problem of great geologic importance, and I believe it a scientific duty to break away from a usage that in *most* instances concealed scientific fact.

The importance of the distinction between "reef" and the material lying between a "reef" and the shore is particularly discussed on page 249.

Ecology of Reef-Forming Corals.

This subject has received the attention of very many investigators, and most of the broad principles have long been known. Darwin clearly recognized the difference in growth-form of exposed-reef corals and the corals that grow in the lagoons.[1] This subject has been discussed at great length by subsequent investigators, of whom I am one, but although facts have been presented in a more or less statistical way, the principle of adaptation of growth form to environment was as clearly perceived by Darwin as it is by anyone today. Dana's conclusions on the relations of corals to the temperature of the ocean have been modified in only a subordinate way. It is scarcely known who first recognized the polymorphism of species of corals according to difference in habit. The recognition of such vegetative adaptation was at least foreshadowed by Klunzinger and Pourtalès. Brook clearly recognized the principle, and during more recent years it has been elaborately discussed by Gardiner, Von Marenzeller, Wood Jones, and many others, including myself. The literature on coral ecology is enormous, and probably the ecologic relations of no other group of marine organisms are so well known.

Recently I have published two summaries on the physical conditions under which coral reefs form,[2] and have discussed in detail the temperature relations of coral reefs in a paper entitled Temperature of the Florida Coral-reef Tract.[3] Dr. A. G. Mayer has given important information on some of the subjects of coral ecology in a paper entitled Ecology of the Murray Island coral reef;[4] and I have given considerable data on the relation between the growth-form of colonies and habitat in my monograph, Some shoal-water corals from Murray Island (Australia), Cocos-Keeling Islands, and Fanning Islands.[5] The last-mentioned paper contains a complete bibliography of my publications on corals and coral reefs up to March, 1917.

In the second of my papers referred to in the preceding paragraph,[2] I state on page 99:

> The conditions necessary for vigorous coral-reef development may be summarized as follows: (1) Depth of water, maximum, about 45 meters; (2) bottom firm or rocky, without silty deposits; (3) water circulating, at times strongly agitated; (4) an abundant supply of small animal plankton; (5) strong light; (6) temperature, annual minimum not below 18° C.; (7) salinity between about 27 and 38 parts per thousand.

To this should be added the statement that the mean temperature of the coldest month must not be lower than about 21° C.

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[1] Structure and distribution of coral reefs, ed. 3, pp. 1–19, 1889.

[2] Vaughan, T. W., Physical conditions under which Paleozoic coral reefs were formed, Geol. Soc. Amer. Bull., vol. 22, pp. 238–252, 1911; The results of investigations of the ecology of the Floridian and Bahaman shoal-water corals, Nat. Acad. Sci. Proc., vol. 2, pp. 95–100, 1916. See also Corals and the formation of coral reefs, Smithsonian Ann. Rept. for 1917 (in press).

[3] Carnegie Inst. Washington Pub. 213, pp. 321–339, 1918.

[4] Idem, pp. 1–48, pls. 1–19, 1918.

[5] Idem, pp. 49–233, pls. 20–93, 1918.

Wherever there are well-developed fossil coral reefs it seems safe to infer that the physical conditions above enumerated prevailed. It is unnecessary to discuss separately each item entered under No. 11 of the summary statement of the periods of coral reef development on page 226. During upper Oligocene time (the time of the deposition of the upper part of the Chattahoochee formation) tropical conditions extended in Georgia as far north as latitude 32° 45′.

Hypotheses of the Formation of Coral-Reefs.

During the past few years elaborate reviews of theories of the formation of coral reefs have been published by Prof. W. M. Davis, the larger of which are referred to in the footnote below.[1] These reviews are valuable in presenting most of the important coral-reef theories, as they are understood by a physiographer, who is convinced of the adequacy of the Darwinian hypothesis. Numbers of complex phenomena associated with coral reefs are not considered, and his presentations are not in all respects satisfying. Prof. R. A. Daly has reviewed the literature on coral-reef theory, particularly from the standpoint of an adherent of the glacial-control hypothesis.[2] The literature on coral reefs is so enormous, that in the present paper consideration can be given only to certain papers that largely deal with coral-reef hypotheses or that contain information on areas herein discussed. The limitations of space cause me to omit references to many papers of much merit.

Three kinds of coral reefs are generally recognized, namely: (1) Fringing or shore reefs which, as the name indicates, occur along the strand line; (2) barrier reefs which occur at variable distances off shore and have lagoons from 1 or 2 to as much as 30 or even 40 fathoms in depth between them and the strand line; (3) atolls, which are ring-like and inclose lagoons above whose surface no land-masses of importance protrude.

As the relations of barrier reefs and atolls to the platforms above which they rise constitute in the opinion of geologists the essential part of the theory of the development of Recent reefs, the warfare of coral reef theory has been waged over the interpretation of these relations, which are the conditions of changing or changed position of the strand line and the part played by reef-forming organisms as constructional agents.

1. According to Darwin[3] and Dana,[4] corals first form a fringing reef off the *sloping* shore of a subsiding land area; the reef grows

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[1] Davis, W. M., Dana's confirmation of Darwin's theory of coral reefs, Amer. Journ. Sci., ser. 4, vol. 35, pp. 173-188, 1913; The home study of coral reefs, Amer. Geogr. Soc. Bull., vol. 46, pp. 561-577, 641-654, 721-739, 1914; A Shaler memorial study of coral reefs, Amer. Journ. Sci., ser. 4, vol. 40, pp. 223-271, 1915; Problems associated with study of coral reefs, Scientific Monthly, vol. 2, pp. 213-333, 479-501, 557-512, 1916. Also several short articles in Nat. Acad. Sci. Proc., vols. 1, 2, 1915-1917.

[2] Daly, R. A., The glacial-control theory of coral reefs, Amer. Acad. Arts and Sci., vol. 51, pp. 157-251, 1915.

[3] Darwin, C. R., Structure and distribution of coral reefs, ed. 3, fig. 5, p. 134, fig. 6, p. 137, 1899.

[4] Dana, J. D., Corals and coral reefs, ed. 3, pp. 263, 267, 1890.

upward at such a rate that its top remains near the surface of the water and through retreat of the shore it is converted into a barrier. Continued subsidence, where the inclosed land area is an inland, may result in the production of an atoll circumscribing a lagoon without any land mass projecting above the water level. But this is not all. The Darwinian hypothesis involves more than mere subsidence and the conversion of a fringing into a barrier reef. It also attempts to account for extensive submarine platforms by assuming that they have been built upon *sloping* basements through agencies dependent on the presence of reefs. (See text-figs. 4, 5, 6.) Dana's interpretation[1] is essentially that of Darwin.

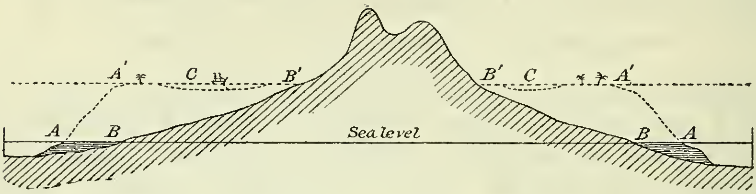

FIG. 4. COPY OF DARWIN'S FIGURE ILLUSTRATING CONVERSION OF A FRINGING INTO A BARRIER REEF, ACCORDING TO HIS HYPOTHESIS. *AA*—OUTER EDGE OF THE REEF AT THE LEVEL OF THE SEA. *BB*—SHORES OF THE ISLAND. *A'A'*—OUTER EDGE OF THE REEF, AFTER ITS UPWARD GROWTH DURING A PERIOD OF SUBSIDENCE. *CC*—THE LAGOON-CHANNEL BETWEEN THE REEF AND THE SHORES OF THE NOW ENCIRCLED LAND. *B'B'*—THE SHORES OF THE ENCIRCLED ISLAND. N. B.—IN THIS, AND THE FOLLOWING CUT, THE SUBSIDENCE OF THE LAND COULD ONLY BE REPRESENTED BY AN APPARENT RISE IN THE LEVEL OF THE SEA.

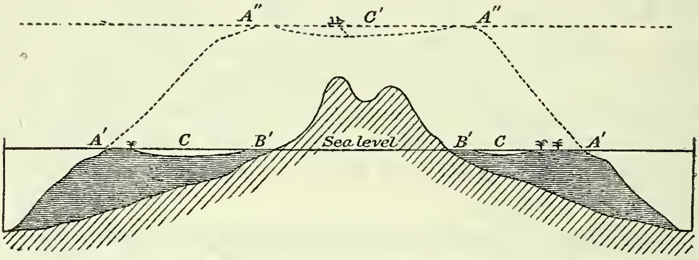

FIG. 5. COPY OF DARWIN'S FIGURE ILLUSTRATING CONVERSION OF A BARRIER REEF INTO AN ATOLL, ACCORDING TO HIS HYPOTHESIS. *A'A'*—OUTER EDGES OF THE BARRIER-REEF AT THE LEVEL OF THE SEA. THE COCOA-NUT TREES REPRESENT CORAL-ISLETS FORMED ON THE REEF. *CC*—THE LAGOON-CHANNEL. *B'B'*—THE SHORES OF THE ISLAND, GENERALLY FORMED OF LOW ALLUVIAL LAND AND OF CORAL DETRITUS FROM THE LAGOON CHANNEL. *A''A''*—THE OUTER EDGES OF THE REEF, NOW FORMING AN ATOLL. *C'*—THE LAGOON OF THE NEWLY FORMED ATOLL. ACCORDING TO THE SCALE THE DEPTH OF THE LAGOON AND OF THE LAGOON CHANNEL IS EXAGGERATED.

That Darwin considered an alternative hypothesis is shown by the following quotation:

> I may here observe that a bank either of rock or of hardened sediment, level with the surface of the sea and fringed with living coral, would be immediately converted into an atoll, without passing, as in the case of a reef fringing the shore of an island, through the intermediate form of a barrier reef.

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[1] Corals and coral islands, ed. 3, figs. pp. 263, 267, 1890.

He adds, however,

> * * * but as we have seen, the larger groups of atolls in the Pacific and Indian Oceans have not been formed on banks of this nature.[1]

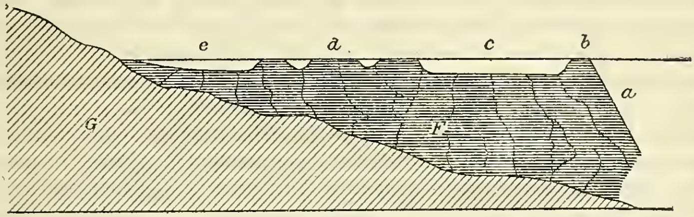

FIG. 6. REPRODUCTION OF J. B. JUKES' SECTION ACROSS THE GREAT BARRIER REEF OF AUSTRALIA. *a.* SEA OUTSIDE THE BARRIER, GENERALLY UNFATHOMABLE. *b.* THE ACTUAL BARRIER. *c.* CLEAR CHANNEL INSIDE THE BARRIER, GENERALLY ABOUT 15 OR 20 FATHOMS DEEP. *d.* THE INNER REEF. *e.* SHOAL CHANNEL BETWEEN THE INNER REEF AND THE SHORE. *F.* THE GREAT BUTTRESS OF CALCAREOUS ROCK, FORMED OF CORAL AND THE DETRITUS OF CORALS AND SHELLS. *G.* THE MAINLAND, FORMED OF GRANITES AND OTHER SIMILAR ROCKS.

2. The first important protest against the Darwinian explanation was by Carl Semper,[2] who, in 1863, after studies in the Pelew Islands, advanced the hypothesis that atolls could be formed in areas of elevation by the solution of the interior of preexistent limestone masses, and that solution, erosion by currents, and wave-cutting could develop platforms behind fringing reefs, thus transforming a fringing into a barrier reef.

3. Murray[3] introduced the idea of banks being built upward by showers of the remains of pelagic organisms until the bathymetric zone of reef-forming organisms is reached, and he called attention to the cutting of volcanic islands down to wave base. His theory has been briefly summarized by himself in the following words:[4]

> That when coral plantations build up from submarine banks they assume an atoll form, owing to the more abundant supply of food to the outer margin, and the removal of dead coral rock from the interior portions by currents and by the action of the carbonic acid gas dissolved in sea-water.
>
> That barrier reefs have been built out from the shore on a foundation of volcanic débris or on a talus of coral blocks, coral sediment, and pelagic shells, and the lagoon channel is formed in the same way as a lagoon.
>
> That it is not necessary to call in subsidence to explain any of the characteristic features of barrier reefs or atolls, and that all these features would exist alike in areas of slow elevation, of rest, or of slow subsidence.

4. H. B. Guppy in 1890 published the following important opinion regarding the relations of barrier reefs to submarine plateaus or ledges:[5]

> I have now gone far enough to establish the probability, judging from the instance of the Australian Barrier-reef, that reefs of this class are in reality, and not in appearance,

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[1] Structure and distribution of coral reefs, ed. 3, pp. 138, 139.

[2] Semper, Carl, Reisebericht, Zeitsch. für wiss. Zoologie, vol. 13, pp. 563-569, 1863.

[3] Murray, John, On the structure and origin of coral reefs and islands, Roy. Soc. Edinburgh Proc., vol. 10, 1879-80, pp. 505-518, 1880.

[4] Idem, p. 517.

[5] Guppy, H. B., The origin of coral reefs, Victoria Inst. Journ. Trans., vol. 23, pp. 51-61, 1890.

situated on the border of a submarine plateau or ledge. Such a position, according to the explanation of barrier-reefs, first advanced by LeConte, and supported by myself, presents the most favorable conditions for reef growth, the corals being limited on the outside by the depth, and on the inside by the sediment in the water. The influences of food-supply and currents act subsequently as auxiliary causes.

What, then, is the explanation of the submarine ledge? The supposition that it is a continuation of the land slope is at once negatived by the fact that the slope of the land in the reef-encircled islands of the Pacific is usually 6 degrees or 7 degrees, sometimes only 3 degrees or 4 degrees, but often as much as 10 degrees, or 12 degrees, whilst the submarine ledge, when stripped of reefs and defined by the 100-fathom line, would possess a scarcely recognizable inclination, represented by a fraction of a degree. It will be found, however, when we examine the contour of such an island as Vanikoro, that the distance of the barrier-reef from the coast may vary according to the slope of the land. Thus, on the west side of this island, the average angle of the land slope is 6 degrees, and the distance of the barrier reef about 2⅕ miles. On the north side the inclination of the land is between 11 degrees and 12 degrees, and the barrier reef is rather over a mile distant. This is just what we should expect. The more gradual the land slope, the broader will be the submarine ledge, cut out in the course of ages by the action of the sea, and the more distant will be the barrier reef that has grown up along its margin. This I believe to be the true explanation of the position of barrier reefs. A submarine ledge is in the first place necessary; and, since the sediment and mud in the shallower waters on the ledge repress the growth of corals, reefs will naturally spring up toward the margin of the ledge, where the water is clearer and where the depth is within that of the reef-coral zone.[1]

5. Admiral Sir W. J. L. Wharton[2] explained the uniform depth of atoll lagoons, whose edges are in various degress encircled by growing coral, by considering that the corals grow upon foundations that are the bases of volcanic islands that have been reduced by wave action to wave base.

6. Alexander Agassiz[3] found older limestone under the recent reefs in many areas investigated by him. He explained atolls by the solution and erosion of the interior of preexisting limestone masses and ascribed the formation of the platforms of barrier reefs to marine erosion without change of sea level.

7. Andrews[4] pointed out that the platform of the Great Barrier Reef of Australia has been submerged at a relatively recent date and that it continues southward beyond the reef, and he inferred that only a minor part of the platform is "formed of coral growth."

8. The opinions of Stanley Gardiner[5] are closely in accord with those of Semper, Murray, Wharton, and Agassiz. According to him submarine planation is effective to depths as great as 200 fathoms.

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[1] Guppy, H. B., The origin of coral reefs, pp. 60, 61.

[2] Wharton, W. J. L., Foundations of coral atolls, Nature, vol. 55, pp. 390–393, 1897.

[3] Agassiz, Alexander, The Coral reefs of the Tropical Pacific, Mem. Mus. Comp. Zool., vol. 27, 1 vol. of text, 3 vols. of pls., 1903.

[4] Andrews, E. C., Preliminary note on the geology of the Queensland coast with references [to the geography of the Queensland and N. S. Wales Plateau, Proc. Linn. Soc. New South Wales, pt. 2, pp. 146–185, 1902.

[5] Gardiner, J. Stanley, The formations of the Maldives, Geographical Journal, pp. 277–296, March, 1902; Fauna and geography of the Maldive and Laccadive Archipelagoes, pp. 182, 183, 1901–3.

9. Hedley and Griffith Taylor[1] accepted Andrews's interpretations and clearly showed that coral reefs of either atoll or linear form that rise above shallow platforms owe their shapes to prevailing winds and currents. They say:

> This explanation differs from that of Sir J. Murray, who considers the atoll form to be assumed by abundant growth of well-fed corals on the margin and the solution of dead coral rock in the interior. But if solution be so destructive, how can a reef form at all?[2]

10. According to Daly[3] the depths in the drowned valleys within barrier reefs, in barrier-reef lagoons, and in atoll lagoons in the Pacific, are closely accordant and he attributes this accordance to Recent rise of sea level subsequent to deglaciation, whereby the depth of water in the Tropics was increased some 33 to 38 fathoms, thus submerging antecedent platforms of marine planation. That glaciation and deglaciation effect the development of living reefs did not originate with Daly, but it is principally he who has elaborated the hypothesis. He gives in his papers an account of the earlier suggestions.

11. Wood Jones[4] considered sedimentation the critical factor in coral-reef theory, as corals grow only where there is comparatively little deposition of sediment. He accepts the conclusions of Hedley and Griffith Taylor on the importance of winds and currents in shaping atolls, and especially attacks the hypothesis of "a deepening or widening of the lagoon by a process of 'solution'."

Although the results of my own investigations will be elaborated on subsequent pages, the following summary statement may here be made: I have greatly multiplied the evidence in favor of Recent submergence in the coral-reef areas in the western Atlantic, the Gulf of Mexico, and the Caribbean Sea, and have shown that the living off-shore reefs in those areas formed either during or after submergence and are growing on submerged basement platforms where conditions are favorable for the life of reef-forming corals. The platforms are continuous beyond the limits of the reefs and their existence is in no wise dependent upon the presence of reefs.

I have also shown that the great Florida Plateau has existed as a plateau since at least late Eocene time; and that some of the West Indian platforms are about as old. As these plateaus existed previous to Pleistocene time they could not have been formed by marine planation during Pleistocene glaciation. Whatever be the cause of shift in position of strand line, off-shore reefs form on shallow submarine flats during or after rise in sea level, provided the rate of movement be not too rapid. This explanation applies to the fossil reefs of

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[1] Hedley, C., and Taylor, T. Griffith, Coral reefs of the Great Barrier, Queensland, Australasian Assoc. Adv. Sci., Adelaide Meeting, pp. 397-413, 1907.

[2] Idem., p. 407.

[3] Daly, R. A., Pleistocene glaciation and the coral-reef problem, Amer. Journ. Sci., ser. 4, vol. 30, pp. 297-308, 1910; The Glacial-control theory of coral reefs, Amer. Acad. Arts and Sci., vol. 51, pp. 157-248, 1915.

[4] Jones, F. Wood, Corals and Atolls, London, 1910.

Florida and the West Indies as well as to the reefs living to-day. I have pointed out that there are in the Virgin and northern Leeward Islands and off the shores of Central America certain submarine terrace flats, one at a depth of about 17 to 20 fathoms, another at a depth of about 26 to 30 fathoms, the deeper flat being separated from the shallower by an escarpment. These relations accord with the demands of the Glacial-control theory as expounded by Daly.

Tests of Coral-reef Hypotheses.

The tests of the theories comprise ascertaining the answers to the following questions:

1. Were the important coral reefs of the world formed during or after the submergence of their basements, either by a sinking of the land or by a rise of ocean level due to some world-wide cause?
2. What is the rôle of corals as constructional geologic agents? What percentage of the sediments around coral reefs is composed of corals, and is the flat area between a barrier reef and the shore due to infilling behind the reef or was there a shallow marginal flat before the reef formed?
3. Can a lagoon channel behind a barrier reef or the lagoon within an atoll rim be formed by submarine solution by sea water or by submarine scour?
4. What and how much effect have wind-induced and other currents in shaping coral reefs?
5. What effect have glaciation and deglaciation had on the development of living coral reefs?

Before considering the fossil and living coral reefs of the West Indies in their bearing on the answers to these questions, some of the more important criteria to be used in answering the questions will be briefly outlined.

CRITERIA FOR RECOGNIZING SHIFT IN THE POSITION OF STRAND LINE.

The criteria for recognizing elevation of a former strand line comprise: (*a*) Coastal terraces bordered inland by escarpments or cliffs that may be inferred to owe their origin to wave cutting; (*b*) wave-cut grooves in cliffs and sea caves that stand too high to have been formed at present sea level; (*c*) elevated beaches or bars, which under proper conditions form on shallow marine terraces and at the mouths of embayments; (*d*) the presence above sea level of organisms that must have lived in the ocean.

The criteria for recognizing submergence of former strand lines comprise: (*a*) Indentation of the coast line caused by the sea invading the lower parts of subaerially eroded valleys, the channels of which in many instances are preserved below sea level across and beyond the existing strand line; (*b*) the presence below sea level of submarine flats separated by relatively steep slopes or escarpments, that are due either to marginal wave cutting by the sea or are due to the formation of a subaqueous profile above a previous profile;[1] (*c*) the presence, especially in limestones, below sea level, of solution wells, pits, and caverns that inferentially were formed subaerially by the solvent action of fresh water; (*d*) the presence inland of free openings that connect with the sea, showing that there are underground channels by which ground water formerly flowed to the sea; (*e*) the presence of submerged peat bogs or swamp deposits composed of plants that grow only at or above sea level; (*f*) the presence below sea level of indurated limestone, the induration of which is due to solution of some of the original material and subsequent redeposition;[2] (*g*) erosion unconformities at the bases of marine formations, showing that there was subaerial erosion of the basement previous to the submergence during which the formation was deposited or accumulated in the sea.

The foregoing statements might be elaborated, but to do so seems unnecessary. The criteria enumerated are those I have actually used in my own work.

Besides ascertaining the proper succession of changes in the position of strand line, it is essential that the amount of the oscillations be measured, that differential crustal movements be noted and dated, and that an estimate be made of the endurance of the strand line in its relation to present sea level.

CRITERIA FOR MEASURING THE AMOUNT OF VERTICAL SHIFT IN STRAND LINE, AND FOR DETERMINING THE RELATIVE AGES OF TERRACES AND THE PHYSIOGRAPHIC STAGE ATTAINED BY A SHORE LINE.

The criteria for estimating the exact amount of rise or fall of sea level are not yet definite, because adequate study has not been made of the factors that determine effective wave base and of the depth to which effective wave cutting extends. Notwithstanding this inadequacy of precise information, an approximation of the amount of change may be made. In the case of elevation, the base of a wave-cut escarpment or cliff, the flats of marine terraces, and wave-cut grooves on sea cliffs, may be assumed to represent approximately former sea level. Approximate measures of the amount of subsidence may be based upon the depth of drowned valleys, the depth below sea level of the bottoms of submerged solution wells and

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[1] For discussions of this subject see as follows:

Barrell, Joseph, Factors in movement of the strand line, Washington Acad. Sci. Journ., vol. 12, pp. 413-420, 1915; Factors in movements of the strand line and their results in the Pleistocene and Post-Pleistocene, Amer. Journ. Sci., ser. 4, vol. 40, pp. 1-22, 1915.

Vaughan, T. W., Some littoral and sublittoral physiographic features of the Virgin and northern Leeward Islands and their bearing on the coral reef problem, Washington Acad. Sci. Journ., vol. 6, pp. 53-66, 1916.

[2] The fundamental principle of this criterion is discussed on p. 250, under the caption "Solubility of calcium carbonate in sea water."

caverns, and the depth to which peat or swamp deposits that were formed at or above sea level are submerged. Where there are recognizable submerged wave-cut scarps, the depth of the base of the scarp below sea level is nearly a measure of the amount of submergence; the depth in the West Indies in some instances probably exceeds the amount of submergence by about 6 fathoms. In the case of islands that rise from a common platform and which biologic and other data show were once parts of one land mass, the depth of water on the common platform may be assumed to be an approximate measure of the amount of the rise of sea level with reference to those islands.

The criteria for determining the relative ages of elevated terraces with reference to each other and for determining the amount of deformation to which they have been subjected are as follows: (*a*) Relative height; (*b*) relative amount of dissection; (*c*) relative degree of inclination and direction of the slope of the terrace flats; (*d*) presence or absence of a succession of higher and lower terrace flats on promontory tips and in places protected from vigorous marine cutting; (*e*) stratigraphic relations of terrace deposits.

Estimates of the endurance of the present relation of sea level to strand line are based upon recognizing the stage of physiographic development of the shore line. Among the important features to be observed are the presence or absence and the character of sea cliffs bordering the shore; the amount of delta and alluvial plain building at the mouths of stream ways; the character of beaches, bars, and spits; the nature and extent of the alluvial deposits back from the shore; the profiles of valley sides; and the axial profiles of the streams.

CRITERIA FOR ASCERTAINING THE RÔLE OF CORALS AS CONSTRUCTIONAL AGENTS.

The failure correctly to evaluate corals as geologic agents has been a defect of nearly all investigations of the so-called coral-reef problem; in fact, usually no attempt has been made to make such an evaluation. This evaluation may be made in several ways, which are as follows: (*a*) In studying fossil reefs exposed to view, the relative proportion of coral to other constituents of the rock should be estimated; (*b*) in studying marine bottom samples, percentage estimates of the proportion of the different ingredients should be made; (*c*) for submerged platforms on which reefs grow, the area of the reefs should be compared with the total area of the platform, an effort should be made to ascertain the nature of the rock underlying the sea floor between the reef and the shore, and the continuity in outline of the platform should be compared with the extent and position of the reefs; (*d*) knowledge of the growth rate of corals, when the relative frequency of specimens is known, permits an estimate of the rate of their constructional work.

This subject as a part of the problem of the formation of coral reefs possesses an importance that can scarcely be overestimated, for it comprises critical tests of both the Darwinian and the glacial-control hypotheses. The topics in the foregoing list will be discussed *seriatim*.

(*a*) Estimate of the relative quantity of coral to other constituents in emerged formations containing reefs, if they have not been extensively recrystallized, is relatively simple, although great precision in quantitative expression is not to be expected. This topic will be further considered in discussing the Caribbean, Floridian, and Bahaman fossil reefs.

(*b*) Percentage estimates of material according to source are difficult, but the results are of great value. The technique of making such estimates is described in a memoir recently published by the Carnegie Institution of Washington.[1]

(*c*) Here it should be emphasized that one of the postulates of the Darwinian hypothesis is that the prism of material included between three surfaces, namely, (1) the sea-bottom landward of the barrier, (2) a surface assumed as an extension of the land slope under sea until it intersects (3) a surface projected downward from the landward face of the reef, is due to the presence of the reef (see figure 4, page 242). Proof that a barrier has formed during or after submergence does not carry with it proof that the prism of material above indicated is due to the presence of the reef.

There are at least three criteria that can be applied in deciding whether or no the flat between the reef and the shore exists independently of the reef. They are as follows: (1) If the flat is dependent on the presence of the reef, where there are breaks in the barrier tongues of deep water should extend landward across the shallow bottom of the flat behind the reef; and where there is no reef there should be either a normal profile of equilibrium or an approach to such a profile, showing a deeper flat than that behind the reef, because of the absence of an off-shore wall behind which sediment could accumulate; but if the flat is independent of the reef, in general it should be continuous irrespective of the presence of the reef and should in places extend beyond the reef limits. (2) If the formation of the flat is dependent on the presence of the reef, the reef should stand on the seaward edge of the flat, that is, the flat should not project seaward beyond the reef. (3) It is often possible to discover the nature of the rock forming the sea floor between a barrier and the

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[1] Vaughan, T. W., in collaboration with Cushman, J. A., Goldman, M. I., Howe, M. A., and others, Some shoal-water bottom samples from Murray Island, Australia, and comparisons of them with samples from Florida and the Bahamas, Carnegie Inst. Washington Pub. 213, pp. 235–297, pls. 94–98, 1918. See especially the article by M. I. Goldman, Composition of two Murray Island samples according to source of material, pp. 249–252.

shore. Such a floor if formed by agencies associated with the presence of the reef will not be composed of rock demonstrably older than the reef, and will not exhibit geologic phenomena that in age clearly antedate the reef; but if it can be shown that the rock of the floor is older than the reef and that the floor has had a geologic history antecedent to the formation of the reef, it is demonstrated that the reef is merely growing on the surface of a flat whose formation is entirely independent of the reef development.

(*d*) The growth rate of corals, which furnishes one of the checks to be applied to the Glacial-control hypothesis of the formation of living reefs, is further considered on pages 253, 254.

SOLUBILITY OF CALCIUM CARBONATE IN SEA WATER.

As the formation of lagoon channels behind barrier reefs and of atoll lagoons by the solvent action of carbon dioxide (CO_2) dissolved in sea water is a part of the coral-reef hypotheses of Semper, Murray, A. Aggassiz, and Gardiner, if lagoons and lagoon channels have been formed in the way indicated, in the Tropics the surface waters of the ocean should contain an excess of carbon dioxide (CO_2) and should exercise a demonstrable solvent effect on calcium carbonate ($CaCO_3$). If it should be found that there is no excess of carbon dioxide (CO_2) in such water and that the water is saturated with reference to calcium carbonate ($CaCO_3$), the hypothesis of the formation of lagoons and lagoon channels in the manner postulated by Murray and others must be definitely abandoned.

In 1913, Mr. R. B. Dole undertook at Tortugas, Florida, certain examinations that were intended to solve this problem, if possible. In 1914 I summarized in the following words the results I had obtained from a study of the bottom samples along the Florida reef tract, those of Drew on dentrifying bacteria, and those of Dole on the chemistry of the waters.[1]

> There are two rival hypotheses for the formation of atolls: One of these attributes them to the submarine solution of the interior of a mass of limestone, the other accounts for them by constructional agencies. In order thoroughly to test the solution hypothesis the results of four lines of investigation were brought to bear upon it, and all are accordant. (1) All the bays, sounds, and lagoons within the Florida reef and key region are filling with sediment; (2) Drew's investigations of dentrifying bacteria show that chemical precipitation of calcium carbonate is taking place in the lagoons; (3) the chemical examination by R. B. Dole of samples of sea water flowing into and out of Tortugas lagoon, collected twice daily for a lunar period, show that although both carbonate and bicarbonate radicles are in solution uncombined carbon dioxide is not present, and that the water possesses no capacity for further solution of calcium carbonate by virtue of its content of free carbon dioxide; (4) the determinations by Dole of the salinity of the water within the Tortugas lagoon and at the southern end of Biscayne Bay show a higher concentration than that in the open sea water on the outside, indicating that tidal inflow and outflow are not sufficient completely to mix the water in the lagoons with the water of the surrounding

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[1] Wash. Acad. Sci. Journ., vol. 4, pp. 27–28, Jan. 19, 1914.

sea and that concentration by evaporation is taking place. As the results of these lines of inquiry are so positive, the formation of lagoons by submarine solution may be definitely eliminated from consideration.

Since the publication of this statement other investigators have made important contributions to this subject, noteworthy among whom are John Johnston, H. E. Merwin, and E. D. Williamson, of the Geophysical Laboratory of the Carnegie Institution of Washington, and Roger C. Wells, of the United States Geological Survey. Wells says:[1]

> In other words, sea water [from the Florida reef] appears to contain so much carbonate that in contact with the atmosphere at 1° C. it neither has nor acquires an appreciable solvent action on calcite.

As I have considered the subject in detail in my paper on the Murray Island bottom-samples[2] and in a paper on "Chemical and organic deposits of the sea"[3] I will merely say that sea water in shoal-water areas within the Tropics can not dissolve calcium carbonate, and that lagoon channels and atoll lagoons are not formed by solution, but are flattish areas more or less completely inclosed by built-up walls.

As lagoons are areas of sedimentation and not of removal of material, their formation by submarine scour may also be discarded.

EFFECTS OF WIND-INDUCED AND OTHER CURRENTS IN SHAPING CORAL REEFS.

This is an old topic; in fact, considerable bibliographic work would be needed to ascertain the names of all the investigators who have contributed to it and who deserve mention. That Darwin at least had an adumbration of the importance of these agents is indicated by his statement regarding Keeling atoll:[4]

> That they [the waves] beat against it in the same peculiar manner in which the swell from windward now obliquely curls round the margin of the reef, was evident from the conglomerate having been worn in to a point projecting from the beach in a similarly oblique manner.

Among recent investigators Hedley and Griffith Taylor, as noted on page 245, Wood Jones,[5] and I, in a number of my papers, two of which are cited below,[6] have devoted attention to this subject. During the field season of 1914 I had numbers of Ekman meter current-measurements made around Tortugas and at other places along the Florida reef tract. The measurements to a certain degree

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[1] Wells, R. C., The solubility of calcite in sea water in contact with the atmosphere, and its variation with temperature, Carnegie Inst. Washington Pub. 213, pp. 316–318, 1918.

[2] Carnegie Inst. Washington Pub. 213, pp. 265–268, 1917.

[3] Geol. Soc. Amer. Bull., vol. 28, pp. 933–944, 1918.

[4] Structure and distribution of coral reefs, ed. 3, p. 22, 1889.

[5] Coral and atolls, pp. 253–261, 1910.

[6] The building of the Marquesas and Tortugas atolls and a sketch of the geologic history of the Florida reef tract, Carnegie Inst. Washington Pub. 182, pp. 55–67, 1914; Sketch of geologic history of the Florida coral-reef tract and comparisons with other coral-reef areas, Washington Acad. Sci. Journ., vol. 4, pp. 26–34, 1914.

give quantatively the relations of currents to land forms, and completely confirm the more qualitative generalizations of Hedley and Griffith Taylor, which in brief are the axis of elongation of linear reefs is parallel to the direction of the dominant current while the bow of a crescentic reef is directed toward the direction whence the dominant current comes. These relations of reef form to current direction are most striking where the reefs rise above comparatively shallow platforms, as along the Great Barrier reef of Australia and along the Florida Keys. In atolls that more or less encircle the flat tops of submarine peaks, although currents are undeniably important in shaping sections of the reefs, they are not of so great importance as reefs that rise above shallow, long, wide platforms.

CRITERIA FOR DETERMINING THE EFFECT OF GLACIATION AND DEGLACIATION ON THE DEVELOPMENT OF LIVING REEFS.

Daly's elaborate paper on the Glacial-control theory of coral reefs has been cited on page 245. If the Glacial-control theory is true the following conditions should prevail: (*a*) There should be evidence of geologically Recent submergence of most of the shore-lines of the earth; (*b*) the average amount of submergence should be equal to the amount of lowering of the ocean-level during Pleistocene glaciation; (*c*) the position of the strand line during Pleistocene glaciation should be indicated by scarps separating flats, and the amount of submergence indicated by their present position below sea level should agree with the amount of raising ocean level due to deglaciation; (*d*) rate of growth corals should be such that since the disappearance of the continental ice sheets coral reefs could grow to a thickness equal to the amount sea level was raised as a result of the deglaciation; (*e*) living barrier coral reefs and atoll reefs should be superposed on antecedent basement flats or platforms. It should here be stated that the fact that there has been local differential crustal movements does not at all invalidate the importance of the Glacial-control theory in its application to the explanation of the modern coral-reef development.

Of the criteria stated in the foregoing list only the amount of vertical change in the position of sea level because of glaciation and deglaciation, the length of time since the disappearance of the great continental glaciers, and the rate of growth of corals need discussion at this place. After their consideration some attention will be given to other criteria of less determined value.

AMOUNT OF VERTICAL DISPLACEMENT OF STRAND LINE BY GLACIATION AND DEGLACIATION.

It is entirely obvious that the withdrawal of water from the ocean to form the Pleistocene continental glaciers would lower sea level, and that the return of the waters so locked up to the ocean upon the melting of the continental glaciers would raise sea level back to where it stood previous to the formation of the continental glaciers, unless crustal changes in the earth counterbalanced the effects of such withdrawal and return of oceanic water. Reference here will be made to only the two latest computations.

W. J. Humphreys, as part of a symposium before the Geological Society of Washington, on March 24, 1915, said:[1]

> The fact that the average thickness of the ice cap during the last glaciation can be only roughly estimated renders any calculation of its effect on ocean level correspondingly doubtful. It does not seem probable, however, that they should have averaged much if any thicker than the present caps of Greenland and of Antarctica, which a number of good observers have estimated to be about 1,000 meters. Taking this value and assuming the deglaciated area to be equal to one-fifteenth the area of the ocean, or, roughly, twice the glaciated area of North America, we estimate the change in sea level to have been about 67 meters. As already stated, this is only an estimated change, but perhaps it is a conservative estimate.

Daly in his paper on the Glacial-control theory of coral reefs summarizes his discussion in the following words:[2]

> Combining results, it is seen that, at the time of maximum glaciation, the tropical seas probably had an average level which was 60 to 70 meters (33 to 38 fathoms) lower than at the present time.

The estimates of Humphreys and Daly are essentially the same. As maximum glaciation was probably not of long duration the greatest effect of submarine terracing would be expected in somewhat shallower depths, probably between 20 and 30 fathoms.

RATE OF GROWTH OF CORALS AND LENGTH OF POST-GLACIAL TIME.

Recently I have published two summaries of the results of my experiments and observations on the growth rate of Floridian and Bahamian corals, and compared my results with those obtained by investigators in the Pacific.[3] The following statements are taken from the second of the papers referred to in the footnote:

> As has been stated, the primary object of this investigation was to get an approximate measure of the rate at which corals might build reefs. In order to make this estimate the true reef corals must be considered separately from those which live in other habitats. The reef species *par excellence* in the Recent and Pleistocene reefs of Florida and the West Indies is *Orbicella annularis;* after it in importance are *Maeandra strigosa*, *M. labyrinthiformis*, and *Siderastrea siderea*. Other corals, the most important of which is *Porites astreoides*, with *Agaricia* and *Favia fragum* of secondary importance, occur in the areas intermediate between the prominent heads. In some areas *Acropora palmata* is the dominant species. The massive heads form the strong framework of the reef, with infilling by other corals and other organisms. Therefore the upward growth rate of *Orbicella annularis* on the reef is critical. * * *

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[1] Humphreys, W. J., Changes of sea level due to changes of ocean volume, Washington Acad. Sci. Journ., vol. 5, pp. 445–446, June 19, 1915.

[2] Amer. Acad. Arts and Sci. Proc., vol. 51, p. 174.

[3] Vaughan, T. W., Geologic significance of the growth-rate of the Floridian and Bahaman shoal-water corals, Washington Acad. Sci. Journ., vol. 5, pp. 591–600, 1915; Growth rate of the Floridian and Bahaman shoal-water corals, in On Recent Madreporaria of Florida, the Bahamas, and the West Indies, etc., Carnegie Inst. Washington Yearbook No. 14, pp. 221–231, 1916.

Using these figures [in the paper referred to] as the basis of a further computation, a reef by the continuous upward growth of corals [*Orbicella annularis*] might attain at a rate of 6 mm. a year a thickness of 25 fathoms=150 feet in 7,620 years; and at a rate of 7 mm. a year it might attain the same thickness in 6,531 years.

Should the growth rate of *Acropora palmata* be taken as a measure, the time to accumulate such a thickness would be considerably less. This species forms spreading, palmate fronds, rising from stout bases. As age advances the fronds thicken and can withstand the pounding of surf and breakers. The average upward growth is between 25 and 40 mm. per year, but as the interspaces between the fronds are considerable in volume, comparisons with *Orbicella annularis* must be based upon relative increases in weight for a known period. * * *

These two estimates [as shown in the paper cited] give a measure of the limits of reef formation under continuously favorable conditions for upward growth. Such corals as *Orbicella annularis* might form a reef 150 feet thick in between 6,500 years and 7,600 years; while such corals as *Acropora palmata* might form a similar thickness in 1,800 years.

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The data available for the Pacific corals are not so abundant as those for the Atlantic, nor have the records, with few exceptions, the same degree of precision. However, they are sufficient for some general comparisons. The general growth rate of branching corals is nearly the same for both regions; but the growth of the massive forms in the Pacific appears to be appreciably more rapid than that of similar forms in the Atlantic. Therefore it seems probable that in the coral reef regions of the Pacific and Indian oceans a reef 150 feet thick may form under favorable conditions in less than 6,000 years. According to Gardiner such a reef might form in 1,000 years.

As the disappearance of the last continental ice sheets is estimated to have been between 10,000 years ago in Scandinavia and Alaska and 40,000 years ago at Niagara, the data presented show that there has been ample time for the development of any known living reef since deglaciation.

EFFECT OF LOWERING OF MARINE TEMPERATURE ON REEF CORALS DURING GLACIATION.

Daly in his paper on the Glacial-control theory devotes much attention to the probable extinction of reef corals over large areas and their restriction to only the hotter parts of the ocean during glaciation.[1] Daly's discussion of this subject is interesting and suggestive, but not really convincing. It is one on which far more research is needed. I rather hope that the data I have recently presented in my paper on the temperature of the Florida coral-reef tract[2] will aid in furnishing a basis for such a computation. That there was a lowering of the vitality of corals over large areas marginal to tropics can scarcely be doubted, but that reef corals thrived throughout Pleistocene time appears more than merely probable.

In this connection this following list of corals from the elevated reefs of Barbados is pertinent. Professor Jukes-Browne sent the collection to me after Prof. J.W. Gregory had published his paper on the Barbadian elevated-reef corals,[3] making the statement that great care had been taken in determining the height above sea level at which

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[1] Amer. Acad. Arts and Sci. Proc., vol. 51, pp. 166-171.

[2] Carnegie Inst. Washington Pub. 213, pp. 319-339, 1918.

[3] Gregory, J. W., Contributions to the paleontology and physical geography of the West Indies, Geol. Soc. London Journ., vol. 51, pp. 255-310, pl. 11, 1895.

each lot was obtained. The collection is now the property of the United States National Museum.

Corals from the elevated reefs of Barbados submitted by Prof. A. J. Jukes-Browne.

Elevation 1,043 feet. Horse Hill, St. Joseph.
Orbicella annularis (Ellis and Solander).
Elevation 845 feet. Cutting side of road, Parris Hill, St. Joseph.
Orbicella annularis (Ellis and Solander).
Elevation 747 feet. Cutting side of road, Market Hill, St. George.
Orbicella annularis (Ellis and Solander).
Elevation 720 feet. Russia Gully, St. Thomas.
Orbicella annularis (Ellis and Solander).
Maeandra labyrinthiformis (Linnaeus).
Elevation 707 feet. Haynesfield, St. John.
Stephanocoenia intersepta (Esper)
Orbicella annularis (Ellis and Solander).
Manicina gyrosa (Ellis and Solander).
Elevation 700 feet. St. Johns Church, St. John.
Maeandra strigosa (Dana).
Elevation 480 feet. Locust Hall, St. George.
Stephanocoenia intersepta (Esper).
Orbicella annularis (Ellis and Solander).
cavernosa (Linnaeus).
Siderastrea siderea (Ellis and Solander).
Elevation 362 feet. Ridge, Christ Church.
Siderastrea siderea (Ellis and Solander).
Elevation 360 feet. Small Ridge, Christ Church.
Orbicella annularis (Ellis and Solander).
Elevation 300 feet. Skeens Hill, near Lower Greys, Christ Church.
Orbicella annularis (Ellis and Solander).
Siderastrea siderea (Ellis and Solander).
Elevation 300 feet. Dayrells Hill, St. Michael.
Manicina gyrosa (Ellis and Solander).
Elevation 180 feet. Codrington Quarry, St. Michael.
Orbicella annularis (Ellis and Solander).
Manicina gyrosa (Ellis and Solander).
Elevation 160 feet. Cutting side of road, Charles Rose gully, St. George.
Maeandra labyrinthiformis (Linnaeus).
Elevation 100 feet. Chelston Quarry, St. Michael.
Meandrina maeandrites (Linnaeus).
Manicina gyrosa (Ellis and Solander).
Siderastrea siderea (Ellis and Solander).
Acropora muricata (Linnaeus).

Elevation 80 feet. Prospect, St. James.
Stephanocoenia intersepta (Esper).
Orbicella annularis (Ellis and Solander).
Maeandra labyrinthiformis (Linnaeus).
Acropora muricata (Linnaeus) s. s. (as pebbles).
Elevation 70 feet. Grazettes, St. Michael.
Stephanocoenia intersepta (Esper).
Orbicella annularis (Ellis and Solander).
Maeandra labyrinthiformis (Linnaeus).
Siderastrea siderea (Ellis and Solander).
Elevation 40 feet. Sandy Lane, St. James.
Orbicella annularis (Ellis and Solander).
Maeandra labyrinthiformis (Linnaeus).
Elevation 40 feet. Colleton, St. Lucy Parish.
Maeandra strigosa (Dana).
Elevation 20 feet. Black Rock.
Acropora muricata (Linnaeus) s. s.

Just how much of Pleistocene time is represented by this collection I can not say, but it is certainly a considerable part of it.

Mr. O. E. Meinzer, in the vicinity of Guantanamo Bay, Cuba, obtained living species of reef corals on Pleistocene terraces between 400 and 500 feet, at 275 feet, 200 feet, 125 feet, and 50 feet above sea level.

It is unfortunate that Daly should have attempted to account for the disappearance in the West Indies of so large a percentage of genera that now persist in the Indo-Pacific by appeal to the lowering of the temperature in the western Atlantic Ocean through Pleistocene glaciation. In a recently published paper[1], as well as the present one, I have shown that the genera had disappeared previous to Pliocene time.

It is at present my opinion that not enough is known regarding the effect of lowering of marine temperature during glaciation to serve as a basis for very strong arguments for or against the validity of the Glacial-control hypothesis.

VALLEY-IN-VALLEY ARRANGEMENT AND CLIFFED SPURS.

Professor Davis says in his Shaler Memorial study of coral reefs:

> Furthermore, if the embayments of a central island within a barrier reef result from the drowning of valleys that were eroded with respect to lowered sea level of a relatively short glacial period, then each valley must be entrenched in the floor of a preglacial valley; and above the head of each embayment resulting from the drowning of a new-cut valley, there should be a "valley-in-valley" landscape, unless the preglacial valley was so young and narrow that its sides were undercut and destroyed by the deepening and widening of the glacial valley.[2]

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[1] Vaughan, T. W., The reef-coral fauna of Carrizo Creek, Imperial County, California, and its significance, U. S. Geol. Surv. Prof. Pap. 98-T, p. 366, 1917.

[2] Amer. Journ. Sci., ser. 4, vol. 35, p. 240, 1915

The character of the entrenching within an established valley after lowering of sea level will depend upon the off shore slope of the sea bottom previous to the lowering of sea level. As any acceleration of headward erosion by a stream depends upon increase in steepness of the longitudinal profile of the stream bed, unless the gradient of the lower course of the stream is considerably increased there will be no visible valley-in-valley landscape after submergence following deglaciation. Subsequently I will show that in the West Indies there is abundant evidence of another kind that during Pleistocene time sea level was lowered, and that at the close of Pleistocene time it was raised. Valley-in-valley arangement is a criterion of very doubtful value.

Professor Davis also insists that if the Glacial-control hypothesis is correct, the spurs of islands within barrier reefs should be cliffed—the cliffs cut during Pleistocene glaciation. As promulgated in print by Professor Davis, I doubt the validity of this criterion. Perhaps the following hypothetical explanation may apply in some instances:

Around volcanic islands, the centers of which are far enough from the shore for the surface profile of the ejecta to have assumed the theoretic catenary curve, marine planation may proceed without at first cutting pronounced cliffs. If the material on the higher slopes is not greatly consolidated, alluviation and surface creep may deliver detritus more rapidly than the sea can remove it by marginal cutting and by undertow and other transporting agents. The sea may thus be held back from the interiorly situated harder volcanic rocks and the development of well-marked sea cliffs may thereby be prevented while the sea bottom would be aggraded near shore and a submarine flat produced. Should sea level then fall so that the shore line would shift to the outer edge of the previously formed flat, erosional processes might obliterate the low scarp carved into unconsolidated colluvial and alluvial material. Under such circumstances, should the sea-bottom gradient be less than that of the stream profiles, the lowering of sea level would not lead to the development of valleys-within-valleys, and alluvial plains might be pushed forward beyond the ends of the interstream spurs. Should sea level rise back to its former stand reef corals might establish themselves on the submerged flat at any place where the proper ecologic conditions might be found and develop into a barrier reef, off a land area on which there would be no valley-in-valley arrangement of stream courses and along whose shores there would be no cliffed spurs. This is an hypothetical instance, but that it is possible is apparently shown by the island of St. Christopher, West Indies, where such an arrangement of central volcanic mountains and relatively flat areas underlain by volcanic ejecta and colluvial and alluvial material intervene between them and the shore. In other volcanic islands the sea may not be held back from the harder rocks and may cliff them.

There are numbers of possibilities which deserve consideration, but the actual explanation of how present conditions were brought about is possible only through detailed field work in each area.

Some other kinds of shore lines may be mentioned. It is well known that one of the important factors in determining the amount of cliffing and the character of the cliffing of some shores is geologic structure. In an uplifted island composed of bedded sediments which have been moderately tilted the highest cliffs will be on the up-dip side along the line of the strike; the cliffs will decrease in height from the up-dip exposure along the line of the dip, and on the side of the island where the rocks pass beneath sea level there may be almost no cliffs. These relations are well illustrated in Anguilla and other islands in the West Indies. After such an earth block has been outlined there may be oscillation of strand line without further local crustal deformation.

The island of St. Croix is interesting in this connection. Just south of its north shore, which is determined by a fault, are maturely dissected mountains which attain an altitude of about 1,000 feet. Off the south foot of the highland is a sloping, slightly undulating plain, underlain by limestone, which extends to the south coast, (See pl. 70, fig. D). If this island were submerged 120 feet the limestone plain would form a submarine flat from one to about three sea-miles wide. Corals might grow on such a flat and form a barrier reef inside which there would be no strongly cliffed spurs along the shore, while the mountains would be in a stage of mature dissection.

AMERICAN TERTIARY AND PLEISTOCENE REEF CORALS AND CORAL REEFS.

Most investigators of the genesis of coral reefs have considered only the modern; but the ancient, or fossil, reefs in many instances afford better opportunities than the living reefs to determine the geologic character of the basement on which the reefs have been built, the change in the relation between the reef basement and sea level, and the importance of corals as constructional agents. The southeastern United States and near-by West Indian Islands furnish numerous examples of both ancient and modern coral reefs, and these have been the subject of investigation for many years. The location of the Tertiary fossil reefs in the southeastern United States, their associated faunas, the inclosing sediments, including in most instances both the overlying and underlying strata, the stratigraphic relations of the successive geologic formations, the geologic structure, and the geologic history, have been ascertained with a fair degree of accuracy. The coralliferous beds range in age from the base of the Eocene to Recent, and the coral fauna of each geologic formation is known with approximate completeness. The total coral faunas have yielded some hundreds of species.

EOCENE REEF CORALS OF ST. BARTHOLOMEW.

The corals obtained from the St. Bartholomew limestone are listed on page 194. Although there are many specimens and species of reef facies, they scarcely form a reef properly speaking. However, the stratigraphic relations are interesting. The best collecting ground is on the northeast face of the northwestward projecting limb of the island, between Anse Lézard at the northwest and Jean Bay at the southeast. Anse Écaille lies between the two bays mentioned. Cleve's [1] account of the geologic succession is correct, perhaps with some modification of his dates of a part of the igneous rocks. The base of the section is composed of volcanic agglomerate, above which there is interbedded agglomerate or sandstone, conglomerate composed of volcanic material, and limestone, succeeded by massive, hard, blue limestone. Most of the corals occur in the lower part of the sedimentary formation, in the limestone or in the softer, more rapidly weathering layers of calcareous sandstone, in which there is rehandled volcanic material. In conglomerate at the base of one exposure I observed boulders of volcanic material as much as 8 inches in diameter. Although, as Cleve stated, there is some interbedding of the limestone and agglomerate in the lower part of the sediments the upper formation rests unconformably on the lower.

The gradation upward into purer, more massive limestone has been mentioned. The presence in the higher limestone of a few corals of the same species as those in the lower beds and the abundance of calcareous algae in some places, indicate a shoal-water deposit; and, as the area of the deposit is relatively extensive, the evidence is in favor of its having been laid down on a submerged flat.

The Jamaican Eocene corals are shoal-water forms but they are really not of reef facies.

WEST INDIAN MIDDLE OLIGOCENE REEFS.

ANTIGUA.

That the bedded volcanic tuffs underlying most of the Central Plain of Antigua dip under the Antigua formation toward the northeast is indicated by the general structure of the island, and is confirmed by a well record, kindly furnished me by Dr. H. A. Tempany, government chemist of the Leeward Islands. The record mentioned is of a well bored on Fitches Creek, half a mile northeast of the southwest boundary of the limestone. Compact, noncalcareous rock was struck below the limestone. In the Central Plain patches of

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[1] Cleve, P. T., On the geology of the northeastern West India Islands. K. svenska Vet.-Akad. Handl. vol. 9, No. 12, pp. 24-27, 1872.

gravel and cobbles overlie the surface of the bedded tuffs at a number of places, two of which are Casada Gardens and Gunthorpe sugar-factory. At Morris Looby Hill, near the head of Willoughby Bay, conglomerate immediately underlies the limestone; and the basal contact of the formation is also exposed on the north side of Willoughby Bay, where it is underlain by conglomerate, mostly composed of basic volcanic material. The main reef occurs within the Antigua formation at or near its base and is exposed along a southwest-northeast line from Willoughby Bay to near Wetherell Point. The Antigua reef therefore grew upon a basement that had been subaerially eroded and was later depressed below sea level. The reef and the limestone of which the reef forms a part were formed during or after the submergence of their basement. Associated with the corals are many specimens of several species of *Lepidocyclina*, which are organisms characteristic of shallow, tropical water. The areal extent of these sediments, coupled with the fact that the deformation of the water-bedded tuffs that lie below the Antigua formation is not much greater than that of the Antigua formation, indicates that they were deposited on a submarine flat. In the northeastern part of the island both the tuffs and the limestone, according to J. W. Spencer, dip northeastward at a rate of 12° to 20°.[1] My own measurements show dips of about 20° toward the north or northeast for the volcanic tuffs and dips between 10° and 15° in amount, and ranging from N. 60° E. to N. 70° E. in direction, for the Antigua formation. The rocks are more disturbed in the Central Plain, where the dips of the volcanic tuffs were measured. Therefore, according to the available evidence the Antigua formation was a relatively extensive formation deposited in shoal water on a flattish floor.

The main reef-coral bed is about 60 feet thick and is near the bottom of the formation. Above it corals are scarcer, but appear to be too sparingly distributed throughout a thickness of about 300 feet of limestone above their profuse development nearer the base, or the Antigua formation seems to have a total thickness of a little more than 350 feet.

PORTO RICO.

The middle Oligocene coral fauna, as has been stated on page 204, occurs in the geologic formation to which Hill applied the name Pepino. This is a hard, calcareous marl, full of coral heads, with occasional indurated strata of white porous limestone. It is well exposed north and northwest of Lares in the Pepino Hills, whence the name for the formation is derived and where the collection of corals submitted to me by Mr. Hill was obtained.[2] This is the for-

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[1] Spencer, J. W., On the geological and physical development of Antigua, Geol. Soc. London Quart. Journ., vol. 57, pp. 494, 496, 1901.

[2] Hill, R. T., Notes on the forest conditions of Porto Rico, U S. Department of Agriculture, Div. of Forestry Bull. No. 25, pp. 14, 15, 1899.

mation to which C. P. Berkey later applied the name Arecibo formation.[1] I have no field acquaintance with the formation but from some notes on it made by Cleve, before it had been named, from the descriptions of Hill and Berkey, and from some of the corals collected by members of the New York Academy Porto Rican investigations, I am inclined to the opinion, that there is not a ''formation'' but a group of formations of similar lithology, for the ''formation'' contains both middle Oligocene (Antiguan) and upper Oligocene (Anguillan) fossils, and probably also some Miocene species. Ultimately the "formation," as Berkey also has suggested, will probably be split into several formations; it seems to me that there will be at least three and perhaps more. Only the stratigraphic relations of the base of the formation particularly need consideration here. These relations are those of unconformity according to Berkey, who says:[2]

> Above it [the Arecibo formation] in all cases lie the recent alluvial deposits and the San Juan formation, and below it lie the older and more complicated igneous and sedimentary rocks. The break between these two represents the chief unconformity in the whole geological column.

An excellent illustration of the unconformity below the ''Arecibo'' is given on page 16, figure 3, of Berkey's paper.

Berkey says in his summary of the geologic history of the island:[3]

> Where more simple marine conditions came into control, as would happen when submergence or planation had masked or destroyed the more elevated source of supply, the deposits became almost wholly reef limestones and shell limestones, with only minor amounts of strictly detrital material irregularly distributed.

The middle Oligocene reef-coral development of Porto Rico, therefore, took place after its basement had been subaerially eroded and then depressed below sea level, and it seems that the basement prior to its submergence had been almost reduced to a peneplain surface.

CUBA.

Reef corals of middle Oligocene age were first collected in Cuba, on Rio Canapu, by Arthur C. Spencer, who obtained three species, all of which also occur in Antigua; but the only at all extensive collection is from the vicinity of Guantanamo, and was made by O. E. Meinzer, who studied in detail the stratigraphic relations of the coralliferous formation. I am taking the following note from a manuscript by Mr. Meinzer, now awaiting publication. That there is a pronounced unconformity is indicated by a conglomerate at the base of the formation. Previous to the submergence, during which the coral reefs were formed, there was a long period of subaerial erosion, but geologic investigations have not been prosecuted over large

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[1] Berkey, C. P., Geological reconnaissance of Porto Rico, New York Acad. Sci. Ann., vol. 26, pp. 12–17, 1915.

[2] Idem. p. 3.

[3] Idem. p. 59.

enough areas in Cuba to draw inferences as to the physiographic features of the land surface resulting from the erosional activities.

WEST INDIAN AND PANAMANIAN UPPER OLIGOCENE REEFS.

ANGUILLA.

Basic igneous rock above which in places there is some sandstone is exposed below the coralliferous limestone at Crocus Bay and Road Bay. The contact is very clearly one of erosion unconformity. The following is a composite of the sections exposed at Crocus Bay:

Geologic section at Crocus Bay, Anguilla.

3.	Hard cavernous limestone, with few or no corals	60 feet.
2.	More or less argillaceous limestone with some beds of harder, purer limestone; contains fossil corals from bottom to top, some coral heads as much as 2 feet in diameter; this member subdivisible into subordinate beds about	200 feet.
1.	Yellowish and brownish clay underlain by dark blue-black clay, or sandstone and conglomerate of igneous material overlying basic igneous rock (exposed at Pelican Point)	5 feet ±.

The exposure at Road Bay is essentially the same as that at Crocus Bay.

The Anguillan reef was evidently formed during submergence after the subaerial erosion of its basement.

It should be emphasized that the richly coralliferous limestone is overlain by more massive, harder, limestone in which there are few or no corals; and that the areal extent of the shoal-water limestone indicates a submarine flat.

CANAL ZONE.

The Emperador limestone, according to Doctor MacDonald, lies unconformably on several of the beds belonging to the underlying Culebra formation, and supplies another instance of a fossil coral reef with an unconformable basal contact.

The stratigraphic relations of the important West Indian and Canal Zone reef corals and coral reefs are summarized in the following table:

Stratigraphic relations of West Indian and Canal Zone Eocene and Oligocene reef corals and coral reefs.

Age.	Locality.	Basal contact.	Overlying rock.	Surface of basement.
Upper Oligocene	Canal Zone (Emperador ls.)	Unconformable on Culebra formation.	....	....
	Anguilla	Unconformable on igneous rock or on sandstone and conglomerate.	Limestone without or with few corals.	Submerged flat.
Middle Oligocene	Antigua	do	do	Do.
	Porto Rico (Pepino formation).	do	do	Do.
	Cuba (Guantanamo)	do	....	Not known.
Upper Eocene	St. Bartholomew	do	Limestone without or with few corals.	Submerged flat.

All of the fossil reefs discussed in the foregoing remarks were formed during periods of subsidence that followed subaerial erosion of their basements. The basal contacts might be interpreted as supporting Darwin's hypothesis, but in four of the six instances the reefs are buried under later nearly pure limestones in which there are few or no corals. What caused the change in the character of the sediments, and coincidently led to the extermination of the reefs is not known; but the organisms in the overlying sediments indicate shallow, tropical waters, and as the geologic formations are areally extensive (relatively speaking), they were evidently formed on submarine flats. The corals began to grow on such flats and were ultimately killed. So long as the ecologic conditions were favorable, the corals flourished, but died when the conditions changed. The formation of the flats can scarcely be attributed to the corals.

WEST INDIAN MIOCENE REEF CORALS.

Meager developments of reef corals during the Miocene occur in Cuba and Santo Domingo, but at present no Miocene reefs are known unless the name reef be applied to the corals found in the La Cruz marl, eastward from La Cruz to the intersection of the railroad with the highway from Santiago to the Morro. The La Cruz marl is a bedded formation in which there are a few reef corals. The presence of pebbles in the basal part of the formation at the south end of Santiago Harbor suggests an erosion unconformity with some older Tertiary formation.

No Pliocene reef corals are at present known in the West Indies. The erroneous suggestion, that a coralliferous limestone exposed in a quarry on Calle Infanta, opposite Castillo de la Punta, Habana, might be Pliocene, has been corrected on page 224. This limestone seems to represent very nearly the same horizon in the Miocene as the Bowden marl of Jamaica; it may be stratigraphically somewhat higher. It contains some corals of reef facies but it can not appropriately be called coral-reef rock. The stratigraphic relations of the base of the deposit are not known.

WEST INDIAN PLEISTOCENE REEFS.

The West Indian Pleistocene reefs, whose stratigraphic relations have been critically investigated and can be discussed here are those of Jamaica and Cuba. Mr. R. T. Hill has placed in my hands a manuscript describing the Pleistocene reefs of Barbados, and Doctor MacDonald will discuss those of Costa Rica and Panama in his memoir on the geology of the Canal Zone and adjacent areas.

The basal contacts of the Jamaican Pleistocene reefs, as has been elaborately presented by R. T. Hill in his account of the Jamaican[1]

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[1] Hill, R. T., The geology and physical geography of Jamaica, Mus. Comp. Zool. Bull., vol. 34, pp. 90-99, 1899.

reefs, at least usually show unconformable relations. Although that Agassiz was aware of the unconformity at the base of the Cuban Pleistocene reefs can be inferred from his descriptions, he did not emphasize the stratigraphic relations; however, he does say regarding the living Cuban reefs: "In Cuba they [the coral reefs] abut upon the Tertiary limestone of its shores." I observed the unconformable relations at Baracoa, and stated that "Upper Oligocene yellowish calcareous marls or limestone are found in the vicinity of Nuevitas; also at *Baracoa, where they immediately underlie the Pleistocene coastal soborruco.*"[1] On page 32 of the same report it is stated: "It should be added here that all of the elevated Pleistocene coral reefs as seen by us and all of those recorded by those whom we consider competent observers, are plastered on the surface of the upper Oligocene [mostly Miocene] formations, or in some instances upon older geologic formations."

Unconformable relations between the elevated Pleistocene reefs and the underlying Miocene limestone or marl are observable at Matanzas, Habana, and Santiago. The rock in the left foreground (pl. 71, fig. A,) is the slightly elevated soborruco (coral-reef rock) that extends into the mouth of Santiago Harbor, clearly showing that the harbor was outlined as a drainage basin previous to the formation of the particular reef now under consideration. The bluff and slopes in the background and on the right side of the illustration are formed in the Santa Cruz marl.

The known unconformable relation at the base of the Pleistocene elevated reefs was the basis of inferred "subsidence of 80 to 100 feet" during the Pleistocene; this subsidence was followed by elevation and channeling in the mouth of the harbor; and this was followed by Recent submergence.[2] I have recently prepared a revised account of the shore-line phenomena of Cuba, and present the following summary for the vicinity of Habana:

1. Stand of land high enough for the subaerial erosion of the basement of a reef that seems to be about 30 feet above sea level at present, and for the outlining by erosion of Habana Harbor.

2. Submergence in Pleistocene time to a stand about 30 feet lower than at present.

3. Emergence in Pleistocene time sufficient to permit the cutting of a channel, now submerged 100 feet in Habana Harbor; the amount of this emergence would be about 100+ feet=130 feet.

4. Submergence, assigned to Recent time, to a depth of about 100 feet.

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[1] Hayes, C. W., Vaughan, T. W., and Spencer, A. C., A geological reconnaissance of Cuba, made under the direction of General Leonard Wood, Military Governor, p. 23. The upper Oligocene in this quotation is now considered Miocene. The italicized part of the sentence is in Roman letters in the original.

[2] Idem., p. 34.

5. There may have been minor oscillations, for instance the 5-foot soborruco may represent slight elevation subsequent to the last submergence.

Mr. O. E. Meinzer, in his manuscript, "Geologic reconnaissance of a region adjacent to Guantanamo, Cuba," referred to on page 204, gives the following summary of events for the vicinity of Guantanamo:

1. (Previous to the formation of the terraces) "Erosion, resulting in the excavation of the principal valleys now in existence, some of them probably below present sea level.

2. Submergence sufficient in amount to bring the land at least 750 feet below the level of the present shore line.

3. Successive stages of emergence and perhaps slight tilting of the land, alternating with stages of quiescene, the emergence being about 850 feet in amount so that the land area stood about 100 feet higher than at present, thereby permitting stream erosion below the present sea level; during the stages of quiescence sea benches and cliffs were formed at different, successive stands of the land.

4. Submergence to the present level, resulting in the drowning of the lower parts of the stream valleys and in the production of innumerable small estuaries, bays, and coves.

5. Filling of the submerged valleys and development of a new sea bench by destructive and constructive processes."

The reefs considered in this section are fringing reefs. They rest unconformably upon their basements, but were formed during pauses in emergence.

TERTIARY AND PLEISTOCENE REEF CORALS AND CORAL REEFS OF THE UNITED STATES.

SOUTHEASTERN UNITED STATES.

In the United States Tertiary reef corals first appear at the base of the Eocene in the Midway group in Alabama, but these are not sufficiently abundant to entitle the deposit to the designation "coral reef."

The oldest Tertiary coral reefs in this province are of middle Oligocene age, and have been studied at Salt Mountain, near Jackson, Alabama, and near Bainbridge, Georgia. The basal contact of the reef at Salt Mountain is not exposed, and its nature is, therefore, unknown. The reef in the basal part of the Chattahoochee formation at Bainbridge, Georgia, rests on the surface of the upper Eocene Ocala limestone, which shows evidence of subaerial erosion, and is exposed from place to place along Flint River throughout a distance of 8 or 9 miles. It is relatively thin, perhaps only 10 to 15 feet thick, and contains a fauna of about 30 species of corals, mingled with which are many specimens of *Lithothamnion* and large *Lepidocyclina*.

The next younger development of reef corals is in the upper part of the Chattahoochee formation and its stratigraphic equivalent, the "silex" bed and limestone of the Tampa formation. Corals are sufficiently abundant to justify being designated "reefs" at several localities, the most important of which are 18 miles south of Tallahassee, Florida, in several counties in southern Georgia, and at Tampa, Florida. Coralliferous limestone of the same or nearly the same age is exposed one-half mile south of River Junction, Florida, and at old Jacksonboro, Georgia. Well borings in Tampa show that beneath the coralliferous limestone is a variable thickness of clay which overlies the irregular surface of the Ocala limestone, indicating subaerial erosion, followed by submergence. The coralliferous beds are stratigraphically below the next younger set of deposits grouped under the Alum Bluff formation, indicating the continuation of subsidence after the formation of the reefs. The thickness of the reefs and coralliferous beds is not great, perhaps between 10 and 20 feet. The fauna comprises about 20 species of corals. Where not silicified and its character may be studied, the limestone associated with the corals is of complex origin. It is partly organic, probably in part a chemical precipitate, and contains terrigenous impurities. This indicates that the reefs and corals of this period grow during subsidence on a previously formed platform, but possess greater value for their aid in stratigraphic correlation than as constructional agents.

The Alum Bluff formation, which, in my opinion, is of Miocene age, according to the usage adopted by the United States Geological Survey is subdivided into three members, which named from the bottom upward are the Chipola marl, Oak Grove sand, and Shoal River marl. The basal Chipola marl member was known only in an area extending from Alum Bluff on Apalachicola River westward to Chipola River until it was recently identified by Miss Julia Gardner from a collection made by Dr. E. H. Sellards at Boynton Landing on Choctawhatchee River, in Washington County. The bed on Chipola River seems conformably to overlie the Chattahoochee formation, it is conformably overlain by higher beds of the typical Alum Bluff formation, and is between 15 and 17 feet thick. Of the four or five species of corals found at this horizon, one is of reef facies, a massive species of *Goniopora*. Subsidence was in progress while these coralliferous beds were being deposited.

Before completing the discussion of the Alum Bluff formation certain events antecedent to its deposition in central peninsular Florida should be stated. Previous to the deposition of Chattahoochee and Tampa sediments, the Ocala limestone was deformed with the production of a low, elongate dome, the axis of which extends from near Gainesville to near Ocala. On both the east coast and the west coast along an east-west line through Gainesville the surface of the Ocala is below sea level and is overlain by younger formations, while along the axis of the dome its surface rises from 80 to a little more than 100 feet above sea level. This low dome formed in the upper Oliogocene sea an island or a group of islands to which I have applied the name "Orange Island." The Chattahoochee and Tampa formations were deposited on the western slope of this island but they are not known in central Florida. The subsidence which brought about the deposition of these two formations continued until the Alum Bluff sea advanced entirely across central Florida, where deposits of Alum Bluff age rest on the surface of the Ocala limestone apparently without the intervention of deposits ot intermediate age.

The portion of the Alum Bluff formation above its basal member contains in central Florida at numerous localities heads of corals of reef facies belonging to the genus *Siderastrea.* At a place near Nigger Sink, about 8 miles north of Alachua, Florida, there is a *Siderastrea* reef, which, according to aneroid barometer measurement, is about 35 feet thick. The sediments associated with the Alum Bluff reef corals are greenish, usually phosphatic sands and clays, and impure phosphatic, in places magnesian limestone. The corals are decidedly subordinate in importance to other constructional agents, although they grew on a subsiding basement.

Alum Bluff sedimentation was succeeded by uplift and subaerial erosion preceding the depression initiating the deposition of the Choctawhatchee Miocene. Although the Miocene Choctawhatchee and Chesapeake faunas comprise about a dozen species of corals of distinctive facies, no reef corals are known as the temperature of the water was evidently too low.

No Pliocene coral reefs are known, but corals of reef facies are well represented in the Caloosahatchee marl, which is largely composed of molluscan shells. The stratigraphic relation of the Caloosahatchee marl to the Miocene has not been definitely ascertained, but available evidence suggests separation by an erosion unconformity. Whatever this relation may be, the formation was deposited during subsidence. Corals are of slight importance as contributors of material to the formation, as Heilprin long ago pointed out.

The following table, which is a slightly revised copy of a table previously published,[1] shows the stratigraphic distribution of coral reefs and reef corals from Oligocene to Recent time, and their relation to changing sea level.

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[1] Vaughan, T. W., and Shaw, E. W., Geologic investigations of the Florida coral reef tract, Carnegie Inst. Washington Yearbook No. 14, p. 238, 1916.

Stratigraphic distribution of coral reefs and reef corals in the southeastern United States from Oligocene to Recent time, and their relation to changing sea level.

Series.	Geologic formations, members, unconformities.		Distribution of reef corals and coral reefs.	Change in relation of basement to sea level.
Recent			Coral reefs	Submergence.
	Erosion unconformity.			
Pleistocene	Key Largo limestone		Coral reefs	Subsidence.
	Erosion unconformity.			
Pliocene	Caloosahatchee marl		Reef corals	Subsidence.
	Erosion unconformity.			
Miocene	Choctawhatchee marl		No reefs, a few corals	Subsidence.
	Erosion unconformity.			
	Alum Bluff formation.	Shoal River marl.	A few corals; slight development of reefs in central and northern peninsular Florida.	Subsidence.
		Oak Grove sand.		
		Chipola marl	A few corals; one species of reef facies.	
Oligocene	Chattahoochee formation	Upper	Coral reefs (Tampa, Fla., etc.)	Subsidence.
		Lower	Coral reefs (Bainbridge, Ga.)	Subsidence.
	Erosion unconformity.			
Eocene	Ocala limestone		No coral reefs	Subsidence.

The table shows, besides the stratigraphic distribution of the reefs and reef corals, that, with possibly one exception, each development occurred during subsidence which followed subaerial erosion.

To consider the basement of these fossil reefs: The geographic extent and composition of the limestones of upper Eocene age, which form the basement of the Floridian plateau, have been ascertained with considerable exactness. The surface outcrop has been mapped in Georgia and Florida, and well borings have revealed the presence of limestone of this age and character under younger formations in west Florida, at Panama City, and in Peninsular Florida, at Tampa, Key West, Key Vaca, and Palm Beach. The limestone is largely composed of the remains of Foraminifera, including myriads of *Nummulites* and orbitoidal Foraminifera, Bryozoa, and some mollusks and echinoids, with which is an undetermined proportion of chemically precipitated calcium carbonate and some terrigenous material. Corals are always rare and are usually absent. The organisms occurring in the formation are characteristic of tropical, shoal water, 50 fathoms or less in depth. As the 100-fathom curve delimits the submerged border of the Coastal Plain, it is evident that the Floridian plateau was a part of the Coastal Plain and had essentially its present outline back in upper Eocene time before the formation of the oldest Chattahoochee reef, which was therefore superposed on a subsiding platform not produced by corals. The paleogeographic development of the Floridian plateau shows that each successive development of Tertiary reefs was on an antecedent platform which was formed by agencies other than those dependent on the presence of coral reefs. In all instances the volume of coral as compared with material from other sources is of minor and usually of negligible importance.

The accompanying map (fig. 7) shows the location of the Oligocene reefs with reference to the Plateau surface.

That Pliocene deposition was followed by uplift, erosion, and depression, is shown by the fact that the Pleistocene shell marls along Caloosahatchee River rest on the eroded surface of the Pliocene. The Pleistocene reefs, the location of which is shown on the map (fig. 8), were formed during subsidence which followed uplift at the close of Pliocene deposition. At the base of the reef, which is 105 feet thick, is a calcareous deposit, 55 feet thick, of undetermined age. Beneath it are 450 feet of sand, mostly quartz, of Miocene age, below which follow in descending order, limestones of Chattahoochee and Ocala age, but without any development of reef-corals. Planimeter measurements indicate an area of 66 square miles for the Pleistocene reef against an area of 1,670 for the chemically precipitated calcium carbonate of the Miami and Key West oolites. I have already published

FIG. 7.—FLORIDA, OCALA LIMESTONE PLATEAU WITH SUPERPOSED OLIGOCENE AND MIOCENE CORAL REEFS AND REEF CORALS. *Oc. ls.*=OCALA LIMESTONE; THE FIGURES ARE FOR THE DEPTHS OF ITS UPPER SURFACE BELOW SEA LEVEL. *Ch*=CHATTAHOOCHEE AND TAMPA OLIGOCENE FORMATIONS. *Al. B.*=ALUM BLUFF MIOCENE FORMATION.

the statement that in Pleistocene time the calcium carbonate chemically precipitated probably predominated over that secreted by corals in the ratio 100:1.[1]

The theory advanced by Louis Agassiz [2] for the building of peninsular Florida is familiar to most geologists through the writings of LeConte. Agassiz says: * * * "the peninsula itself has once been a reef at least as far as the 28th degree of north latitude, as is shown by the investigation of the Everglades, and by the examination of the rocks at San Augustine." According to LeConte's map about half of peninsular Florida was formed through the agency of coral reefs.[3] (See figure 8, above.)

FIG. 8. FLORIDA, LOCATION OF PLEISTOCENE CORAL REEFS AS SHOWN BY +, AND THE LOCATION OF THE AGASSIZ-LECONTE BOUNDARY OF SUPPOSED CORAL FORMATION.

Eugene A. Smith, in 1881, showed that Eocene deposits extend south of Ocala into the peninsula; Heilprin showed that corals are unimportant to the latitude of Lake Okechobee; Alexander Agassiz

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[1] Vaughan, T. W., Sketch of the geologic history of the Florida coral-reef tract and comparison with other coral-reef areas, Journ. Washington Acad. Sci., vol. 4, p. 26, 1914.

[2] U. S. Coast and Geodetic Survey Ann. Rept. 1851, pp. 145-160, 1852.

[3] Elements of geology, ed. 4, p. 163.

accepted the results of Smith and Heilprin but contended that the southern end of the peninsula is composed of wind-blown coral sand. Later investigations have established that the material comprising this part of the peninsula is neither coral sand nor is it wind-blown. Antecedent to the Recent reef out of an area of between 25,000 and 30,000 square miles, perhaps as much as, but probably less than, 66 square miles may now be attributed to coral.

The data on the fossil reefs of the Southeastern States may be summarized as follows:

1. Corals have played a subordinate part, usually a negligible part, in the building of the Floridian plateau.
2. Every conspicuous development of fossil coral reefs or reef corals took place during subsidence.
3. In every instance the coral reefs or reef corals have developed on platform basements which owe their origin to geologic agencies other than those dependent on the presence of corals.

PLIOCENE REEF CORALS FROM CARRIZO CREEK, CALIFORNIA.

Mendenhall[1] has described in detail the relations of the coralliferous beds at this locality, and I have republished his statements in my account of the collection of corals made by him and Dr. Stephen Bowers.[2] There is here another instance of a richly coralliferous formation with an erosion unconformity at its base.

Living Coral Reefs of the West Indies, Florida, and Central America.

No general account of the position and general features of the living reefs within the region above mentioned will be given here, as the subject has been fairly well treated by Alexander Agassiz for the West Indies and Central America,[3] and during the past eight years I have published a number of papers, listed in the footnote,[4] on the

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[1] Mendenhall, W. C., Notes on the geology of Carrizo Mountain and vicinity, San Diego County, California, Journ. Geology, vol. 18, pp. 336-355, 1910.

[2] Vaughan, T. W., The reef-coral fauna of Carrizo Creek, Imperial County, California, and its significance, U. S. Geol. Survey Prof. Paper 98-T, pp. 355-386, plates 92-102, 1917.

[3] Agassiz, A., A reconnaissance of the Bahamas and of the elevated reefs of Cuba in the steam yacht *Wild Duck*, Mus. Comp. Zool. Bull., vol. 26, pp. 145-166, 1894.

[4] Vaughan, T. W.:

Sketch of the geologic history of the Floridian Plateau, Science, new ser., vol. 32, pp. 24-27, July 1, 1910.

A contribution to the geologic history of the Floridian Plateau, Carnegie Inst. Washington Pub. No. 133, pp. 99-185, 1910.

Studies of the geology and of the Madreporaria of the Bahamas and of southern Florida, Carnegie Inst. Washington Year Book No. 11 (for 1912), pp. 153-162, 1913.

Remarks on the geology of the Bahamas and on the formation of the Floridian and Bahaman oolites, Washington Acad. Sci. Journ., vol. 3, pp. 302-304, May 19, 1913.

With L. V. Pirsson, A deep boring in Bermuda Island, Amer. Jour. Sci., ser. 4, vol. 36, pp. 70-71, July, 1913.

Sketch of geologic history of the Florida coral reef tract and comparisons with other coral reef areas, Washington Acad. Sci. Journ., vol. 4, pp. 26-34, Jan. 19, 1914; abstract, Geol. Soc. America Bull., vol. 25, pp. 41-42, March, 1914.

The reef corals of southern Florida, Carnegie Inst. Washington Year Book No. 12 (for 1913), pp. 181-183, 1914.

[Footnote continued on page 272.]

Floridian, Bahamian, West Indian, and Central American reefs. In addition to my studies in the field and my work on charts and maps in the office, I have compiled all available information on Pleistocene and Recent strand-line movement along the Atlantic coast between Argentina on the south and New England on the north.

The discussion to follow will present evidence on Recent change in the position of strand line, on the amount of change, and on the relations of the living coral to the basements on which they have formed for the West Indies from Antigua along the Caribbean arc to Cuba, the Bahamas, the Bermudas, Florida, and Central America. Accounts of these areas will be followed by remarks on some other West Indian Islands, on the Brazilian reefs, on the Argentine shore line, and on the shore line of the United States between Florida and Cape Cod.

[Footnote continued from page 271.]

Investigations of the geology and geologic proccesses of the reef tracts and adjacent areas in the Bahamas and Florida, Carnegie Inst. Washington Year Book No. 12 (for 1913), pp. 183–184, 1914.

The platforms of barrier coral reefs, Amer. Geog. Soc. Bull., vol. 46, pp. 426–429, 1914.

Preliminary remarks on the geology of the Bahamas with special reference to the origin of the Floridian and Bahama oolites, Carnegie Inst. Washington Pub. No. 182, pp. 47–54, 1914.

The building of the Marquesas and Tortugas atolls and a sketch of the geologic history of the Florida reef tract, Carnegie Inst. Washington Pub. No. 182, pp. 55–67, 1914.

Study of the stratigraphic geology and of the fossil corals and associated organisms in several of the smaller West Indian Islands, Carnegie Inst. Washington Year Book No. 13 (for 1914), pp. 358–360, 1915.

Geological investigations in the Bahamas and southern Florida, Carnegie Inst. Washington Year Book No. 13 (for 1914), pp. 227–233, 1915.

Reef corals of the Bahamas and southern Florida, Carnegie Inst. Washington Year Book No. 13 (for 1914), pp. 222–226, 1915.

Coral reefs and reef corals of the southeastern United States, their geologic history and their significance, Abstract, Science, new ser., vol. 41, pp. 508–509, April 2, 1915; Geol. Soc. America Bul., vol. 26, pp. 58–60, 1915.

Introductory remarks to symposium on the factors producing changes in position of strand line during the Pleistocene and post-Pleistocene, Washington Acad. Sci. Journ., vol. 5, pp. 444–445, June 18, 1915.

[Résumé of the present status of the geologic correlation of the Cretaceous and Tertiary formations of the Antilles], Washington Acad. Sci. Journ., vol. 5, p. 489, July 19, 1915.

Memorandum on the geology of the ground waters of the Island of Antigua, B. W. I., West Indian Bull., vol. 14, No. 4, 4½ pp., 1915. Imperial Dept. of Agri. for the West Indies.

The geologic significance of the growth rate of the Floridian and Bahaman shoal-water corals, Washington Acad. Sci. Journ., vol. 5, No. 17, pp. 591–600, Oct. 19, 1915.

On Recent Madreporaria of Florida, the Bahamas, and the West Indies, and on collections from Murray Island, Australia, Carnegie Inst. Washington Year Book No. 14 (for 1915), pp. 220–231, 1916.

And Shaw, E. W., Geologic investigations of the Florida coral-reef tract, Carnegie Inst. Washington Year Book No. 14 (for 1915), pp. 233–238, 1916.

Study of the stratigraphic geology and of the fossil corals and associated organisms in several of the smaller West Indian Islands, Carnegie Inst. Washington Year Book No. 14 (for 1915), pp. 368–373, 1916.

Present status of the investigations of the origin of barrier coral reefs, Amer. Journ. Sci., ser. 4, vol. 41, No. 241, pp. 131–135, January, 1916.

The results of investigations of the ecology of the Floridian and Bahaman shoal-water corals, Nat. Acad. Sci. Proc., vol. 2, pp. 95–100, February, 1916.

Some littoral and sublittoral physiographic features of the Virgin and northern Leeward Islands and their bearing on the coral reef problem, Washington Acad. Sci. Journ., vol. 6, No. 3, pp. 53–66, Feb. 4, 1916; also abstract Geol. Soc. America Bull., vol. 27, No. 1, pp. 41–45, 1916.

The corals and coral reefs of the Gulf of Mexico and the Caribbean Sea (abstract of paper read before special meeting of Amer. Ass. Adv. Sci., in cooperation with Pan-American Congress), Science, new ser., vol. 43, pp. 250–251, February 18, 1916.

In collaboration with Cushman, J. A., Goldman, M. I., Howe, M. A., and others: Some shoal-water bottom samples from Murray Island. Australia, and comparisons of them with samples from Florida and the Bahamas, Carnegie Inst. Washington Pub. No. 213, pp. 235–297, pls. 94–98, 1918.

Chemical and organic deposits of the sea, Geol. Soc. American Bull., vol. 28, pp. 933–944, pls. 47, 48, 1918.

ANTIGUA-BARBUDA BANK.

The islands of Antigua and Barbuda rise from a bank which is bounded by the 100-fathom curve and is 50 miles in length along a north-south line, and from 13 to 20 miles in width. Antigua is near the southern and Barbuda near the northern end, with water from 15 to 18 fathoms in depth between them. (See text fig. 9.)

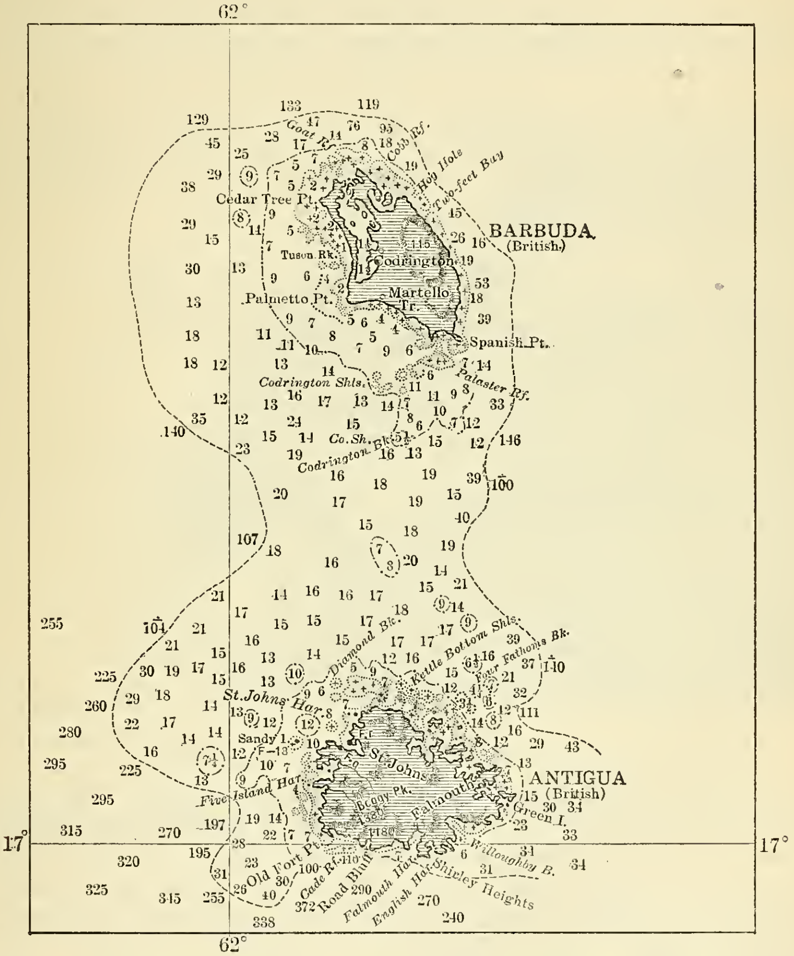

FIG. 9.—CHART OF ANTIGUA—BARBUDA BANK. FROM U. S. HYDROGRAPHIC CHART NO. 2318. SCALE, 1 INCH=ABOUT 12.8 NAUTICAL MILES.

The shore line of Antigua is deeply indented by numerous bays and harbors, as St. John, Five Islands, and Falmouth harbors, and Willoughby, Nonsuch, and Belfast bays (pl. 68, figs. A, B, and text fig. 10). The absence of terraces and elevated wave-cut cliffs is especially noteworthy. The discovery in St. John Harbor, at a depth of 20 feet below sea level, of a 4-foot bed of peat, which is not composed of marine plants (according to Mr. C. A. Davis), adds confirmation to the inference from the indented shore line and the absence of elevated terraces and wave-cut cliffs that the last important movement of the strand line was one of submergence. Present sea-level relations have persisted long enough for the development of sea cliffs, in places 100 feet or more high, for the alluvial fillings at the heads of the bays, and for the extension inland of alluvial deposits along the streamways. There is some evidence of a slight upward movement of the land, a few feet, less than 10, since the submergence.

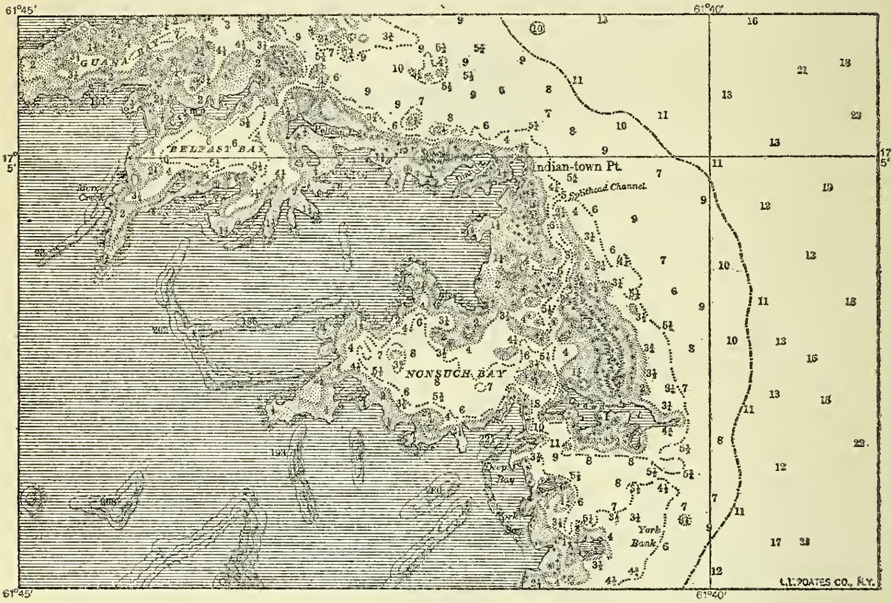

FIG. 10.—CHART OF PART OF EAST COAST OF ANTIGUA. FROM U. S. HYDROGRAPHIC CHART NO. 1004.

Barbuda, which is composed of limestone and has a maximum height of about 200 feet, has no marked indentations of its shore line; but Dr. H. A. Tempany informs me that fresh-water springs emerge below sea level in the lagoon about one-half mile south of Codrington village, a fact of significance in probably indicating submergence.

The similarity of the land mollusca of Antigua and Barbuda lend support to the inference from physiographic data that these islands were part of one land mass in Pleistocene time and have been severed by submergence, and as the water between the islands is 18 fathoms deep, the sea level must have risen at least that amount. A submerged steep slope off the southeast side of Antigua at depths between 100 and 150 feet accords with submergence to a depth of at least

18 fathoms, and indicates submergence of about 120 feet or 20 fathoms. (See fig. 11 below.)

Barrier coral reefs occur around Antigua off the mouth of Nonsuch Bay, off the southwest angle of the island, and there is a discontinuous barrier off the west side of the island. There are other reef patches, some of which are almost barriers. Barbuda has barrier reefs, Cobb and Goat reefs, off its northern end.

These reefs of Antigua and Barbuda occur on a platform which has been submerged. That the platform or flat lying between Antigua and surrounding Antigua is in origin independent of the corals growing on its surface is shown not alone by its continuity irrespective of the presence of corals. That a land area existed between Antigua and Barbuda in Pleistocene time is clearly shown by the land mollusca; while the submerged steep slope or scarp shows that the flat existed and was marginally cut by the sea while it stood about 120 feet higher than at present.

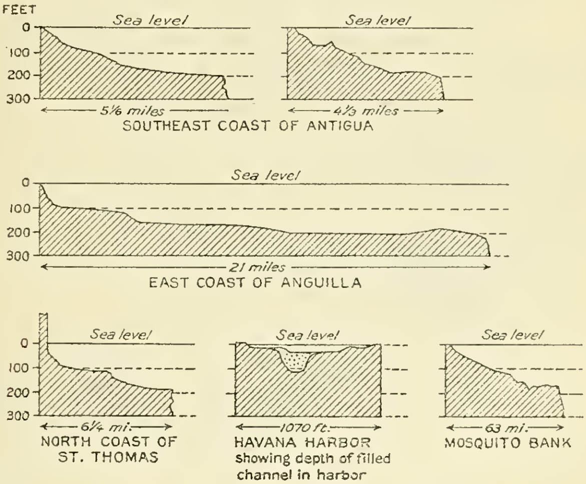

FIG. 11.—SUBMARINE PROFILES OFF WEST INDIAN ISLANDS AND ACROSS MOSQUITO BANK.

ST. MARTIN PLATEAU.

J. W. Spencer has applied this designation to the plateau on which St. Bartholomew, St. Martin, and Anguilla stand. This plateau, as bounded by the 100-fathom curve, is irregular in shape and is 75 miles long by 45 miles wide. The maximum depth of water between St. Bartholomew and St. Martin is 16 fathoms and between St. Martin and Anguilla 14 fathoms. (See text fig. 12.)

The shore line of St. Bartholomew is indented, the indentations are usually divided by beaches into an inner or lagoon part and an outer bay or harbor part (pl. 68, figs. C, D). The beaches may have been elevated between 3 and 5 feet. The lagoons behind the beaches are the salt ponds of the island. There is an entire absence of elevated terraces, unless some apparent shoulders on outlying islets, not actually visited by me, should be slightly elevated sea-cut benches. Wave-cut cliffs margin the rocky shores, and alluvial flats occur around the heads of the bays.

The shore line of St. Martin is indented. Each reentrant into the land is usually divided by a transverse beach into an inner lagoon or salt pond and an outer bay portion; and alluvial flats margin the heads of the reentrants and project inland between the hills. The spurs along the shore are truncated by wave-cut cliffs (see pl. 69, fig. A) and exhibit no definite terracing. Older beach rock was seen at the northeast end of Blanche Point, perhaps indicating slight differential uplift for that locality.

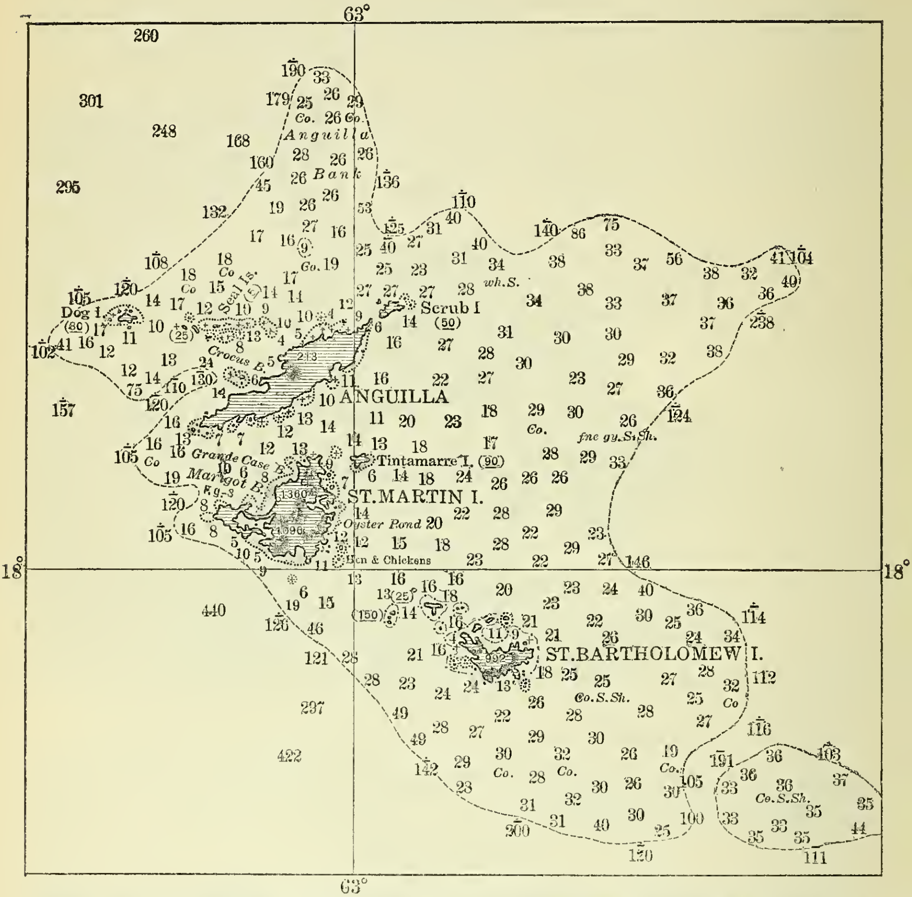

FIG. 12.—CHART OF ST. MARTIN PLATEAU. FROM U. S. HYDROGRAPHIC CHART NO. 2318. SCALE, ONE INCH=ABOUT 12.8 NAUTICAL MILES.

The shore line of Anguilla (see pl. 69, figs. B, D), although not so conspicuously indented as that of St. Bartholomew and St. Martin, is indented, and a number of instances, Road Bay, for example, of the separation by beaches of an inner lagoon from an outer bay are present. Three instances of inclosed basins having underground communication with the sea were noted (pl. 69, fig. C). No definite terraces are present and wave-cut cliffs are greatly developed.

That the last important change of sea level was by submergence of the land is evident from the character of the shore line in St. Bartholomew, St. Martin, and Anguilla; and in Anguilla additional evidence is afforded by the underground communication between inclosed basins in the limestone and the sea. Stable condition of the shore line for a considerable time is attested by the wave-cut cliffs, the development of the beaches, the alluvial fillings at the heads of reentrants into the landmass, and in St. Martin by the presence of unterraced flood plains along the streamways.

In my paper on the littoral and sublittoral physiographic features of the Virgin and northern Leeward Islands, referred to in the footnote on page 272, I have shown that on the windward side of the St. Martin plateau there is an outer deeper flat, 26 to 36 fathoms below sea level, with a maximum length east and west of over 30 miles, and that this flat may be subdivisible into two subordinate terrace flats. The scarp on the landward side of the deeper flat in places is about 50 feet high, in depths between 20 and 28 fathoms; above the deeper flat is a shallower one, whose outer edge is about 20 fathoms under the sea (see text-fig. 11, p. 275). Other submarine evidence of submergence in this area is given in my paper cited. At the time the shore line around the St. Martin Plateau was about 20 fathoms lower than at present, Anguilla, St. Martin, and St. Bartholomew must have been united. The biologic evidence at present available is not sufficient to be decisive, but all that is known accords with this interpretation. Notches on the outer edge of the plateau simulate hanging valleys and may represent the outer ends of valleys cut while the sea stood about 40 fathoms lower than now; but the information on these is too scant to justify more than a suggestion.

The hydrographic chart does not show well the reefs of these islands, nor does the British Admiralty West India Pilot give a good description of them. Because of rough weather most of my own observations were made from the shore. Coral reefs occur across the entrances to most of the bays on the northeast and southeast sides of St. Bartholomew; reefs are well developed on the east side of St Martin, off North Point, and on the southeast side of Tintamarre Island; and there are dangerous reefs off the southeast coast of Anguilla and on the north coast of the east end of the island. Seal Island reefs occur on a ridge extending westward from the northeast end of Anguilla. Some of these reefs are of the barrier type, as navigable channels lie between them and the shore, one at Forest Point is an instance.

The reefs of the St. Martin Plateau are superposed on an antecedent platform that was brought into its present relations to sea level by geologically Recent submergence to an amount of about 20 fathoms.

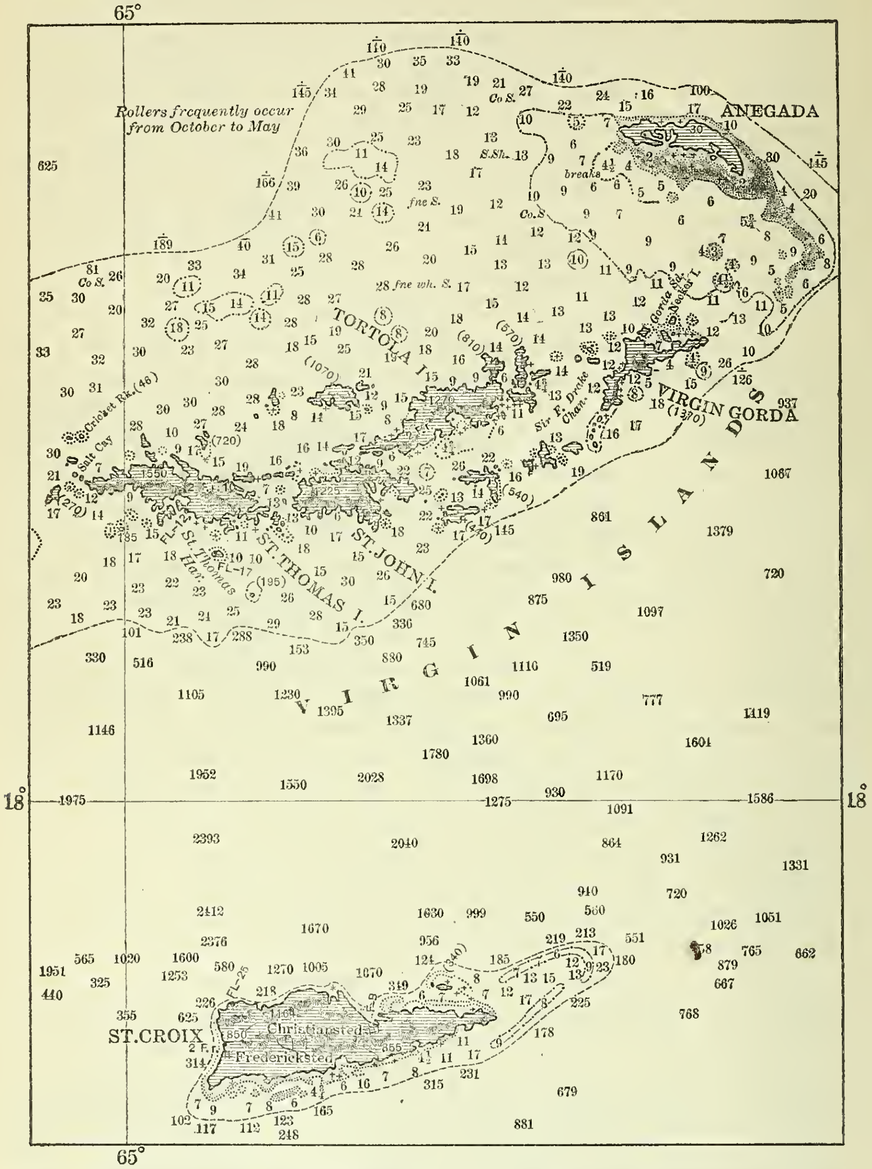

FIG. 13.—CHART OF VIRGIN ISLANDS AND ST. CROIX. FROM U. S. HYDROGRAPHIC CHART NO. 2318. SCALE, ONE INCH=ABOUT 12.8 NAUTICAL MILES.

ST. CROIX ISLAND.

This island rises above a bank about 30 miles long and 10 miles wide. The distance from the shore to the 100-fathom curve is usually less than three-quarters of a mile on the west end; and on the north side west of Sugar Bay the distance ranges from one-quarter to one-half mile. Off the south shore the distance to the 100-fathom curve in places slightly exceeds 3 miles; off the east end for 7 miles the water is less than 40 fathoms deep, while off the north coast the platform gradually narrows westward until near Salt River Point its width is less than one-half mile.

There is a long, disconnected barrier reef off most of the south coast, and barrier reefs are present off the north coast to a short distance west of Christiansted. The indented, ragged coast line and the depth of water on the platform so clearly point to the same conclusion as that already drawn from a study of Antigua, St. Bartholomew, etc., that reiteration is not necessary.

VIRGIN BANK.

The Virgin group of islands consists of about 100 small islands and keys (text fig. 13). The bank above which they rise is an eastward prolongation of that on which Porto Rico stands. The chart shows the indented coast line and the extensive, relatively shoal platform above the surface of which the islands project. The maximum depth of water between the islands is about 17 fathoms. St. Thomas well exhibits the coastal phenomena to which attention has already been so often directed—reentrants with alluvial fillings at their heads, unterraced alluvial bottoms along streamways, and wave-cut cliffs on the unterraced promontories (pl. 70, figs. A, B, C).

In my paper on some littoral and sublittoral physiographic features of the Virgin and northern Leeward Islands, already referred to, it has been pointed out that there are three terrace flats under the sea off St. Thomas, St. John, Tortola, and Virgin Gorda (see text fig. 11, p. 275). On the leeward side the deepest lies between 26 and 30 fathoms in depth and is separated by a scarp or steep slope on its landward side from a flat ranging from 14 to 20 fathoms in depth, which in turn is separated by a steep slope from a flat ranging from 6 to 10 fathoms in depth. On the windward side the respective depths are 26 to 34 for the deepest flat, 14 to 20 fathoms for the intermediate flat, and 7 to 10 fathoms for the shallowest one. The intermediate flat is narrow or absent on the promontory tips on the windward side, while it is preserved on the leeward side, strongly suggesting, if not actually proving, that the intermediate flat is older than the deeper one and was cut away in exposed places while the deeper one was forming. This evidence necessitates the deduction that in recent geologic time the Virgin Islands, except minor differential crustal movement in the vicinity of Anegada, have been submerged to a depth of about 20 fathoms, and that they were previously joined to Porto Rico, a deduction completely corroborated by biologic evidence, for Dr. L. Stejneger says in his herpetology of Porto Rico that "St. Thomas and St. John form only a herpetological appendix to Porto Rico," and Dr. P. Bartsch informs me that the testimony of the land mollusca is the same as that of the reptiles and batrachians. Indentations at depths of about 40 fathoms in the outer edge of the submarine bank simulate hanging valleys that may have been formed while the sea level was 40 fathoms lower than at present.

In the Virgin Islands there are three tiers of coral reefs, namely, (1) on the outer edge of the deepest flat, (2) on the outer edge of the intermediate flat, (3) within depths of 10 fathoms or less. The reefs could not have been formed on the deepest flat while the scarp on the landward side of the flat was being cut, and the other reefs are clearly younger than the basements above which they rise, for their basements existed and had had a complicated history prior to the formation of the living reefs. In fact, the basements were dry-land surfaces during at least a part of Pleistocene time.

CUBA.

The principal contributors to the literature on the shore-line phenomena of Cuba are W. O. Crosby,[1] Alexander Agassiz,[2] R. T. Hill,[3] Vaughan and Spencer,[4] and Hayes, Vaughan, and Spencer.[5] I have in papers cited on pages 271, 272 referred to some of the features of the Cuban shore line as bearing on the conditions under which the *living coral reefs* off the shores of the island have formed. W. M. Davis has recently alluded to the origin of the pouch-shaped harbors,[6] and here it may be well to direct attention to a criticism made by him in his article cited in the foot note. He says:

> It is, however, worth noting that the embayments here considered have a quite different relation to the adjacent coral reefs from that found, according to Hayes, Vaughan, and Spencer, in the pouched-reef [7] harbors of Cuba: All the embayments I saw inside of sea-level barrier reefs in the Pacific islands occupy valleys older than the reefs; but in Cuba the valleys, and still more the subsidence which drowned them in producing the pouched harbors, are described by the above-named authors as younger than the elevated reefs which inclose them; and such valleys do not bear on the origin of the reefs, as appears from the following extract: * * *

The extract is followed by comment, then by a quotation from Crosby and one from Hill, after which he says: "Without additional

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[1] Crosby, W. O., On the elevated reefs of Cuba, Bost. Soc. Nat. Hist. Proc., vol. 22, pp. 124-130, 1883.

[2] Agassiz, A., A reconnaissance of the Bahamas and of the elevated reefs of Cuba in the steam yacht *Wild Duck*, January to April, 1893, Mus. Comp. Zool. Bull., vol. 26, pp. 108-136, 1894.

[3] Hill, R. T., Notes on the geology of the island of Cuba, Mus. Comp. Zool. Bull., vol. 16, pp. 278-281, 1895.

[4] Vaughan, T. W., and Spencer, A. C., The geography of Cuba, Amer. Geog. Soc. Bull., vol. 34, pp. 105-116, 1902.

[5] Hayes, C. W., Vaughan, T. W., Spencer, A. C., Report on a geological reconnaissance of Cuba, pp. 123, 1902.

[6] Davis, W. M., A Shaler Memorial study of coral reefs, Amer. Journ. Sci., ser. 4, vol. 40, pp. 227-228 1915.

[7] "Pouched-reef harbors" are words not used in the publication under discussion by Professor Davis.

field study it is impossible to say which one of these views is correct, but the features of the Pacific reefs that I have seen support Hill's explanation." I have twice published the statement that "Hayes, Vaughan, and Spencer have shown, as is evidenced by the pouch-shaped harbors of the Cuban coast and filled channels, such as the submerged filled channel in Habana Harbor, that the last movement of the Cuban coast has been downward with reference to sea level," and that "the platform on which *the Cuban reefs grow*[1] has been brought to its present position by subsidence." These remarks apply to the present living coral reefs and not to the elevated reefs, and the conditions presented by the pouch-shaped harbor is only a part of the evidence showing recent submergence of the Cuban shore line.

Professor Davis's remark that "all the embayments I saw inside the sea-level barriers in the Pacific occupy valleys older than the reefs" has no application whatever to the protecting effect a fringing reef may have on the shore of a land during elevation subsequent to the formation of a fringing reef, thereby permitting erosional agencies to operate more rapidly on the softer rocks lying back from the shore. The words in the Cuba report are: "Wherever the conditions are favorable for the growth of corals a fringing reef is built * * *."

On preceding pages of this paper I have shown that there were coral reefs in Cuba in middle Oligocene time; that there were reef corals in both upper Oligocene and Miocene time (this Miocene is called upper Oligocene in the Cuba report); and that there are Pleistocene as well as living reefs. In the Miocene La Cruz marl in the vicinity of Santiago the greatest abundance of reef corals is not at the present head of Santiago Harbor, but it is seaward of the town of Santiago, east of La Cruz. (For a view seaward through the mouth of Santiago Harbor, see pl. 71, fig. B.) Whether the coral heads are sufficiently abundant to have retarded erosion toward the mouth of the harbor, while it was more rapid on the landward side, I am not prepared to say. This, however, was not a fringing reef, should it be appropriately considered a reef.

As to whether the elevated Pleistocene fringing reefs extended up to the sides of the outflowing water at the harbor mouths, thereby maintaining restricted outlets, or whether channels have been cut across the reefs after uplift, either of the alternatives is possible. Off the mouths of bays in Antigua, channels are maintained across living barrier reefs, which are tied to the shore at one end; while off Virgin Gorda, a barrier reef extends perpendicularly across the axis of the mouth of a submerged valley. These are living reefs, which have grown up during or after submergence and are younger

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[1] Not italicized in the original. Note use of present tense, "*grow*."

than the valleys landward of them. However, as the elevated Cuban reefs under consideration are fringing reefs, it seems to me more probable that they never extended across the harbor mouths; and I will add that the harbor basins had been formed, at least in large part, before the development of the now elevated fringing Pleistocene reefs.

Crosby, in 1883, seems to have been the first one to recognize the significance of the pouch-shaped harbors of Cuba. He says:[1]

> * * * During this period of elevation, Cuba, like most rising lands, had few harbors, but when subsidence began the sea occupied the channels and basins which had been excavated and cleared out by the rivers, and thus a large number of harbors came into existence. * * * They are half-drowned valleys filled to a considerable depth with land detritus, conditions which could not exist if the land was rising or had risen.

There are very many pouch-shaped along the Cuban coast. The following table presents information on 15 of them:

Principal Cuban harbors.

Name.	Shape.	Maximum width, sea-miles.[1]	Maximum known depth in channel or harbor.	Channel length, sea-miles.	Channel within narrowest part.	Height of adjacent land.	
						East side.	West side.
NORTH COAST.							
			Feet.		*Feet.*	*Feet.*	*Feet.*
Bahia Honda	Palmately digitate	3.00	[2] 59	1.50	2,180	30–40	60
Cabañas	Trilobate	6.00	79	.50	1,825	160	160
Mariel	Irregularly digitate	1.50	[3] 72	.60	900	....	....
Habana	Trilobate	[4] 2.00	[5] 60	.75	470	200	±10
Nuevitas	Bilobate	7.00	[6] 137	4.38	1,400	Flat.	Flat.
Padre	Irregularly bilobate	7.50	75	1.75	900	Flat.	[7] Flat.
Banes	Palmately digitate	3.25	85	1.50	450	[8] 100	[9] 150
Nipe	Unequally bilobate	....	[10] 234	[5] 2.00	2,900	[8] 200	[9] 200
Livisa and Cabonico	do	8.00	[11] 168	.50	1,300	50–75	75–100
Tanamo	Irregularly bilobate	5.38	156	.63	600	120–176	120
SOUTH COAST.							
Baitiqueri	Trilobate head	.60	[12] 33	.18	300	590	600
Guantanamo	Irregularly dumb-bell shaped.	5.00	59	3.75	6,530	436	310
Santiago	Unilateral	1.00	68	.38	675	230	220
Enseñada de Mora	....	....	58	....	....	....	....
Cienfuegos	Unilateral	4.25	[13] 139	2.13	1,200	130	157

[1] 1 sea-mile=6,081 feet.
[2] 110 feet outside at channel mouth.
[3] 90 feet in channel mouth.
[4] About.
[5] Submerged channel 100.
[6] 100 feet frequent.
[7] Coral rock according to A. Agassiz.
[8] South.
[9] North.
[10] 180 feet and over frequent.
[11] 150 feet frequent.
[12] 78 feet at mouth.
[13] 214 feet off Pta. Pasa Caballos.

It is important to note that where the harbors are digitate in shape, Bahia Honda for instance, one or more streams enter each digitation, and that the mouths of the streams are either embayed or, in places, swamps and delta plains have formed. The pouch-shaped harbors are not the only indentations of the shore line, for the lower courses of all the larger streams are more or less embayed.

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[1] Crosby, W. O., On the elevated reefs of Cuba, Bost. Soc. Nat. Hist. Proc., vol. 24, pp. 124–130, 1883.

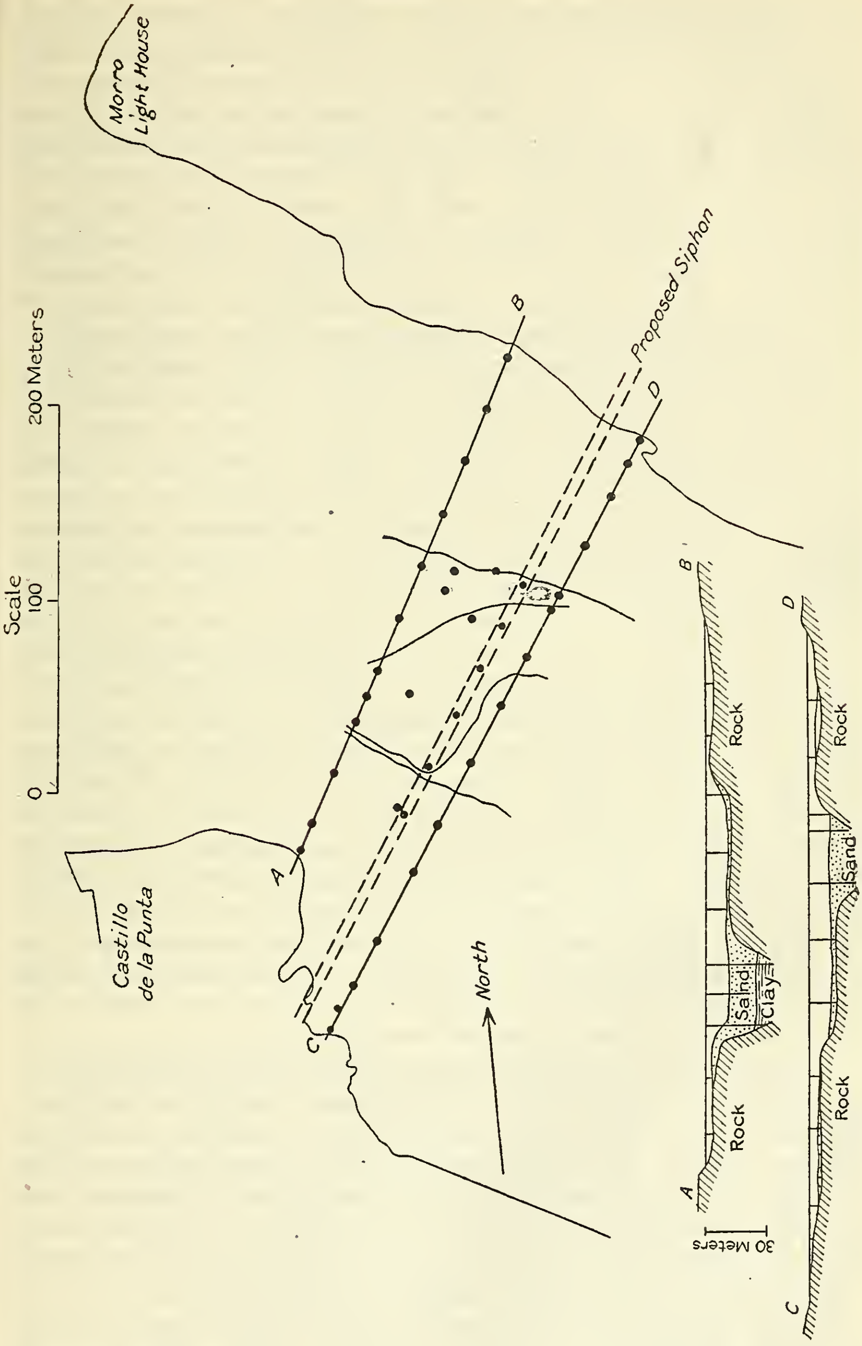

FIG. 14.—PLAN AND CROSS-SECTION OF FILLED CHANNEL IN HABANA HARBOR. AFTER HAYES, VAUGHAN, AND SPENCER.

How are the harbors to be explained? Doctor Hayes and I believed we found the answer in the conditions at present existing along Yumuri River, near Matanzas. The river here empties into the sea through a narrow gorge cut through Miocene limestone and marls (see pl. 71, fig. C). The top of the gorge is 200 feet above sea level, while farther back from the stream altitudes of 400 feet or slightly more are attained. Above the gorge, the Yumuri and its tributary, Rio Caico, have sunk their courses through the limestone, have removed it, and have developed wide, almost base-level valleys (see pl. 71, fig. D), on the underlying softer sandstone and shale. If this basin were depressed sufficiently to let the sea into it through Yumuri gorge a pouch-shaped harbor would result.

Additional evidence bearing on the problem of the origin of these harbors was obtained from records of borings. Mr. C. A. Knowlton, an engineer at Santiago, reported to us that in boring wells in the valley of San Juan River, 3 miles southeast of Santiago, he found at a depth of 70 feet below sea level what appeared to be stream gravel. Even more convincing evidence was obtained in Habana Harbor. In the preparation of plans for a sewerage system the Military Governor had a series of borings made across the harbor. This harbor occurs in a rather wide valley surrounded by sides which slope upward from sea level to an altitude of about 200 feet. The borings revealed a submerged terraced valley within the wider valley and in the middle of the inner valley a channel reaching a depth of more than 30 meters (about 100 feet) below sea level (see text-fig. 14). The depth of the first flat above the sides of the channel is about 13 meters (about 42 feet) below sea level. This flat is now covered with sand and the submerged channel is filled with sand and clay. There are at present no known processes whereby such a channel and terrace could be developed and then buried, except by a higher stand of the land enabling a stream to cut a trench and develop a terrace, followed by a lower stand of the land which submerged both the channel and the terrace and resulted in their burial by sediment deposited over them.

It appears to me that there is no escape from the interpretation, made first by Crosby, that the pouch-shaped harbors are drowned drainage basins. Before the accumulation of the data by Hayes, Spencer, and me, Hill endeavored to explain them without a shift in height of strand-line, but after the additional information was presented to him he abandoned his interpretation and accepted ours. There is a statement to this effect in a manuscript by him now in my possession, and this citation is made with his authority.

The factors producing the peculiar form of the harbors will now be briefly considered. According to Crosby, Hill, and the account in our report on Cuba, fringing reefs are supposed to have restricted the mouths of the streams, either by growing up to the edges of the outflowing water, a channel thereby being maintained, or because of their greater hardness they offered greater resistance to erosion than did the softer rocks on their landward side. It is my present opinion that the hypothesis of the reefs having more than a secondary importance in the development of these features must be discarded for the following reasons: First, that such physiographic forms are in no wise dependent on the presence of coral reefs is shown by their frequency in areas underlain by Cretaceous limestones in Texas. Hillcoat Valley in the southwest quarter of the Nueces quadrangle, Texas, is such a basin, with a narrow outlet into Nueces River. This is only one of a number of instances that might be given. In physiographic form this basin and its outlet resemble the pouch-shaped harbors of Cuba. Second, there is no evidence that corals had any more influence in Cuba than in Texas, for instance, Yumuri gorge at Matanzas is about 200 feet deep. The highest important elevated coral reef rocks occur at an altitude of about 35 feet above sea level off the sides of the stream mouth. The stream has cut and maintained a gorge through about 165 feet of limestone and marl which are topographically above the reef and which are not coral reef rocks, but which are bedded and were formed by other agencies. Other instances of these relations might be given.

The conditions around the Habana Harbor are interesting in this connection. Limestone of upper Oligocene or Miocene age occurs at the Morro and forms the higher land along the shore east of the city, and it outcrops at lower altitudes in the western part of the city; but the drainage at the south end of the harbor has cut through the limestone and exposed the underlying rocks, serpentine, rotten diorite, etc.; and that underground solution is active is indicated by the presence of springs along the serpentine contact. The conditions are here favorable for erosion by both mechanical cutting and solution in the area lying behind, while a channel has been maintained across the limestone on the sea front. This basin after it was outlined was submerged.

It is intended to give a much fuller discussion of the Cuban harbors in a paper now almost ready for press. The differences in form, and the causes to which the differences are due, are worthy of far more detailed treatment than is practicable in this place. I will end this part of the present discussion by saying that corals have in certain instances played a subordinate rôle by narrowing the mouth of a harbor and by preserving a constricted outlet. That the outlets of the basins here considered were constricted by reef rocks, now elevated, is shown by the conditions in Habana and Santiago harbors, and that similar constriction is now taking place by similar agencies is exemplified in many of the West Indian Islands. As the coral rock is usually harder than the rocks on which it rests, after its emergence it protects the narrow exit behind which erosion is more rapid and enlarges the basin.

From the remarks already made it appears unnecessary to discuss specially which are the older—the drainage basins occupied by the harbors or the coral reefs now elevated about 30 feet. However, that the Santiago basin is older than the coastal soborruco is shown by finding the soborruco within the harbor mouth; and as I found recent species of reef corals, apparently in place, on the east side of Habana Harbor, south of the Morro, at a height of 30 feet above sea level, the 30-foot reef seems to extend into the mouth of Habana Harbor. The valleys are clearly older. On page 264 of this paper a special point was made of the unconformity between the elevated Pleistocene reefs and the underlying Miocene material and the inference was drawn that the reefs were formed during subsidence after erosion of the basement under them. This is precisely the interpretation Professor Davis had made of the relations in the elevated reefs of the New Hebrides, but it seems such relations may develop in the same cycle, and, in my opinion, they are of slight importance in their bearing on the general theory of coral-reef formation.

The Isle of Pines furnishes important information on changes in sea level around Cuba. This island is nearly opposite Habana, 60 miles south of the south coast of Cuba, from which it is separated by water less than 10 fathoms deep. It comprises two parts, a southern which is mostly swamp, and a northern which is topographically higher. The surface of the northern division is mostly a plain, really a peneplain (see pl. 72, fig. A), above whose surface stand monadnocks of harder rocks (pl. 72, fig. B). This island is very different from the main island for, as no Tertiary or Cretaceous marine deposits are known to occur on it, it appears to have remained above sea level during these periods, but it has experienced the later changes of sea level which affected the larger island and during Pleistocene time it was joined to Cuba. The peneplain was formed at a lower level than that at which it now stands, it was then sufficiently uplifted to permit streams to cut into it, and has then been depressed, thereby drowning the mouths of the streams, but not bringing the plain surface so low as it formerly stood (pl. 72, fig. C). The coast line of the Isle of Pines and that of Cuba immediately north of it both are indented by the embayment of stream mouths through geologically recent submergence.

That the Isle of Pines was joined to Cuba during Pleistocene time is shown convincingly by its land fauna. Every species of reptile, except one, found on it, Dr. L. Stejneger informs me, is known to occur in Cuba, and two species of the mammalian genus *Capromys* are common to both. Dr. Paul Bartsch tells me that the Isle of Pines is only "a chunk of Cuba" and that its land Mollusca represent a faunal area as closely related to the faunal areas of Cuba as are the different faunal areas in Cuba to one another; that is, faunally, the Isle of Pines is simply a portion (a faunal area) of Cuba. Therefore, it is clear that the Isle of Pines has been severed from Cuba in the latest Pleistocene or Recent geologic time.

Practically all the Cuban shore line has now been considered except that on the north side of the Province of Pinar del Rio, within the Colorados Reefs. Guadiana Bay is a nearly typical estuarine embayment, while slighter embayment of other stream mouths is indicated, and lines of islands extend seaward from some headlands. The shore line clearly indicates submergence. Mr. J. B. Henderson and Doctor Bartsch, however, tell me that there is positive evidence of minor uplift west of Guadiana Bay. [1]

The Cuban shore line as a whole shows evidence of Recent or latest Pleistocene submergence, and this submergence has influenced the modern coral-reef development.

Regarding the amount of Recent submergence of the Cuban shore line, reference to the table on page 282 shows that there is close accordance in the depths of the channels or harbors, except certain ones that will be discussed later. These indicate that prior to the last submergence the land stood about 100 feet or slightly more, about 20 fathoms, higher than at present. The amount of emergence would establish a broad land connection with the Isle of Pines.

The discrepant harbors are Nuevitas Bay, which shows an excess of only about 27 feet, Nipe and Tanamo bays, and the channel leading from Livisa and Cabonico bays, on the north coast, and Cienfuegos on the south coast. The harbors with the discrepant depths on the north coast all occur on the north side of the Province of Oriente and at the eastern end of the Province of Camaguey. They seem to indicate deeper submergence than at other places and that the submergence has not been uniform in amount for the entire coast. However, the depths do not contradict a Recent rise of sea level to an amount of about 20 fathoms. The harbor of Cienfuegos would be expected to be abnormal, for the fault line which runs northward from Cape Cruz intersects the shore line at its mouth (see text-fig. 15). It is possible that structural relations have also influenced the depths in the other harbors and channels that are discrepant. Regarding these it will be said that except Nuevitas Harbor they occur within a linear distance of 31 miles. Nipe Harbor, the westernmost of the group, lies on the north side of Loma de Mulas, while it, Livisa, Cabonico, and Tanamo harbors all are on the north side of Sierra Cristal.

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[1] Henderson, J. B., Cruise of the *Tomas Barrera*, pp. 161-164, New York, 1916.

The great extent and relatively uniform height of a coral-reef terrace between 30 and 40 feet above sea level favors the interpretation that the geologically Recent shift in position of strand line has been without pronounced crustal deformation.

The relations of the off-shore reefs to the platforms on which they grow will now be briefly considered. A detailed description of the reefs is unnecessary here, as it would be only a repetition of that already given by A. Agassiz[1] and the accounts contained in the West Indies Pilot.[2] It need only be stated that the best developed off-shore reefs on the north coast are the Colorados Reefs, between Bahia Honda and Cape San Antonio; and that off the south coast the best are those between Trinidad and Cape Cruz and those east and west of the Isle of Pines. Mr. John B. Henderson has devoted attention to the Colorados Reefs in his "Cruise of the *Tomas Barrera*." Have the reefs off the south coast grown up on the surface of preexistent platforms or are the platforms due to infilling behind a reef during subsidence?

The area between Trinidad and Cape Cruz will be considered first. The fact that the reefs form disconnected hillocks or mounds, sometimes of mushroom shape, above a plain surface, which in places is 50 miles wide along a line perpendicular to the shore, while on the seaward side of the reefs there are large areas of shallow platforms, without any margining reefs, seems conclusive evidence against the platform having been caused by infilling behind reefs.

The following, in my opinion, is the correct explanation: The littoral geologic formations from Cape Cruz to Trinidad are mostly upper Oligocene or Miocene marls and limestones which dip under the sea at relatively low angles. They dip into the Cauto Valley, which is a gently pitching syncline, and into its seaward continuation, the Gulf of Guacanayabo. The embayment northeast of Boca Grande passage is probably also synclinal in structure. The abrupt undersea termination of the platform is most reasonably explained by a submarine fault which runs from Punta Sabanilla, at the mouth of Cienfuegos Harbor, to Cape Cruz. The coral reefs have grown up on the surface of a plain underlain by geologic formations that were gently tilted seaward and faulted along the line indicated.

That the Isle of Pines was joined to Cuba during Pleistocene time has, I believe, been shown in a convincing manner. As the Miocene and upper Oligocene formations from Batabano to Pinar del Rio dip under the sea at low angles they must underlie the flat bottom of the Gulf of Batabano. That the submarine slope from East Guano Key to off Cape San Antonio is determined either by a fault or by a very steep flexure is clearly indicated, as off the south shore of the

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[1] Bull. Mus. Comp. Zool., vol. 26, pp. 133-136, 1894.

[2] West Indies Pilot, vol. 1, pp. 199-332, 1913 (U. S. Hydrographic Office).

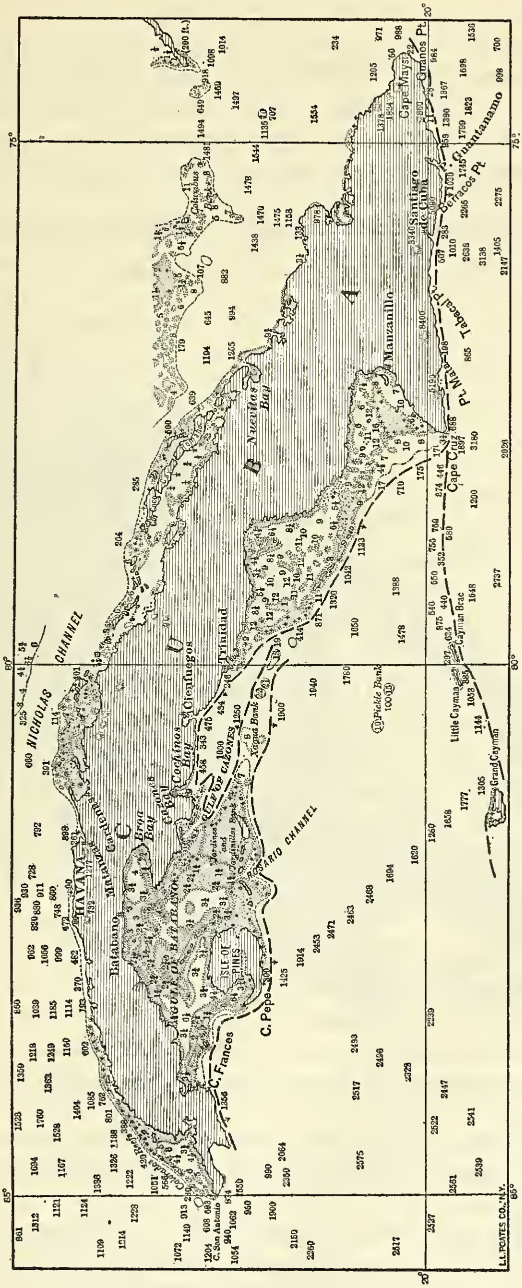

FIG. 15.—CHART OF SOUTH COAST OF CUBA, SHOWING SUBMERGED FLAT AND INFERRED FAULT LINES. FROM U. S. HYDROGRAPHIC CHART NO. 1290.

Isle of Pines the descent from the shore in 9 sea-miles is 13,080 feet, a slope of about 1 in 4. The Gulf of Cazones appears to have been outlined by faulting. This shelf differs from the one considered in the preceding paragraph, in that the Isle of Pines, whose area is about 1,200 square miles, stands on its outer margin, and apparently has affected the course of the fault. However, there was here also an undersea flat, which was produced by the gentle seaward tilt of low-lying geologic formations, and its outer margin was also determined by faulting. The living reefs are growing on its submerged unfaulted part, above which they rise as disconnected patches or as a broken barrier.

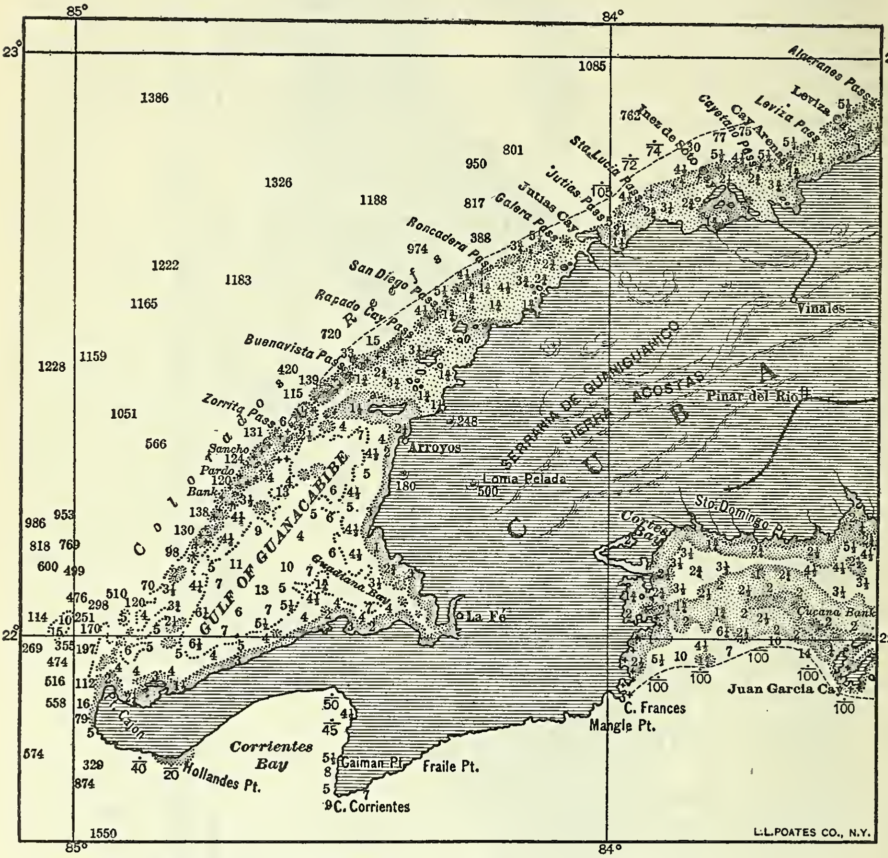

FIG. 16.—CHART OF COLORADOS REEFS, CUBA. FROM U. S. HYDROGRAPHIC CHART NO. 966.

The Colorados reefs (text-fig. 16) grow as patches of barrier reefs or upon a shelf, which, according to Henderson, largely consists of coral rock that had been uplifted above the sea and then depressed.[1]

The conditions under which the Cuban offshore reefs are growing can be very easily summarized, as follows: (1) They are superposed

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[1] Henderson, John B., Cruise of the *Tomas Barrera*, pp. 62–64, 126–130, 1916.

on flats submerged in geologically Recent time; (2) the amount of the submergence of Cuba was about 100 feet.

BAHAMAS.

Alexander Agassiz has in his reconnaisance of the Bahamas[1] the following very significant statement:

> May we not to a great extent measure the amount of subsidence which must have taken place at certain points of the Bahamas by the depth attained in some of the so-called ocean holes, as marked on the charts? Of course we assume that they were due in the aeolian strata to the same process which has on the shores of many islands formed potholes, boiling holes, banana holes, sea holes, caverns, caves, sinks, cavities, blowholes, and other openings in the aeolian rocks. They are all due more or less to the action of rain percolating through the aeolian rocks and becoming charged with carbonic acid, or rendered acid by the fermentation of decomposed vegetable or animal matter or by the action upon the limestone of sea water or spray under the most varying conditions of elevation and of exposure. None of them have their upper openings below low-water mark, though some of them may reach many feet below low-water level. Ocean holes were formed in a similar way at a time when that part of the bank where they exist was above high-water mark, and at a sufficient height above that point to include its deepest part. The subsidence of the bank has carried the level of the mouth and of the bottom of the hole below high-water mark.
>
> From the description of the strata which crop out upon the banks in the vicinity of some of the ocean holes at Blue Hole Point, there seems to be little doubt that the stratification characteristic of the aeolian rocks has been observed.

The deepest of the holes mentioned by Agassiz has a depth of 38 fathoms, "in the extension of the line of Blossom Channel leading from the Tongue of the Ocean up on the bank."

I have had opportunities to study such "holes" or solution wells, above sea level in Florida and have examined many of them, both above and below sea level, in the Bahamas. Mr. E. W. Forsyth sounded other "holes" and reported the results to me.[2] The depths of the holes range from about 2 fathoms to as much as 33 fathoms, the deepest hole in Fat Turtle Sound, North Bight, Andros Island, sounded by Mr. Forsyth. As in my opinion Agassiz's deduction as to the origin of these holes is incontrovertible, they indicate a stand of the land during Pleistocene time at least 228 feet higher than at present. Shattuck[3] and Miller accept a higher stand of 300 feet, followed by submergence of 300 feet, and conclude that this movement in strand-line position was followed by emergence, to an amount between 15 and 20 feet. From my own experience in the Bahamas the last change in the position of strand line was accompanied by minor differential crustal movement. For instance, at Nicollstown Light, Andros Island, a sea cave stands at such a height above the sea as to show conclusively an elevation of 18 feet above the position

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[1] Mus. Comp. Zool. Bull., vol. 26, pp. 41–42, 1894.

[2] Vaughan, T. W., Carnegie Inst. Washington Yearbook No. 13, p. 229, 1915.

[3] Shattuck, G. B., and Miller, B. L., Physiography and geology of the Bahama Islands, The Bahama Islands, pp. 19, 20, 1905.

at which it was formed; but 4,000 feet southeast of the cave the elevation is only about 4 feet in amount. I have given more information on this minor uplift in the paper referred to in the footnote.[1]

Agassiz, Shattuck, and Miller, and I agree as to the geologically Recent submergence of the Bahamas.

The accompanying diagram (text-fig. 17) indicates the relations of the barrier reef off the west side of Andros Island to the platform on the edge of which it is growing. This reef is growing on the edge of a platform that had stood above sea level at least as much as 192 feet. It was perforated by solution wells and then submerged. The perforations in the platform show that it antedates the barrier reef, and that its formation is not dependent on agencies associated with the presence of the reef. There is here another instance of a reef formed during or after submergence, and superposed on the surface of an antecedent platform.

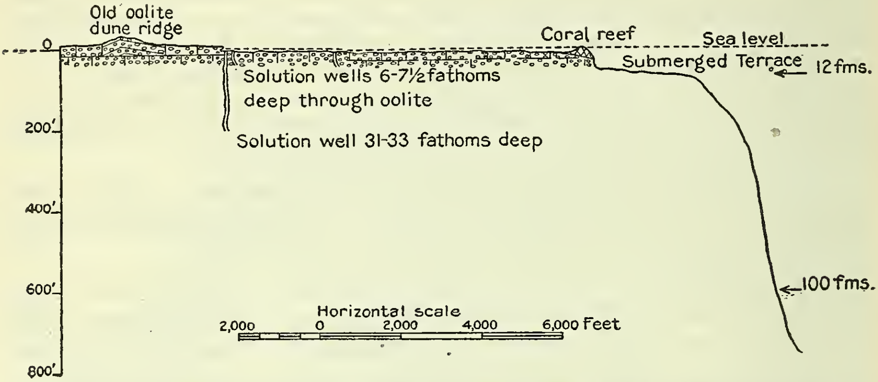

FIG. 17.—DIAGRAMMATIC SECTION ACROSS THE BARRIER REEF, ANDROS ISLAND, BAHAMAS.

The relative importance of the constructional rôle of the living reef will be briefly mentioned. The Pleistocene oolite of the Bahamas is not coral-reef rock, as was contended by A. Agassiz. It is composed of calcium carbonate chemically precipitated on extensive submarine flats.[2] I have several times published the estimate "that on Andros Island, Bahamas, the ratio of the constructive work of the present reef to that of agencies that previously resulted in the formation of the Pleistocene oolite is approximately as 1 to several thousand, or, as a constructive agent, chemical precipitation has been several thousand times more effective in forming limestone than corals."[3]

Before passing to the discussion of the next area it should be pointed out that the amount of submergence of the Bahamas, 228

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[1] Carnegie Inst. Washington Yearbook No. 13, p. 229, 1915.

[2] For the most recent discussions of this subject, see Vaughan, T. W., Some shoal-water bottom samples from Murray Island, etc., Carnegie Inst. Washington Pub. 213, pp. 277–280, 1918; Chemical and organic deposits of the sea, Geol. Soc. Amer. Bull., vol. 28, pp. 933–944, 1918.

[3] Wash. Acad. Sci. Journ., vol. 4, pp. 26, 27, 1914; Carnegie Inst. Washington Pub. 213, p. 279, 1917.

feet, is greater than that, about 120 feet, indicated for the areas already considered, unless the notches in the outer edges of the St. Martin Plateau and the Virgin Bank really indicate a position of sea level 40 fathoms lower than present sea level.

BERMUDAS.

Alexander Agassiz has given a good account of proto-Bermuda, that is of the extent and general physical character of the Bermudas previous to the submergence that has left the group in very nearly the form in which we now know it.[1] Recently Prof. L. V. Pirsson has contributed two highly valuable articles to the literature on the geology of the islands, basing his interpretations largely upon a study of samples from a well bored in Southampton Parish, on the slope of a hill about a mile west of the lighthouse on Gibbs Hill, from a height of 135 feet above sea level to a depth of 1,413 feet below the surface, or to a depth of 1,278 feet below sea level.[2]

There were penetrated in the well mentioned three major classes of material, as follows: (1) From the surface to a depth 383 feet below it, limestone; (2) from 383 feet to 600 feet, oxidized volcanic material; (3) below 600 feet to 1,413 feet, with one slight exception, basaltic, usually black lava. Pirsson concludes the first of his two articles with the following statement:

> It appears to the writer that what has been learned regarding the history of the Bermuda volcano has an important bearing on the question of the way in which the platforms on which coral islands, barrier reefs and atolls are situated, have been formed. There is of course nothing new in the idea that these may be volcanic in origin, only in Bermuda we have once more a positive demonstration of the fact. We have also seen that, provided the volcanic masses are of sufficient antiquity, they may, even though of great size, have been reduced to sea level, furnishing platforms of wide extent. As mentioned above, such masses reduced to sea level would continue to project from the ocean abysses indefinitely and many of them may be of great geologic age. There is nothing in the mere size of any of the atolls of the Pacific which would preclude their being placed on the stumps of former volcanic masses; it is not intended to assert by this that the foundation in every case is necessarily a volcanic one. If such masses have once been brought down to sea level and continue to exist and that level changes within limits from time to time by warpings in different places of the sea floor, or by an accumulation of ice on the lands and its melting, as suggested by Daly, then conditions of shallow water over them may be established suitable for their colonization by those organisms concerned in the production of the so-called coral reefs, which may be formed under the conditions postulated by Vaughan.

It was the understanding between Professor Pirsson and me that I should prepare a report on the calcium-carbonate samples. The following is a preliminary statement, accompanied by determinations of the Foraminifera by Dr. Joseph A. Cushman.

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[1] Agassiz, Alexander, A visit to the Bermudas in March, 1894, Mus. Comp. Zool. Bull., vol. 26, pp. 273–277, pl. 2, 1895.

[2] Pirsson, L. V., Geology of Bermuda Island, I. The igneous platform, Amer. Journ. Sci., ser. 4, vol. 38, pp. 189–206; II. Petrology of the lavas, Idem., pp. 331–344, 1914.

Preliminary description of the limestone samples and list of species of Foraminifera from the Bermuda well.

No. of specimen and depth below surface.	Description.	Species of Foraminifera.
1 (0-6 feet)	Light cream-colored limestone; mixture of calcite and aragonite; most of the constituent particles angular; largely or mostly broken remains of organisms; occasional small round grains 0.10 mm. or less in diameter, may be aggregates of chemically precipitated calcium carbonate. Largely or mostly an organic limestone.	*Textularia agglutinans* d'Orbigny. *Polystomella striatopunctata* Fichtel & Moll. *Polystomella* species. *Amphistegina lessonii* d'Orbigny. *Quinqueloculina reticulata* d'Orbigny. *Q. oblonga* Montagu. *Q. auberiana* d'Orbigny. *Peneroplis pertusus* Forskål. *Orbiculina adunca* Fichtel & Moll.
2 (61-110 feet)	Light cream-colored limestone; mixture of calcite and aragonite; constituent particles mostly angular, Foraminifera and broken tests of other organisms present; a few rounded grains 0.04 mm. or less in diameter, may be aggregates of chemically precipitated material. Largely or mostly an organic limestone.	*Textularia agglutinans* d'Orbigny. *Polystomella striatopunctata* Fichtel & Moll. *Polystomella* species. *Amphistegina lessonii* d'Orbigny. *Quinqueloculina reticulata* d'Orbigny *Q. auberiana* d'Orbigny. *Orbiculina adunca* Fichtel & Moll.
3 (110-216 feet)	Light cream-colored limestone; mixture of calcite and aragonite, apparently but little aragonite; largely a recrystallized limestone, without conspicuous grains; some small pockets contain pulverulent calcium carbonate; some pieces granular. A few grains 0.05 to 0.8 mm. in diameter resemble small oolite grains. The rock is mostly a foraminiferal limestone, the Foraminifera embedded in a cryptocrystalline matrix.	*Clavulina angularis* d'Orbigny. *Planorbulina larvata* Parker & Jones. *Truncatulina* species. *Polystomella striatopunctata* Fichtel & Moll. *Amphistegina lessonii* d'Orbigny. *Triloculina* cf. *T. circularis* Bornemann. *Orbiculina adunca* Fichtel & Moll.
4 (216-241 feet)	Whitish limestone, very slight yellowish tinge, some blackish particles; mixture of aragonite and calcite; specimen consists mostly of broken rock fragments; an occasional small pebble, one 2.5 mm. as maximum diameter; constituent material largely organic, Foraminifera, fragments of mollusks, shells, etc. Most small particles angular; a few less than 0.12 mm. appear oolitic. One 0.09 by 0.17 mm. in size had form of an oolitic ellipsoid. Mostly an organic limestone.	*Truncatulina* species. *Pulvinulina canariensis* d'Orbigny. *Polystomella striatopunctata* Fichtel & Moll. *Polystomella* species. *Amphistegina lessonii* d'Orbigny. *Triloculina linneana* d'Orbigny. *Orbiculina adunca* Fichtel & Moll.
5 (241-286 feet)	Whitish, faintly yellowish, pulverulent limestone; mixture of calcite and aragonite. Comparatively few tests of organisms, some Foraminifera, many small rounded grains and cryptocrystalline material. Some of the round grains appear oolitic; one of these is 0.11 by 0.15 mm. in size. It appears that a considerable proportion of this bed is a chemical precipitate.	*Bolivina* species. *Truncatulina* species. *Discorbis vilardeboana* d'Orbigny. *Amphistegina* species. *Quinqueloculina reticulata* d'Orbigny. *Biloculina* species.
6 (286-331 feet)	White, pulverulent limestone; mixture of calcite and aragonite. No organic tests were observed. Round grains up to 0.1 or 0.2 mm. appear to be oolite; small round grains 0.04 mm. in diameter. Much cryptocrystalline material. This bed appears to be largely a chemical precipitate.	None reported.
7 (331-341 feet)	White, friable limestone; mixture of calcite and aragonite. Round grains which range in diameter from 0.22 to 0.45 mm., may be oolitic. Small grains, 0.09 mm. in diameter seem definitely oolitic. Besides the rounded, there are broken angular grains and much cryptocrystalline material. Few or no organic tests. This appears to be largely a chemical precipitate.	*Amphistegina* species.
8 (341-383 feet)	Light-colored, earthy, yellowish-gray, impure limestone; some iron pyrites; mostly calcite, if aragonite is present the proportion is small. Many Foraminifera, *Nummulites*, fragments of coral, Bryozoa, etc.; many rounded grains which may be detrital; no definitely oolitic grains were observed. A thin section shows many Foraminifera embedded in a cryptocrystalline matrix. This bed is an impure, foraminiferal, shoal water limestone. It may contain some chemically precipitated material.	*Nummulites* species.

This examination reveals three kinds of limestone, the uppermost of which subsequently may be subdivided. The three divisions are as follows:

Specimens 1–4 (0–241 feet) represent a limestone which is largely or mostly of organic origin, but which may contain a few grains of chemically precipitated material. This corresponds to the upper faunal division recognized by Cushman.

Specimens 5–7 (241–341 feet) represent a pulverulent limestone, composed of rounded grains imbedded in finely crystalline material. The grains in their size and shape resemble oolite, and some grains showed with greater or less distinctness suggestions of oolitic structure. The foraminiferal fauna is meager, but it differs from that of specimens 1–4 and the underlying bed represented by specimen 8. It seems safe to draw the inference that this division of the limestone is in part, at least, a chemical precipitate.

Specimen 8 (341–383 feet) represents an impure, foraminiferal, earthy limestone, or a calcareous marl, in which there may be some chemically precipitated material. This bed is the uppermost in which the *Nummulites* reported by Cushman occur. It was also found in the underlying bed No. 9, 383–393 feet.

Probable geologic age of the limestone in the Bermuda well.

[Height of well mouth above sea level, 135 feet.]

Samples.	Probable geologic age.
From 1–241 feet	Recent and Pleistocene.
From 241–286 feet	Pliocene or Miocene.
From 331–341 feet	Nothing determinable.
From 341–393 feet	Oligocene or Eocene (*Nummulites*).
From 393–485 feet	Eocene? (no *Nummulites*).

An outline of the geologic history of the Bermudas subsequent to the volcanic activity seems to be as follows:

Doctor Cushman's identification of the Foraminifera from the Bermuda well shows the presence of an undetermined species of *Polystomella* between 393 and 480 and between 480 and 485 feet. These depths are well down in the oxidized zone and indicate marine conditions which persisted throughout the deposition of the superincumbent material. Other Foraminifera occur between 383 and 393, one of them being a species of *Nummulites*, which was also obtained from the basal bed of limestone at a depth of 341 feet. As the genus *Nummulites* is, according to our present knowledge, confined to the upper Eocene and Oligocene formations in the southeastern United States and the West Indies, the inference may be drawn that the Bermuda samples between 341 and 393 feet probably represent a geologic formation of either Eocene or Oligocene age, and that those from 393–485 feet represent a formation of probably Eocene age.

Until the specimens of *Nummulites* from the Bermuda well have been identified with species of known stratigraphic position a more definite statement can not be made. It appears safe to assign an Eocene or pre-Eocene age to the Bermudian volcanic activity.

The calcareous sediments, therefore, began to accumulate on a submerged volcanic basement in Eocene or lower Oligocene time, and the submergence progressed until the basement, in probably Miocene time, was entirely blanketed by calcareous deposits 100 feet thick, which differ in their physical aspect both from the underlying nummulitic rock and the overlying organic limestone. This rock is probably in considerable part a chemical precipitate. The well samples indicate no stratigraphic break at either its top or it base.

The limestone from a depth of 241 feet to the surface is a shoal-water, organic deposit, in which living species of Foraminifera are abundant. Its age is probably Pleistocene, although the lower part may prove to be Pliocene. The shoal-water nature of the limestone indicates continued slow subsidence.

The subsidence which apparently had been interrupted by no period of emergence since Oligocene time was succeeded in Pleistocene time by uplift to an amount of probably more than 100 feet. All the surface rock of the Bermudas except some in areas of low elevation is considered by the geologists who have visited the islands to be eolian deposits. However, certain of the published illustrations suggest that in some exposures there are in the bedding horizontal planes intersecting the inclined layers. Cross-bedding between horizontal planes is a structure characteristic of shoal-water or beach deposits but not of eolian deposits. A more critical study of the bedding of the Bermudian rocks may discriminate elevated cross-bedded water-laid and eolian deposits. However this may be, the period of uplift under consideration was the time of the Greater Bermuda, which has been admirably described by William North Rice, A. Agassiz, and A. E. Verrill. According to the latter, the area of Greater Bermuda was somewhat more than 230 square miles, or about 11 times that of the present land surface, which is estimated as having an area of 19⅓ square miles.[1] The evidence indicates that the elliptical area inclosed by the outer reefs was entirely above sea level, as perhaps also were the surfaces of Challenger and Argus banks.

The last important change in the relations of sea level was, as Verrill has so ably shown, submergence to an amount of about 100 feet, reducing the land area from that of 230 square miles during the period of Greater Bermuda to that of 19⅓ square miles, the present

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[1] Conn. Acad. Arts and Sci. Trans., vol. 12, p. 52, 1905.

area. The evidence is not decisive as to there having been a slight emergence, of 6 to 10 feet, since the great submergence.

As Verrill has shown, the Bermuda limestone is composed not of coral débris, except in a subordinate proportion, but is made up of broken, more or less triturated, calcareous tests, largely of mollusks. He designates the material as "shell sands." The Bermudas are, therefore, inappropriately called "coral islands." The recent corals are growing on a foundation of older lime rock, brought into its present relation to sea level by submergence.

In that the last dominant change in the position of its strand line was by submergence, Bermuda accords with the Florida coast, the Bahamas, Cuba, and most of the smaller West Indian islands.

FLORIDA.

Strand-line oscillation in Florida has attracted the attention of many geologists, among whom may be mentioned Shaler, Heilprin, and Dall of the earlier investigators, and Matson, Sanford, Sellards, Shaw, and myself of the later ones. Shaw and I have recently reviewed the subject.[1] That subsequent to formation of the Pleistocene barrier reef of Florida, the reef tract was elevated to a height about 50 feet above its previous stand and that this elevation was followed by submergence to an amount of about 30 feet is shown by (1) a submerged cave at Miami; (2) submerged solution well below sea level, near East Bahia Honda Key;[2] (3) submerged peat bed at Key West; (4) submerged indurated, cemented, recrystallized oolite under the Marquesas; (5) submerged wave-cut terrace front at Tortugas.

In addition to this evidence Shaw and I say in the paper cited:

> Additional deductions of importance may be made from the submarine physiography at depths beyond 10 fathoms. Although the investigations are at present only in a preliminary stage, it may be said that along the sides of the Gulf Stream from opposite Miami to Satan and Vestal Shoals, just west of Sand Key, the Coast and Geodetic Survey charts indicate fairly uniform slopes from 10 to 100 fathoms, but there may be narrow terraces which are not brought out by the soundings. West of Vestal Shoal the sea bottom drops suddenly from 10 to 20 fathoms, with a flat or gently sloping surface between 21 and 28 fathoms. South of Coalbin Rock there is an escarpment between 10 and 30 fathoms, a flat or gentle slope between 30 and 40 fathoms, and another flat or gently sloping area between 40 and 50 fathoms. The soundings are not sufficiently numerous to trace surfaces with a feeling of confidence, but the scarp from 10 to between 25 and 30 fathoms is clear cut and can be followed for 25 miles to the west end of the Quicksands. Westward in the vicinity of Tortugas there are, besides, the bottom of Tortugas lagoon and the surface of the shoal 7 to 10 miles west of Loggerhead Key, two undersea terrace plains, one at a depth of 15 to 17 fathoms, the other, which is a large plain west of Tortugas, ranges in depth from 28 fathoms on its landward to 36 fathoms on its seaward edge, and has an east and west width of 10 miles. The 15 to 18 fathom flat is especially well developed south and southwest of Tortugas. It is

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[1] Vaughan, T. W., and Shaw, E. W., Geologic investigations of the Florida coral-reef tract, Carnegie Inst. Washington Yearbook No. 14, pp. 232–238, 1916.

[2] Oral communication of Mr. Samuel Sanford.

separated by a scarp from the 28 to 36 fathom flat, and by another scarp from the shallower levels in Tortugas. The presence of the continuous scarp from Coalbin Rock to off the west end of the Quicksands, with a depth of 25 to 30 fathoms at its foot, and the presence of a terrace 28 to 36 fathoms deep, 10 miles wide, and bounded on its landward margin by a similar scarp, suggest that the portion of the Florida reef tract west of Key West at one time stood some 20 fathoms higher than now, while the 15 to 18 fathom terraces suggest another, shallower stand of sea level.

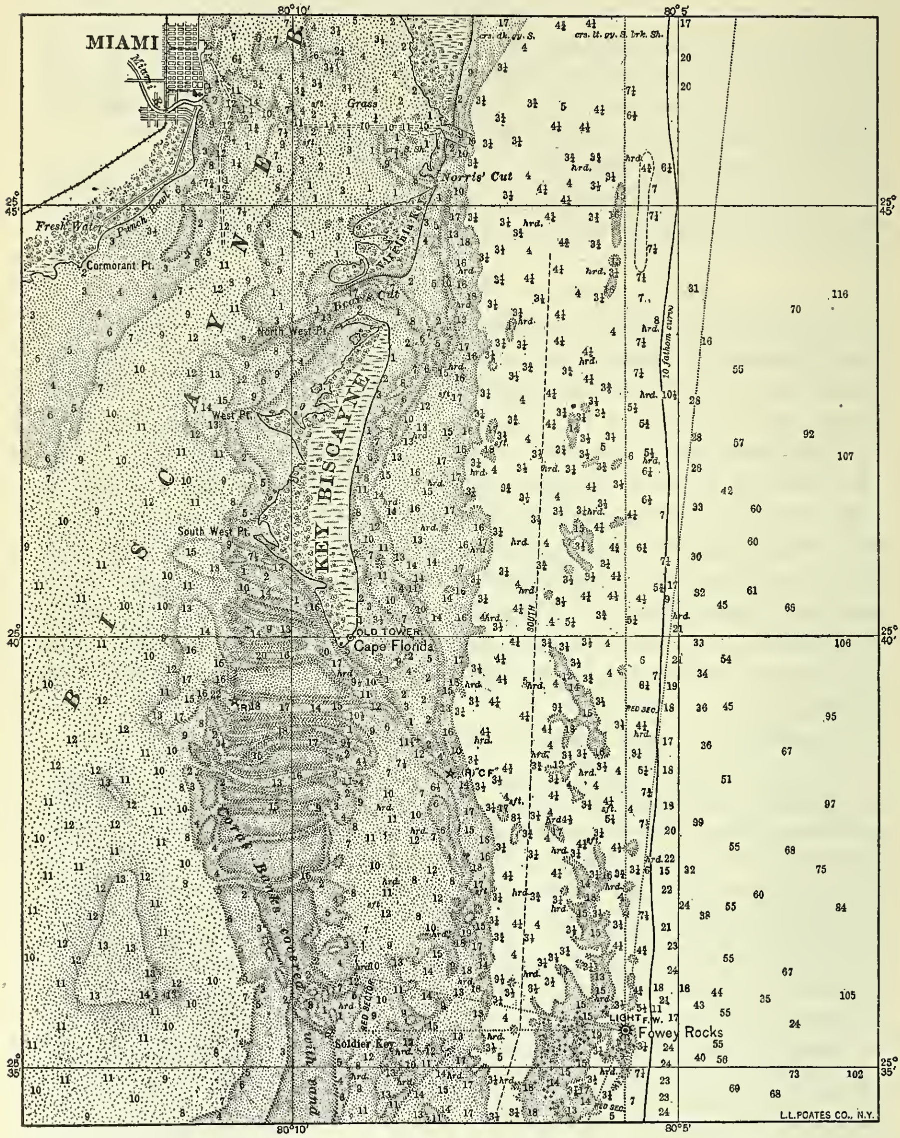

Fig. 18.—Chart of northern end of Floridian barrier reef. From United States Coast and Geodetic Survey chart no. 165.

Although the tracing of the oscillations of the Florida reef tract can not now be made in detail, it seems probable that it at one time stood more than 120 feet higher than at present (and has been submerged to a similar amount). Besides the suggested larger swing there have been intermediate stands of sea level and numerous minor oscillations. The last movement of importance was one of submergence, but subsequent to it there has been a minor uplift of some 10 feet or slightly more in the vicinity of Miami.

The accompanying figure (fig. 18) shows that the flat that the living barrier-reef margins or above which coral-reef patches rise extends beyond the northern reef limits, near Fowey Rocks. The living barrier reef has developed seaward of the Pleistocene barrier near the edge of a previously prepared platform, for the continuity of the platform irrespective of the presence of the reefs shows that its origin is independent of them.

CAMPECHE BANK.

The best known reef on the Campeche Bank is Alacran Reef, which was described by A. Agassiz in considerable detail in 1888.[1] (See pl. 73, photograph of model.) Heilprin in 1891[2] said regarding Yucatan, "the evidence is all but conclusive that there has been recent subsidence"; but I am unable to discover in his article the basis of this opinion. Dr. C. W. Hayes orally informed me shortly before his deeply lamented death that there is clear evidence of recent submergence around Terminos Lake at the base of the peninsula on its west side. The lagoons between Progreso and Holbox Island are strongly suggestive of submergence. There is a steeper slope between about 20 and 28 on the outer edge of the bank, indicating change in position of sea level by submergence, similar to the change already recorded for St. Thomas and other West Indian islands.

In this connection the following quotation from Alexander Agassiz will be introduced:[3]

> In fact, what I have seen so far in my exploration of the coral reefs of the West Indies would show that wherever coral reefs occur, and of whatever shape, they form only a comparatively thin growth upon the underlying base, and are not of great thickness. In Florida they rest upon the limestones which form the basis of the great peninsula. On the Yucatan Bank they are underlain by a marine limestone. In Cuba they abut upon the Tertiary limestones of its shore. Along Honduras, the Mosquito Coast, and the north shore of South America they grow upon extensive banks or shoals, parts of the shore plateau of the adjoining continent, where they find the proper depth.

I doubt if there is any one bold enough to claim that Campeche Bank has been formed by infilling behind a barrier reef, for it is too obviously due to a large gentle flexure of the earth crust or some other kind of broad structural uplift, and that in suitable places coral grows on the surface of the submarine plateau formed in the manner indicated. E. W. Shaw[4] collected a few bottom samples 6 to

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[1] Agassiz, A., Three cruises of the *Blake*, vol. 1, p. 71, 1888.

[2] Heilprin, A., Geological researches in Yucatan, Phila. Acad. Nat. Sci. Proc. for 1891, p. 148.

[3] Mus. Comp. Zool. Bull., vol. 26, p. 172, 1894.

[4] Shaw, E. W., Oral communication.

8 miles off shore at Progreso, and in these he found only two fragments of coral, the main mass of the samples being shell fragments.

HONDURAN REEFS.

Although this is an important barrier reef, its length being 125 sea-miles, I know of no adequate published description of it, nor of any published account of the shore line or of the oscillations of the strand line behind it. The configuration of Honduras Bay and of the Gulf of Dulce, which lies inland from it and is connected with it by a waterway, as well as that of Chetumal Bay, points clearly to submergence. The reef occupies the outer edge of a platform 10 to 22 miles wide and is separated from the shore by a channel from 11 to 33 fathoms deep. This is a remarkably continuous barrier reef, but it shows discontinuity at its southern end and therefore evidence of superposition.

MOSQUITO BANK.

Hayes, although he was not giving particular attention to coral reefs, has made one of the finest studies of a shore line in a coral-reef area as yet published.[1] The following is quoted from his article:[2]

> 7. In middle Tertiary time the region was elevated and subjected to long-continued subaerial degradation, and the narrower portion of the isthmus was reduced to a peneplain, with monadnocks at the divide near the axis. There is no evidence that open communication has existed between the two oceans across this portion of the isthmus since the middle Tertiary uplift.
>
> 8. In post-Tertiary time the region was again elevated and the previously developed peneplain deeply trenched.
>
> 9. A recent slight subsidence has drowned the lower courses of the river valleys, and the estuaries thus formed have subsequently been filled with alluvial deposits.

J. E. Spurr furnished me a note[3] confirming Hayes's deduction regarding the submergence of the lower courses of the streams on the east coast of Nicaragua. Subsequently I had profiles drawn across Mosquito Bank (see text fig. 11, page 275).[4] These indicate submergence to an amount of about 20 fathoms. As on Mosquito Bank there is a submerged terrace front between about 20 and 25 fathoms in depth, the bank had to exist previous to formation of that feature, and as the living reefs grow on the shallower flats, which according to available evidence was out of water during at least a part of Pleistocene time, they are necessarily superposed on an antecedent basement. Furthermore, the enormous area of the flat and the relatively small areas occupied by living reefs, lead to the same conclusion—that is, the living reefs are merely growing on parts of a submarine plateau where conditions favor their life.

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[1] Hayes, C. W., Physiography and geology of region adjacent to the Nicaragua Canal route, Geol. Soc. Amer. Bull., vol. 10, pp. 285-348, pls. 30-32, 1899.

[2] Idem, p. 348.

[3] Amer. Geog. Soc. Bull., vol. 46, p. 429, 1914.

[4] Wash. Acad. Sci. Journ., vol. 6, pp. 57, 62, 1916.

The shore-line phenomena of Panama and Costa Rica have been carefully described by D. F. MacDonald in his forthcoming report on the physiography and geology of the Canal Zone and adjacent areas. His conclusions in general accord with those I have expressed for other areas.

SOME OTHER WEST INDIAN ISLANDS.

R. T. Hill in 1899 [1] pointed out "that Jamaica was once a more extensive land than now, with benched and terraced margins which were submerged by subsidence," and that "similar submerged plains are now occupied by the growing reefs around the island." Hill appears to hold the view that the reefs were formed during uplift, after submergence, and as regards the elevated fringing reefs I believe he is correct. In fact, Mr. Meinzer and I make a similar interpretation of the conditions under which the coral-reef terraces of Cuba were formed. But, it seems to me that the barrier reef off Morant Point, Jamaica, has been formed after an episode of submergence. The pouch-shaped harbors of Jamaica suggest that considerable stretches of the Jamaica shore line have undergone recent submergence.

I have compiled information on the shore lines of other West Indian islands, but to present more seems unnecessary. Possibly except a reef off the southeast side of Barbados, all the off-shore West Indian reefs on which I have obtained information have formed on preexisting flats or plateaus during or after an episode of submergence.

BRAZIL AND ARGENTINA.

Herbert M. Smith,[2] it seems, was the first to recognize evidence of submergence on the east coast of South America, and Rich [3] has made a pertinent application of Smith's observations and deductions to the coral-reef problem. Smith says:

> Such an estuary as I have described could only have been formed by the subsidence of the land over a great area, and the encroachment of the sea on some former Amazons and its tributaries.

During late geologic time there is in the region of the Amazon evidence of a higher followed by a lower stand on the land.

Branner has made the most careful study of the shore line of Brazil, and summarizes his conclusions as follows: [4]

> 8. Although no changes of level are known to have taken place within the historic period, there are evidences of both elevation and depression of the Brazilian coast in late Geologic times.

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[1] Mus. Comp. Zool. Bull., vol. 36, pp. 99, 100.

[2] Smith, Herbert M., Notes on the physical geography of the Amazon Valley, Amer. Naturalist, vol. 19, pp. 27-37, 1885.

[3] Rich, John L., The physiography of the lower Amazon Valley as evidence bearing on the coral-reef problem, Science, new ser., vol. 45, pp. 589-590, June 8, 1917.

[4] Branner, John Casper, The stone reefs of Brazil, their geological and geographical relations, with a chapter on the coral reefs, Mus. Comp. Zool. Bull., vol. 44, pp. 168, 169, 1904.

9. The evidences of depression consist of:

(*a*) The open bays: Rio de Janeiro and Bahia.

(*b*) The partly choked-up bays, such as Santos and Victoria.

(*c*) The coast lakes formed by the closing of the mouths of estuaries such as Lagoa Manguaba, Lagoa do Norte, Jiquia, Sinimbu, etc.

(*d*) Embayments altogether filled up.

(*e*) The islands along the coast are nearly all close in shore and have the appearrance of having been formed by depression of the land.

(*f*) The buried rock channels at Parahyba, now filled with mangrove swamps and mud, show a depression of at least twelve metres since those channels were cut.

(*g*) Wind-bedded sand below tide level on Fernando de Noronba.

10. The evidences of elevation consist of:

(*a*) Elevated sea beaches especially well shown about the Bay of Bahia, and along the coast of the State of Bahia.

(*b*) Marine terraces about Ilheos in the State of Bahia. These are about eight metres above tide level.

(*c*) Horizontal lines of disintegration about one metre above high tide in granites and gneisses at and about Victoria, State of Espirito Santo.

(*d*) Burrows of sea urchins so far above low tide that sea urchins can not now live in them. These are well shown at Pedras Pretas on the coast of Pernambuco.

11. Of the two movements the depression has been much the greater and was the earlier.

12. The great depression probably took place in early Pliocene times.

Additional evidence in support of the submergence of the Brazilian coast is given by O. P. Jenkins.[1]

That the last dominant shift in the position of the strand line in eastern Brazil was by submergence, it seems to me, is incontrovertible, and that the Brazilian reefs are merely growing on the surface of a submerged continental shelf is too obvious to need defense. In these relations the Brazilian reefs accord with all other American offshore reefs, perhaps with the exception of the Barbadian reef specially mentioned on page 301. Professor Branner dates the submergence whereby the Brazilian harbors were brought into being, as Pliocene; whereas the submergence in the other areas discussed is clearly Recent. Without definite evidence I should not be justified in giving the drowning a later date than that assigned to it by Professor Branner; but I now know that I assigned too great antiquity to some physiographic features I considered about the same time that he was engaged on his work on the Brazilian stone reefs; for instance, the higher Cuban terraces are Pleistocene and *not* Pliocene, as I said in the Cuba report previously cited. May not the antiquity of the submergence of the Brazilian coast be less than Professor Branner inferred? May not both the submergence and the minor uplift following it be post-Pleistocene in age? Should the two events mentioned be geologically Recent; the shore-line history of Brazil would parallel that of eastern Central America.

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[1] Jenkins, O. P., Geology of the region about Natal, Rio Grande do Norte, Brazil, Amer. Philos. Soc. Proc., vol. 52, pp. 431-465, 1913.

Willis has directed attention to two areas of submergence by downwarping along the Argentine coast, namely, the embayment of the Rio de la Plata and Bahia Blanca;[1] but Barrell is of the opinion, from the character of the submarine profiles, that there has been submergence of the coast subsequent to the warping.[2] That there has been in late geologic time a rising of ocean level on the Argentine coast seems a justified deduction.

ATLANTIC COAST OF THE UNITED STATES NORTH OF FLORIDA.

That the last shift in position of strand line from the Georgia-Florida line at least to Narraganset Bay has been by submergence is so clearly shown by drowned stream mouths, resulting in estuaries and harbors, is so well known to geologists that no detailed presentation of evidence is necessary. Northward from near Boston there has been subsequent to submergence, emergence, probably due to crustal rebound after deglaciation and relief of the pressure exerted by the superincumbent continental glaciers.

TYPES OF WEST INDIAN AND CENTRAL AMERICAN LITTORAL AND SUBLITTORAL PROFILES AND THEIR RELATIONS TO CORAL REEFS.

In my paper on littoral and sublittoral physiographic features of the Virgin and northern Leeward islands,[3] I pointed out that there are four types of sublittoral profiles in the West Indies (see fig. 19) as follows: (1) That found off volcanic islands, such as Saba, into the sides of which the sea has cut relatively narrow platforms; (2) fault plane profiles, such as the north side of St. Croix; (3) wide undersea flats, where planation agencies have long been active, as off Anguilla and north of St. Thomas; (4) submarine banks, such as Saba, Pedro, and Rosalind, which have no bordering land, and whose upper surfaces lie between 9 and 30 fathoms below sea level. All of these areas have undergone geologically Recent submergence. Where do the offshore reefs occur?

There is no barrier reef on the fault slope on the north side of St. Croix. No reef started as a fringing reef, then increased in thickness and grew seaward so as to form a prism of coral-reef rock and material caught behind the reef, so as to become converted according to the Darwinian hypothesis into a barrier reef; but there is a barrier off the south side of the island, where gently dipping limestones pass below the sea and produce a platform on the surface of which at the proper depth a barrier reef has formed. Off the fault shore of the south side of Oriente province, Cuba, there is no barrier reef, but farther west, between Cape Cruz and Trinidad where there

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[1] Willis, Bailey, Geologic notes, in Hrdlicka, A., Early man in South America, Bur. Amer. Ethn. Bull. 52, pp. 16-18, 1912.

[2] Barrell, Joseph, Factors in movements of the strand line and their results in the Pleistocene and post-Pleistocene, Amer. Journ. Sci., ser. 4, vol. 40, p. 6, 1915.

[3] Washington Acad. Sci. Journ., vol. 6, pp. 53-66, 1916.

is a submerged flat underlain by gently dipping limestones there are offshore reefs, some of which have the barrier form. Where there are extensive offshore flats at the proper depths, if the other ecologic conditions are favorable, reef corals grow upon the surface of the flats and form either patches, stacks, or barriers.

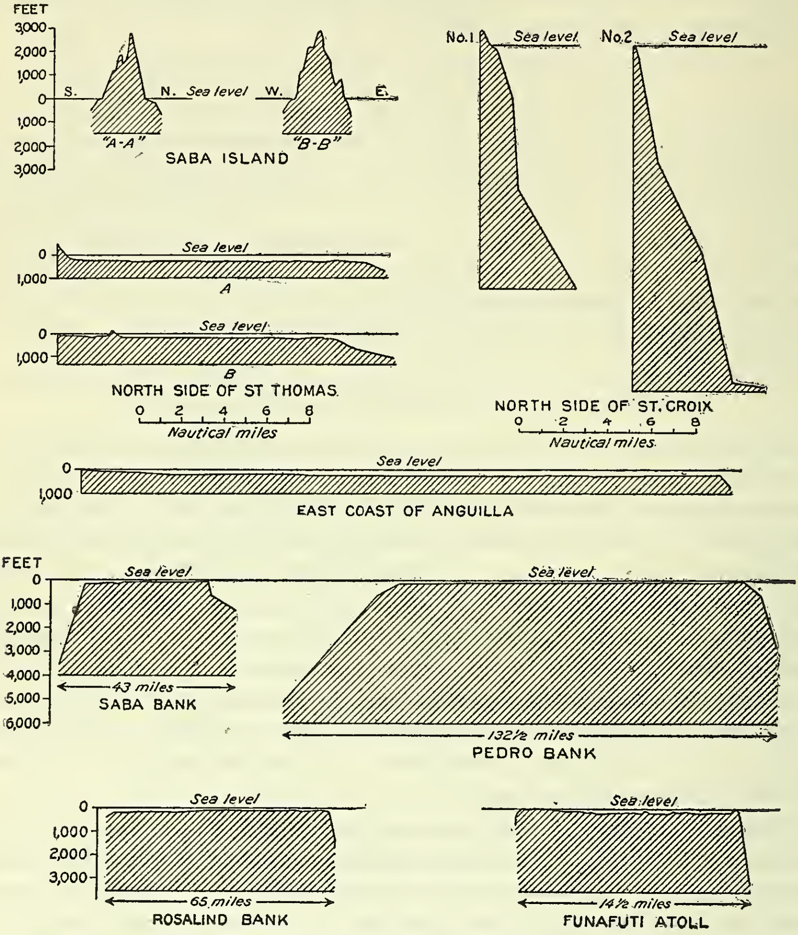

FIG. 19.—TYPES OF WEST INDIAN SUBLITTORAL PROFILES AND PROFILE OF FUNAFUTI ATOLL.

It seems that no one would try to explain Saba, Rosalind, or Pedro Bank as the result of infilling behind barrier reefs. They are submarine plateaus, leveled by planation agencies, which almost certainly were both subaerial and submarine, and they have been submerged in Recent geologic time. There is a rather meagre growth of reef corals on their windward sides; but these banks are scientifically of great importance, for, except that the coral growth is not so luxuriant, they essentially duplicate the great atolls in the Pacific.

SUBMERGED BANKS NORTH OF THE CORAL REEF ZONE IN THE WESTERN ATLANTIC OCEAN.

That there are off the Atlantic coast of Central and North America, north of the temperature zone in which coral reefs now exist, submarine banks at suitable depth below sea level for the growth of reef-forming corals, has been stated in several of my papers.[1] There are six submarine banks projecting seaward from the eastern part of Central and North America. Named in order from the south northward these banks are, first, three on which there are coral reefs, namely, Mosquito Bank off Nicaragua and Honduras, Campeche Bank off Yucatan, and the Floridian Plateau; and, second, three on which there are no coral reefs, namely, Georges Bank, the banks off the coast of Nova Scotia, and the Grand Banks of Newfoundland. The presence of such banks is entirely independent of corals, but corals will grow on the surface of such banks where the necessary ecologic conditions prevail.

SUMMARY OF THE CONDITIONS UNDER WHICH THE AMERICAN FOSSIL AND LIVING CORAL REEFS FORMED.

1. The elevated Pleistocene fringing reefs of the West Indies are separated by erosion unconformities at their bases from the geologic formations that they overlie, but they were usually, if not invariably, formed during intermittent uplift following considerable depression.
2. The offshore reefs, whether forming parts of more or less bedded formations or forming patches, stacks, or barriers of living reef, were formed during or after submergence, as is shown in the case of the fossil reefs by unconformable basal contacts wherever basal contacts could be studied, and in the case of the living reefs by a great variety of evidence indicating geologically Recent submergence.
3. The offshore reefs grew upon or are growing upon antecedent flats, only a small part of the surface of which was or is covered by reefs. The flats existed prior to the submergence during or after which the reefs developed. Corals are constructional geologic agents and help build up the sea bottom, but the large flats on which they grow would exist were there no corals. Such flats are not confined to the temperature zone in which corals live.
4. The submergence of the basements of the fossil reefs seems more reasonably explained as the result of differential crustal movement; but the development of the living reefs seems in large part a result of geologically Recent rise in the stand of ocean level, for nearly the entire eastern shore of the Americas from Argentina on the south to Cape Cod on the north exhibits evidence of Recent submergence, after which there has been in some places minor emergence by differential crustal movement. The amount of the submergence usually seems

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[1] Science, new ser., vol. 41, pp. 508, 509, April 2, 1915; Geol. Soc. Amer. Bull., vol. 26, pp. 58–60, 1915; Amer Journ. Sci., ser. 4, vol. 41, p. 134, 1916; Carnegie Inst. Washington Yearbook No. 14, p. 238, 1916.

to be about 20 fathoms, but in places some facts indicate that the maximum is between 30 and 40 fathoms. Although more accurate investigations of the amount of the submergence are needed, the available evidence accords with the hypothesis that glacial control is one of the important factors in bringing about the formation of living coral reefs.

Coral reefs of the Pacific Ocean.

It is manifestly impracticable to consider in this chapter more than a few of the important reefs of the Pacific Ocean. Those selected for discussion are the Great Barrier of Australia, the barrier reef off New Caledonia, and those off the Fiji and Society islands. Finally a few paragraphs will be devoted to atolls.

GREAT BARRIER REEF OF AUSTRALIA.

The literature on the Great Barrier Reef is very extensive, and includes contributions from numbers of investigators, among whom Jukes, Saville-Kent, H. B. Guppy, Alexander Agassiz, A. C. Haddon, Wood Jones, E. C. Andrews, C. Hedley and Griffith Taylor, Edgeworth David, W. M. Davis, and A. G. Mayer may be mentioned. R. A. Daly and I have based statements regarding it upon cartographic studies. No attempt will here be made to review all the literature, and attention will be mostly confined to those papers that, in my opinion, correctly interpret the relations of the reef.

Andrews in 1902 published a remarkable paper [1] on the shore line of Queensland and the platform on which the Great Barrier Reef stands. This paper contains an excellent account of the physiography of the Queensland coast, applying the deductions based upon the physiographic study to the conditions under which the reef developed, and in it is recognized the significance of a continuous platform and an interrupted reef. Because of the embayed shore line Andrews correctly inferred submergence of the Australian continental shelf, and he makes the important statement:

> * * * the continuance in width of the shelf southwards of the limits of reefs (coralline), and the great shoals thereon, points to a minor part only of the shelf being formed of coral growth.[2]

A few years later Hedley and Griffith Taylor published a valuable paper on the same subject.[3] They accepted Andrews's deduction

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[1] Andrews, E. C., Preliminary note on the geology of the Queensland coast with references to the geography of the Queensland and N. S. Wales Plateau, Linn. Soc. N. S. Wales, Proc. for 1902, pt. 2, pp. 146–185, 1902.

[2] Idem, p. 177.

[3] Hedley, C., and Taylor, T. Griffith, Coral reefs of the Great Barrier, Queensland: A study of their structure, life distribution, and relation to mainland physiography, Australasian Assoc. Adv. Sci., Adelaide Meeting, Jan. 1907, pp. 394–413, 3 pls. 1908.

regarding submergence and devoted particular attention to the effects of wind-induced currents in shaping atolls. They also say:

> It may be allowed, though Darwin deprecated the idea, that the continental shelf was ready prepared with numerous banks representing eroded islands, just reaching to within the required distance of the surface, when the first coral builders came.[1]

On a subsequent page they add:

> Whatever the history of the Great Barrier Reef was, the reefs of the Coral Sea, such as Lihou Reefs, Flinders Reefs, and Herald Cays, shared in it.[2]

I have stated in one of my papers:[3]

> An inspection of the admiralty charts for the eastern coast of Australia shows conclusively that the platform on which the Great Barrier Reef of Australia stands has an existence independent of the Great Barrier Reef, and that corals have established themselves on this platform where the conditions favorable for their life are realized.

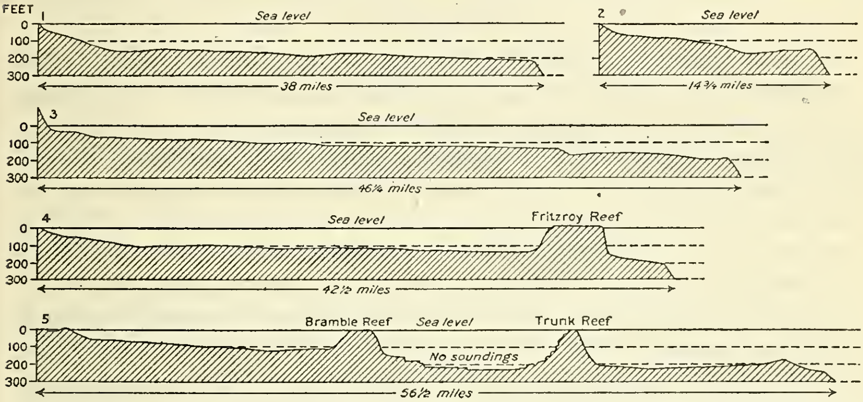

FIG. 20.—PROFILES ACROSS CONTINENTAL SHELF, EAST SIDE OF AUSTRALIA. THE LATITUDE AT THE INTERSECTION OF EACH PROFILE WITH THE SHORE LINE IS FOLLOWED BY A STATEMENT OF THE DIRECTION OF THE PROFILE FROM THE SHORE.

SOUTH OF THE SOUTHERN END OF THE GREAT BARRIER REEF:

1. FROM SHORE EAST OF LEADING HILL, S. LAT. 25° 26′ 15″, SOUTH 82° EAST.
2. FROM BASE OF SANDY CAPE, S. LAT. 24°, 53′ 40″, NORTH 68° EAST.
3. FROM TOOWONG HILL, S. LAT. 24° 22′ 4″, NORTH 45° EAST, PASSING BETWEEN LADY ELLIOT AND LADY MUSGROVE ISLANDS.

ACROSS THE GREAT BARRIER REEF:

4. FROM RODD PENINSULA, S. LAT. 24° 0′ 0″, NORTH 50° EAST.
5. FROM GEORGES POINT, HINCHINBROOK ISLAND, S. LAT. 18° 25′ 40″, NORTH 72° 30′ EAST.

Daly has given cross-sections of the Australian shelf both south of and across the Great Barrier Reef in two of his papers,[4] and I have presented a series of cross-sections in one of mine,[5] both of us basing our profiles on the British Admiralty charts. There is one important fact shown by both Daly's and my profiles, but which Daly seems not to have emphasized. It is that the platform not only continues

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[1] Coral reefs of the Great Barrier, Queensland, p. 406.

[2] Idem., p. 413.

[3] Washington Acad. Sci., Journ., vol. 4, p. 32, 1914.

[4] Daly, R. A., The glacial-control theory of coral reefs, Amer. Acad. Arts and Sci., vol. 51, p. 197, figs. 21–24, 1915; Problems of the Pacific Islands, Amer. Journ. Sci., ser. 4, vol. 41, p. 179, figs. 26–29, Feb. 1916.

[5] Washington Acad. Sci. Journ., vol. 6, p. 64, profiles Nos. 1–5, 8–14, 1916.

southward from the reef limits, but in many places the barrier reef stands not on the margin of the shelf but miles landward from the edge. (See text-fig. 20.) There is also a significant terrace front at depths somewhat deeper than 120 feet. These profiles should be compared with those for the West Indies (fig. 11, p. 275). They tell essentially the same story. The platform can not be due to the presence of the Great Barrier Reef, for in many places it projects beyond the reef. I state in my paper cited:

> The evidence in favor of a shore line between 25 and 30 fathoms below present sea level is strong, if not conclusive, and supports the deduction that the living barrier reef is growing on what was a land surface in Pleistocene time, an interpretation essentially that proposed by E. C. Andrews in 1902.[1]

NEW CALEDONIA.

I have seen no good account of the coast of New Caledonia, off whose shores is one of the most important barriers known. According to P. Marshall, [2]"the northeast coast is practically straight, but many inlets that form excellent harbours penetrate the southwest coast." The chart shows indentations in the north coast, although they are not so deep as those on the south. I find references to the shore-line features in two of Professor Davis's papers,[3] and from them certain information may be obtained. The shore line is embayed, there are deltas mostly contained in the embayments between headlands that are strongly cliffed on the sea front. The present barrier reef has developed subsequent to the truncation of the headlands and subsequent to the submergence that has caused the embayment of the coast. Just how much of the platform surmounted by the

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[1] W. M. Davis has published since the manuscript of this paper went to press an article entitled: The Great Barrier Reef of Australia (Amer. Journ. Sci., vol. 44, pp. 339-350, Nov., 1917), in which he criticizes me and others because we have not "satisfactorily explained" the origin of the form of "the continental mass." Among the statements of Professor Davis is "Vaughan's view is based on the physiographic investigations of parts of the eastern coast of Australia by Andrews (1903); * * *", after he had introduced two quotations from my paper on the littoral and sublittoral physiographic features of the Virgin Islands, etc., as given in abstract (Amer. Geolog. Soc. Bull., vol. 27, pp. 41-45, 1916). Professor Davis has drawn an erroneous deduction regarding my cartographic studies of the Great Barrier Reef. They could not have been based on Andrew's work, because Andrews neither published nor made comment on a series of profiles across the Australian platform, such as those I had prepared. Furthermore, my emphasis of the fact, which it seems I was the first to point out—namely, that the present Great Barrier Reef in places stands some miles landward from the margin of the continental shelf—and my deduction therefrom, that the platform can not be attributed to infilling behind the reef, do not warrant the inference that "Vaughan * * * has excluded coral-reef agencies from any part in forming the platform itself * * *." I not only do not know how the Australian continental shelf was formed, but I do not know how any one of a number of hypothesis can be tested. I, therefore, endeavored to confine my discussion to matters on which evidence is procurable, and said nothing regarding the origin of the platform. Professor Davis advances the hypothesis that the platform on which the present Great Barrier is growing is a "mature reef-plain", formed in a previous physiographic cycle, and that it has been recently submerged. Whether reefs in past geologic time formed a rampart on the edge of the Australian continental shelf and a plain resulted from infilling behind the barrier can at present be neither proved nor disproved and on this subject I have expressed no opinion.

[2] "Oceania," Handb. regionalen Geologie, vol. 7, Abt. 2, p. 23, 1912.

[3] Davis, W. M., Shaler Memorial study of coral reefs, Amer. Journ. Sci., ser. 4, vol 40, pp. 232, 233, 240 243, 245, 270, 1915; Problems associated with the study of corals, The Scientific Monthly, vol. 2, fig. 15 on p 25, p. 27, 1916.

Caledonian barrier is due to the cut and fill process of marine planation at and below sea level during the cliffing of the promontories and to the sediment deposited in the sea, derived through the erosion of mature valleys, I can not say with certainty, but that so much material deposited in the sea would under the influence of waves and currents form a submarine plain is a warranted deduction; and as the barrier reef is crossed by gaps and is discontinuous at both the southeast and northwest ends, the deduction seems safe that it is superposed on a submerged platform of antecedent existence.

FIJI ISLANDS.

That the barrier reefs off the Fiji Islands have developed during or after submergence of their basements is obvious from an inspection of the charts to anyone familiar with the physiography of shore lines. The numerous reproductions of British Admiralty charts in A. Agassiz's volume on the Fiji Islands[1] is valuable and convenient for such a cartographic study. That the indentations of the shore line in the Fijis are due to the drowning of the lower parts of subaerially formed valleys has been pointed out by many geologists, the first of whom appears to have been Dana, who says:[2]

> There is, further, not merely probable but positive evidence of subsidence in the deep coast indentations of the high islands within the great barriers. The long points and deep fiordlike bays are such as exist only where a land, after having been deeply gouged by erosion, has become half submerged. The author was led to appreciate this evidence when on the ascent of Mount Aoraion Tahiti, in September of 1839. Sunk to any level above that of five hundred feet the erosion valleys of Tahiti would become deep bays, and above that of one thousand feet, fiordlike bays, with the ridges spreading in the water like spider's legs; and this is a common feature of the islands and islets within the lagoons of barrier islands. The evidence of subsidence admits of no doubt. It makes the conclusion from the Gambier group positive; and equally so that for Raiatea and Bolabola represented on the charts in Darwin's "Coral Islands;" the Exploring Isles and others of the Fiji group; and that for islands, great and small, in the Louisade Archipelago and in other similar groups over the ocean.

This statement was misinterpreted by Davis as being confirmation of Darwin's theory of coral reefs,[3] which, as is more than once pointed out in the present paper (see especially p. 249), carries with submergence an hypothesis of platform building. Evidence of subsidence does not prove that the flat lying between a barrier reef and the shore has been formed by infilling behind the barrier.

Daly made a definite statement in 1910 in a list of "maximum depths recorded for the drowned portion of these valleys," in which

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[1] Agassiz, Alexander, The Islands and Coral Reefs of Fiji, Mus. Comp. Zool. Bull., vol. 33, pp. 167, 112 plates, 1899.

[2] Dana, J. D., Corals and coral islands, ed. 3, pp. 273, 274, 1890.

[3] Davis, W. M., Dana's confirmation of Darwin's theory of coral reefs, Amer. Journ. Sci., ser. 4, vol. 35, pp. 173-188, Feb. 1913.

he includes Mbengha and Moala of the Fiji group.[1] Subsequently Davis, in several of his papers, cited and others have similarly interpreted the estuarine character of the lower ends of the valleys.

Were the platforms on which the Fijian reefs stand, or which they margin, formed by infilling behind barriers or are the reefs merely superposed on antecedent platforms? In 1914 I published the following statement:

> Having presented criteria for recognizing the relations of continental and large insular platforms supporting barrier reefs to the presence of the reefs, islands such as those in the Society and Fiji groups may be considered. * * * A study of the charts of barrier reef islands, as Viti Levu, Fijis, and Tahiti, Society Islands, shows that the platforms are independent of the presence of reefs, and therefore the relations in these islands are similar to those indicated for barriers off continental shores, for here the reefs are also superimposed on platforms antedating their presence.

Plate 7 of Agassiz's work on the Fiji Islands, already cited, shows the continuity of the platform northward and westward from Ovalau without any margining barrier reef. In my opinion these relations clearly show that the reef, where it is present, is merely superposed on an antecedent platform, and that the suggestion of Davis, that the entire platform is due to infilling behind a reef which in places has ceased to grow, is farfetched.

Recently E. C. Andrews and W. G. Foye have published important papers on the Fijis. Andrews in his paper says:

> The Viti Levu salt water arms, therefore, with their contained deltas, suggest the submergence of the Viti Levu coastal lowland in recent time, with the consequent drowning of the lower portions of the river courses.
>
> The island is girt with a Great Barrier Reef, several hundreds of miles in length, broken here and there by passages. The present Great Barrier Reef, which rises to the level of the sea, has thus, in all probability, been built up by coral-reef organisms upon the submerged lowlands of Viti Levu.[2]

Andrews similarly interprets the conditions of development of the barrier reef off Vanua Levu. The interpretations advanced by Andrews essentially accords with mine; that is, the reefs are superposed on a depressed platform that was previous to its submergence a coastal lowland.

Foye [3] makes the following statement regarding Viti Levu:

> In general the present coral reefs are developing on platforms which originated during the deposition of the coastal series.[4]

Regarding Vanua Levu he says:

> I visited only the eastern and central portions of Vanua Levu. The modern fringing reefs are here developing either along the shore line of recently submerged volcanic rocks or on coastal flats formed of the fine ash swept from the elevated hills of sub-

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[1] Daly, R. A., Pleistocene glaciation and the coral reef problem, Amer. Journ. Sci., ser. 4, vol. 30, p. 306, November, 1910.

[2] Andrews, E. C., Relations of coral reefs to crust movements in the Fiji Islands, Amer. Journ. Sci., ser. 4, vol. 41, p. 138, 1916.

[3] Foye, W. G., The geology of the Fiji Islands, Acad. Nat. Sci. Proc., vol. 3, pp. 305-310, April, 1917.

[4] Idem. p. 306.

> marine tuffs. The most recent movements have been differential, and while uplift has taken place at the southeastern side of the island, subsidence has occurred to the east and north. The modern barrier reef occurs where subsidence has taken place either due to tilting or faulting during uplift.[1]

Concerning the Lau Islands, he states:

> Within quite recent times the islands have subsided 50 to 90 feet and the modern coral reefs are developing on the eroded and submerged platforms.[2]

One paragraph of Foye's conclusions is as follows:

> The data assembled by Daly and Vaughan convince the writer that Pleistocene platforms exist very generally throughout the coral seas. Yet while this is true, the platforms in Fiji are post-Pleistocene in their development. The writer was unable to discover any evidence of Pleistocene wave-cut platforms.[3]

The second one of Foye's papers[4] contains the following significant statement:

> There is another method by which atolls develop. The limestone islands are rapidly eroded to sea level by atmospheric solution. Evidence of this process may be seen in the diminishing limestone masses within the lagoons of many of the Lau islands. By tidal scour and wave action platforms are developed slightly below sea level. Examples of such platforms may be seen about Fulanga and Ongea. It is significant, however, that most of these islands have lagoons 10 to 15 fathoms in depth. Such depths can not be ascribed to erosion, but must be the result of recent submergence. * * *

The information bearing on the Fijis may be summarized as follows:

1. The fringing reefs have unconformable basal contacts, as do those of the West Indies.
2. The barrier reefs are superposed on antecedent platforms of diverse origin during or after submergence.
3. The submergence is concomitant with, if not actually due to, differential crustal movement.
4. In that they were formed during or after submergence and are superposed on antecedent platforms, the offshore reefs of the Fijis accord with all others, perhaps except a Barbadian reef, so far considered.

SOCIETY ISLANDS.

TAHITI.

That Tahiti had undergone subsidence is implied in statements by Dana,[5] the occasional harbors being mentioned in two places in his book. W. M. Davis says:[6]

> The cliff-rimmed island of Tahiti, the largest and youngest of the group, has suffered moderate subsidence after its cliffs were cut, but its bays are now nearly all filled with delta plains; hence a pause or stillstand has followed its latest sinking.

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[1] The geology of the Fiji Islands, Acad. Nat. Sci. Proc., p. 308, April, 1917.

[2] Idem, p. 309.

[3] Idem, p. 309, 310.

[4] Foye, W. G., The geology of the Lau Islands, Amer. Journ. Sci., ser. 4, vol. 43, pp. 343-350, May, 1917.

[5] Corals and coral islands, ed. 3, pp. 149, 158, 246, 247, 1890.

[6] Amer. Journ. Sci., ser. 4, vol. 40, p. 271, 1915.

The condition of the reef between Taunoa Pass and Point Venus is interesting in this connection. Alexander Agassiz has given a good description of this part of the reef and reef platform and has reproduced the British Admiralty chart of it.[1] Agassiz says:

> Reef patches, the remnants of a former barrier reef, extend westward from Venus Point parallel with the shore of Matavai Bay, forming the chain of Toa Tea reefs, but they are merely patches of Nullipores, with here and there diminutive coral heads which have taken no part in the building of these reefs.

There is along the Toa Tea Reefs a great break in the continuity of the reef, but the platform continues, irrespective of the presence or absence of a margining barrier. The depths in Matavai Bay, 16 to 17 fathoms, seem to be the maximum, are about the same as in Papiete Harbor, outside which there is a well-developed reef crossed by Papiete Pass. These reefs, also, seem to me to have grown up disconnectedly on a submerged coastal flat.

SMALLER ISLANDS OF THE SOCIETY GROUP.

Alexander Agassiz has described each of these islands in his coral reefs of the Tropical Pacific,[2] and P. Marshall has made the observations and deductions recorded in the following quotation:[3]

> This reef marks the edge of the platform of marine erosion as described by Agassiz, but the original margin of the land before depression as described by Darwin and Dana. * * *
>
> It is evident that if the coral reef rises on the edge of a platform of marine erosion this very erosion would have worn the spurs back in such a way that they would terminate in steep cliffs. In no instance at Huaheine, Raiatea, or Tahiti that the author observed, did the spurs have an abrupt termination. The lower slopes of the islands are in all cases notably less steep than the upper slopes.
>
> The deep inlets that intersect the coast line of Huaheine, Tahaa, and Raiatea are clearly due to stream erosion. Prolonged marine action would have shallowed or filled them up or at least would have built up bars of coastal débris across the entrances.
>
> The author is therefore strongly of opinion that the absence of cliffs at the termination of radiating spurs, the presence of deep water in the lagoon, and of far-reaching inlets, prove that marine erosion has not had any influence on the form of these islands at the present sea level. * * *
>
> Finally the deep inlets appear to be drowned stream valleys and their nature strongly supports the belief that they have been subjected to an important movement of subsidence.

Mehetia is interesting in that it is a young volcanic island, with a strongly cliffed shore, a very narrow or no platform, and no coral reefs around it, only a few coral patches. That the other islands, Murea, Huaheine, Raiatea, Tahaa, Bora-Bora, and Maupiti have undergone geologically Recent submergence and that the barrier reefs have developed during or after submergence, can not be controverted. Is the reef flat due to marine planation and to terrigenous sediments

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[1] Agassiz, Alexander, The coral reefs of the Tropical Pacific, Mus. Comp. Zool. Mem., vol. 28, pp. 152-154, pl. 209, 1903.

[2] Idem, pp. 140, 141, 156-167.

[3] Marshall, P., Oceania, Handb. regionalen Geologie, vol. 7, Abt. 2, p. 13, 1912.

carried by the streams to the sea prior to the submergence after which the living reefs have formed? Unless sediment was delivered to the sea so rapidly that a coastal plain pushed forward beyond the interstream divides as to protect them from attack by the sea, their seaward ends should have been cliffed, should the flat have been formed in the manner suggested. What are the submarine profiles off the spur ends? Are there submerged cliffs at the divide tips? One of Agassiz's illustrations[1] represents a cliff of considerable height at one place on the shore of Maupiti. In my opinion sufficient evidence is not available to establish how the reef flats of these islands were formed, and they may be made to accord with whatever theory of reef-flat formation an author may prefer. Should it ultimately be proved that these barrier reefs accord with the Darwinian hypothesis, a few instances in which that hypothesis applies will have been discovered.

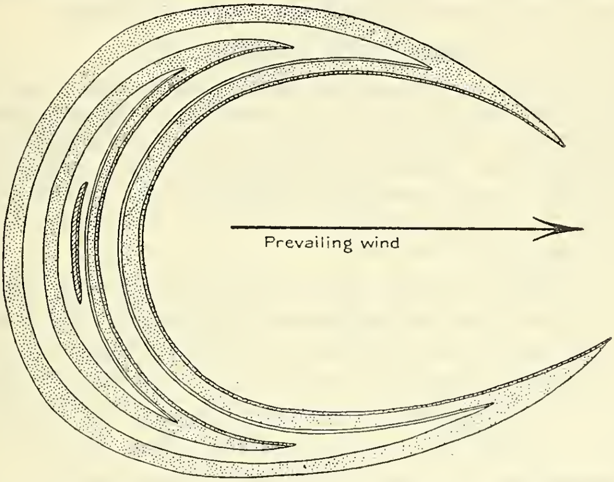

FIG. 21.—DIAGRAM TO SHOW HOW A LINEAR REEF LYING ACROSS THE WIND IS FORMED INTO A HORSESHOE. (AFTER HEDLEY AND GRIFFITH TAYLOR.)

ATOLLS.

There are two kinds of atolls: Those of the first kind rise above relatively shoal-water platforms, and are represented by the atolls of the Great Barrier Reef of Australia, those of the Floridian reef-tract, and the *faros* of the Maldives. That there was never any central land area for these atolls is perfectly obvious. Hedley and Griffith Taylor, in their paper, cited on pages 245, 251, have shown how the atolls along the Great Barrier have been shaped by the prevalent, mostly wind-induced, currents; and I have shown in my papers on the Marquesas and Tortugas atolls that precisely the same principles apply to them. The principles involved are illustrated by the accompany-

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[1] The Coral Reefs of the Tropical Pacific, pl. 104, fig. 4.

ing diagram (fig. 21), which is copied from Hedley and Griffith Taylor. Stanley Gardiner has given good descriptions of the faros of the Maldives.[1] He says in a footnote on the page referred to:

> The technical term *atoll* is derived from the Maldivan *atolu*, signifying a province for governmental purposes. There are 13 of these in the Maldives, and many consist of the islands on separate banks, most of which have distinct encircling series of reef reaching the surface. Many of the individual reefs are themselves ring-shaped with pools of water several fathoms deep in their centers. There are obvious disadvantages in using diminutives of the terms *atoll* and *lagoon* as applying to such. They are situated on shallow banks, and many are actually larger than some of the isolated ring-shaped reefs of the Pacific, which arise separately in the deep basin of that ocean. I therefore propose to borrow further the Maldivan terms, *faro* and *velu*, the former signifying such a small ring-shaped reef of an atoll or bank and the latter its central basin. I, further, following the Maldivan use of the term *velu*, apply it to deep pools even in the long, linear, circumscribing reefs of many of the banks, as I conceive that such pools have in all these reefs on banks the same mode of origin.

On page 171 of the same work, Gardiner says:

> Each large reef on the bank is a separate entity that has grown up and pursued its history by itself, influenced it is true by the reefs in its vicinity but never directly connected with them. It is only now that the bank is at all approaching the condition of the perfect atoll. Having seen how small faro may be formed from their earliest beginnings, we now see in North Mahlos the further fortune of such atolls. their joining together where possible to form long linear reefs with the loss perhaps of the whole inner part of their own reefs.

The second kind of atolls more or less margin and more or less completely encircle the flat summits of eminences rising from oceanic depths. The Darwinian explanation of the formation of such atoll rings is illustrated by figure 5, page 242, of this paper. Have these atolls formed in accordance with the postulates of the Darwinian hypothesis, or have more or less perfect rings developed on the edges of submarine flats, with or without submergence?

The origin of the first kind of atolls has been ascertained with so high degree of probability that it amounts to certainty. They have been formed on relatively shoal submarine flats, during or following submergence, and have been shaped by the prevalent currents. But a basement platform for the second kind of atolls can not be traced beyond the atoll limits, at least in our present state of knowledge. However, in case of atolls of an area so large as Rangiroa, in the Paumotus, for instance, the presumption is against their derivation from barrier reefs according to the Darwinian hypothesis. They are too large, and, as Wharton long ago pointed out, their bottoms are too nearly level. If the Darwinian explanation were true, lagoon floors should be concave, more or less bowl shaped. That small, flat, summit areas may result from subaerial degradation and marine planation is known in many instances. That volcanic

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[1] Gardiner, J. Stanley, The fauna and geography of the Maldive and Loccadive Archipelagoes, vol. 1, pt. 2, p. 155, 1901-1903.

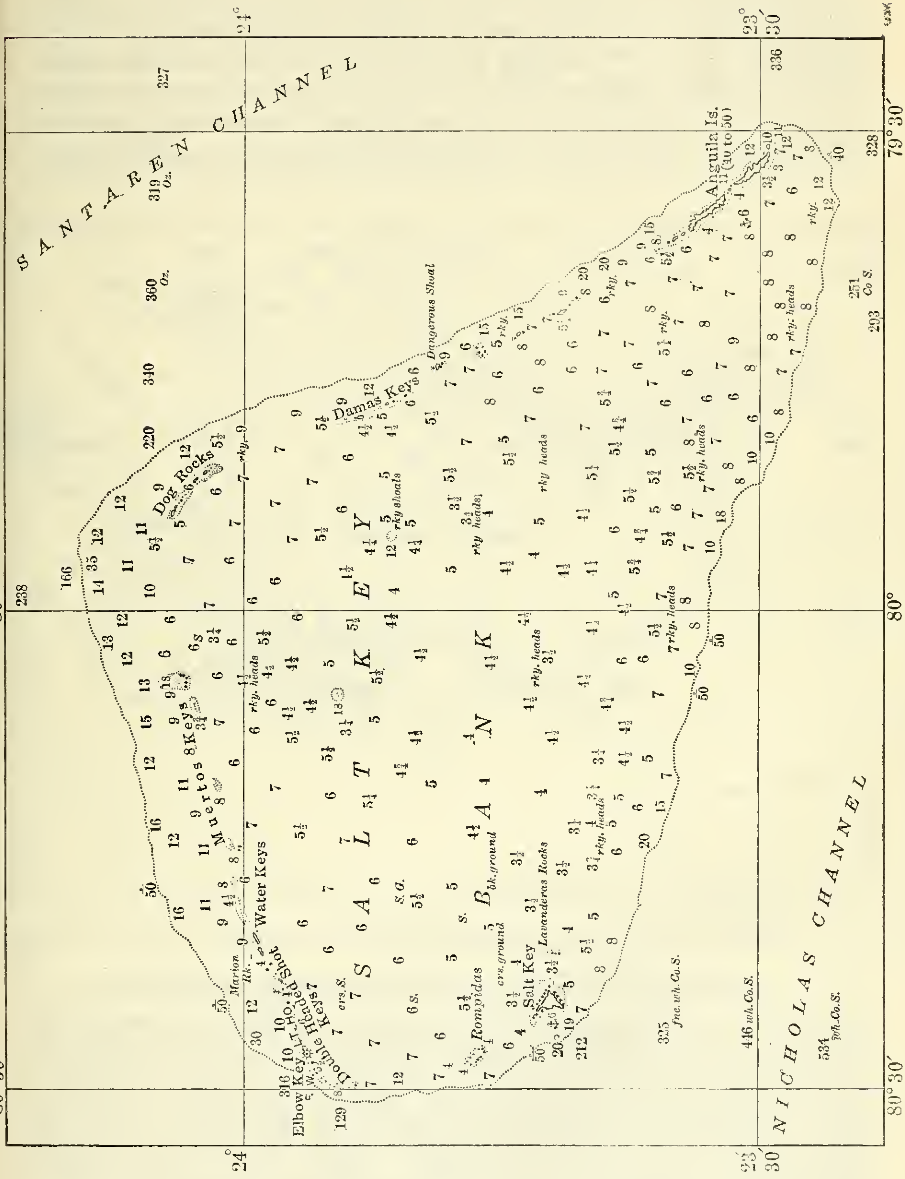

FIG. 22.—CHART OF SALT KEY BANK. FROM U. S. COAST AND GEODETIC SURVEY CHART NO. 15.

piles may be cut to wave base is known, and on page 311 of this paper Foye is quoted on a process by means of which reduction of limestone masses to sea level or slightly below sea level is accomplished.

In this connection Salt Key Bank, which lies between the Straits of Florida, Santaren Channel, and Nicholas Channel (text-fig. 22), is interesting, as it is 61 nautical miles long by 37 nautical miles wide. Except a few marginal islets and elongate keys, it ranges between 3½ and 8 fathoms in depth. Alexander Agassiz visited and described this bank [1] and says that it is composed of eolian rock similar to the Bahamas. The bank looks as if it were once a part of the Bahamas and was dissevered by faulting between it and the Bahamas. Whether that suggestion is or is not true, there is here a large level bank, obviously not formed according to the Darwinian hypothesis, that might serve an atoll foundation. Saba, Pedro, and Rosalind banks in the Caribbean Sea have been mentioned on pages 303, 304. Figures 23–25 illustrate them.

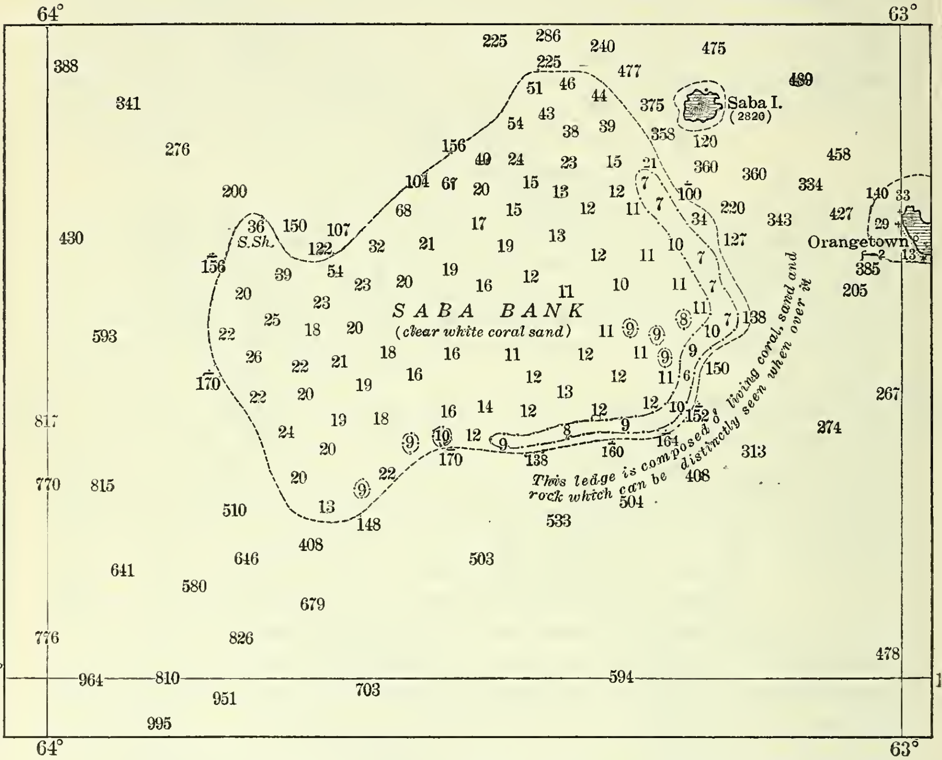

Fig. 23.—Chart of San Saba bank. From U. S. hydrographic chart No. 2318.

It is not practicable to work out the geology of the foundations of the Paumotuan and the Maldive and Laccadive atolls, but the

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[1] A reconnaissance of the Bahamas, etc., Mus. Comp. Zool. Bull., vol. 26, p. 81, pls. 1 and 31, 1894.

probability seems distinctly in favor of their being submerged plateau surfaces, upon which coral reefs, mostly marginal, have established themselves during and subsequent to moderate submergence.

I will revert to Admiral Wharton's emphasis of the levelness of the floors of atoll lagoons (depth 24 to 26 fathoms), to his statement, "inside the low rim of growing coral which encircles their edges in various degrees," and to his question "What causes this remarkable similarity of depth and this extraordinarily even surface over these large banks?" As I believe this short article by Admiral Wharton is one of the truly great contributions to our knowledge of coral reefs, the temptation to quote all of it is great. In it he points out one of the fundamental defects of the Darwinian hypothesis, namely, that the lagoon floor is not basin shaped as it should be if the atoll is due to the upgrowth of a reef that began on the slopes of a volcanic cone. He says: "I have no hesitation in saying that a flat floor is an invariable characteristic of a large atoll, and I can not find his 'deeply concave surface' in any large atoll. On the contrary, a flat surface is found in all of these, whether the rim be above or below the surface."

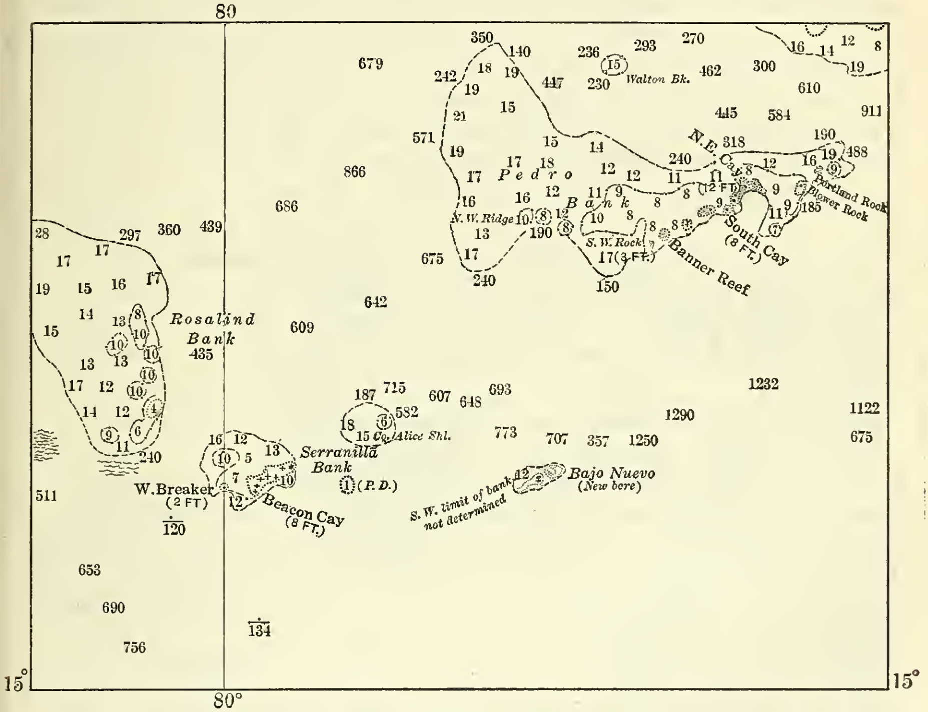

FIG. 24.—CHART OF PEDRO BANK. FROM U. S. HYDROGRAPHIC CHART NO. 1290. SCALE 1 INCH = 48 NAUTICAL MILES.

Daly in his two papers cited has made an elaborate study of the depths of atoll lagoons of the Pacific and Indian oceans and has compared the depths in them with the depths in the lagoon channels of the same region. As the data compiled by him can not be repeated here, his later discussion in his paper on the Glacial-control theory may be consulted.[1] Daly says:

> "Since probably not more than 5 m. to 25 m. can be allowed for the thickness of the post-glacial calcareous veneer in the wider lagoons, the accordance of platform depth for the wider lagoons and reefless banks seems clear. Their range of 60–90 m. represents magnitudes of the same order as the depths computed for the Pleistocene wave-formed benches."

I have pointed out the similarity in the depths on Saba, Pedro, and Rosalind banks, to those on the atoll-lagoon floors of the Pacific and Indian oceans—that is, the depths are between 20 and 30 fathoms.

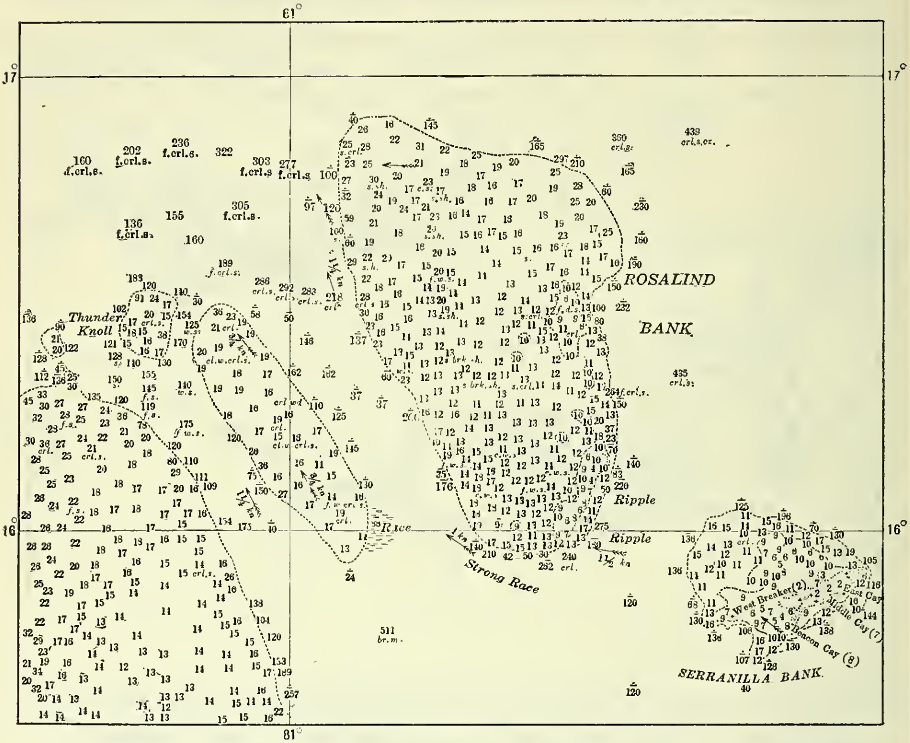

FIG. 25.—CHART OF ROSALIND AND SARRANILLA BANKS. FROM U. S. HYDROGRAPHIC CHART NO. 364.

The possibility of the formation of atoll lagoons by submarine solution was eliminated in the discussion on page 250 of this paper. Atoll rims are formed by constructional processes. That the greater abundance and luxuriance of reef-forming organisms on the peripheries of atolls is due mostly, if not solely, to the intolerance of such organisms to sediment, is shown by certain of my experiments. If the colonies are protected from sediment, the growth of corals within a lagoon may exceed that of corals on the outside.

It is my belief that the coral reefs forming atoll rims are superposed on platforms that antedate the formation of the living reefs, and which have undergone a moderate submergence in Recent geologic

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[1] Amer. Acad. Arts and Sci., vol. 51, pp. 178–199, 1915.

time. It is reasonable to ascribe this submergence to rise in ocean level because of deglaciation, because the order of magnitude of the submergence is the same as the order of magnitude expected from deglaciation. Marginal wave-cut benches should exist, or should have existed around the atoll banks. Perhaps more accurate hydrographic surveys and more detailed studies of the submarine profiles will discover them.

Conclusions.

The results of an examination of the Tertiary, Pleistocene, and living coral reefs and reef corals of the West Indies, Central America, and the Southeastern United States are as follows:

1. The fringing reefs have formed usually, if not invariably, during periods of intermittent uplift, following considerable submergence.

2. All the important offshore reefs, both fossil and living, possibly except the reefs off the southeast coast of Barbados, have developed during or following submergence after the subaerial erosion of their basements.

3. Most of the fossil offshore reefs, all of those on which information has been obtained, and all of these living reefs are superposed on antecedent flattish basements or platforms. Where there are no platforms, as off fault shore lines and young volcanic islands, there are no offshore reefs.

4. Although corals are constructional geologic agents, they are subordinate to other limestone forming agencies, and none of the American platforms were formed by infilling behind a barrier.

5. Submarine flats and plateaus at proper depths below sea level to have furnished basements for offshore reefs are not confined to the temperature zone suitable for coral growth. Such extralimital banks are Georges Bank, the banks off the coast of Nova Scotia, and the Grand Banks of Newfoundland. Reefs form on such banks where the proper ecologic conditions for the life of reef building corals prevail.

6. The submergences during and after which the fossil reefs were formed were almost certainly due to differential crustal movement; the submergence of the basement of the living reefs is probably due to complex causes, for there was differential crustal movement in the area under consideration during Pleistocene time, also at some places within it during Recent time, and, in addition to these more or less local movements, there seems to have been during Recent time a general submergence of the eastern coast of America from Argentina to New England. The amount of the general Recent submergence lies between 40 and slightly more than 20 fathoms; an amount of the order of magnitude that would be expected to result from the effect of deglaciation in raising sea level. The principal wave-formed Pleistocene plain now lies between 26 and 36 fathoms

in depth, and is separated by an escarpment from a shallower plain that now ranges between 17 and 20 fathoms in depth. What appear to be marginal hanging valleys north of St. Thomas and on the St. Martin Plateau, and solution wells, in the Bahamas, 33 to 38 fathoms deep, suggest that there may have been a short stand of sea level about 40 fathoms below its present stand.

7. The fact that the terrace flat between 17 and 20 fathoms in depth is cut away on promontory tips on the windward side of St. Thomas, while it is preserved in protected areas, indicates that the higher flat is older than the lower, and that it has been resubmerged after the development of the lower flat. The general similarity of the submarine profiles off Antigua, on the St. Martin Plateau, and on Mosquito Bank favors the inference that there was in those areas a similar lowering and subsequent rise of sea level. The submerged channel within the channel at the mouth of Habana Harbor, and similar phenomena at other localities around the Cuban coast, show that during later Pleistocene time Cuba stood more than 100 feet higher than immediately previous to the cutting of these valleys within older valleys, and that after the valleys-within-valleys were formed there was submergence to an amount of about 100 feet. Fall of sea level during Pleistocene time and rise during Recent time is indicated for the Bermudas, the Bahamas, Florida, Central America, and the mouth of the Amazon, as well as for the areas just mentioned. These phenomena are in essential accord with the demands of the Glacial-control hypothesis.

8. The principal living West Indian and Central American reefs are superposed on submarine flats or plateaus of *pre-Pleistocene* age, that were dry-land areas during at least a part of Pleistocene time, and while they were dry land they were wave cut and remodeled around their margins by submarine planation.

9. There are two kinds of atolls, namely, (*a*) those that rise above relatively shoal-water platforms and were shaped by the prevalent currents, which are largely wind induced; (*b*) those that more or less completely encircle the flat summits of eminences that rise from ocean depths. These rings are formed by constructional geologic agencies, because, as submarine solution by sea water in such areas and at such depths is chemically impossible, a lower, flat area, surrounded by a higher rim can not be formed by submarine solution or by any other known destructional agencies. The depths on such banks as Saba, Pedro, Rosalind, etc., indicate that they were in large part, at least, above water during part of Pleistocene time, and that the flat summits are largely due to processes operative in *pre-Pleistocene* time. What the processes were that caused the leveling of the summits is a matter of pure speculation, but it seems probable that they were subaerial erosion and submarine planation.

The living coral rims on the banks enumerated have formed during and subsequent to Recent submergence.

A review of the conditions under which the principal barrier reefs in the Pacific Ocean were formed leads to essentially identical conclusions. Those of the Australian Great Barrier, of New Caledonia, the Fiji Islands, and Tahiti are superposed on antecedent platforms that have been submerged in Recent geologic time. The submergence of the Australian continental shelf apparently can be assigned to Recent rise of sea level because of deglaciation, as it seems that most of the surface of the platform was exposed as a dry-land area by withdrawal of water from the ocean during at least a part of Pleistocene time. The submergence of the Fijian platforms is concomitant with, if not entirely due to, differential crustal movement. The superposition of the barrier reefs off the shores of the smaller Society Islands on antecedent platforms is not proved. Evidence sufficient for the basis of an opinion is not available. The absence of reefs around Mehetia, where there is no shore platform, is significant. That the barriers off the other smaller islands were formed after the submergence of their basements is clear. The small cliffs at the spurs ends, in my opinion, do not constitute evidence against the presence of shore platforms, flats, or lowlands, antecedent to submergence. That ocean level in the Indo-Pacific, because of deglaciation, in Recent time has risen to an amount of about 60 meters (about 33 fathoms) as postulated by Humphreys and Daly, and that this rise of ocean level had influenced the development of living coral reefs, is, I believe, so well established as to be almost if not quite incontrovertible.

The rims of the large atolls, and perhaps of the smaller ones also, are growing, in my opinion, on the surfaces of, mostly the edges of, flat summit areas that have undergone geologically Recent submergence. These flats, I believe, were mostly formed in *pre-Pleistocene* time, and it is my opinion that they were largely out of water, or were very near the surface of the water, during Pleistocene time. If they projected above the water for an appreciable time, they should have been wave cut around their edges by the lowered Pleistocene sea, and evidence of such benching should be sought. I believe the evidence will not be found on the hydrographic charts at present available, for the object of the published charts is to guide navigators rather than to serve as a basis for physiographic studies of the sea bottom in depths where navigation is safe.

From what precedes I believe it is clear that I consider that there are two factors that determine the vigorous development of offshore reefs, which under the most favorable conditions form barriers or atoll rims, the other proper ecologic conditions also being present. The first factor is the existence of an offshore flat, which may have a land area on one side and open ocean on the other or which may be the top of an oceanic eminence. The second factor is gradual submergence. The vigor of offshore reefs where these conditions prevail can be correlated with certain ecologic demands of reef-forming corals.

Reef corals thrive on offshore flats, near or against ocean water, because they are there removed from the deleterious effects of both land-derived and other sediment. Some of these relations are well exemplified in the barrier reef off the east side of Andros Island, Bahamas. This reef grows on the outer, windward, edge of a small shallow flat, against the deep water of the Tongue of the Ocean. As the winds set landward across the reef no oceanic or land-derived sediment is deposited on the reef, it is bathed by the purest ocean water, and receives the largest amount of animal plankton that that part of the sea can supply. On the great shoals of the Bahama Banks and in the shoal waters of Florida behind the reefs the winds stir up the mud on the bottom; the sediment while in suspension kills the plankton; when it settles it kills those bottom-living organisms that can not endure being covered by mud. On such flats reef-forming corals can not live. On shallow banks coral reefs therefore thrive best on the windward sides. However, if the flat extends far enough offshore for land-derived sediment not to reach the reef and if the depth is sufficient for waves under ordinary conditions not to stir up the mud on the bottom, but not too deep for the growth of reef corals, barriers may develop on the leeward sides of islands. A land area to the windward may actually favor coral growth, as it breaks the force of the winds. A position on an offshore flat, particularly on the windward edge of a flat, insures a supply of the purest ocean water and an abundance of animal plankton.

The gradual submergence of an offshore flat perpetuates the favorable conditions for the life of reef-building corals, and gives an opportunity for continual growth upward. With upward growth during slow submergence of the basement the ecologic conditions for the life of reef-forming corals are made better, for the deleterious effects of sediment are minimized.

As regards the life of corals, the method of bringing about these conditions is of no importance. Whether the flat was formed by marine planation, by alluviation and the building of a coastal flat, by base-leveling through subaerial erosion, by the formation of a submarine plain of deposition, or by any other special process, is unimportant, provided the flat be formed. Whether the submergence be caused by differential crustal movement, local or remote, or by rise in ocean level due to the melting of glaciers, is unimportant, provided there be gradual submergence of the basement.

The manner of producing the result is subordinate to the result. However the conditions may be brought about, preexistent flats and gradual submergence are two factors needed to supply continuously favorable conditions for the growth of reef-forming corals. The importance of deglaciation on modern coral-reef development consists in its having caused a gradual and moderate increase in the depth of the ocean, thereby producing submergence both in rate and amount favorable for the growth of reef-forming corals.

The general conclusions here expressed are similar to those previously published in a number of my papers. Before discussing the bearing of my conclusions regarding the formation of coral reefs on the theories advanced by others, I will give brief attention to some remarks by Prof. W. M. Davis. The following paragraph is copied from a paper by him entitled: The origin of coral reefs.[1] Similar remarks occur in others of his papers.

> Reefs and Reef-Platforms. A modification of Darwin's theory has lately been proposed by Vaughan, who regards recent submergence proved by the embayments of the central islands as the determining cause for the upgrowth of existing barrier reefs but who interprets the deeper and larger part of the entire reef mass as an independent "platform" of earlier origin. As this investigator has not yet published his views regarding the origin of the reef-platforms his modification of Darwin's theory will not be here discussed further than to note that it seems inapplicable to many barrier reefs in the Fiji and Society groups; that the discontinuity of certain barrier reefs seems to be explicable on the assumption of imperfect upgrowth during and after a recent and rapid subsidence as well as on the assumption of independent origins for the reefs and their platforms; and that, while the extension of reef-platforms outside of the coral zone as in the case of the Great Barrier reef of Australia, truly suggests a dual origin of reef masses, this does not exclude the contemporaneous growth of platform and reef within the coral zone during long-continued but irregular or intermittent subsidence.

Most of the objections raised by Professor Davis have been answered on preceding pages of this paper. It will be obvious to those who have read what I have said that my inferences as to submergence are by no means confined to the evidence of embayments in shore lines. In fact, many submerged areas show no clear-cut shore-line embayments. It will also be obvious that the interpretation I am making did not originate with me. E. C. Andrews, in 1902, after his work on the Great Barrier reef of Australia, put forward in essential principles the same explanation.

In answer to Professor Davis's statement "regarding the origin of the reef platform," I will say that the recognition of the fact of superposition does not require knowledge of the constitution or origin of the basement on which an object or structure has been superposed. We may recognize the fact that a book lies on a table without knowing the kind of material of which the table is composed or the process of its

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[1] Nat. Acad. Sci. Proc., vol. 1, pp. 146-152, March, 1915.

manufacture; there is controversy as to the origin of the Sunderland terrace in Maryland and Virginia, but no geologist will deny that certain houses have been built on the surface of the Sunderland terrace flat; although the geologic history of the pre-Cambrian formations in Michigan and in other areas adjacent to the Great Lakes may be inadequately known, no one is justified in denying for such a reason that glacial deposits overlie the geologically old rocks, as it is obvious that the overlying material has in some way been placed on the underlying. The superposition of a geologic formation on another may be recognized without knowing the complete history of either the upper or the lower. The oligocene coral reef along Flint River near Bainbridge, Georgia, rests on the eroded surface of an upper Eocene limestone now designated the Ocala limestone. That knowledge of the Ocala limestone may not be adequate does not invalidate the recognition of the facts that the fossil reef overlies it and that an erosion period intervened between its deposition and the growth of the reef, which obviously formed during or after the submergence of its basement.

To ascertain the origin of the submarine flats on which offshore reefs stand is important in the advancement of our knowledge of geologic history, and I have acquired as much information on the subject as I could. I am completely convinced that there is no one explanation that can be applied to all of them. The following kinds have already been recognized: (1) Slightly tilted bedded tuff, as in the fossil reefs of Antigua; (2) slightly tilted bed of limestone, as off the south coast of St. Croix and Cuba; (3) submerged coastal flats, as in the Fiji Islands; (4) submerged peneplained surfaces, as in the fossil reefs of Porto Rico; (5) submarine plains due to uplift of considerable areas of the ocean bottom and to the deposition of organic deposits on such a surface, as the Floridian Plateau previous to the formation of the middle and upper Oligocene reefs of Florida and southern Georgia; (6) flats of complex and not definitely known origin, such as those of the Antigua-Barbuda Bank, the Virgin Bank, and the continental shelves of tropical America and Australia. Plains suitable for the growth of corals have been formed by subaerial and submarine deposition, and by both subaerial base-leveling and submarine plantation. Nearly every, if not every, plain-producing process operative in tropical and subtropical regions has taken part in the formation of plains on which corals have grown or are growing where the plains have been brought below sea level and where the other ecologic conditions for offshore reef formation obtain.

I will revert to this subject in discussing the Glacial-control theory and in making suggestions as to future research.

Bearing of these Conclusions on Hypotheses of the Formation of Coral Reefs.

How do my results compare with the theories and hypotheses advanced by others? Before considering my conclusions in their relation to those reached by other investigators, I wish to make a few general remarks on the literature appertaining to coral reefs. It is a subject that, in order to be properly treated, requires a considerable diversity of knowledge, as biologic, oceanographic, and geologic problems are involved. Very rarely has it been practicable for a man to be a specialist in all of these fields. Usually, as any investigator has been specially qualified in only one or two of them, he has paid particular attention to those subjects with which he was familiar, and nearly always did good work in those subjects; but in those fields in which he has been only casually engaged, his work is nearly always amateurish, and his conclusions are in many instances erroneous. Should we expect a man who is primarily a biologist to be an expert in geology, especially when he attempts geologic work after he arrives at the place where he expects to conduct his investigations, without having had previous experience? Should we expect a man who has riveted his attention on dry-land physiography, and who has not thought of biologic problems or of the physiography of the sea bottom to take information from those branches of science? In reading the many publications on coral reefs, I am impressed with the particular, personal interests of the investigators, but what strikes me more forcibly is the excellence of nearly all the papers. I know no paper by a serious scientific man on a coral-reef area that does not contain records of valuable observations and correct conclusions. I have had the wish to write an account of the very gradual growth of the knowledge we now have of coral reefs, and point out how each of the successive workers has contributed toward making that knowledge what it now is. It would be a record of honorable achievement. In the short review to follow I trust I may point out some of the substantial additions to be credited to those whose opinions I shall discuss.

1. The Darwin-Dana hypothesis, in my opinion, is correct as regards the formation of offshore reefs during and after submergence; but as regards the formation of a prism of reef material, the upper surface of which forms a flat behind the barrier, their theory is wrong for every area on which we have definite information. Although the theoretic possibility of the conversion of a fringing reef into a barrier and a barrier into an atoll may not be denied, no instance of such conversion has yet been discovered. The inferences of Darwin as to areas of subsidence and of elevation, as shown on plate 3 of his work, are largely in error, for barrier reefs are present where there is not general crustal subsidence, as Foye points out in his paper on the

geology of the Fiji Islands, where "since the Pleistocene period the algebraic sum of the movements has been positive and uplift has resulted."[1] Very many similar instances, the Bermudas, the Bahamas, Florida, and Cuba among them, can be given. The criticisms of the Darwin-Dana hypothesis apply to the recent publications of W. M. Davis.

2. Semper, Alexander Agassiz, and others, who have maintained that barrier coral reefs have formed in areas of uplift, are correct, if the sum total of the movements since some date back in Tertiary time be considered, and their observations and deductions are valuable in that they emphasize these facts; but they are in error in that they failed to take into account that in many areas there is incontrovertible evidence showing submergence of the basements of the now-living reefs. Semper made astute observations on currents, but his deductions as to the formation of lagoons by destructional processes are not warranted.

3. Sir John Murray invented a very stimulating hypothesis, and correctly emphasized the necessity of taking submarine planation into account in studies of the basements of coral reefs. He, however, overlooked important facts clearly proving Recent submergence in coral-reef areas, and his theory of the formation of atoll lagoons and lagoon channels through submarine solution by sea water is entirely disproved, and there are no other known destructional processes whereby lagoons may be formed, for lagoons are areas of sedimentation in which filling predominates over removal of material.

4. Guppy is correct in his interpretation of offshore reefs being superposed on submarine platforms or "ledges," and he made numerous valuable contributions to our knowledge of coral reefs, but he failed to take into account evidence showing Recent submergence.

5. Admiral Sir W. J. L. Wharton made one of the greatest contributions to our knowledge of atolls when he discovered the flatness of the floors and the uniformity of depth in atoll lagoons, and he pointed out the inadequacy of the Darwinian hypothesis to explain these phenomena. He emphasized the importance of submarine planation in leveling the top of peaks that reach or almost reach sea level, and definitely suggested the superposition of coral patches and atoll rims on flats produced in that way. He not only did not oppose the subsidence of such flats, but he thought that they frequently do "subside and that some of the deeper lagoons may owe their depths of 50 fathoms or so to such a movement, quite apart from subsidence of large areas which we know occurs." The only emendations of these statements that I can suggest is that the probable effects of glaciation and deglaciation might have been considered.

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[1] Nat. Acad. Sci. Proc., vol. 3, p. 309, 1917.

6. Alexander Agassiz correctly observed the superposition of the living coral reefs of the Bermudas and the Bahamas on older limestone foundations that stood above sea level previous to the submergence which made possible the formation of reefs in the places where they now grow. He also pointed out the superposition of the Floridian, Cuban, and Central American living reefs on antecedent platforms or older limestone. He showed that in several areas in the Pacific the sum total of local crustal movements since some time in the Tertiary period had been upward. But he failed to take account of Recent submergence in Florida, the West Indies, and Central America, and he advanced the hypothesis that the living offshore reefs of the Pacific are superposed on wave-cut platforms without change of sea level by submergence of the land. I believe Agassiz correct in his emphasis of the need of an antecedent platform for the vigorous growth of offshore reefs; but he did not recognize the clear evidence of Recent submergence of the shores of the reef-encircled islands, and unfortunately tried to explain the formation of lagoons by submarine solution and scour.

7. E. C. Andrews, I believe, is incontrovertibly correct in the essentials of his interpretation of the conditions under which the Great Barrier Reef of Australia has formed; that is, it is superposed on that part of the recently submerged Continental Shelf of Australia that lies within the temperature zone favorable for the life of reef-forming corals.

8. Stanley Gardiner, who has made great contributions to our knowledge of Indo-Pacific corals and coral reefs and whose work on the oceanography of the Indian Ocean is justly rated as classic, committed the same errors in interpreting the geologic relations of coral reefs as did Murray and Agassiz. He failed to infer submergence from shore line characters and advocated the formation of lagoons through submarine solution by sea water.

9. Hedley and Griffith Taylor agreed in all the essentials of Andrews's interpretation of the conditions under which the Australian Great Barrier formed; they opposed Murray's solution hypothesis for the formation of lagoons, and correctly emphasized the importance of currents, largely wind induced, in the shaping of the atolls along the Great Barrier.

10. Daly did not originate the Glacial-control theory of coral reefs, but he is its principal exponent. The following ascertained relations of living offshore coral reefs conform to the demands of this hypothesis: (*a*) They are superposed on antecedent basement flats; (*b*) the amount of recent submergence, between 30 and slightly more than 20 fathoms, without deducting the amount of Recent up-building of the sea bottom, which probably is as much as a few fathoms, is of the order of magnitude expected from deglaciation; (*c*) the

rate of growth of corals is known to be of such an order of magnitude as to account for the thickness of any known living coral reef by the growth of coral-reef organism since the disappearance of the last great continental glaciers. As Daly is not a specialist on corals, he has made some errors in his discussions of the geologic history and ecology of corals, but these errors do not affect the validity of glacial control being one of the dominant factors in modern coral-reef development. The only important point on which I am not in agreement with him is the evaluation of Pleistocene marine planation. I have shown that the Floridian Plateau has existed as a plateau at least since late Eocene time, and there have been extensive submarine flats in certain West Indian areas since late Eocene or Oligocene time. The submarine profiles that I have drawn for the West Indies, Central America, and Australia indicate Pleistocene benching in depths between 26 and 36 fathoms, without deducting anything for Recent upbuilding of the sea bottom. Certain West Indian and Central American reefs and the Australian Great Barrier, I, therefore, believe are growing on what were dry-land areas during at least a part of Pleistocene time. It, therefore, seems to me that many of the flats discussed by Daly are of *pre-Pleistocene* age, and that he has over-evaluated Pleistocene marine planation. Daly admits that there has been local crustal movement in some coral-reef areas.

11. Wood Jones is undoubtedly correct in attaching great importance to the effects of sediment on the formation of coral reefs. No one who has had actual experience with coral reefs can for a moment doubt it. He also correctly accepts the interpretations of Andrews and of Hedley and Griffith Taylor for the Great Barrier of Australia, joining with the latter two in their opposition to the solution hypothesis and in their emphasis of the effects of wind-induced currents in shaping the segments of a reef. He, however, appears not to have appreciated the importance that, in my opinion, should be attached to submergence as factor in coral-reef formation.

12. My own opinions can be very simply stated: (*a*) Fringing reefs seem always to have unconformable basal contacts; they may be formed after submergence that is not followed by uplift or during intermittent uplift that follows submergence; that is, they may form during periods of either emergence or submergence of land areas. Are the basal contacts really significant? Must not these contacts in the very nature of the case be unconformable? If the basement has moved up with reference to sea level and a reef begins along the strand line, the basement of the reef will certainly be different from the reef itself and there will be an obvious unconformity. If the land mass subsides and a fringing forms along shore, the base of the reef will surely exhibit unconformable relations. I am unable to imagine a fringing without an unconformable basal contact. I never saw one that did

not have such a contact. (*b*) Offshore coral reefs, barriers, and atolls, form on antecedent flattish basements during and after submergence in areas where the general ecologic conditions are suitable for coral growth, as stated on page 240. This generalization applies to fossil as well as to living reefs. (*c*) Recent rise of sea level because of deglaciation has made conditions favorable for coral-reef formation over enormous areas, and it is one of the important factors in causing the great development of coral reefs at the present time. But in some areas, as in the Fijis, the flats on which the reefs are growing are coastal flats that have been brought below sea level by tilting, as described by Andrews and Foye. (*d*) The theoretic possibility of the progressive change of a fringing reef into a barrier and later into an atoll, according to the Darwin-Dana hypothesis, may not be denied, but no instance of such a transformation has as yet been discovered. (*e*) The coral-reef investigation is of value to geology, not so much because of what has been discovered regarding corals as it is that it has led to the study of a great complex of geologic phenomena among which corals and coral reefs are only incident. Further investigations of the phenomena associated with coral reefs are among the great desiderata of geologic research.

Suggestions as to Future Investigations.

Before closing this discussion I will present a few suggestions that to me appear pertinent.

1. It is my belief that, although ecologic notes are of much value in systematic work, not a great deal more advantage will result from such ecologic investigations in areas where corals are luxuriant as those conducted by Gardiner, Wood Jones, and others, including myself. We need to know more of the physiology of corals, but such researches must be conducted by expert physiologists. There is great need for ecologic work in the waters northward and southward from the coral-reef zone. Within the coral-reef zone there are three faunas delimited by depth and temperature. What happens outside the coral-reef zone? Do the deeper-water forms live in shallower water as the high latitudes are attained? Is it depth or temperature that causes the vertical faunal distribution within the Tropics? More knowledge of the ecologic relations of the deeper-water faunas in the Tropics and of the faunas in both shoal and deep water in the temperate zones of the ocean is of great importance to geologists, for such knowledge would furnish a basis for interpreting the physical conditions under which some of the fossil faunas lived. For some years I have wished to make an investigation of the kind outlined, but other duties have prevented the fulfilment of my desire. There is a large amount of morphologic work needed, both on the skeletons and on the soft parts of corals, but particular consideration of this subject is scarcely in place here.

2. The study of sediments in coral-reef areas has scarcely been initiated. Accurate determination of the source of the constituents of calcium-carbonate bottom-deposits should be made, the deposits should be classified according to their constituents, at least the area occupied by each kind of deposit should be ascertained as nearly as is practicable, and an endeavor should be made to ascertain the rates at which the different kinds of sediments accumulate. The results from investigations of this kind are of vital importance to geology, for only by firmly basing our inductions on wide and accurate knowledge of what is now happening in the ocean can we hope to make reliable deductions concerning the origin of and the conditions under which older sediments were formed. The quantitative evaluation of the work done by the different agents cooperative in the production of the different kinds of sediments should be an object constantly in mind. Although this is essentially a new field of research, during the past few years a number of investigators have notable achievements to their credit.

3. Detailed studies of the general geology of tropical islands and continental areas adjacent to tropical and subtropical waters should be undertaken wherever possible. These investigations should include consideration of the stratigraphic and structural geology, the petrography of both the igneous and sedimentary rocks, very detailed work on the stratigraphic paleontology, and the physiography of the land areas. We now know that, by combining knowledge gleaned from the study of many relations, it is possible not only to recognize for an area the succession of rocks, their age equivalents in other areas, and their deformational history, but that it is also possible to ascertain the successive physiographic stages and other physical conditions throughout at least a considerable part of the history. The structural relations of the successive formations, the nature of the contacts of formations, and the character of the sediments, are among the criteria to be used in making the latter kind of deductions. Of how many tropical areas are there topographic maps on a scale of 1 : 62,500 or of 1 : 125,000? Many areas, where the geology is very complicated, should be mapped on a scale of at least 1 : 20,000. The very detailed studies of a few carefully selected areas would supply keys for other areas and thereby accelerate work in other areas. Detailed work of the kind suggested should be done in Antigua, St. Bartholomew, St. Martin, and Anguilla, in the West Indies, for each of these islands typifies certain phenomena that are critical in elucidating the history of the West Indies, Central America, the southern United States, and northern South America.

4. Biogeographic investigations supply a basis for deductions regarding former land connections and the dates of the separation of islands that may have been parts of large land masses.

5. Shore-line history is obviously an essential part of the study of coral reefs. But the entire story can not be deduced from the information furnished by all of the lines of investigation above suggested. The configuration of the sea bottom needs to be studied, both in plan and profile. Notwithstanding the great amount of work that has been done on oceanic hydrography, close attention to the minor configuration of the sea bottom and attempts to draw inferences from such studies are of very recent date. Since most hydrographic charts were not intended to serve as a basis for such researches, we are fortunate that we can extract so much information from them. Although it is probable that a much larger amount of data is on the charts than has as yet been utilized, that additional hydrographic research is needed is obvious. What are submarine slopes off the divide ends in reef-encircled islands? What is the character of the slopes off both the reefs and the breaks in the reefs? The problem of submerged terraces, flats and fronts, has barely been touched. How extensively are such features present, and what is their significance? These considerations lead to inquiries regarding wave base, the rate of motion of the water, the erosional and transporting power of the water while in motion at different rates, and the relations of erosion and transportation to depth. Although the factors mentioned are among those that determine the profile of subaqueous equilibrium and must be considered in their relation to it, there are other factors, among which are the initial slope of the bottom, the hardness and degree of consolidation of the material forming the bottom, and the attitude, height, and hardness of the rocks at the shore. More information on this complex of problems is urgently needed.

Sea level rises or falls with reference to the land, or the land rises or falls with reference to the sea level. That there have been many shifts in the position of the strand line since the beginning of Pleistocene time is known to every geologist. He also knows that in many areas shifts have been caused by tilting or flexing of parts of the earth's crust, and that there must have been lowering of sea level while there were great continental ice sheets, followed by rise of sea level when the ice sheets melted. How much of the geologically Recent change in the position of strand line is to be attributed to climatic causes and how much to differential crustal movement? More accurate and areally more extensive studies of shore-line history should enable a more precise evaluation of the effects due to each than is now possible. Such investigations must not be confined to tropical and subtropical areas—they must be world wide.

Then there is the problem of Pleistocene wave cutting. I believe, for reasons stated elsewhere, that Daly has overevaluated the effects of Pleistoceme marine planation. Has either of us really enough information to be convincing? Should answers to the questions raised in the preceding two paragraphs be forthcoming, and if we can make reliable estimates of the duration of the Pleistocene, the amount of marine planation while sea level was lowered in the Pleistocene might be more nearly approximated.

In conclusion, I wish to say that the questions and suggestions contained in the foregoing remarks have grown out of a study of corals and coral reefs and the phenomena associated with them; and although it may have been shown, that corals are not so important as they were once considered to be, geolgists should be grateful for the romantic interest inspired by these lowly animals, for this interest has led us into the presence of some of the profoundest problems of geology. Perhaps the interest will endure and it may lead us to a better understanding of the world of which we form a part.

SYSTEMATIC ACCOUNT OF THE FAUNAS.

Class ANTHOZOA.

MADREPORARIA IMPERFORATA.

Family SERIATOPORIDAE Milne Edwards and Haime.

1849. *Seriatoporidae* Milne Edwards and Haime, Comptes Rend., vol. 29, p. 262.
1869. *Pocilloporidae* Verrill, Essex Inst. Proc., vol. 6, p. 90.
1870. *Stylophoridae* Verrill, Conn. Acad. Arts and Sci. Trans., vol. 1, p. 514.

In a recent publication[1] I have stated that while I seriously doubted the propriety of placing *Stylophora* and *Pocillopora* in separate families, the traditional usage was followed. Additional study since that statement was written has convinced me that *Stylophora, Seriatopora,* and *Pocillopora* all belong to the same family. In fact, it seems that both *Seriatopora* and *Pocillopora* are derived from *Stylophora,* mostly through retrogression in the development of the septa. It is hoped to present in a future paper the evidence on which this suggestion is based.

Genus STYLOPHORA Schweigger (emend. Milne Edwards and Haime).

1819. *Stylophora* Schweigger (part), Beobacht. auf Naturf., pl. 5.
1820. *Stylophora* Schweigger, Hand. Naturg., p. 413.
1830. *Stylophora* and *Sideropora* de Blainville, Dict. Sci. nat., vol. 60, pp. 319, 351.
1835. *Anthopora* Gray, Zool. Soc. London Proc. for 1835, pt. 3, p. 86.
1846. *Sideropora* Dana, U. S. Expl. Exped. Zooph., p. 517.
1850. *Stylophora* Milne Edwards and Haime, Ann. Sci. nat., ser. 3, Zool., vol. 13, p. 102.
1857. *Stylophora* Milne Edwards and Haime, Hist. nat. Corall., vol. 2, p. 133.
1861. *Stylophora* de Fromentel, Intr. Polyp. foss., p. 179.
1884. *Stylophora* Duncan, Linn. Soc. London Journ., Zool., vol. 18, p. 45.

Type-species.—Madrepora pistillata Esper.

Duncan in his papers on the Fossil Corals of the West Indies either describes as new or lists the following species:

From the Eocene of Jamaica:
Stylophora contorta (Leymerie) + 1 var.

From the Eocene of St. Bartholomew, Cleve collection:
Stylophora compressa[2] Duncan.
distans (Leymerie).

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[1] Carnegie Inst. Washington Pub. 213, p. 73, 1918.

[2] Although I have studied the collection from St. Bartholomew submitted to Duncan, I could recognize only one species which I have divided into four varieties.

Stylophora conferta Reuss.
  tuberosa Reuss.
  affinis Duncan (described from Santo Domingo).
  granulata Duncan (described from Bowden, Jamaica).

From Santo Domingo:
  Stylophora affinis Duncan.
    var. *minor* Duncan (a valid species).
  raristella (Defrance).

From Bowden, Jamaica:
  Stylophora granulata Duncan.

From St. Croix, Trinidad:
  Stylophora minuta Duncan.
  raristella (Defrance).
  mirabilis Duncan (not Duchassaing and Michelotti).

I described in 1900 [1] *Stylophora ponderosa* from the Oligocene of Salt Mountain, near Jackson, Alabama, and *Stylophora minutissima* from the Oligocene of Blue or Russell Spring, near Bainbridge, Georgia.

I recognize as valid the six species described as new by Duncan and the two later described by myself. Duncan's identifications of West Indian specimens with European species are all discarded as they are probably erroneous.

In addition to the six species here described as new, I have described six other species in manuscript not yet published, making a total of at least 20 species of *Stylophora* known to me from the American Tertiary formations. The stratigraphic range of the genus in America is from the upper Eocene to Miocene.

STYLOPHORA IMPERATORIS, new species.

Plate 74, figs. 1, 1*a*, 2, 3, 4, 4*a*, 5.

Corallum attaining a rather large size, the basal part of some colonies as thick as a man's wrist. The cross-section of branches ranges in form from subelliptical to curved lamellate. The following are the diameters of the broken ends of the specimen, which is 62.5 mm. long, represented by plate 74, figure 1.

Diameters in millimeters of branches of Stylophora imperatoris.

	Lesser diameter.	Greater diameter.
Basal end	14.5	27.0
Smaller branch	13.0	17.5
Wider branch	9.5 to 16	34

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[1] U. S. Geol. Survey Mon. 39, p. 132, 1900.

The branch terminals are compressed and often form sinuous plates. Thickness just below the summits about 3 mm.; width very variable, ranges from 6 or 7 up to 25 mm. Nodule-like growths are frequent on the sides of older branches.

Calices on older parts of the corallum from 1 to 1.3 mm. in diameter, therefore rather large and conspicuous; intervening walls from 0.75 to 2 mm. across, usually about 1.25 mm. Near and on the branch summits the calices are usually crowded and slightly less than 1 mm. in diameter. Upper margin of the calices usually more prominent than the lower, sloping slightly downward, externally finely costulate.

Septa, 6 primaries distinct, well developed, extending to the columella, the directives more prominent than the other primaries; secondaries are small or obsolete, if they were present they usually have been destroyed in the type and paratypes of the species.

Columella, a small, only slightly prominent style.

Coenenchyma dense; its surface beset with pointed granulations.

Localities and geologic occurrence.—Canal Zone stations 6016, in the Emperador limestone, quarry, Empire, where some hundreds of specimens were obtained; 6024*b*, lower end of culvert, Panama Railroad (relocated line), on Rio Agua Salud, in the upper bed, collected by T. W. Vaughan and D. F. MacDonald. Station 6026, in the Culebra formation, 2½ miles south of Monte Lirio, Panama Railroad (relocated line), collected by T. W. Vaughan and D. F. MacDonald.

Anguilla, station 6894, bluff, south side of Crocus Bay, in the lower 50 feet of the exposure, collected by T. W. Vaughan. (See pl. 74, figs. 4, 4*a*.)

Doctor MacDonald obtained the specimen represented by plate 74, figure 5, at station 1863 of the canal commission, on the west side of Gaillard Cut, between points opposite Cucaracha and Paraiso, station 5853 of the United States National Museum locality register. The specimen came from a layer, about 2½ feet thick, consisting of pebbles, gravel, and tuffs cemented with calcareous material; below the layer is gray, flaggy sandstone and tuff beds; above it is gray, flaggy sandstone, in thin layers separated by partings of carbonaceous black shale. The geologic horizon therefore seems to be in the Culebra formation, probably near its top. The specimen appears to be a form of *Stylophora imperatoris* in which the calices are more crowded than usual, as it agrees with that species in all other characters.

Type.—No. 324752, U.S.N.M.

Paratypes.—Nos. 324753, 324754, U.S.N.M.

STYLOPHORA PANAMENSIS, new species.

Plate 75, figs. 1, 1*a*.

Corallum, branches more or less contorted plates (see pl. 75, fig. 1). The thickness of the lower end of the type is 12.5 mm.; width, exceeds 28 mm.; length from base to summit, 38 mm.

Calices small, apertures from 0.5 to 0.75 mm. in diameter; crowded, maximum distance apart 1 mm., usually less than 0.5 mm.—that is, less than a calicular diameter apart. Margins very slightly or not at all elevated; upper wall in places forms an obscure upper lip.

Septa, the six primaries distinct, fuse in the calicular axis, directive plane well marked; secondaries not recognizable in the type-specimens and appear to be absent, but it is possible that they were present and have been destroyed by fossilization.

Columella a compressed style, not prominent.

Coenenchyma, surface badly worn in the type, but some granulations may be distinguished.

Locality and geologic occurrence.—Canal Zone, station 6016, in the Emperador limestone, quarry, Empire, collected by T. W. Vaughan and D. F. MacDonald.

Type.—No. 324763, U.S.N.M.

S. panamensis has smaller and more crowded calices than *S. imperatoris.*

STYLOPHORA AFFINIS Duncan.

1863. *Stylophora affinis* DUNCAN, Geol. Soc. London Quart. Journ., vol. 19, p. 436, pl. 16, fig. 4.

1866. *Reussia affinis* DUCHASSAING and MICHELOTTI, Sup. Corall. Antilles, p. 70 (of reprint).

1867. *Stylophora affinis* DUNCAN, Geol. Soc. London Quart. Journ., vol. 24, p. 25.

1870. *Reussia affinis* DUCHASSAING, Rev. Zooph. Antilles, p. 26.

Original description.—"Corallum branched, large; branches nearly cylindrical, leaving the stem at an acute angle, slightly flattened on one side. The largest stem is four-fifths inch in diameter. Blunt, aborted, branchlike swellings exist on some of the larger stems. Corallites radiating from the center of the stem and branches, separated by about their own width of dense coenenchyma, which is seen, in the larger specimens, to be very slightly cellular. Walls not distinguishable from the coenenchyma in the substance of the mass, but slightly raised into a very shallow crateriform edge on the surface. Calices circular, a very little raised as crateriform elevations, very numerous, disposed irregularly, but very nearly equidistant in some places and less so in others; margins sharp. Diameter one-thirtieth inch [0.83 mm.], rarely larger. The calicular margin, when well preserved, looks like a little ring placed on the intercalicular space, and the small styliform columella renders the appearance very distinct. Intercalicular spaces marked by a continuous and rigid line, which, being in the part of the spaces at the base of the calicular elevations, and being continued round each calice, is, from its general straightness, formed into irregular polygons. The line is sensibly raised, convex, and now and then dentated. Between the line and the calicular margin there are distinct papillae, one row at the very marginal edge, the other corresponding to it a little lower down the calicular wall; a third is sometimes seen; and in places where there is an unusual distance between the calices, and when the 'line' is wanting, the papillae are numerous, distinct, and a little smaller. The line and the papillae form a very marked distinction. Between some calices there are faint elevations. Septa whole, not exsert, but little visible in perfect calices, but very distinct when the coral is worn. Upper margin perfect and concave upward, the septa appearing festooned to the columella; they are delicate, very little thicker at the wall than elsewhere, and join the columella high up near its point. The papillae at the calicular edge extend a little on the wall, and may be considered as rudimentary septa and costae; if so, there is a second cycle, and also a third in half of each system. The persistence of six septa, nearly all of the same size, is very remarkable. Columella styliform, large and dense in the corallite, and forming a rounded-off cylinder with a sharpish rounded tip, which is very distinct halfway down the calice. Calicular fossa shallow, about half as deep as broad. Endothecal dissepiments stout, transverse, numerous. The walls and columella do not fill up the lower parts of the corallites. Increase by extracalicular gemmation.

"From the Nivajé shale. Coll. Geol. Soc."

Duncan reports the species from the Nivajé and Cerro Gordo shales, Santo Domingo.

I have received 22 specimens labeled *Stylophora affinis* from the Museum of Comparative Zoology, and 6 from the Philadelphia Academy of Sciences. I have separated four of the specimens belonging to the former institution and have described them as a new species. Six specimens are *S. affinis*, 9 are worn but probably are *S. affinis*, 2 seem to be different and possibly belong to a different species, 1 I refer to Duncan's *S. granulata*. I think that two of Philadelphia Academy are referable to *S. affinis*, the four others are probably worn specimens of the same species.

In the specimens that I have referred to *S. affinis* the upper margin of the calice is more prominent than the lower forming a small, projecting lip. Duncan's description in other respects is satisfactory. As the surface of specimens is easily worn by rolling, the upper lip of the calice and the surface ornamentation being destroyed, the positive identification of many specimens is rendered impossible. On the tips of the branches, which are blunt and rounded, the calices are crowded, with no development of intervening coenenchyma.

Miss Maury obtained in Santo Domingo a single specimen, a piece of a small branch, of this species, on Rio Gurabo, zone D, associated with *Madracis decactis* (Lyman), *Pocillopora crassoramosa* Duncan, *Stephanocoenia intersepta* (Esper), *Orbicella limbata* (Duncan), *Orbicella cavernosa* var. *cylindrica* (Duncan), and *Syzygophyllia dentata* (Duncan), I collected at station 3446, in the La Cruz marl, first deep cutting east of La Cruz, near Santiago, Cuba, casts of the surface of a species of *Stylophora*. Squeezes of the surfaces of these casts agree completely with specimens from Santo Domingo identified by me as *S. affinis*. I am therefore attaching that name to the specimens. It is probable that similar casts from other localities in Cuba represent the same species.

STYLOPHORA PORTOBELLENSIS, new species.

Plate 76, figs. 1, 1a.

Corallum ramose, branches compressed, more or less contorted flabellate at the terminals. Growth form, therefore, similar to that of *Stylophora imperatoris*. The type is 37.5 mm. long; smaller diameter of basal end 10 mm., width of base about 13 mm.; maximum width of branch in horizontal plane about 22 mm., thickness at same level 10 mm.

Calices shallow, diameter averages about 0.75 mm. or slightly less; distance apart approximately equals the calicular diameter, in places less, 0.25 to 0.5 mm.; margins flush with the coenenchymal surface, in places slightly elevated on the upper side, but not enough to form a distinct upper lip.

Septa, six primaries distinct, rather thin, extend to the columella; no vestige of secondaries was observed.

Columella, a pointed style, moderately prominent, thickened below the bottom of the calice.

Coenenchyma dense or costulate with an intercalicular ridge and cells on its sides. The surface is worn, but vestiges of small granulations may be recognized. Axis of the corallum spongy.

Locality and geologic occurrence.—Panama, probably from near Porto Bello, collected by D. St. Clair; geologic horizon unknown.

Type.—No. 324762, U.S.N.M.

This coral has considerable resemblance to *Stylophora goethalsi*, but its calices are distinctly larger, and their upper margins are in some places slightly raised. *Stylophora imperatoris* has larger calices with distinct upper lips. *Stylophora portobellensis* appears most closely related to *Stylophora affinis* Duncan, from the Nivajè shale of Santo Domingo.

STYLOPHORA GOETHALSI, new species.

Plate 75, figs. 2, 3, 4.

Corallum ramose, with branches subelliptical or much compressed in cross-section, in this character resembling *S. imperatoris*. Branch summits frequently or usually with digitiform protuberances (see pl. 75, fig. 2).

Calices shallow, decidedly small, 0.5 to 0.75 mm. in diameter; and relatively distant, from a calicular diameter up to 1.5 mm. apart.

Calicular margins obscurely or not at all elevated; without a protuberant upper lip.

Septa, six distinct primaries, about equal in size, extend to the columella; secondaries much smaller, but can be distinguished in the better preserved calices.

Columella a small, slightly compressed, fairly prominent style.

Coenenchymal surface closely set with pointed granulations.

Locality and geologic occurrence.—Canal Zone, at stations 6016, quarry in the Emperador limestone, Empire, Canal Zone, collected by T. W. Vaughan and D. F. MacDonald; 6026, in the Culebra formation, 2½ miles south of Monte Lirio, Panama Railroad (relocated line), collected by T. W. Vaughan and D. F. MacDonald.

Cotypes.—No. 324767, U.S.N.M. (3 specimens).

Stylophora goethalsi resembles the Santo Domingan species, *S. minor* Duncan, which is ramose and has small calices, from 0.5 to 0.75 mm. in diameter. The end of the branches in *S. goethalsi* are more compressed than in *S. minor*, its calices are slightly larger, and its secondary septa are better developed. Although closely related, they appear to belong to distinct species.

STYLOPHORA MACDONALDI, new species.

Plate 75, figs. 5, 5*a*, 6, 6*a*, 7, 7*a*.

Corallum composed of elongate, slender, curved branches and branchlets, with bluntish, rounded summits. The only branch terminal that is perfect is represented by plate 75, figure 5. The following are measurements of four broken branches:

Measurements in millimeters of branches of Stylophora macdonaldi

Branch No.	Length.	Diameter of smaller end.	Diameter of larger end.
1	15.5	3.5 by 5.0	5.0 by 5.3
2	19.0	4.0 by 6.5	5.5 by 7.5
3	21.5	4.5 by 5.0	5.0 by 6.5
4	28.0	4.0 by 4.0	4.5 by 5.5

Just below the place of bifurcation the parent branch is considerably compressed; in one branch the greater diameter below a fork is 12 mm., while the lesser diameter is only 6.5 mm.

Calices rather shallow, but distinctly excavated; diameter, 1 mm.; distance apart from 0.5 to 1.5 mm., usually less than the calicular diameter; margins usually slightly or not at all raised, but knots correspond to the outer ends of the septa. There is no upper lip to the calices.

Septa, six well-developed, strong, subequal primaries extend to the columella; secondaries small but usually distinct. Subequal knots correspond to the outer ends of the two cycles of septa, and a smaller knot with no corresponding septum usually occurs between each pair of larger knots.

Columella, a distinct, round, moderately prominent style, very slightly compressed in the directive plane.

Coenenchymal surface roughly granulated, from 1 to 4 rows of granules between calices, depending on their distance apart.

Localities and geologic occurrence.—Canal Zone, in the Emperador limestone at stations, 6016, quarry, Empire; 6024*b*, lower end of culvert, Panama Railroad (relocated line), on Rio Agua Salud in the upper bed, collected by T. W. Vaughan and D. F. MacDonald.

Cotypes.—No. 324769, 324770, U.S.N.M. (7 specimens).

Of other species of *Stylophora* with which I am acquainted *S. macdonaldi* seems to resemble most *S. granulata* Duncan from Bowden, Jamaica. *S. granulata* has deeper calices, less developed secondary septa, and in some specimens the upper lip of the calices is more prominent than the lower.

STYLOPHORA GRANULATA Duncan.

1864. *Stylophora granulata* DUNCAN, Geol. Soc. London Quart. Jour., vol. 21, p. 10, pl. 2, fig. 3.

1867. *Stylophora granulata* DUNCAN, Geol. Soc. London Quart. Jour., vol. 24, p. 25.

1873. *Stylophora granulata* DUNCAN, Geol. Soc. London Quart. Jour., vol. 29, p. 551.

Original description.—"The corallum is ramose; the branches are nearly cylindrical, often flattened on one side, and leave the stem at an acute angle. The calices are placed irregularly, and are separated by a coenenchyma, which is sharply granular, and which has very rarely any grooves or continuous ridges on its surface. The calices are circular, not inclined, very deep, and are surrounded by a raised ring formed by the septa and costae. The columella is situated deeply; it is cylindrical below, and sharp where free, but it does not reach the level of the calicular margin; it is delicate, and six large septa are attached to it low down. The septa are in two sets. The superficial septa are from eighteen to twenty in number; six are continuous with the large septa, and the rest taper finely internally and externally, the spindle-shaped process being one-half septum and the rest costa. The processes are close, radiate, and horizontal. Diameter of calices, one-thirtieth inch [0.8 mm.].

"Localities: Bowden and Vere, Jamaica."

Duncan, in 1873, cites this species from St. Bartholomew, but this, I am convinced, is an erroneous identification.

There are two small broken branches of this species in the collection of Mr. T. H. Aldrich, obtained at Bowden, Jamaica, and presented to the United States National Museum.

Specimen No. 1.—Small branch, 16 mm. long, diameter of lower end 4 mm.; upper end flattened, bifurcating, greater diameter 5.5 mm., lesser 3 mm.

Diameter of calices very slightly less than 1 mm., separated by about the same width of coenenchyma. The margin is usually a very slightly elevated rim without an elevated lip around which are 12 to 18 small costae. In a few instances the costae continue from one calice to the next, but usually the intercalicular coenenchymal surface is merely granulate. There are from two to six indefinite zones or wavy lines of granulations between two calices. The granulations are subconical, round-pointed. Limits of zooids sometimes faintly indicated by a slightly raised granulated line. Calices moderately deep. Six principal septa, the second cycle represented by small short septa, variable number of rudimentary members of the third. The upper margins are slightly exsert.

Columella does not reach to level of calicular margin, sharp-pointed.

Specimen No. 2.—A small somewhat compressed, broken branch, 16 mm. long; greater diameter of lower end, 6.5 mm., lesser, 5 mm.; greater diameter of upper end, 6 mm., of lesser, 4 mm. Diameter of calices very slightly more than 1 mm. Width of intervening coenenchyma averages about the same as the diameter of the calices. Calicular rim a little elevated, and slightly swollen around the base.

Costae longer than in No. 1. Granulations about the same in both specimens. Elevated line between zooids usually distinct.

There is in this collection a third specimen which is probably only a variation of the same species. It is a fragment of a branch 14 mm. long. The diameter of the calices is about 0.75 mm.; the calicular rims are not elevated but usually tend to be depressed. The coenenchymal surface is very densely and minutely granulate. The limits of adjoining zooids are indicated either by a very faint raised or by an impressed line.

Localities and geologic occurrence.—Besides occurring in the Bowden marl of Jamaica, *Stylophora granulata* is also found in Cuba at stations 3476, Baracoa, and 3461, gorge of Yumuri River, Matanzas, collected by T. W. Vaughan.

Santo Domingo, station 7781, Rio Cana, zone H, collected by Miss C. J. Maury.

STYLOPHORA CANALIS, new species.

Plate 76, figs. 2, 2*a*.

Corallum of type, a small, nodular mass, 42 mm. long, 23 mm. tall, and from 10 to 14 mm. thick (see pl. 76, fig. 2, for view, natural size, of the upper surface).

Calices shallow, fairly large, 1 mm. in diameter; usually 1 mm. apart. Margins not elevated; the walls barely distinguishable from the surrounding coenenchyma.

Septa in two distinct cycles; only the six primaries reach the columella, but the secondaries are well developed.

Columella, a pointed style.

Coenenchymal surface crossed by costules, along which are relatively coarse granulations. In places the coenenchyma appears cellular, as the costules are not solidly fused but have cellules developed between them.

Locality and geologic occurrence.—Canal Zone, station 6016, in the Emperador limestone, quarry, Empire, collected by T. W. Vaughan and D. F. Macdonald.

Type.—No. 324775, U.S.N.M.

This species most closely resembles a species from the base of the Chattahoochee formation, on Flint River, 4½ miles below Bainbridge, Georgia, but it differs from the latter species in two characters, namely, the outer ends of the principal septa are not produced into prominent teeth, and in places the coenenchyma is distinctly cellular.

STYLOPHORA PONDEROSA Vaughan.

1900. *Stylophora ponderosa* VAUGHAN, U. S. Geol. Survey Mon. 39, p. 132, pl. 13, fig. 16; pl. 14, figs. 1, 1*a*, 1*b*.

One of the specimens obtained by me in Antigua seems referable to this species. The upper surface has four nipple-shaped elevations on it; the largest is about 15 mm. in diameter at the base, about 5 mm. tall, and about 5 mm. in diameter just below the rounded summit. Except such protuberances, the surface is flattish, with some undulations. The size of the calices and the septal characters are as in the cotypes of *S. ponderosa*.

Localities and geologic occurrence.—Alabama, Salt Mountain, 6 miles south of Jackson, just above the top of the Vicksburg group, collected by T. W. Vaughan.

Antigua, station 6854, Rifle Butts, in the Antigua formation, collected by T. W. Vaughan.

Genus POCILLOPORA Lamarck.

1816. *Pocillopora* LAMARCK, Hist. nat. Anim. sans Vert., vol. 2, p. 273.
1918. *Pocillopora* VAUGHAN, Carnegie Inst. Washington Pub. 213, p. 75.

Type species.—*Pocillopora acuta* Lamarck.

Duncan described two fossil species of *Pocillopora* from the West Indies, *P. crassoramosa*[1] from the Nivajè shale of Santo Domingo, and *Pocillopora tenuis*[2] from Antigua. I have seen good suites of

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[1] Geol. Soc. London Quart. Journ., vol. 20, p. 40, pl. 5, figs. 2*a*, 2*b*, 1864.

[2] Idem, vol. 24, p. 21, pl. 1, figs. 5*a*, 5*b*, 5*c*, 1867.

specimens of *P. crassoramosa*, but have seen none of *P. tenuis*. *P. crassoramosa* has thickish branches on which verrucae may be well developed or obsolete; *P. tenuis* appears to be of more or less massive growth-form and has across the corallite cavities thin tabulae, the spaces between which are not filled by steroplasmic deposit.

I have specimens representing four additional American fossil species of the genus. They are all branching forms. I collected one of the species at Willoughby Bay, Antigua, in the Antigua formation; and another in the upper Oligocene marl at Baracoa, Cuba. The specimen at the latter locality was obtained in association with *Stylophora granulata* Duncan, which was originally described from the Bowden marl of Jamaica. Miss Carlotta J. Maury obtained *P. crassoramosa* in Santo Domingo in what she designates zone D, which is above the horizon of the Bowden marl. The geographic range of the genus in the West Indies is, therefore, from the Antiguan Oligocene to a horizon appreciably above that of the Bowden marl.

POCILLOPORA ARNOLDI, new species.

Plate 76, figs. 3, 3*a*, 3*b*.

The type, which is a fragment of a branch, is 28 mm. long, diameter of lower end 6.5 by 12 mm., diameter of upper end 5.5 by 9 mm. The cross section of the branch is strongly compressed, and one side near and at a place of bifurcation is concave instead of being convex. There are no verrucae.

Calices slightly oblong, lesser diameter about 0.75 mm., longer diameter, parallel to the axis of the branch, from 1 to 1.25 mm. Cavities rather deep, about 0.5 mm., and steep-walled. Intercorallite areas flattish, arched, or slightly crested in profile, of unequal width, from 0.3 mm. to 1 mm. across. Coenenchymal surface granulo-costulate, granulations fairly coarse.

Septa rudimentary, occur as low, blunt-topped, perpendicular ridges on the inside of the calicular walls. In some calices 12 of these ridges may be distinguished. The bottom of the calice is flat or very gently concave; no vestige of a columella could be found.

Coenenchyma solid; corallite cavities solidly filled except a few in the axis of the branch.

Locality and geologic occurrence.—Canal Zone, station 6444, quarry in the Emperador limestone, Empire, collected by Dr. Ralph Arnold, whose name I take pleasure in attaching to this well-marked species.

Type.—No. 324782, U.S.N.M.

Of the other five fossil species of *Pocillopora* known from the Tertiary formation of the West Indies and Central America, the unnamed species from Antigua, previously mentioned, is the most similar. The latter species is composed of small, more or less compressed branches, it has no verrucae, the calices are rather deep, the septa are perpendicular ridges down the inside of the calicular walls, and there is no trace of a columella. In these characters the two are similar. The species from Antigua differs from *P. arnoldi* by having larger calices, lesser diameter 1 mm. or more, usually more than 1 mm., and the calicular margin is rather persistently marked by a slightly raised acute rim. A description of the species from Baracoa, Cuba, follows.

POCILLOPORA BARACOÄENSIS, new species.

Plate 77, figs. 1, 1*a*.

This species may be characterized as follows:

The corallum is branching; it has no verrucae and no columellar tubercle. The branch is regularly subcircular or broadly elliptical in cross section, 10.5 mm. in diameter at lower end. The calices are very shallow and are subcircular in outline, about 0.75 mm. in diameter, distance apart usually slightly more than the calicular diameter. Thick short septa join the columellar plug to the wall. Coenenchyma very dense.

These characters are different from those of any of the other known American species.

Locality and geologic occurrence.—Cuba, station 3476, in yellow, argillaceous marl, Baracoa, associated with *Stylophora granulata* Duncan, collected by T. W. Vaughan. The geologic horizon of this species is that of the Bowden marl.

Type.—No. 324783, U.S.N.M.

POCILLOPORA GUANTANAMENSIS, new species.

Plate 77, figs. 2, 2*a*.

Corallum composed of irregularly shaped, more or less compressed and contorted branches, among which there is considerable anastomosis. The branches may be as much as 27 mm. wide, 7.5 mm. thick near the summit, and 12 mm. thick at the base. The branch on which these measurements were made is 41 mm. long. Verrucae entirely absent on the type.

Calices from 0.75 to 1.25 mm. in diameter; usually less than or about their diameter apart. They are deep pits without any trace of septa, except that in a few calices what appear to be thick directives are recognizable on the plug forming the calicular floor. Calicular margins usually even with the coenenchymal surface; in some calices they are somewhat tumid and slightly elevated.

The columella is only a plug. Stout, horizontal tabulae present.

Coenenchyma very dense. Surface in type worn, but apparently beset with spines or granulations and not costulate.

Locality and geologic occurrence.—Cuba, station 7514, about 5 miles nearly due east of Monument H4 on the east boundary of the

U. S. Naval Reservation, Guantanamo, altitude about 400 feet a. t., in beds of the age of the Antigua formation, collected by O. E. Meinzer.

Type.—No. 324784. U.S.N.M. This species differs so markedly from the other West Indian species of *Pocillopora* that comparisons with the other species seem unnecessary.

Genus **MADRACIS** Milne Edwards and Haime.

1849. *Axhelia* Milne Edwards and Haime, Comptes Rend., vol. 29, p. 69.
1849. *Madracis* Milne Edwards and Haime, Comptes Rend., vol. 29, p. 70.
1861. *Reussia* Duchassaing and Michelotti, Mém. Corall. Ant., p. 63 (of reprint).
1871. *Pentalophora* Saville-Kent, Proc. Zool. Soc. London for 1871, p. 283.
1884. *Madracis* Duncan, Linn. Soc. London Journ., Zool., vol. 18, p. 45.
1900. *Madracis* Vaughan, U. S. Geol. Survey Mon. 39, p. 128.
1901. *Axhelia* Vaughan, U. S. Fish Commission Bull. for 1900, vol. 2, p. 294.
1902. *Madracis* Verrill, Conn. Acad. Arts and Sci. Trans., vol. 11, p. 108.

Type-species.—Madracis asperula Milne Edwards and Haime.

MADRACIS MIRABILIS (Duchassaing and Michelotti).

1861. *Stylophora mirabilis* Duchassaing and Michelotti, Mém. Corall. Ant., p. 62 (of reprint), pl. 9, figs. 6, 7.
1901. *Axhelia mirabilis* Vaughan, U. S. Fish Commission Bull. for 1900, vol. 2, p. 295, pl. 1, figs. 3, 3*a*.

A single fragment of a branch from Limon, Costa Rica, is 23 mm. long, 2 mm. in diameter at the lower end, and 3 mm. in diameter just below trifurcation at the upper end. The fragment is slightly arcuate in form, not quite straight, and is not so crooked as is usual in the specimens of *M. mirabilis* with which I have compared it. The septa are less exsert around the calicular margins then is usual in the species. Although there are the differences indicated, they are of the kind that may be produced by vegetative causes.

Locality and geologic occurrence.—Costa Rica, hills of Port Limon, No. 669 of H. Pittier collection; geologic horizon not known.

Cuba, station 3461, gorge of Yumuri River, Matanzas, 19 fragments collected by T. W. Vaughan in a marl of lower Miocene (Bowden) age.

These fragments perhaps should be referred to a new species; but they appear more probably to be only a variant of *M. mirabilis*.

Family ASTROCOENIIDAE Koby.

Genus **ASTROCOENIA** Milne Edwards and Haime.

1848. *Astrocoenia* Milne Edwards and Haime, Comptes Rend., vol. 27, p. 469.
1900. *Astrocoenia* Gregory, Palaeontol. Indica, ser. 9, vol. 2, pt. 2, p. 59. (Synonymy and elaborate discussion.)

Type-species.—Astrea numisma Defrance.

Besides the five species of *Astrocoenia* recognized in the present paper, I have described one under the name of *Stylocoenia duerdeni* from the Eocene of Jamaica,[1] which also occurs in the upper Eocene of St. Bartholomew. I describe as new the species from Antigua (*A. decaturensis*), to which Duncan applied the name *Astrocoenia ornata*.[2] This species is also found in the coral reef at the base of the Chattahoochee formation on Flint River, near Bainbridge, Georgia, and near Guantanamo, Cuba. More critical study may lead to the recognition of one or two additional species. The names of all European species applied by Duncan and others to West Indian forms probably should be dropped from the literature.

ASTROCOENIA D'ACHIARDII Duncan.

Plate 78, figs. 2, 2*a*.

1873. *Astrocoenia d'achiardii* DUNCAN, Geol. Soc. London, Quart. Journ., vol. 29, p. 554, pl. 20, figs. 7, 7*a*.

1899. *Astrocoenia d'achiardii* VAUGHAN, Mus. Comp. Zool. Bull., vol. 34, p. 229.

Dr. C. W. Hayes obtained in Nicaragua, "on or near the Pacific coast," a specimen of *Astrocoenia* (pl. 78, figs. 2, 2*a*) that seems referable to *A. d'achiardii*.

The corallum is ramose; branch somewhat compressed, lesser diameter of lower end 10.5 mm., greater diameter only slightly more than the lesser.

Calices from 2 to 3 mm. in diameter, measured between thecal summits; the diameter of the largest calice is 3 mm. Maximum thickness of walls between adjoining calicular cavities, 1 mm. Depth of calices about 1 mm.

Eight prominent septa reach the columella, with a small septum between each pair of the larger. The large septa are narrow above the bottom of the calice, where they widen and fuse to the columella, around which they show decided thickening. The calicular cavity, therefore, is steep-sided and relatively flat-bottomed.

The columella is a slightly prominent, compressed style.

Locality and geologic occurrence.—Nicaragua, on or near the Pacific coast, in the Brito formation, collected by C. W. Hayes. Dr. Hayes says regarding the Brito formation.[3]

> The greater part of the Brito formation is apparently barren of organic remains. The only location at which fossils have been found are on or near the Pacific coast. This, however, may be due to the fact that the rock exposures are not elsewhere of such a character as to facilitate the discovery of fossils, and the latter may possibly be more generally distributed than present knowledge would indicate. The fossils are confined almost wholly to the limestones and marly beds. They consist of corals, molluscan, and foraminiferal remains.

The Foraminifera, according to Dr. Joseph A. Cushman, indicate an Eocene age.

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[1] Mus. Comp. Zool. Bull., vol. 34, p. 235, pl. 37, figs. 1-4, 1899.

[2] Geol. Soc. London Quart. Journ., vol. 19, p. 425, pl. 14, fig. 7, 1863; Idem., vol. 24, p. 23, 1867.

[3] Geol. Soc. Amer. Bull., vol. 10, p. 312, 1899.

Astrocoenia d'achiardii was described from the upper Eocene of St. Bartholomew. Finding it on the Pacific coast of Nicaragua is additional evidence in favor of connection between the Atlantic and Pacific oceans across Central America during upper Eocene time.

ASTROCOENIA GUANTANAMENSIS, new species.

Plate 79, figs. 1, 1*a*, 2.

Corallum massive, with a rather uniformly rounded or more or less tuberose surface. Type 55 mm. long, maximum width about 31 mm., height 38 mm. The corallum may be much larger.

Calices polygonal, shallow, almost superficial, small; maximum size about 1.75 mm. in diameter, 1.5 mm. usual, smallest calices about 1 mm. in diameter, measured between thecal summits. Intercorallite walls acute or flattish, usually less than 0.25 mm. wide, maximum width 0.5 mm.; crossed by subequal costae corresponding to all septa unless very narrow, when the edge of the wall is dentate instead of costate.

Septa 16 in number, 8 reach the columella; 8 small, about half the length of the principals; in most instances they are thicker in the wall than at their inner ends. Margins of the longer with about three dentations on each. Septal faces with sharp granulations.

Columella, a small, erect, central style.

Localities and geologic occurrence.—Cuba, station 7522, Mogote Peak, 0.5 mile east of east boundary of United States Naval Reservation, Guantanamo, south side of peak, altitude about 375 feet a. t., collected by O. E. Meinzer (type).

Antigua, station 6865, Jackass Point, St. John, collected by T. W. Vaughan.

Panama, station 6587, Tonosi, collected by D. F. MacDonald.

Type.—No. 324794, U.S.N.M.

Astrocoenia guantanamensis is most nearly related to *Astrocoenia incrustans* (Duncan) which is from the upper Eocene St. Bartholomew limestone, and is the next species here described. The calices of *A. incrustans*, a description of which follows, are rather deep and the intercorallite areas are flattish and costate.

ASTROCOENIA INCRUSTANS (Duncan).

1873. *Stephanocoenia incrustans* DUNCAN, Geol. Soc. London Quart. Journ., vol. 29, p. 553, pl. 20, fig. 6.

1899. *Stephanocoenia incrustans* VAUGHAN, Mus. Comp. Zool. Bull., vol. 34, p. 229.

Original description.—"The corallum is low in height, and incrusts rocky surfaces. The corallites are united by their rather thick walls, and are parallel. The calices are quadrangular or pentangular, and their margins are marked by the septa of the adjacent corallites.

The septa are subequal at the wall, and 16 in number; but only eight reach the small and deep styloid columella; the others project very slightly, and are moniliform on their free edge. The pali are attached to the eight larger septa.

"Height of corallum, one-tenth inch [=2.5 mm.]. Breadth of calice, one-twentieth inch [=1.25 mm.]."

The following notes are based on the type-specimen:

It is a small thin fragment, 17.5 mm. long, 8 mm. wide, and 4 mm. thick.

The calices are moderately deep polygonal, many are elongate, the smaller ones measure 0.9 mm. in diameter, an elongated one is 1.2 mm. wide and 2 mm. long. The walls are thin, about 0.2 mm. wide; however, the upper edges of the septa are flattened and somewhat expanded. No mural styles.

Septa, 16 in number, equal in thickness at the wall, thicker than the spaces between; 8 extend to the columella, the laminae thinner between the portions surrounding the columella and the outer ends. The other 8 septa are short. The margins are finely dentate. Distinct pali absent. Apparently dissepiments are present.

Columella styliform, rather prominent, compressed.

This coral can not be referred to *Stephanocoenia* because there are no pali and the septal margins are dentate, instead of being entire. However, it exhibits all the characteristics of *Astrocoenia.* In the size of the calices, number of the septa, and character of the septal margins it resembles *A. duerdeni* (Vaughan), but differs from that species by the apparent absence of mural spines Notwithstanding this, it is not impossible that the type-specimen could be a portion of a corallum of *A. duerdeni*, the styles being absent from the area whence it was derived.

Locality and geologic occurrence.—Island of St. Bartholomew, P. T. Cleve, collector; subsequently collected by T. W. Vaughan; in the upper Eocene St. Bartholomew limestone.

Type.—University of Upsala.

ASTROCOENIA DECATURENSIS, new species.

Plate 78, figs. 3, 3*a*, 4, 4*a*.

1863. *Astrocoenia ornata* DUNCAN, Geol. Soc. London Quart. Journ., vol. 19, p. 425, pl. 14, fig. 7. (Not Milne Edwards and Haime.)

1864. *Astrocoenia ornata* DUNCAN, Geol. Soc. London Quart. Journ., vol. 24, p. 23.

Corallum massive, rather large, upper surface with numerous gibbosities. One specimen has a base 14 by 17 cm., respectively, as the smaller and greater diameter, and is about 8 cm. in height, another has 19 cm. as the greatest diameter of the base.

Corallites polygonal, separated by walls that are never very thick, rarely as much as 1 mm., upper edge usually if not always marked by a small raised, granulated line. The distal ends of the septa are produced as short costae to this line and often a granulation occurs between each pair of costae. The diameter of the corallites ranges from 1.5 to 2.5 mm.; about 2 mm. is the average. Calices shallow.

Septa distant, normally 16 in number, of which 8 extend to the columella, occasionally 20, with 10 reaching the columella. Their outer ends are slightly prominent on the wall and are equal in size. The inner margins lie almost in a straight line or are very slightly excavated but are regularly finely dentate, with four to seven teeth to each septum. These teeth are moderately acute and are directly obliquely upward and inward. Granulations on the faces minute, pointed.

Endothecal dissepiments present, thin, not abundant.

Columella a strong style, upper end pointed but not very prominent. There is some thickening of the inner ends of the larger septa where they fuse to the columella.

Localities and geologic occurrence.—Georgia, station 3383, Hale's Landing on Flint River, 7 miles below Bainbridge; and station 3381, Blue Springs, 4 miles below Bainbridge, collected by T. W. Vaughan.

Island of Antigua, West Indies, in the Antigua formation, collected by Robert T. Hill.

Cuba, station 7523, south side of Mogote Peak, altitude 250 feet a. t., one-half mile east of east boundary of the United States Naval Reservation, near Guantanamo, collected by O. E. Meinzer.

Type.—Cat. No. 324789, U.S.N.M.

Paratype.—Cat. No. 324788, U.S.N.M.

Astrocoenia ornata Duncan from Antigua (No. 12948, coll. Geol. Soc. London) is a massive species of *Astrocoenia.* It is silicified; the corallites are crowded, polygonal, intervening walls thin, diameter of corallites, 1.5 to 1.75 mm. Septa, 8 principal, 8 rudimentary, thin and distant. Columella, a slender style.

ASTROCOENIA MEINZERI, new species.

Plate 79, figs. 3, 3a.

Corallum composed of thick branches, with broadly elliptical cross-section. Type, a broken, bifurcating branch. Length from broken base to fork, 50 mm.; diameter of basal end, 23.5 by about 24 mm. Diameter of broken end of branch at fork, 23 by 24 mm. Length of broken lateral branch from fork, 21 mm.; diameter of distal broken end, 17.5 by 20.5 mm.

Calices rather large, diameter measured between thecal summits from 2.5 to 3 mm.; depth, 1.25 to 1.5 mm. Intercorallite walls from 0.5 to 1.5 mm. across where well preserved, about 0.75 mm. usual. In places the top of the wall is acute, but this condition is probably due to weathering. Where the walls are wide there is usually a distinct intercorallite groove. Thick costae or mural teeth are probably present on perfect specimens, but they are not distinct on the type, as its surface is worn.

Septa 16 in number; 8 principals extend to the columella, and 8 are short but thick. The principal septa slope in a concave curve to the bottom of the calice, and are narrow nearly to the level of the bottom of the calice; the smaller septa are narrow. All septa are thick in the wall, and the principals are fused by their thickened inner ends around the columella. About seven small dentations were counted on one long septum. Septal faces with small granulations.

Columella a low style, with rounded upper end; it with the inner septal ends fused around it forms a rather large columellar mass.

Thickish dissepiments are present.

Locality and geologic occurrence.—Cuba, station 7522, Mogote Peak, 0.5 mile east of east boundary of United States Naval Reservation, Guantanamo, south side of peak, altitude about 375 feet a. t., collected by O. E. Meinzer.

Type.—No. 324791, U.S.N.M.

The species most nearly related to *Astrocoenia meinzeri* is *A. d'achiardii* Duncan from the upper Eocene St. Bartholomew limestone. The branches of *A. d'achiardii* are more irregular in form, for the same size branch the calices are larger, up to 3.5 mm. in diameter, the intercorallite walls are not so wide, the outer part of the septal margins are steeper, and the septal dentations are coarser. Notwithstanding these apparent differences, it should be admitted that larger collections may lead to combining the two supposed species.

ASTROCOENIA PORTORICENSIS, new species.

Plate 76, figs. 4, 4*a*; plate 78, figs. 1, 1*a*.

1901. *Astrocoenia ornata* VAUGHAN, Geol. Soc. London, Quart. Jour., vol. 57, p. 497.

Not:

1838. *Porites ornata* MICHELOTTI, Specim. Zooph. diluv., p. 172, pl. 6, fig. 3.

1857. *Astrocoenia ornata* MILNE EDWARDS and HAIME, Hist. nat. Corall., vol. 2, p. 257

The following is a description of the type (pl. 76, figs. 4, 4*a*):

Corallum forming flattened, even palmate branches. The type-specimen, which is broken, has a greatest width of 53 mm., length 105 mm., and a thickness of 15.5 mm. at the lower and of 7.5 mm. at the upper end.

Calices, diameter from 1.0 to 1.5 mm., excavated but rather shallow, outline polygonal, united by compact, rather narrow walls, which range from 0.2 to 0.5 mm. across. The distal ends of the septa form low costae.

Septa, 16 in number, 8 reach the calumella and 8 are short or even rudimentary; a few dentations, usually about 3 or 4 on the margin of each principal septum. Interseptal loculi about as wide as the thickness of the septa.

Columella an erect style, which does not reach the level of the upper edge of the wall; its upper termination rounded; cross-section elliptical.

Endothecal dissepiments present.

Localities and geologic occurrence.—Island Antigua in the Antigua formation. Collected by R. T. Hill and by T. W. Vaughan.

Porto Rico, station 3191, 4 miles west of Lares, in the Pepino formation, collected by R. T. Hill.

Canal Zone, station 6024*b*, in the Emperador limestone, at the crossing of the Panama Railway over Rio Agua Salud, collected by T. W. Vaughan and D. F. MacDonald.

Type.—No. 324785 U.S.N.M., from 4 miles west of Lares, Porto, Pepino formation, collected by R. T. Hill.

Paratype.—Cat. No. 324786, U.S.N.M.

The foregoing description is based on the type-specimen and does not take into consideration the variation of the species. I obtained a good suite of specimens at two exposures of the Antigua formation on the island of Antigua. The branches range in form from greatly compressed to subcylindrical (see pl. 77, figs. 1, 1*a*, illustrations of a specimen from Willoughby Bay, Antigua). A segment from near the base of a subcylindrical branch was collected on Rio Agua Salud, Canal Zone.

Genus **STYLOCOENIA** Milne Edwards and Haime.

1849. *Stylocoenia* MILNE EDWARDS and HAIME, Comptes Rend., vol. 27, p. 469.

Type-species.—*Astrea emarciata* Lamarck.

STYLOCOENIA PUMPELLYI (Vaughan).

1900. *Astrocoenia pumpellyi* VAUGHAN, U. S. Geol. Survey Mon. 39, p. 149, pl. 17, figs. 7, 7*a*.

This species seems to belong to the genus *Stylocoenia*, as it has intercorallite pillars; but as some septa show dentations on their margins, the original generic identification may be correct. It occurs in the base of the Chattahoochee formation, near Bainbridge, Georgia, and not in Vicksburgian deposits, as I stated in the original description.

Localities and geologic occurrence.—Georgia: Station 2326, Russell Spring, Flint River, 4 miles below Bainbridge, collected by R. Pumpelly (type, Cat. No. 158315, U.S.N.M.); station 3381, same locality as the preceding, collected by T. W. Vaughan; stations 3383, collected by T. W. Vaughan, and 7078, collected by T. W. Vaughan, C. W. Cooke, and W. C. Mansfield, Hales Landing, Flint River, 7 miles below Bainbridge, in the base of the Chattahooche formation.

Antigua: Station 6881, Willoughby Bay, collected by T. W. Vaughan in the Antigua formation.

Family OCULINIDAE Milne Edwards and Haime.

Genus OCULINA Lamarck.[1]

1816. *Oculina* LAMARCK, Hist. nat. Anim. sans Vert., vol. 2. p. 283.
1849. *Oculina* MILNE EDWARDS and HAIME, Comptes Rend., vol. 29, p. 68.
1850. *Oculina* MILNE EDWARDS and HAIME, Mon. Brit. foss. Cor., Intr., p. XIX.

Type-species.—*Madrepora virginea* Ellis and Solander.

OCULINA DIFFUSA Lamarck.

1816. *Oculina diffusa* LAMARCK, Hist. nat. Anim. sans Vert., vol. 2, p. 285.
1901. *Oculina diffusa* ? variety VAUGHAN, U. S. Fish Commission Bull. for 1900, vol. 2, p. 294, pl. 1, figs. 5, 5*a*.
1915. *Oculina diffusa* VAUGHAN, Washington Acad. Sci. Journ., vol. 5, p. 596.
1915. *Oculina diffusa* VAUGHAN, Carnegie Inst. Wash. Yearbook No. 14, p. 227.

Doctor MacDonald obtained seven pieces of branches of this species at the locality mentioned below. They are slender and resemble fragments from specimens of *Oculina diffusa*, which grow either in water 10 to 16 fathoms deep or where the water is very quiet. The specimens from Panama nearly duplicate those I described from Porto Rico.

Locality and geologic occurrence.—Canal Zone, station 5849, swamp, Mount Hope, Pleistocene, collected by D. F. MacDonald.

OCULINA VARICOSA LeSueur.

1820. *Oculina varicosa* LE SUEUR, Paris Mus. Mém., vol. 6, p. 291, pl. 17, fig. 19.
1902. *Oculina varicosa* VERRILL, Conn. Acad. Sci. Trans., vol. 11, pl. 32, figs. 2, 3, 4 (refs. to literature).

A single nearly typical fragment of a branch was obtained.

Locality and geologic occurrence.—Canal Zone, station 5849, swamp, Mount Hope, Pleistocene, collected by D. F. MacDonald.

ARCHOHELIA, new genus.

Archohelia differs from *Oculina* solely by having a persistent axial corallite, whereas in *Oculina* there is no axial corallite. Pali or paliform teeth are present on all but the last cycle of septa. Columella trabecular, with some papillae on its upper surface.

Type-species.—*Archohelia limonesis* Vaughan.

The relations of this genus to the species described in my monograph on the Eocene and lower Oligocene coral faunas of the United States[2] under the names *Astrohelia neglecta*, *A. burnsi*, *Oculina vicksburgensis*, *O. mississippiensis*, *O. singleyi*, *O. alabamensis*, *O. harrisi*,

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[1] Toula (K. K. Geolog. Reichsanstalt Jahrb., vol. 61, p. 489, pl. 30, fig. 1, 1911) applies the name *Oculina gatunensis* to a piece of a branch of coral, but his description and figure are inadequate for the identification of the species.

[2] U. S. Geol. Survey Monograph 39, pp. 114-124, 1900.

O. aldrichi, and *O.* ? *smithi* should be indicated. The species mentioned have axial corallites and generically resemble *Archohelia* except in the details of the inner ends of the septa. The type-species of *Astrhelia* (the correct spelling of the name, instead of *Astrohelia*) is *Madrepora palmata* Goldfuss, which has no definite axial corallites, and I have seen no pali or paliform lobes on its septa. The species to which I applied the names *Astrohelia neglecta* and *A. burnsi*, as they possess axial corallite should be taken out of the genus *Astrhelia*. As it is not practicable just now to revise critically the Eocene and lower Oligocene species listed above, it will here only be mentioned that they probably should be transferred to *Archohelia*.

ARCHOHELIA LIMONENSIS, new species.

Plate 80, figs. 1, 1*a*, 1*b*, 2, 3.

Corallum composed of relatively slender branches. The following are measurements of the cotypes:

Dimensions in millimeters of cotypes of Archohelia limonensis.

Branch.	Length.	Diameter.		Calices.	
		Lower end.	Upper end.	Diameter.	Exsert.
1	25	4.5	4	2.5–3	1–3.5
2	31	4.5	4	2–2.6	0.5–3.5
3	33	4	3.5	2.3–3	1–7

The cavity of the axial corallite is about 2.25 in diameter. The foregoing tables give the dimensions and amount of the projection of the radial calices—the diameters stated are as measured from the outside of the walls. The distance between adjacent calicular margins is about 2.5 mm. on branch No. 2; in extreme cases it ranges up to as much as 7 mm., as between some calices on branch No. 3. The arrangement is in more or less definite spirals. Subequal or slightly alternating costae, with closely granulate surfaces, correspond to all septa just below the calicular edges; lower down on the corallite limbs they flatten and become subequal; they may continue on the coenenchymal surface or disappear. The calicular cavities are excavated; moderately deep, about 1.5 mm.

Septa normally in three complete cycles; primaries as a rule slightly larger than the secondaries, both cycles reach the columella, and have subequal, slightly exsert upper margins; tertiaries smaller than the secondaries and have lower upper margins. Inner edges of the tertiaries usually free, but in some systems they fuse to the sides of included secondary septa. Single or double paliform teeth on the inner ends of the primaries and secondaries. Septal faces closely granulate.

Columella papillate.

Coenenchyma dense; with or without costal prolongations from the calicular peripheries; fine granulations scattered over its surface.

Localities and geologic occurrence.—Costa Rica, Limon, as follows: Station 2692, collected by R. T. Hill; Moin Hill, Niveau *d* and No. 461, collected by H. Pittier; station 5884*b*, Moin Hill, collected by D. F. MacDonald. The geologic horizon seems to be Pliocene.

Florida, station 3300 in the Pliocene Caloosahatchee marl of Shell Creek, collected by Frank Burns.

Cotypes.—No. 324809, U.S.N.M., from Niveau *d*, Moin Hill, Port Limon (3 specimens).

Family EUSMILIIDAE Verrill.

Genus ASTEROSMILIA Duncan.

1867. *Asterosmilia* DUNCAN, Roy. Soc. Philos. Trans., vol. 157, p. 653.
1873. *Asterosmilia* DUNCAN, Geol. Soc. London Quart. Journ., vol. 29, p. 553.
1884. *Asterosmilia* DUNCAN, Linn. Soc. London Journ. Zool., vol. 28, p. 61.,

Type-species.—*Trochocyathus abnormalis* Duncan.

When Duncan described this genus he referred to it his *Trochocyathus abnormalis*, changing the name to *anomala*, and refigured the species. He also described two additional species as *Asterosmilia exarata* and *A. cornuta*, a synonym of *A. abnormalis*, and failed to designate a type-species for the genus. *Trochocyathus abnormalis* was described with much care, while the descriptions of the two other species are short and unsatisfactory. *A. cornuta* is a synonym of *A. abnormalis*. It therefore seems best to take the species I have selected, as indicated above, as the type-species of the genus.

Duncan described three species of *Asterosmilia* from the Tertiary formations of Santo Domingo, namely, *Trochocyathus abnormalis*,[1] for which the genus *Asterosmilia* was subsequently erected, *A. cornuta*, and *A. exarata*,[1] and one species *A. pourtalesi* from the upper Eocene St. Bartholomew limestone. I consider *A. cornuta* a synonym of *A. abnormalis*, and transfer Duncan's *Trochocyathus profundus* from the genus in which it was originally placed to *Asterosmilia*, leaving four described fossil species in the genus. Pourtalès described from the West Indies one recent species that belongs to *Asterosmilia*, his *A. prolifera*, originally named *Ceratocyathus prolifer*, and of which Lindstrom's *Paracyathus arcuatus* is a synonym. I here describe an additional new species, namely, *A. hilli*, from Bowden, Jamaica, and Limon, Costa Rica, and have described two additional species from Santo Domingo, in a paper not yet published, making eight, the total number of American species at present known to belong to the genus.

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[1] Collected by A. Olsson on Provision Island, Costa Rica, in the Gatun formation. Footnote added to page proof.

ASTEROSMILIA HILLI, new species.

Plate 80, figs. 4, 5, 6, 6*a*.

1899. *Asterosmilia* species VAUGHAN, Mus. Comp. Zool. Bull., vol. 34, p. 149.

I find it difficult to explain why a species so common as this one could have so long remained undescribed. There are from Bowden, Jamaica, 41 specimens in the Henderson and Simpson collection, 20 in the Hill collection, and 9 in the T. H. Aldrich collection, making a total of 70 specimens that I have studied from this one locality. A series of ten of the best specimens of the Henderson and Simpson collection have been selected as the cotypes.

Corallum cornute with a pointed base and attached, at least in its early stages, rather slender, curved in the plane of the greater transverse axis of the calice. The following table gives the measurements and number of septa in the type specimens.

Dimensions of and number of septa in Asterosmilia hilli.

Specimen No.	Greater diameter of calice.	Lesser diameter of calice.	Height of corallum.	Number of septa.
	mm.	*mm.*	*mm.*	
1	4	3	6.5	About 24, and probably some rudimentary.
2	4	3.75	7	24, and a few rudimentary.
3	4	3.5	9	24, and a few rudimentary.
4	4.5	4	10.5	24+17 of the fourth cycle.
5	6.5	5.5	12	24+20 of the fourth cycle.
6	7	6	15	24+20 of the fourth cycle.
7	6	5	15.5	Calice broken on side.
8	9	7	18.5	24+20 of the fourth cycle.
9	9.5	8.75	19	48, fourth cycle complete.
10	[1] 10	[1] 9	25	48, four complete cycles.

[1] About.

The calice is oblique, its upper edge being considerably higher than its lower. In the measurements given above the height of the corallum is measured from the tip of the pedicel to the highest point of the calicular margin.

The wall is only moderately thick, externally there is a variable amount of pellicular coating. Costae corresponding to all septa, distinct, but usually not prominent. There is a fair amount of variation in the costal characters. In some specimens the costae of all cycles are equal or subequal, low, flattish or only slightly crested; in others, those corresponding to the septa of the first and second cycles of septa are decidedly more prominent than the intervening costae. Those corresponding to the third cycle of septa may be slightly more prominent than those corresponding to the fourth. Sometimes costae of both kinds are combined in one specimen. Rather often in an intercostal space there is a raised thread or line which does not correspond to a septum. Minute, crowded granulations are scattered over the surfaces of the costae and in the intercostal spaces.

Septa, thin, distant, those of the first and second cycles have slightly exsert margins. In adult specimens, 19 to 25 mm. tall, there are four complete cycles, in younger specimens the fourth cycle is incomplete. The members of the first and second cycles are of equal size, extend to the columella, and are decidedly thicker than the other septa. The members of the fourth cycle are thinner and shorter than those of the third. The septal margins are subentire, arched above and fall at a very steep angle to the bottom of the calicular fossa. Septal faces finely striate, with more or less elongate granulations along the courses of the striae. Line of divergence of the striae very close to the inner side of the wall. Wide, tall, thin, pali, rounded above, stand before the septa of the third cycle, from whose inner margin they are separated by a deep notch. The width of a palus is about 1 mm., height, 1.5 mm.

Dissepimental endotheca, present, but not abundant. The dissepiments thin.

The columella in fully grown specimens, prominent, compressed or even distinctly lamellar in appearance. In young and broken specimens it appears to be composed of interfused processes from the inner ends of the septa, it is decidedly vesicular. Calice, rather deep, 3 to 4 mm.

Localities and geologic occurrence.—Jamaica, Bowden, collected by J. B. Henderson and C. T. Simpson and R. T. Hill.

Costa Rica, "Colline en démolition," Limon, Costa Rica, No. 618 of H. Pittier's collection.

Cotypes.—Nos. 324815, 324816, U.S.N.M. (10 specimens).

The specimens from Limon, Costa Rica, are essentially duplicates of those from Bowden. One specimen with a greater calicular diameter of 9.5 mm. has a few quinary septa.

Genus STEPHANOCOENIA Milne Edwards and Haime.

1848. *Stephanocoenia* Milne Edwards and Haime, Comptes Rend., vol. 27, p. 469.
1848. *Stephanocoenia* Milne Edwards and Haime, Ann. Sci. nat., Zool., ser. 3, vol. 10, p. 300.
1850. *Stephanocoenia* Milne Edwards and Haime, Mon. Brit. foss. Cor., Intr., p. XXX.
1857. *Stephanocoenia* Milne Edwards and Haime, Hist. nat. Corall., vol. 2, p. 264.
1884. *Antillastraea* Duncan, Linn. Soc. London Journ., Zool., vol. 28, p. 108.

Type-species.—Astrea intersepta Lamarck = *Madrepora intersepta* Esper.

STEPHANOCOENIA INTERSEPTA (Esper).

1795. *Madrepora intersepta* Esper, Pflanzenth., Fortsetz., p. 99, pl. 79, figs. 1–3.
1816. *Astrea intersepta* Lamarck, Hist. nat. Anim. sans Vert., vol. 2, p. 266.
1848. *Stephanocoenia intersepta* Milne Edwards and Haime, Comptes Rend., vol. 27, p. 469.

1848. *Stephanocoenia intersepta* Milne Edwards and Haime, Ann. Sci. nat., ser. 3, Zool., vol. 10, p. 300, pl. 7, figs. 1, 1*a*, 1*b*.
1848. *Stephanocoenia michelinii* Milne Edwards and Haime, Ann. Sci. nat., ser. 3, Zool., vol. 10, p. 301.
1864. *Plesiastraea spongiformis* Duncan, Geol. Soc. London Quart. Journ., vol. 20, p. 39, pl. 4, figs. 6*a*, 6*b*.
1866. *Stephanocoenia debilis* Duchassaing and Michelotti, Sup. Mém. Corall. Antilles, p. 76, pl. 9, figs. 7, 8.
1884. *Antillastraea spongiformis* Duncan, Linn. Soc. London, Journ., Zool., vol. 18, p. 108.
1895. *Stephanocoenia intersepta* Gregory, Geol. Soc. London Quart. Journ., vol. 51, p. 276.
1900. *Stephanocoenia intersepta* Vaughan, U. S. Geol. Surv. Mon. 39, pp. 152, 153.
1900. *Plesiastraea goodei* Verrill, Conn. Acad. Arts and Sci. Trans., vol. 10, p. 553, pl. 67, fig. 1.
1901. *Stephanocoenia intersepta* Vaughan, Geol. Reichs. Mus. Leiden Samml., ser. 2, vol. 2, p. 20.
1902. *Plesiastraea goodei* Verrill, Conn. Acad. Arts and Sci. Trans., vol. 11, p. 106, fig. 1, p. 172, pl. 31 (not pl. 30 as given in the text), figs. 1, 1*a*.
1915. *Stephanocoenia intersepta* Vaughan, Carnegie Inst. Wash. Yearbook No. 13, p. 222.
1916. *Stephanocoenia intersepta* Vaughan, Carnegie Inst. Wash Yearbook No. 14, p. 221.

Although the original description of Lamarck is brief, it is good. According to him, "Cette espèce forme de large plaques un peu convexe, et offre à sa surface un réseau assez fin, constitué par les bords réunis des cellules. On voit un petit axe au centre de chaque ètoile." He placed *Madrepora intersepta* Esper doubtfully in its synonymy. Esper says regarding his specimens of the species: "Es kommt diese Koralle von den ostindischen Meeren; ich habe sie gleichfalls durch die Güte des Herrn Prediger Chemnitz, mitgetheilt erhalten." It appears that Chemnitz had specimens from both the Atlantic and the Indo-Pacific and that he gave numbers of them to Esper. Apparently in some instances the locality labels were confused, and that this is one of them, for Esper's figures (pl. 79, figs. 1–3) are fairly good for the West Indian and Floridian species to which the specific name *intersepta* is now applied, and seem to me to represent no other living species of coral with which I am familiar.

The corallum is massive, either subhemispherical or pulvinate in form. The corallites are not protuberant, joined directly by their walls or by costae, in the latter case exothecal dissepiments may be present. The diameter of the calices ranges between 2 and 3 mm. Septa in three cycles. Primaries and secondaries bear well-developed pali, by which they are joined to the columella. Tertiaries thin and relatively short. Septal margins subentire or very finely dentate. Columella, a compressed style of nearly the same height as the pali. Endothecal dissepiments subhorizontal, thin, average about 0.5 mm. apart.

As this is the type-species of the genus *Stephanocoenia*, the following notes on its finer structure will be repeated, with slight emendation, from my paper on the Eocene and lower Oligocene corals of the United States (1900): The septa are composed of ascending trabeculae; near the wall is a line of divergence. External to this line the trabeculae pass upward and have a slight inclination outward. The trabeculae on the inner side of the line of divergence pass upward and incline inward. The trabeculae are fine, measuring from 0.027 to 0.04 mm. across. A study of the lines of growth across the trabeculae indicate an entire or very obscurely dentate septal margin. The growth segments of the septa are well defined; the distance across one measured along the line of divergence is about 0.32 mm. on an average. The distal ends of the septa do not thicken sufficiently to form a pseudotheca. In places dark centers or a dark band can be seen in the theca between the septal ends; that is, the wall belongs in the euthecal class. In some instances the wall is clearly formed by peripherally placed dissepimenta. The corallites are rather often joined by their costae. In such instances the wall of one corallite is usually formed by dissepiments. There is usually distinguishable a central erect piece, around which the principal septa fuse by their inner margins. In some instances the columella appears to be formed merely by the fusion of the septal margins. In one calice the axis of the columella is vacant, the septal margins having fused around it. The pali in cross section show as thickenings on the inner septal ends. The inner ends of the tertiary septa are free.

The above description should be compared with Felix's description of *Stephanocoenia formosa* (Goldfuss).[1] I should also like to call attention to a statement by Miss Ogilvie, that "it is doubtful if they (*Astrocoenia* and *Stephanocoenia*) are represented in recent seas."[2] She evidently did not know that the type-species of *Stephanocoenia* is the recent *S. intersepta* (Esper). So if there is any doubt, it is that the genus is found fossil earlier than late Tertiary.

It is astonishing to find the following statement in a recent paper by Felix:[3] "Von dieser Art, welche heutzutage in Australischen Meeren lebt, liegen mir zwei examplare vor. Fossil findet sich in dem Pliocänen Mergel von Rangoen auf Java." Such a statement when the species he is discussing is one of the most widespread and best known of those in Pleistocene deposits adjacent to and in the Recent waters of the western Atlantic Ocean, the Caribbean Sea, and the Gulf of Mexico!

Synonymy.—Gregory in 1895 gave full references to the literature on this species up to that date, except that he did not place *Stephanocoenia debilis* Duchassaing and Michelotti in its synonym.

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[1] Deutsch. Geolog. Gesell. Zeitschr., vol. 50, pp. 252-254, pl. 2, fig. 1.

[2] Roy. Soc. London Trans., vol. 187, p. 307, 1896.

[3] Königl. Sächs Gesell. Wiss., Leipzig, Math. Phys. Kl., vol. 64, p. 444, 1912.

While in Turin in 1897 I examined the specimens identified by Duchassaing and Michelotti as *Stephanocoenia intersepta* and *S. michelini.* They belong to the same species. It is said of *S. debilis:* "Bien que les dimensions des calices de cette espèce soient les mêmes que dans la *Stephanocoenia michelini,* elle s'en distingue pourtant par la muraille, par les cloisons plus minces, et par les palis qui atteignent la hauteur de la columelle." The only character of apparent value is the height of the pali, which are as tall as the columella. The pali and columella are usually of nearly the same height in the species; in areas on some specimens the columella is somewhat taller; in other areas the pali are taller.

I examined Duncan's type of *Plesiastraea* [later described as *Antillastraea*] *spongiformis* and a specimen identified by him as *Stephanocoenia intersepta.* The corallites of the former are united by their costae, and where the costae meet there is often a second wall outside the true corallite wall. The second specimen had been cut, the larger piece bearing the label *Stephanocoenia intersepta;* the smaller piece, which fits into the larger, was labeled *Plesiastraea spongiformis.* Duncan, it seems, could not distinguish between the two. I agree with Gregory in placing *Plesiastraea spongiformis* in the synonym of *Stephanocoenia intersepta.*

Plesiastraea goodei Verrill, fragment of the type No. 36497, U.S.N.M., is precisely the same as *Stephanocoenia intersepta*—there are no differential characters.

Distribution of Stephanocoenia intersepta.—Just how old, geologically, this species is, is not definitely known.

Jamaica.—There is a specimen in the United States National Museum bearing the station number 2580, which is for the collection made by Messrs. J. B. Henderson and C. T. Simpson in the Bowden marl of Jamaica.

Santo Domingo.—Miss C. J. Maury obtained five specimens of this much-named species, as follows:

Rio Gurabo: Zone D, associated with *Stylophora affinis* Duncan, *Madracis decactis* (Lyman), *Pocillopora crassoramosa* Duncan, *Orbicella limbata* (Duncan), *Orbicella cavernosa* var. *cylindrica* (Duncan), *Syzygophyllia dentata* (Duncan); zone E, associated with *Placocyathus* new species, *Placocyathus variabilis* Duncan, *Stylophora* new species, *Madracis decactis* (Lyman), *Syzygophyllia dentata* (Duncan), *Pavona* new species. Limestone, Los Quemados, associated with *Placocyathus variabilis* Duncan. As zones I and H of Miss Maury's section represent the Bowden fauna, zones E and D are stratigraphically above the Bowden.

Cuba.—I collected a specimen near the Morro, at the mouth of Santiago Harbor, altitude about 240 feet above level. This specimen may be of Pleistocene age. The general basement country rock is

Miocene limestone and marl, which contain some corals of reef facies; and on this basement there are in places well-developed Pleistocene coral reefs. Therefore, the specimens of *Stephanocoenia intersepta* might be of Miocene age. Other specimens from stations 3436 and 3449, south side of the trocha in Santiago, seem definitely to belong in the La Cruz marl and to be of pre-Pleistocene age.

Doctor Pittier obtained a specimen of the species at the "Colline en démolition," Limon, Costa Rica, apparently in association with *Asterosmilia hilli, Dichocoenia tuberosa,* and *Balanophyllia pittieri.* The horizon would therefore be near that of the Bowden marl.

Pleistocene.—General in the elevated reefs of the Caribbean and Gulf region: Barbados (low-level reefs); Curaçao and Arube; Key Vaca, Florida.

Recent.—The West Indies in general, northward to the Bermudas; Florida; British Honduras.

Although I have often picked up specimens of this species where they had been washed up by the waves, both in Florida and in the Bahamas, I have not certainly seen it alive on the reefs. As the color of the living polyps is brown, while alive it so closely resembles *Siderastrea radians* that only very close examination will distinguish between them, probably on the reefs it was mistaken for the latter. That it is a common associate of the usual West Indian reef corals is shown by its usual presence among them in the fossil reefs. This species ranges into slightly deeper water than most of the West Indian reef corals. I dredged it at a depth of 4–9 fathoms off Nassau, Bahamas, and at a depth of 16 fathoms off Tortugas, Florida.

Genus DICHOCOENIA Milne Edwards.

1848. *Dichocoenia* Milne Edwards and Haime, Compt. Rend., vol. 27, p. 469.

1857. *Dichocoenia* Milne Edwards and Haime, Hist. nat. Corall., vol. 2, p. 199 (type-species, figured, pl. DI, figs. 10*a*, 10*b*).

1917. *Dichocoenia* Vaughan, U. S. Geol. Surv. Prof. Pap. 98–T, p. 370.

Type species.—Dichocoenia porcata Milne Edwards and Haime.

DICHOCOENIA TUBEROSA Duncan.

Plate 79, figs. 4, 4*a*, 4*b*.

1863. *Dichocoenia tuberosa* Duncan, Geol. Soc. London Quart. Journ., vol. 19, p. 432, pl. 15, figs. 5*a*, 5*b*.

This name has been placed in the synonymy of the living *Dichocoenia stokesi* Milne Edwards and Haime by both Gregory [1] and myself.[2] One-half of Duncan's type is in the United States National Museum, No. 155275, presented by the officers of the Geological Society of London. Although *D. tuberosa* is very similar to *D. stokesi, D. tuberosa* has a penduncular base and granulate costal markings below the calicular surfaces in all the specimens I have

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[1] Geol. Soc. London Quart. Journ., vol. 51, p. 268, 1895.

[2] U. S. Geol. Survey Prof. Pap. 98–T, p. 371, 1917.

examined. As I am able to recognize the species I am treating it as valid. Duncan records the form from the "Nivajè shale and tufaceous limestone of Santo Domingo."

Locality and geologic occurrence.—Costa Rica, "Colline, en démolition," Limon, No. 618 of H. Pittier collection, associated with *Asterosmilia hilli*, *Stephanocoenia intersepta*, and *Balanophyllia pittieri*. A single, small, immature specimen. The illustrations present its characters well enough to make a detailed description unnecessary.

Santo Domingo, Rio Gurabo, zone F, of Miss C. J. Maury's section, associated with *Placocyathus variabilis* Duncan and *Antillia dubia* (Duncan).

Genus EUSMILIA Milne Edwards and Haime.

1848. *Eusmilia* Milne Edwards and Haime, Comptes Rend., vol. 27, p. 467.

Type-species.—*Madrepora fastigiata* Pallas.

EUSMILIA FASTIGIATA (Pallas).

1766. *Madrepora fastigiata* Pallas, Elench. Zooph., p. 301.
1895. *Eusmilia fastigiata* Gregory, Geol. Soc. London Quart. Journ., vol. 51, p. 260 (with synonymy).
1895. *Eusmilia knorri* Gregory, Geol. Soc. London Quart. Journ., vol. 51, p. 261 (with synonymy).
1901. *Eusmilia knorri* Vaughan, Geol. Reichs. Mus. Leiden Samml., ser. 2, vol. 2, p. 13.
1902. *Eusmilia aspera* Verrill, Conn. Acad. Arts and Sci. Trans., vol. 11, p. 114, fig. 3.
1915. *Eusmilia fastigiata* Vaughan, Washington Acad. Sci. Journ., vol. 5, p. 596.
1916. *Eusmilia fastigiata* Vaughan, Carnegie Inst. Washington Yearbook No. 14, p. 227.

Study of large suites of *Eusmilia* convince me that *Eusmilia fastigiata* (Pallas) and *E. aspera* (Dana) = *E. knorri* M. Edwards and Haime are not specially separable, as there is great variation and complete overlapping in the columellar characters by which they were distinguished.

Localities and geologic occurrence.—Canal Zone, Pleistocene at stations 5849, Mount Hope; Costa Rica, 6251, Monkey Point, collected by D. F. MacDonald.

General in the living and Pleistocene coral reefs of Florida, the West Indies, and the Caribbean coast of Central America.

Family ASTRANGIIDÆ Verrill.

Genus CLADOCORA Ehrenberg.

1834. *Cladocora* Ehrenberg, Corallenth. Roth. Meer., p. 85 (of separate).
1848. *Cladocora* Milne Edwards and Haime, Comptes Rend., vol. 27, p. 493.

Type-species.—*Caryophyllia cespitosa* Lamarck.

CLADOCORA ARBUSCULA (Le Sueur).

1820. *Caryophyllia arbuscula* Le Sueur, Paris Mus. Mém., vol. 6, p. 275, pl. 15, figs. 2*a*–2*d*.
1901. *Cladocora arbuscula* Vaughan, U. S. Fish Commission Bull. for 1900, vol. 2, p. 298, pl. 2, figs. 3, 3*a* (with synonymy).

This species is common in the Pleistocene marls near Colon.

Locality and geologic occurrence.—Canal Zone, station 5850 and 6039, Pleistocene, Mount Hope, collected by D. F. MacDonald. Living in Florida and the West Indies on reef flats and in water from 8 or 9 to about 20 fathoms deep.

Family ORBICELLIDAE Vaughan.

Genus ORBICELLA Dana.

1846. *Orbicella* Dana, U. S. Expl. Exped. Zooph., p. 205.
1849. *Phyllocoenia* Milne Edwards and Haime, Comptes Rend., vol. 27, p. 469.
1901. *Orbicella* Vaughan, Geol. Reichs Mus. Leiden Samml., ser. 2, vol. 2, p. 21.
1902. *Orbicella* Verrill, Conn. Acad. Arts and Sci. Trans., vol. 11, p. 93.
1918. *Orbicella* Vaughan, Carnegie Inst. Washington Pub. 213, p. 85.

Type-species.—*Madrepora annularis* Ellis and Solander.

Of this perplexing genus of corals, the following species and varieties are treated as valid in the present papers:

Orbicella annularis (Ellis and Solander).
    limbata (Duncan).
    imperatoris, new species.
    altissima (Duncan).
    antillarum (Duncan).
    cavernosa (Linnaeus).
        var. *endothecata* (Duncan).
        var. *cylindrica* (Duncan).
    aperta (Verrill).
    bainbridgensis, new species.
    costata (Duncan).
    canalis, new species.
    tampäensis, new species.
        var. *silecensis*, new variety
    brevis (Duncan).
    insignis (Duncan).
    intermedia (Duncan).
    gabbi, new species.

As synonymy is discussed on subsequent pages, it is here only necessary to say that under the name *Astraea megalaxona*[1] Duncan described from Antigua a silicified coral which is not determinable; that his *Astraea crassolamellata*[2] and its varieties are here referred to

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[1] Geol. Soc. London Quart. Journ., vol. 19, p. 420, pl. 13, figs. 12*a*, 12*b*, 1863.
[2] Idem., p. 412, pl. 13, figs. 1–7.

the fungid genus *Diploastrea* Matthai; his *Astraea cellulosa* [1] is made the type-species of a new genus, *Antiguastrea,* and his *Astraea antiguensis* [2] and *Astraea tenuis* [3] are referred to the fungid genus *Cyathomorpha* Reuss.

Although inadequacy of information regarding four species, *O. altissima, O. antillarum, O. insignis,* and *O. intermedia,* described by Duncan, renders the preparation of an adequate synoptic table impracticable, an attempt will be made to summarize the most striking characters. With one exception, the species fall into two larger groups: the members of the first group normally have only three cycles of septa; those of the second group have four cycles, the fourth cycle is incomplete in some specimens, while in other specimens a variable number of quinary septa are present. One species, *Orbicella gabbi* Vaughan, has five cycles of septa.

SYNOPSIS OF AMERICAN SPECIES OF ORBICELLA.

Species with 3 cycles of septa.

Calices usually 2 to 3 mm. in diameter; costae subequal; primary and secondary septa equal, extend to the columella.......... 1. *O. annularis* (Ellis and Solander).

Calices 3 to 4 mm. in diameter; costae usually alternately large and small; secondary septa thinner than the primaries, but usually reach the columella 2. *O. limbata* (Duncan).

Calices 3.5 to 5 mm. in diameter; costae prominent, thin; secondary septa usually about half as long as the primaries, tertiaries small and thin. 3. *O. imperatoris,* new species.

Calices 7.5 mm. in diameter; costae tolerably developed, subequal; primary and secondary septa subequal, extend to the columella... 4. *O. antillarum* (Duncan).

Species of Orbicella with the 4th cycle of septa nearly or quite complete.

Calices 5 mm. in diameter; costae unequal, thicker than the septa, last "order" of costae well developed, contrasting with rudimentary septa; septa irregular in arrangement, *36 in number, 6 septa in each of 6 systems*.. 5. *O. altissima* (Duncan).

Calices from 5 to 11 mm. in diameter; costae correspond to all septa, usually subequal; septa normally in 4 complete cycles, subequal over top of wall, first 3 cycles reach columella, no pali.................................. 6. *O. cavernosa* (Linnaeus).

  Costae strongly alternating in size, fourth cycle small and thin without obvious corresponding septa .... 6*a*. var. *endothecata* (Duncan).

  Corallites smaller than in 6*a* (5 to 6 mm. in diameter), about 38 septa, last cycle of costae rudimentary or obsolete.... 6*b*. var. *cylindrica* (Duncan).

Similar to *O. cavernosa* except that the first three cycles of septa are thinner and taller, strongly contrast in height with the quaternaries.. 7. *O. aperta* (Verrill).

Calices 6 to 7 mm. in diameter; costae low, equal; septa low and subequal on mural summit; primaries and secondaries with rather wide erect, paliform lobes, youngest septa composed of incompletely fused spines. 8. *O. bainbridgensis,* new species.

Calices 7.5 to 8.5 mm. in diameter; costae highly developed, alternate in size except at calicular margin; septa normally in 4 cycles, thin except in wall of some specimens, paliform lobes and thickenings distinct but rather small, tertiaries usually shorter than secondaries.................................. 9. *O. costata* (Duncan).

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[1] Geol. Soc. London Quart. Journ., vol. 19, p. 417, pl. 13, fig. 10.

[2] Idem, p. 419, pl. 13, fig. 8.

[3] Idem, p. 421, pl. 13, fig. 11.

Calices 5 to 9 mm. in diameter; costae subequal or alternately large and small below calicular edge. Septa in 4 or nearly 4 complete cycles; primaries as a rule notably larger than the secondaries, with a prominent tooth on inner end; secondaries smaller, but with paliform tooth on inner end of each; tertiaries still smaller; quaternaries very small.......................... 10. *O. canalis*, new species.

Calices 6 to 10 mm. in diameter, exsert 4 to 4.5 mm.; costae very prominent, no or only rudimentary costae correspond to last cycle of septa; septa in 3 or 4 sizes, margins of primaries exsert as much as 1.5 mm... 11. *O. tampäensiss*, new species.

Calices not so elevated as in 11; small but distinct costae correspond to last cycle of septa........................ 11*a*. var. *silecensis*, new variety.

Calices 5 mm. in diameter, protuberant but rather low; costae strongly alternating in size; primary septa the largest; fourth cycle incomplete 12. *O. brevis* (Duncan).

Calices 10 mm. in diameter; costae long, slender, subequal, occasionally a rudimentary costa with no corresponding septum; septa delicate, long, slender, distant, fourth cycle incomplete.................................... 13. *O. insignis* (Duncan).

Calices 5 mm. in diameter; in places small costae between larger ones; a few quaternary septa.................................... 14. *O. intermedia* (Duncan).

The numbers preceding the names in the synopsis correspond to numbers before the names heading the following descriptions.

As *Orbicella gabbi* is the only species with 5 complete cycle of septa, it needs no special caption nor is *O. irradians* included in the key.

1. ORBICELLA ANNULARIS (Ellis and Solander).

Plate 80, figs. 7, 7*a*, 7*b*; plate 81, figs. 1, 1*a*, 2; plate 82, figs. 1, 1*a*, 2; plate 83, figs. 1, 2, 3, 3*a*; plate 84, figs. 1, 2, 3, 3*a*.

1786. *Madrepora annularis* Ellis and Solander, Nat. Hist. Zooph., p. 169, pl. 53, figs. 1, 2.

1786. *Madrepora faveolata* Ellis and Solander, Nat. Hist. Zooph., p. 166, pl. 53, figs. 5, 6.

1790. *Madrepora acropora* Gmelin, Linn. Syst. Nat., ed. 13, p. 3767.

1790. *Madrepora faveolata* Gmelin, Linn. Syst. Nat., ed. 13, p. 3769.

1794. *Madrepora acropora* Esper, Pflanzenth., Fortsetz., vol. 1, p. 21, pl. 38.

1816. *Astrea annularis* Lamarck, Hist. nat. Anim. s. Vert., vol. 2, p. 259.

1821. *Astrea annularis* Lamouroux, Exp. Méth. Genres des Polyp., p. 58, pl. 53, figs. 1, 2.

1821. *Astrea faveolata* Lamouroux, Exp. Méth. Genres des Polyp., p. 58, pl. 53, figs. 5, 6.

1834. *Explanaria annularis* Ehrenberg, Corallenth. Roth. Meer., p. 84 (of separate).

1846. *Astraea* (*Orbicella*) *annularis* Dana, U. S. Expl. Exp. Zoophytes, p. 214, pl. 10, fig. 6.

1857. *Heliastraea annularis* Milne Edwards and Haime, Hist. nat. Corall., vol. 2, p. 473.

1861. *Heliastraea annularis* Duchassaing and Michelotti, Mém. Corall. Antilles, p. 76 (of reprint).

1861. *Heliastraea acropora* Duchassaing and Michelotti, Mém. Corall. Antilles, p. 76 (of reprint).

1861. *Heliastraea lamarcki* Duchassaing and Michelotti, Mém. Corall. Antilles, p. 76 (of reprint).

1863. *Cyphastraea costata* (part) Duncan, Geol. Soc. Lond. Quart. Journ., vol. 19, pp. 441 and 443.

1863. *Astraea barbadensis* Duncan, Geol. Soc. Lond. Quart. Journ., vol. 19, pp. 421 and 444, pl. 15, figs. 6*a*, 6*b*.

1864. *Orbicella annularis* VERRILL, Mus. Comp. Zool. Bull., vol. 1, No. 3, p. 48.
1865. *Orbicella annularis* VERRILL, Boston Soc. Nat. Hist. Proc., vol. 10, p. 323.
1866. *Heliastraea annularis* DUCHASSAING and MICHELOTTI, Sup. Mém. Corall. Antilles, p. 84 (of reprint).
1866. *Heliastraea lamarcki* DUCHASSAING and MICHELOTTI, Sup. Mém. Corall. Antilles, p. 84 (of reprint).
1866. *Heliastraea acropora* DUCHASSAING and MICHELOTTI, Sup. Mém. Corall. Antilles, p. 84 (of reprint).
1866. *Heliastraea barbadensis* DUCHASSAING and MICHELOTTI, Sup. Mém. Corall. Antilles, p. 85 (of reprint).
1866. *Cyphastraea costata* DUCHASSAING and MICHELOTTI, Sup. Mém. Corall. Antilles, p. 85 (of reprint).
1868. *Heliastraea barbadensis* DUNCAN, Geol. Soc. Lond. Quart. Journ., vol. 24, p. 24.
1868. *Cyphastraea costata* DUNCAN, Geol. Soc. Lond. Quart. Journ., vol. 24, p. 24.
1895. *Orbicella acropora* GREGORY, Geol. Soc. Lond. Quart. Journ., vol. 51, p. 272.
1895. *Cyphastraea costata* GREGORY, Geol. Soc. Lond. Quart. Journ., vol. 51, p. 274.
1895. *Echinopora franski* GREGORY, Geol. Soc. Lond. Quart. Journ., vol. 51, p. 274, pl. 11, figs. 2*a*, 2*b*.
1901. *Orbicella acropora* VAUGHAN, Geolog. Reichs. Mus. Leiden Samml., ser. 2, vol. 2, p. 22.
1901. *Orbicella acropora* VAUGHAN, U. S. Fish Commission Bull. for 1900, vol. 2, p. 301, pls. 6, 8.
1902. *Orbicella annularis* VERRILL, Conn. Acad. Arts and Sci. Trans., vol. 11, p. 94, pl. 15, fig. 1.
1902. *Orbicella annularis* var. *stellulata* VERRILL, Conn. Acad. Arts and Sci. Trans., vol. 11, p. 96, pl. 15, fig. 2.
1902. *Orbicella hispidula* VERRILL, Conn. Acad. Arts and Sci. Trans., vol. 11, p. 100, pl. 15, figs. 3, 3*a*, 3*b*.
1902. *Orbicella annularis* VAUGHAN, Biol. Soc. Washington Proc., vol. 15, p. 56.
1903. *Orbicella annularis* DUERDEN, Nat. Acad. Sci. Mem., vol. 8, p. 564, pls. 8–10, figs. 64–73.
1915. *Orbicella annularis* VAUGHAN, Washington Acad. Sci. Journ., vol. 5, p. 596.
1916. *Orbicella annularis* VAUGHAN, Carnegie Inst. Washington Yearbook No. 14, p. 227.

Subsequent study has led me to believe that changes should be made in the synonymy as given in the first of my papers cited in the synonymy. *Phyllocoenia limbata* Duncan, *P. limbata* var. *tegula* Duncan, and *Plesiastraea ramea* Duncan represent one species and it is separable from *Orbicella annularis*. As *Phyllocoenia limbata* is the older name, the species should be designated *Orbicella limbata* (Duncan). The most conspicuous difference between it and *O. annularis* consists in its primary septa being markedly more developed than the secondaries.

Orbicella annularis is the principal coral of the outer reefs in Florida, the West Indies, and on the Caribbean side of Central America. It is general in the elevated Pleistocene of the same region.

Prof. J. Graham Kerr, of the University of Glasgow, has kindly sent me photographs of the type of this species, which is preserved in the Hunterian Museum at that institution, and I have based the following description on them:

The corallum is head-shaped, with a greater diameter of 107 mm. and a lesser of 86.

The calices are circular, 2 mm. in diameter, margins slightly elevated, joined by equal costae, distance apart usually about 1 mm., occasionally 2.

Septa 24 in number, alternately larger and smaller; the larger are rather thick and reach the columella; the intermediate ones are short and their inner ends are free.

Columella spongy, well developed, its diameter about one-third that of the calice.

A comparison of the photographs with specimens shows that the traditional *Orbicella annularis* of the Caribbean and Gulf region is correctly identified.

There are in the collection of the United States National Museum a number of specimens that are almost duplicates of the type-specimen, except that they are not worn, as is the type. These specimens form the basis of the succeeding description (see pl. 81, figs. 1, 1*a*).

The corallum forms rounded masses rising above a rather large, firmly attached base, which is, however, less in diameter than the maximum diameter of the corallum. Frequently there is a projecting or incrusting edge whose lower surface is covered by epitheca. The upper surface may be uniformly rounded, undulate, or lobed. The size, of course, is variable; the masses may be several feet in diameter.

The calices are circular, or slightly deformed. Their diameter, measured between thecal summits is from 2 to 2.5 mm. In depressions on the surface they may be smaller, about 1.5 mm., but these are abnormal. Their edges are from 0.5 to almost 2 mm. apart, about 1 mm. is probably an average. The calicular edges are slightly elevated. The intercorallite areas are costate. Costae correspond to all septa; subequal or alternating in size, those of adjoining calices meeting; edges dentate; thicker than the width of the intercostal spaces and moderately elevated.

Septa in three complete cycles, primaries and secondaries equal, rather stout, extending to the columella and fusing to it; tertiaries shorter, about half the length of the primaries, somewhat thinner, inner edges free. Margins of the primaries and secondaries decidedly exsert; their inner edges fall perpendicularly to the bottom of the calicular fossa, and bear just above the columella one or two prominent teeth, with a few smaller teeth above; the septal arch is either very gentle, obtuse, or it may be truncate, its dentations fine; the outer margins steep, but more inclined than the inner, dentations relatively coarse. Septal faces finely granulate; in longitudinal sections, the inner edges are lacerate, the last cycle with perforations.

Endothecal dissepiments delicate, thin, nearly horizontal, slightly inclined downward from the corallite walls. In this series of specimens the corallite walls are thick and close together, those of adjacent corallies sometimes being solidly fused together; usually, however, there is some exotheca, consisting of stout, subhorizontal dissepiments.

Columella well developed, formed by interlacing processes from the inner edges of the septa; diameter from one-third to one-half that of the calice; its upper surfcce about 1 mm. below the thecal margin.

These specimens, it should be repeated, are typical, and except in size and to a certain extent in the configuration of the surface show almost no variation. They come from the following localities: Dry Tortugas, Florida, Dr. Edward Palmer, collector, 8 specimens; east end of Hog Island, Bahamas, B. A. Bean, collector, 1 specimen; Florida and the Bahamas, many specimens, collected by T. W. Vaughan and others. There are other specimens, bearing the indefinite label "West Indies" or having no locality stated. These localities indicate that the species in its typical form is of general occurrence in the coral reef areas around the Caribbean Sea and Gulf of Mexico.

The recent specimens in the United States National Museum show at least four kinds of variation from the typical form.

Variation No. 1 (pl. 84, fig. 2).—This variation is, I believe, only a growth form. It, in its structural features, is the same as the typical form, except that the septa near the growing edge are less exsert and the exotheca appears to be absolutely solid. The corallum is an obtuse, compressed column, with an undulated surface. Greater diameter of the base, 62 mm.; lesser 52 mm.; height 72 mm.

Locality.—Dry Tortugas, Florida.

Variation No. 2 (pl. 81, fig. 2).—The general growth form is similar to that of typical specimens, except that the surface is thrown into gibbosities of irregular shape and size; these are often about a centimeter in height and several centimeters in diameter. The calices are larger than in the typical specimens, often measuring 3, occasionally 4 millimeters in diameter, between thecal summits. The thecal edges are slightly elevated; the margins of the primaries and secondaries decidedly exsert, not infrequently standing 2 mm. above the intercorallite furrow. The three characters here mentioned are the distinguishing ones of this variation, namely, gibbosities on the surface; larger calices; and more exsert septa.

Localities.—Dry Tortugas, Florida, Dr. Edward Palmer, collector, 1 specimen; east end of Hog Island, Bahamas, B. A. Bean, collector. 1 specimen; and two other specimens, without locality labels.

Variation No. 3 (pl. 82, fig. 2) is represented by a single specimen. The corallum is discoid, lower surface flat, upper surface convex, some irregularities. Greater diameter, 22.7 cm., lesser, 19.2 cm; thickness in the center about 5 cm., on the edge, 3 cm.

Calices with elevated margins and crowded together, the different corallite walls almost contiguous; margins of primary and secondary septa decidedly exsert. Diameter of calices about 2.75 mm.

The distinguishing characters of this variation are its discoid form, its crowded calices, its decidedly exsert septal margins.

Locality.—Fort Taylor, Key West, Florida.

Variation No. 4 (pl. 82, figs. 1, 1*a*) is represented by the specimens that I have described from Mayaguez, Porto Rico, in my "Stony corals of the Porto Rican waters."[1] The following description is based on them:

The corallum forms ascending masses; the largest specimen is about 20 cm. tall; diameter above flared-out base about 13.5 cm. The base of each specimen is considerably produced as a wide, free edge invested below by epitheca.

Calices with very slightly or only moderately elevated margins, diameter measured between thecal summits, from 3.25 to 4 mm.; rather shallow; distance apart, from a thin dividing edge to 2.5 mm.; about 1.5 mm. is probably the average. Thin costae moderately prominent, subequal, or alternating in size, correspond to all septa; those from one calice extend across the intercorallite spaces and meet those from the adjacent calices.

Septa thin, 24 to 28 in number, one-half of them extend from the wall to the columella, and have decidedly exsert margins; the other half are not so tall and are short, their inner ends free.

Endotheca and exotheca as in the typical specimens, except that they are more delicate.

These differ from typical specimens by their much lighter texture, which, of course, is determined by their thinner skeletal structures, the wide, flaring, free edges of the base, and their larger calices. The calices overlap in size those of variation No. 2, otherwise I should consider the specimens as representing a distinct species.

Variation No. 5 (pl. 83, figs. 1, 3, 3*a*).—*Orbicella hispidula* Verrill.[2] The following is the original description:

> Coral an incrusting mass over 125 mm. across, and from 5 to 20 mm. thick. The texture is rather solid and heavy, there being much solid exotheca between the calicles, which are rather far apart, the interspaces being mostly equal to, and often exceeding, their diameter.
>
> The calicles are round, regularly stellate, a little prominent, with swollen, sloping, costate rims much as in those of *O. annularis*, which they resemble in size, though distinctly larger. The septa are in three very regular cycles; the twelve principal

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[1] Bull. U. S. Fish Commission for 1900, vol. 2, p. 301, pls. 6, 7, 1901.

[2] Conn. Acad. Arts and Sci. Trans., vol. 11, pp. 100, pl. 15, figs. 3, 3*a*, 3*b*.

ones are wide, nearly equal, all reaching the rather large columella; their edges are perpendicular and finely, sharply serrate, with slender, rough teeth, which extend also over their prominent, obtuse, or subtruncate summits, giving them a rough appearance under a lens; their surfaces are also rough or hispid with numerous conical grains. The septa of the third cycle are narrow, straight, and usually reach about halfway to the columella.

The costae are thick, not very high, meeting or inosculating between the calicles, and covered with a single row of small, slender, rough spinules. The columella is well developed, formed of contorted trabecular processes, and often having a small pit in the center and a few erect spinules, similar to the slender, rough, paliform teeth that often (but not regularly) stand at the base of some of the 12 larger septa.

In sections the walls are very thick and nearly solid. The endothecal dissepiments are small, thin, irregularly convex or flat above. The calicles are not filled up below, or only slightly encroached upon, by a deposit between some of the septa. Diameter of the calicles 3 to 3.5 mm.; distance between them mostly 2 to 4 mm., often more.

Florida Reefs (Maj. E. B. Hunt), Yale Museum, No. 98. Near Nassau, N. P. (coll. R. P. Whitfield), Amer. Mus., New York.

This has the general appearance of *O. annularis*, but with calicles larger than usual and decidedly farther apart. The walls and exotheca are much thicker and more solid, and the endothecal cells are fewer and less regular. The sharply spinulose and hispid septa and costae are also characteristic. The exothecal deposits are nearly as solid as in *Oculina*.

A Nassau specimen, in the American Museum, is an irregular, rounded mass, about 5 inches in diameter, and 3 to 4 thick, with a a lobulated surface. The coral is heavy and solid; the surface of the coenenchyma is spinulose; the costae well developed. The calicles are more variable in size than in the type, in some places being one-half smaller and closely crowded. Coll. R. P. Whitfield.

The form of *O. hispidula* Verrill, in which the upper surface is lobulate, is common on the reef off Cocoanut Point, Andros Island, Bahamas, where a suite of 12 specimens was obtained by the *Anton Dohrn* expedition in 1914. The calices of most of these specimens are precisely as in the type of Professor Verrill's *O. hispidula* (fragment of type No. 40476, U.S.N.M.) and Gregory's *Echinopora franski* (fragment of type No. 156455, U.S.N.M.), but in both growth form and calicular characters there is intergradation with the more usual characters of *O. annularis*. Plate 76, figures 3, 3*a* illustrates the appearance of one of the specimens with lobulate surface.

A specimen from Port Castries, Santa Lucia (pl. 83, fig. 2), shows a variation worthy of note. In all of the variations so far described, the primary and secondary septa are constantly subequal, uniformly reaching the columella. In the Santa Lucia specimen a secondary septum in some systems is shorter and thinner than a primary; and in some calices there are as many as 30 septa. This specimen is of importance for comparison with *Phyllocoenia sculpta* var. *tegula* Duncan and *Echinopora franksi* Gregory.

These remarks cover the variation of the recent specimens that I have actually been able to study. Pourtalès, Verrill, and Duerden, however, have added other observations.

Pourtalès says of the species:

> The same remarks about variation, given under the head of *O. cavernosa*, can be applied to this species; there are very fine examples in the museum of the great variation of form of the calicles in the same specimen.
>
> It is very common in Florida on the reef and in the channels, and forms large hemispherical masses nearly up to low-water mark. The central and highest part often dies out from being left uncovered at very low tide and the mass then assumes an annular form through the decay of the dead part.[1]

Verrill writes:

> It shows considerable variation in the size of the calicles; in the extent to which they are crowded together; in the prominence of their borders above the intervening exotheca; in the prominence of the septa above the walls; and in the extent to which the small septa of the third cycle are developed. But yet these variations, so far as I have seen, never go so far as to render difficult the recognition of the species unless the specimens are badly worn.
>
> * * * * * * *
>
> When well grown it forms hemispherical or spheroidal masses, up to 5 feet or more in diameter. But it also grows in irregular incrusting plates, and sometimes in nodose or lobulate masses, or even in branched forms.[2]

Duerden, in describing specimens from Jamaica, says:

> The species occurs on coral areas in small or large, fixed, nearly spheroidal masses; also as an incrustation occupying areas several feet across. Small isolated colonies are sometimes conical. In places it is an important constituent of the reefs.[3]

This is one of the species to which I devoted a great deal attention in my study of the living reefs in Florida and the Bahamas, and have inserted references to two of my papers (1915, 1916) in which it is considered. It is preeminently the great reef-building species of the Pleistocene and Recent reefs in Florida and the West Indies. Where there is sand on the bottom, it forms tall, thick, round-topped columns.

VARIATION OF FOSSIL SPECIMENS.

There are specimens, particularly those of known Pleistocene age, similar to the typical form of the species, except that there may be variations in the size of the calices; those of a specimen from Fort Nassau, Curaçao, range from 3 to 4.5 mm. in diameter, measured between thecal summits; those of another specimen from Westpunt, Curaçao, are from 2.5 to 3 mm. in diameter. The former possesses the largest calices of any specimen of the species I have seen.

The variations not included in the preceding remarks may be divided into two classes, dependent upon growth—namely, *a*, explanate or incrusting; *b*, columnar.

A. Growth from explanate or incrusting.

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[1] Mus. Comp. Zool. Ill. Cat. No. 4, p. 72, 1871.

[2] Conn. Acad. Arts and Sci. Trans., vol. 11, pp. 95, 96, 1902.

[3] West Indian Madreporarian Polyps, Nat. Acad. Sci. Mem., vol. 8, p. 564, 1903.

Gregory[1] was mistaken in referring the specimens described by him as *Echinopora franksi* (see pl. 84, fig. 4) to the genus *Echinopora*. The following is the original description:

> *Diagnosis.*—The coral has a broad base; from this pass outward short, thick, rapidly tapering expansions.
>
> Corallites long, often an inch in length. Their distance one from the other varies from half their diameter to the whole.
>
> Septa strongly dentate; inner teeth paliform, in three cycles. Those of the first cycle always unite to the columella; those of the second cycle often do so, but may join the primary septa; those of the third cycle are much smaller and independent, but a few may unite with the septa of the other orders.
>
> Columella of very loose tissue; half the diameter of the corallite. Endotheca scanty. Coenenchyma thinner than in other species of the genus. Echinulations of the surface coarse. Epitheca thick and well developed.
>
> *Dimensions.*—Diameter of an average corallite, 3 mm.; height of corallite varies from 10 to to 25 mm.; thickness of wall varies from 1½ to 3 mm.
>
> *Distribution. Recent:* West Indies. *Fossil:* Barbados: Lowlevel Reefs, near Bridgetown.

Cotypes.—British Museum (Natural History); a piece of one of the cotypes in the United States National Museum, No. 156,455.

A comparison of this description with the notes on the variation of *Orbicella annularis* will show that it presents no important difference from variations of the species already recorded. Its growth form is explanate, the exotheca is solid, and the secondary septa often, but not always, reach the columella.

B. Growth from columnar (pl. 84, figs. 3, 3*a*.)

These are the specimens referred to in my paper "Some fossil corals from the elevated reefs of Curaçao, Arube, and Bonaire,"[2] obtained by Mr. v. Koolwijk at Westpunt, Curaçao. Three of the specimens are in the United States National Museum, and they form the basis of the following description:

The corallum forms ascending, compressed, obtuse columns.

Dimensions in millimeters of variant of Orbicella annularis from Curaçao.

Specimen No.	Greater diameter of base.	Lesser diameter of base.	Height.	Remarks.
	mm.	*mm.*	*mm.*	
1	37.5	25	60	Bifurcation 32 mm. above base.
2	30+	23	71	Constricted above base; gradually enlarging above the constriction.
3	27.5	21	91	Figured, pl. 84, figs. 3, 3*a*.

Calices 2.5 to 3.5 mm. in diameter; from less than 1 mm. to 2 mm. apart. The upper margin is usually not elevated, while the lower one is, thus tilting the calicular orifices. The maximum length of the lower limb of the calice is about 3 mm. Subequal, relatively thick, dentate costae correspond to all septa.

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[1] Geol. Soc. London Quart. Jour., vol. 51, p. 274, pl. 11, figs. 2*a*, 2*b*, 1895.

[2] Geolog. Reichs. Mus. Leiden Samml., ser. 2, vol. 2, Heft I, p. 26.

The usual number of septa is three complete cycles; primaries and secondaries subequal, reach the columella; tertiaries short, inner edges free. The septa present only one noteworthy difference from what is usual in *O. annularis;* that is, the margins of the primaries and secondaries are less exsert.

Columella not very large, loose, trabecular.

The three salient characteristics of this variant are (1), its growth form; (2), the tilted calices; (3), the lower (less exsert) margins of the primary and secondary septa.

Geologic horizon.—Pleistocene.

NOTES ON SYNONYMY.

A number of other names need to be considered in greater or less detail.

Gregory [1] applied the name *Orbicella acropora* (Linnaeus) to this species. He accepted the determination of the species by Milne Edwards and Haime,[2] who separated it from *O. annularis* by its having no septa corresponding to the last cycle of costae. Gregory showed that occasionally in typical specimens of *O. annularis* the last cycle of septa may be absent while the costae are present, thus breaking down the character used by Milne Edwards and Haime to distinguish the species. I accepted Gregory's conclusion, and followed him in my paper on Some fossil corals from the elevated reefs of Curaçao, Arube, and Bonaire, and subsequent papers. Professor Verrill, in his Variations and Nomenclature of Bermudian, West Indian, and Brazilian reef corals,[3] declares that *Madrepora acropora* Linnaeus "is utterly indeterminable," and takes the next later specific name, *annularis* Ellis and Solander, for the species. Subsequent study convinced me that Professor Verrill is right, and I published my change of opinion in a paper on Some recent Changes in the Nomenclature of West Indian corals.[4] Therefore, I now believe that *Madrepora acropora* Linnaeus should be considered as undeterminable and that the name should be dropped from coral nomenclature.

The type-specimen of *Madrepora faveolata* Ellis and Solander is preserved in the Hunterian Museum of the University of Glasgow, where I have seen it, and Prof. Graham Kerr has kindly sent me a photograph. It is a worn specimen, considerably infiltrated with calcium carbonate, and is probably the same as *Orbicella annularis.*

Astraea (*Orbicella*) *stellulata* Dana has been carefully redescribed by Professor Verrill from Dana's types, which are preserved in the Yale University Museum. The following is his description:

> They [5] are beach-worn specimens of a true *Orbicella*, more or less infiltrated with calcium carbonate, to which the unusual solidity of the walls and exothca, in some

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[1] Geol. Soc. London Quart. Journ., vol. 51, p. 272, 1895.

[2] Hist. nat. Corall., vol. 2, p. 477 1857.

[3] Conn. Acad. Arts and Sci. Trans., vol. 11, p. 94, 1902.

[4] Biol. Soc. Washington Proc., vol. 15, p. 56, 1902.

[5] Conn. Acad. Arts and Sci. Trans., vol. 11, p. 96, pl. 15 ,fig. 2, 1902.

parts, as seen in sections figured by Dana, seem to be partly due. In other parts the structure is nearly as in *O. annularis*, to which it probably belongs, though there are differences in the sections not due to infiltration. Its septal arrangement is the same as in ordinary specimens of the latter, those of the third cycle being distinct, but narrow and thin. The borders of the calicles seem to have been but little raised, and the septa rather thinner than usual, and not much exsert, but the poor condition of the specimens renders these characters rather uncertain.

The calicles are rather smaller (2 to 2.5 mm. in diameter) than is usual in *O. annularis*. The thin septa are in three regular cycles; those of the third cycle are very thin and reach only one-fourth or one-third to the columella, which is well developed. The septa are a little thickened at the wall; their faces are only slightly granulated. There are a few, irregular, small teeth on their inner edges where best preserved; upper ends are all worn off; some have a paliform tooth at the base. The costae are well developed, inosculating, with irregular exothecal dissepiments between them, as in *O. annularis*. But in some vertical sections the walls appear as narrow, solid structures (where unaltered); in the sections the columella region is loosely filled with stout ascending trabeculae; the endotheca consists of small, very thin, nearly horizontal dissepiments, inclining downward a little, and often in two series. No. 4266.

Their origin is uncertain, but it appears to be West Indian. They are in the same beach-worn state as several other types of West Indian corals studied by Professor Dana. Apparently most West Indian corals, in good condition, were scarce in American museums at the time when he wrote his great work.

It appears to be a small or somewhat dwarfed variety of *O. annularis*. I have seen fresh specimens of a similar variety from the Florida reefs.

This may well be identical with *M. stellulata* Ellis and Solander, but the latter can not be determined with any certainty from the figure, which represents a badly worn specimen. Its calicles, as figured, are mostly even smaller than in Dana's type, and somewhat unequal in size; the walls appear to be as solid as in the latter; the calicles project slightly as in *annularis;* 12 to 15 septa are figured, all perfect; columella is as in *annularis*. There is much more reason for calling this a variety of *O. annularis* than there is for identifying it with *Solenastraea hyades*, as Gregory has done. There is no evidence that it is a *Solenastraea*.

Fortunately Dana's *Orbicella stellulata* is a synonym of *O. annularis* and is not even of varietal importance. Professor Verrill says, "This may well be identical with *M. stellulata* Ellis and Solander," an opinion from which I emphatically dissent. The figures of Ellis and Solander are of a *Solenastrea* (Nat. Hist. Zooph., pl. 53, figs. 3, 4); the costae do not continue from one calice to those of adjacent calices, and the exotheca, as is shown by the side of figure 3, is typical of *Solenastrea*. Furthermore, in the description of the species it is stated, "interstitiis planiusculis scabriusculis," the intercorallite areas are not "radiate" as in *annularis*. The *Heliastraea stellulata* of Milne Edwards and Haime (see pl. 80, figs. 7, 7*a*, 7*b*) is not the *Madrepora stellulata* of Ellis and Solander; it is probably the same as *Orbicella annularis*.

There is much doubt about the *Cyphastraea oblita* Duchassaing and Michelotti. The following is the original description:

Espèce arrondie, avec des étoiles arrondies et à bord un peu elévé: côtes rares, presque confluentes; les intervalles de l'une à l'autre étoile sont garnies de granulations; la columelle est grande et papilleuse.

La *Cyphastrea oblita* a les bords moins elévés, et les cloisons plus debordantes que celles de la *Cyph. microphthalma* qui sont aussi garnies d'une petite dent subpaliforme qui manque dans la *Cyph. oblita*. St. Thomas.

I found in the Museum of Natural History at Turin a specimen labeled "*Cyphastrea oblita.*" It is a specimen of *Orbicella annularis.* Another specimen bearing the same label, seen in the Muséum d'Histoire Naturelle at Paris, is a *Solenastrea.*[1] The latter is a rounded head with a greater diameter of about 130 mm. The calices range in diameter from 2 to 3 mm.; distance apart from somewhat less to slightly more than 1 mm., occasionally 2 mm. Margins of the calices marked by a slightly raised rim. Costae insignificant, occasionally extending from one calice to the next. Septa in three complete cycles, primaries and secondaries reaching the columella; tertiaries shorter, with inner edges free, i. e., not fused to the sides of a lower cycle. Pali variable in development; in some calices they are large, flattened above, before all septa except the last cycle; in others, several teeth indicate the position of a palus. Columella, lax and papillary. This specimen is the same as the *Heliastraea abdita* Duchassaing and Michelotti.

The original description of *Cyphastrea oblita* is not adequate for identification. One of the specimens from the Duchassaing and Michelotti collection is *Orbicella annularis,* the other the same is their own *Heliastraea abdita.* Because the Paris specimen is probably the type I am placing the species in the synonymy of *Solenastrea bournoni* M. Edwards and Haime (see p. 400).

Heliastraea rotulosa Duchassing and Michelotti is a growth form of *O. annularis,* judging by the description. I did not find the type in Turin.

The specimens determined by Duchassing and Michelotti as *Heliastraea acropora* (Linnaeus) and *H. lamarcki* Milne Edwards and Haime are, according to specimens bearing those names in the Museum of Natural History at Turin, referable to *Orbicella annularis.*

The type of Duncan's *Cyphastraea costata* from Barbuda is preserved in the Geological Society of London, and I studied it there. The specimen shows no noteworthy variation from the usual *Orbicella annularis,* except that its calices are from 3 to 4 mm. in diameter, usually 3.5 mm. Another specimen, from Santo Domingo, labeled *Cyphastraea costata* is a *Solenastrea.* The specimens determined by Gregory as *C. costata* were studied in the British Museum of Natural History; they are *O. annularis.*

Astraea barbadensis Duncan is a specimen of *O. annularis* from the Pleistocene reefs of Barbados.

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[1] Illustrations of this specimen have been published by me in U. S. Geol. Surv. Prof. Pap. 98–T, pl. 99, figs. 3, 3*a*, 1917.

Gregory refers *Heliastraea altissima* Duncan to the synonymy of this species, but I doubt the correctness of his conclusion and am treating it as valid.

Geologic distribution.—Pleistocene and Recent, throughout the elevated reef areas of the West Indies, eastern Central America, and Florida.

Duncan[1] has listed *Astraea barbadensis*, one of the synonyms of *O. annularis*, from the "marl formation" of Antigua, remarking that it is "greatly altered by fossilization; the calicular surface is subplane, and the calices are seen as prominent columnar casts." Should Duncan's identification be correct, the geologic range of *O. annularis* extends from Oligocene time to the present. Mr. R. T. Hill obtained in Antigua a silicified specimen that looks like *O. annularis*, but I am not sure that it is that species.

Costa Rica, station 4269, Port Limon, collected by Doctor Wailes in beds referred to the Pliocene. There are three dissociated corallites which have the general characters of *Orbicella annularis*, but are not absolutely typical, for the primary septa are appreciably but not strikingly thicker than the secondaries. They are, therefore, somewhat intermediate between typical examples of the species and *Orbicella limbata* (Duncan).

2. ORBICELLA LIMBATA (Duncan).

Plate 85, figs. 1, 1*a*, 2, 2*a*, 2*b*, 3, 4, 4*a*.

1863. *Phyllocoenia sculpta* var. *tegula* DUNCAN, Geol. Soc. London Quart. Journ., vol. 19, p. 432.
1863. *Phyllocoenia limbata* DUNCAN, Geol. Soc. London Quart. Journ., vol. 19, p. 433.
1864. *Plesiastraea ramea* DUNCAN, Geol. Soc. London Quart. Journ., vol. 20, p. 39, pl. 5, figs. 1*a*, 1*b*.
1866. *Phyllocoenia limbata* DUCHASSAING and MICHELOTTI, Sup. Mém. Corall. Antilles, p. 76 (of reprint).
1866. *Plesiastraea ramea* DUCHASSAING and MICHELOTTI, Sup. Mém. Corall. Antilles, p. 87 (of reprint).
1868. *Phyllocoenia limbata* DUNCAN, Geol. Soc. London Quart. Journ., vol. 24, p. 23.
1868. *Plesiastraea ramea* DUNCAN, Geol. Soc. London Quart. Journ., vol. 24, p. 25.
1870. *Phyllocoenia limbata* DUCHASSAING, Rev. Zooph. et Spong. Antilles, p. 28.
1870. *Plesiastraea ramea* DUCHASSAING, Rev. Zooph. et. Spong. Antilles, p. 30.

Original description of *Phyllocoenia limbata:*[1]

Corallum in the shape of *Stylina limbata* Edwards and Haime. Stem large and cylindrical. Corallites numerous, irregularly placed. Calices separated by much coenenchyma, circular and but slightly elevated. Costae covering much surface. Slightly dentate where they approach, and turning aside from those of other calices; they are not continuous, not very prominent, and slightly granular. Septa not projecting far inwards, laminae granular; their upper margin is neither incised nor dentate; in six systems of generally three cycles, though occasionally of four. Pri-

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[1] Geol. Soc. London Quart. Journ., vol. 19, 1863, p. 433.

mary septa largest. Columella rudimentary. Endotheca abundant. Diameter of calice, with costae, one-fifth inch [5 mm.].

The deficient columella is the only point in which this species differs from *Madrepora limbata* Goldfuss, which has been determined by Milne Edwards to be a *Stylina*.

From the yellow shale of San Domingo. Coll. Geol. Soc.

Original description of *Plesiastraea ramea:*[1]

> Corallum in gibbous masses or more or less cylindrical processes with irregular swellings. Calices distant, very slightly exsert, circular, and unequal in size. Septa thick at the wall, thin internally, unequal in size, according to the orders; finely dentate above, but sparely granular laterally. In six systems of three cycles, with occasionally an additional order in one-half of a system. Pali very small. Columella lax, papillated, and small. Fossa moderately deep. Costae well developed, subequal, and marked by three or four dentate projections; they are evidently covered with a fine epitheca, which is not granular; where the epitheca is worn the costae are seen to be smaller, the tertiary being much smaller than the others; all project, however. Exotheca moderately developed and often becoming indurated. Endothecal dissepiments fragile, but horizontal and frequent. Height, some inches; diameter of branches 1 inch, more or less; diameter of corallites four-thirtieths inch [3.3 mm.]; distance between corallites about one-tenth inch [2.5 mm.].
>
> From the silt of the Sandstone plain, San Domingo. Coll. Geol. Soc.

I examined Duncan's types of *Phyllocoenia limbata* and *Plesiastraea ramea* in the Geological Society of London and made a note that the latter, except that its septa are broken down and the calices have a hollowed-out appearance, is the same as the former.

In my Some fossil Corals from the elevated Reefs of Curaçao, Arube, and Bonaire, and my Stony Corals of the Porto Rican waters, I placed in the synonymy of *Orbicella acropora* (=*O. annularis*), the three names of Duncan, cited above, considering the specimens to which they were applied as growth forms of that species. More detailed studies, subsequently made, have led me to believe that I was mistaken in that course. This coral is very similar to *O. annularis*. However, there appear to be two constant differences—namely, the primary septa within the calices are uniformly thicker and usually longer than the secondaries (this lesser development of the secondaries is not occasional as in *O. annularis* but constant) and small, but distinctly developed, pali occur before the primary and secondary septa.

I have for study one specimen from Duncan's original material, labeled *Plesiastraea ramea* Duncan, No. 155273, U.S.N.M., kindly sent to the United States National Museum by the authorities of the Geological Society of London (see pl. 85, figs. 1, 1*a*); 10 specimens belonging to the Museum of Comparative Zoology, 4 specimens collected by Miss C. J. Maury in Santo Domingo, and material obtained by myself near Santiago, Cuba. The first specimen is not in very good condition for study, and does not fit Duncan's description well. The Museum of Comparative Zoology specimens, however,

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[1] Geol. Soc. London. Quart. Jour., vol. 19, 1863, p. 421.

fit exactly, omitting the remarks about the costae being covered by epitheca. The figures presented on plate 85, figs. 2, 2*a*, 2*b*, and 3, are based on these specimens.

Phyllocoenia sculpta var. *tegula* Duncan.[1] As I do not find Duncan's description of this coral satisfactory, and as the authorities of the Geological Society of London have kindly sent one of the original specimens to the United States National Museum (No. 155274), (see pl. 85, figs. 4, 4*a*), I submit the following description:

Corallum, a rather thick folium; the specimen here described is unfortunately broken on all its edges, its original dimensions are therefore unknown. Its present length is 62 mm.; width 40 mm.; greatest thickness, 15.5 mm.; thickness near outer edge 5.5 mm. Base invested with a coarsely wrinkled epitheca.

The calicular margins are on the same level as the flat exothecal surfaces, or are very slightly raised. In form the calices are circular or somewhat deformed. Diameter from about 2 mm., to 2.5 by 3.25 mm.; distance apart, from 1 to 3 mm. Intercorallite areas with costae, beaded on the edges, equal or alternating in size, corresponding to all septa, those of one calice meeting those of the adjoining calices.

Septa usually in three complete cycles, primaries and secondaries larger, and usually thicker, than the tertiaries, primaries average larger than the secondaries. All the primaries and most of the secondaries reach the columella.

Columella trabecular.

Locality and geologic occurrence.—Nivajè shale, Santo Domingo, t. Duncan.

Miss Maury obtained specimens in Santo Domingo as follows:

Rio Cana, zone H, associated with *Placocyathus*, new species, *Stylophora granulata* Duncan, *Antillia bilobata* Duncan, *Orbicella bainbridgensis* Vaughan?, *Solenastrea bournoni* M. Edwards and Haime, *Syzygophyllia gregorii* (Vaughan), and *Siderastrea siderea* (Ellis and Solander). Rio Gurabo, zone D, associated with *Stylophora affinis* Duncan, *Madracis decactis* (Lyman), *Pocillopora crassoramosa* Duncan, *Stephanocoenia intersepta* (Esper), *Orbicella cavernosa* var. *cylindrica* (Duncan), *Syzygophyllia dentata* (Duncan); zone not stated, associated with *Pocillopora crassoramosa*, *Thysanus grandis* (Duncan), and *Syzygophyllia dentata* (Duncan).

I collected in 1901 a fine specimen of this species east of La Cruz, at the crossing of the highway from Santiago to the Morro over the railroad, near Santiago, Cuba. Other corals collected there, including *Stylophora* species (probably *S. affinis* Duncan), *Solenastrea bournoni* M. Edwards and Haime, a species of *Thysanus* (aff. *T. excentricus* Duncan), *Siderastrea siderea* (Ellis and Solander), and *Goniopora*

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[1] Geol. Soc. London Quart. Journ., vol. 19, p. 432, 1863.

jacobiana Vaughan, indicate similarity in horizon with zone D of the Rio Gurabo section.

3. ORBICELLA IMPERATORIS, new species.

Plate 86, figs. 2, 3, 4, 5.

Corallum forming rounded masses 16 cm. or more in diameter.

Calices in the type-specimen are not much elevated but have a distinct, somewhat raised wall; in other specimens the corallites may project as much as 2.5 to 3 mm. Calicular diameter, 3.5 to 5 mm.; distance between calices, from 2 to 3.5 mm. Corallites joined by prominent, rather thin, distant costae, which correspond either to all cycles of septa or to the primaries and secondaries.

Septa, typically in three complete cycles; the 6 primaries prominent, thicker than the members of the higher cycles, and extend to the columella; the secondaries usually do not reach the columella, only about half as long as the primaries; tertiaries shorter and thinner than the secondaries. The septa are usually distant in the wall. The third cycle of septa is incomplete in some calices; while in large calices a few secondaries may reach oı almost reach the columella.

Columella formed by the fusion of the inner edges of the primary septa.

Endotheca well developed as dissepiments. Exotheca well developed between the strong costae, about 3 dissepiments within 1.5 mm.

Localities and geologic occurrence.—Canal Zone, Panama, in the Emperador limestone, at stations 6015 and 6016, quarries in Empire, and 6017, one mile from Empire toward Las Cascadas, collected by T. W. Vaughan and D. F. MacDonald; station 6256, in the Emperador limestone, 1½ miles south of Miraflores, collected by D. F. MacDonald.

Cuba, station 3450, 4 miles north of the City of Pinar del Rio, and station 3451, one-half mile west of Cienaga railroad station, near Habana, collected by T. W. Vaughan; station 3566, Bejucal, collected by Arthur C. Spencer; station 7544, Rio Yateras, near Guantanamo, collected by O. E. Meinzer. N. H. Darton, collected at station 7664, on the north slope of La Piedra, northeast of Jamaica, which is northeast of Guantanamo, a specimen of *Orbicella* apparently referable to this species. The calices are rather large, 7 mm. in diameter, and nearly all of the secondary septa reach the columella. It seems very near *O. antillarum*. The specimens from Ciénaga, Cuba (pl. 86, fig. 5), is illustrated as well as the cotypes from Panama.

Anguilla, stations 6893 and 6967, Crocus Bay, collected by T. W. Vaughan.

Cotypes.—No. 324884, 324902, 324903, U. S. N. M.

Paratype.—No. 324878, U. S. N. M.

This species is distinguished by the small size of its calices, its prominent costae, its 6 long septa, with intermediate septa shorter according to cycle.

4. ORBICELLA ANTILLARUM (Duncan).

1863. *Astraea antillarum* DUNCAN, Geol. Soc. London Quart. Journ., vol. 19, p. 443.

1866. *Astraea antillarum* DUCHASSAING and MICHELOTTI, Sup. Corall. Antilles, p. 86 (of reprint).

1867. *Heliastraea antillarum* DUNCAN, Geol. Soc. London Quart. Journ., vol. 24, p. 24.

1870. *Heliastraea antillarum* DUCHASSAING, Rev. Zooph. Antilles, p. 30.

This coral was doubtfully referred by me[1] to the synonymy of *Orbicella cavernosa;* but, as there is doubt, it is here accorded specific treatment.

Original description.—"A specimen in the form of a rolled flint, found with silicified wood, has the corallum large, tall, probably resmbling in shape that of the San Domingan *A. exothecata.* Corallites close, unequal in size, but quite distinct; the transverse section shows them to be circular in outline. Septa in six systems of three cycles. The primary and secondary septa are nearly equal, and reach to the columella; the tertiary are small and straight; all are slender, wide apart, and very distinct. Costae tolerably developed, subequal. Walls moderately developed, by no means strong. Columella small, and occupying a small space. Endotheca greatly developed, vesicular, and forming cells between the septa. Exotheca well developed; large cells broad, others squarer, with shelving dissepiments. Diameter of the corallites three-tenths inch [7.5 mm.]. The interspaces are filled with opalescent or porcellanous silica; sclerenchyma often destroyed. Coll. Geol. Soc."

Locality.—Montserrat.

Duncan[2] lists a coral as *Astraea antillarum* variety, and makes the following note: "With more distant calices than the type, produced costae, and a less perfect development of the third septal cycle. The exact locality is not known, but the coral, from its mineralogical characters, appears to have been obtained from Antigua. Brit. Mus."

Regarding the apparent absence of a fourth cycle of septa, it will be noted that as they are often very small and may be broken away, something especially likely to occur in worn specimens such as fossils usually are, they may have been present, but were subsequently destroyed. The size of the calices, 7.5 mm. in diameter, suggests the presence of quaternary septa. Additional material from Montserrat is needed to solve the question.

5. ORBICELLA ALTISSIMA (Duncan).

1867. *Heliastraea altissima* DUNCAN, Geol. Soc. London Quart. Journ., vol. 24, pp. 12, 24, pl. 2, fig. 3.

Original description.—"The corallum is very massive and tall, and its upper surface is subplane and wider than the base. The calices

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[1] Geologisch. Reichs. Mus. Leiden Samml., ser. 2, vol. 2, pt. 1, p. 28, 1901.

[2] Geol. Soc. London Quart. Journ., vol. 20, p. 36, pl. 4, fig. 2.

are barely above the common surface, they are circular, but occasionally deformed, and they are slightly unequal in size. The calicular fossa is shallow, and the calicular margins are broader than the septa. The columella is small, distinct, lax, and parietal. The costae are well marked, unequal, and rarely touch, and they are thicker than the septa. The costae of the highest order are well developed, and contrast with their rudimentary septa. The septa are delicate, they are thinner midway than elsewhere, and those which reach the columella have a paliform tooth; they are not exsert, and are only slightly dentate. The septa are very irregular in their arrangement. There are six systems, and in most of them there are three cycles with or without a part of a fourth in one-half of the system, so that there are constantly six septa in a system instead of eight. The endotheca is well developed; and the dissepiments are close, stout, and nearly horizontally parallel. The exotheca is abundant, forming small cells with arched outlines. Height of corallum 6-8 inches. Diameter of calices two-tenths inch [=5 mm.]."

Locality.—St. Croix, Trinidad.

Gregory[1] places Duncan's *Heliastraea altissima* in the synonymy of *Orbicella acropora* (Linnaeus), without giving his reason. He may be right, but the calices are large for *O. acropora* (here called *O. annularis*), and judging from the presence of quaternary septa it is almost certainly distinct. According to Duncan's figure every other septum reaches the columella, a septal arrangement which is one of the characteristics of *O. annularis*. I did not see the type in London, and think that until it is restudied or additional material has been collected at the type locality, it will not be possible to reach a positive decision as to the validity of the species.

6. ORBICELLA CAVERNOSA (Linnaeus).

Plate 87, figs. 1, 1*a*, 1*b*, 1*c*; plate 88, figs. 1, 2, 3, 3*a*, 3*b*.

1766. *Madrepora cavernosa* LINNAEUS, Syst. Nat., ed. 12, vol. 1, p. 1276.
1901. *Orbicella cavernosa* VAUGHAN, Geolog. Reichs. Mus. Leiden Samml., ser. 2, vol. 2, p. 27 (Synonymy with exceptions noted below).
1902. *Orbicella cavernosa* VERRILL, Conn. Acad. Arts and Sci. Trans., vol. 12, p. 102.
1915. *Orbicella cavernosa* VAUGHAN, Washington Acad. Sci. Journ., vol. 5, p. 596.
1916. *Orbicella cavernosa* VAUGHAN, Carnegie Inst. Washington Year Book No. 14, p. 227.

In my first paper referred to in the synonymy I placed *Astraea endothecata*, *Astraea cylindrica*, and *Astraea brevis* of Duncan in the synonymy of this species. *A. endothecata* and *A. cylindrica* now seem to me to deserve varietal recognition and *A. brevis* should be treated as a valid species until additional information concerning it is available. Duncan's *Astraea antiguensis*, which I doubtfully

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[1] Geol. Soc. London Quart. Journ., vol. 51, p. 272, 1895.

placed in the synonymy of *O. cavernosa,* has the general appearance of *Orbicella,* but it is a fungid coral and is referred to the genus *Cyathomorpha. Astraea antillarum,* given by me as doubtfully a synonym of *O. cavernosa,* should for the present at least be treated as a valid species.

As so many of the species related to *O. cavernosa* must be considered in this paper, it is desirable to describe all those members of the group found in the American Tertiary formations and now living in the western Atlantic Ocean. The systematic rank of the forms described on the following pages is open to debate, and I wish here to express my recognition of other methods of treatment. As the forms, whether they be designated "species," "subspecies," "variations," or merely "variants," exist, and as they have geographic and geologic significance, they should be discriminated and characterized. In comparison with these desiderata nomenclatorial considerations are of secondary importance.

Orbicella cavernosa is so variable that great difficulty has been experienced in constructing an intelligible description. A very interesting specimen, obtained by Prof. J. E. Duerden in Jamaica and presented by him to the United States National Museum, will first be described in detail, as it shows within itself a wide range of variation and indicates the lines of variation of other specimens more constant in their character (see pl. 87, figs. 1, 1*a*, 1*b*, 1*c*).

The corallum is oblong; upper surface convex but not uniformly arched or domed; base epithecate. Length, 25 cm.; breadth, 20 cm.; thickness, 11.3 cm.

The specimen has two different kinds of calices. Those of one kind are rather distant, protuberant, and have subequal, not very tall, thick, dentate costae (pl. 87, fig. 1). The transverse outline is circular or broadly elliptical, diameter between thecal summits 8 mm.; one of the elliptical calices has a greater diameter of 11 mm., lesser about 9 mm. The costae are about 1 mm. tall. The distance apart, measured between the outer costal edges, is from almost contiguous to 6 mm. The free limb of the corallite is subcylindrical and projects between 6 and 7 mm. The calices, as is shown by plate 87, figures 1, 1*a*, are not uniformly distributed, and vary in size, form, and prominence.

In a fully developed calice there are 48 septa, every other one extending to and fusing to the columella. All the septa, particularly the principals, are rather thick. The margins are dentate, within the calicular cavity, they fall abruptly to the bottoms of the calices, which are 3 to 4 mm. deep, and there the principals extend to the columella. There are septal teeth around the periphery of the columella but they are not in the form of well-developed pali or paliform lobes.

The columella is large, trabecular, with a papillate upper surface; diameter, as much as 4 mm. The columellar elements are rather often twisted and present a whorled appearance.

Endothecal dissepiments rather delicate; exotheca, coarse and very vesicular.

The calices of the other kind (pl. 87, fig. 1*a*) in their typical development are smaller than those above described, their edges are only slightly elevated, and the septa and costae are decidedly thin and exsert. Diameter of the calices from 5 to 8 mm.; septal margins 2 mm. tall.

The differences between these two kinds of calices are so great that it seems scarcely possible that they could belong to the same species; however, they occur on the same corallum where perfect intergradation can be traced.

Pourtalès, as far back as 1871,[1] published the following important notes on this species:

> There is considerable variation among the specimens from Florida in the Museum of Comparative Zoology, enough apparently to warrant placing them among the three species mentioned in the synonymy; but by carefully examining the different parts of each specimen, passages from one to the other can be found. Thus young polypidoms, expanding rapidly laterally and with rather distant polyps, appear at first to differ considerably from strongly convex ones with crowded calices; the costae are larger, flatter, and less sharply denticulate, and the border of the calicles less elevated.
>
> The size of the calicles, relied on to divide the genus into groups by Milne Edwards and Haime, is a very uncertain character; one specimen has in one part the calicles varying from 3.5 to 4 mm., in another from 7 to 8 mm. The same specimen has in some parts the contiguous walls united solidly, with very few or no exothecal cells, in others separated by an abundant cellular exotheca. In worn specimens the last cycle disappears first, for that reason probably *Orbicella* (*Madrepora*) *radiata* Ellis has been characterized by the Milne Edwards and Haime as having but three cycles.

Verrill gives the following description:[2]

> Much of the confusion in regard to the name of this species is due to the fact that it was generally described and figured from badly beach-worn specimens by the earlier writers. Such specimens have the septa and calicles worn away and the hard exotheca thus becomes prominent around the excavate calicles, so as to greatly change the appearance of the coral. Another cause is the rather wide variations in the size of the calicles.
>
> The normal or average specimens have the calicles about 6 to 8 mm. in diameter, but occasionally a specimen occurs in which part or all of them may be 9–10 mm., or rarely, even 11 mm. in diameter. Sometimes, on crowded parts of large specimens, the diameter may be only 4 to 5 mm. The degree of elevation of the calicles is also more or less variable on a single specimen.
>
> The calicles may be pretty close together, where crowded, but in other cases they are separated by spaces of 4 to 6 mm. or more. The costae are usually well developed as denticulated, rounded, radial ribs, usually 48 in number.
>
> The septa are generally about 48, arranged in four regular cycles, but several of those of the last cycle are often rudimentary or lacking, reducing the number to 40–44

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[1] Mus. Comp. Zool. Ill. Cat., No. 4, p. 76.

[2] Trans. Conn. Acad. Arts and Sci., vol. 11, pp. 102, 103, 1902.

They differ in breadth and thickness according to the cycles; those of the last cycle are very thin and often bend toward and join those of the third cycle. The principal septa are exsert, denticulated, and thickened at the wall. The columella is usually well developed and broad. The paliform teeth are distinct, but not very prominent. It sometimes forms hemispherical masses 4 to 5 feet or more in diameter.

This species appears to be rare at the Bermudas, and probably occurs only on the outermost reefs. The only specimen seen by me from there was from near the North Rocks. (Centennial collection.) It is a hemisphere about 11 inches in diameter, of the typical form. It is common on the Florida reefs and throughout the West Indies, Bahia, Brazil; (Yale Mus.);=var. *hirta*, nov., with elevated corallites; roughly serrate' thin costae and septa; calicles deep, 5–6 mm. broad; septa narrow, perpendicular within, usually 40–44.

The description of the Jamaican specimen, when taken in connection with the notes by Pourtalès and Verrill, gives a good idea of the extent of the variation of the species except in one particular, that of the septal arrangement. The normal, fully developed calices have four complete cycles of septa; however, sometimes the fourth cycle may not be complete while at others there may be a few quinaries. In the recent specimens the tertiaries usually, but not invariably, extend to the columella.

The characters common to all of the specimens may be briefly summarized as follows:

Corallum massive, base epithecate, upper surface flat, irregularly convex, or domed. Calices more or less elevated, diameter from 5 to 11 mm., externally costate, costae normally subequal. Septa normally in four complete cycles, the members of the first three cycles extend to the columella, but the fourth may not be complete, and sometimes there may be a few quinaries. Columellar trabecular, well developed, large, with a papillary upper surface.

Remarks on the synonomy of O. cavernosa.—The names *O. radiata* (Ellis and Solander), *O. argus* (Lamarck), *O. conferta* (Milne Edwards and Haime), and *O. cavernosa* var. *hirta* Verrill, are definitely placed in the synonymy of *O. cavernosa*, and it is thought probable that *O. braziliana* Verrill, should be referred to it. These names will be discussed seriatim.

Gregory applies *O. radiata* to this species, as he considers the Linnaean definition of *Madrepora cavernosa* insufficient, an opinion with which I do not agree. All the Linnaean descriptions are unsatisfactory, but in this instance Linnaeus refers to the figures of Seba, he places the *Madrepora astroites* of Pallas in its synonymy, and he states "Habitat in O. Americano." Taking all things together, the original diagnosis with the references seem to me sufficient for purposes of identification—in fact, the brief Latin description is not bad. *O. radiata* was supposed to differ from *O. cavernosa* by possessing only three cycles of septa. Pourtalès states, in the quotation already made from him, that "In worn specimens the last cycle disappears first; for that reason probably *Orbicella* (*Madrepora*) *radiata* Ellis and Solander has been characterized by Milne Edwards and Haime as having but three cycles."

Lamarck's *Astrea argus* is a new name for the *Madrepora cavernosa* Esper. The reason for his giving it is not evident.

The specimen identified by Ehrenberg as *Explanaria argus*, which is the type of Milne Edwards and Haime *Astrea conferta*, is in the Berlin Museum für Naturkunde, and the following notes are based upon it:

The specimen is much worn and is apparently somewhat fossilized. The calices are not regularly rounded, but frequently are of irregular polygonal outline. The greater diameter of an average calice is 8.5 mm.; lesser 7 mm. Thickness of wall between the calices is 2.5 mm. In one calice there were 21 large and 21 smaller septa; there may be four complete cycles in some calices. The columella is very large and vesicular and occupies the greater part of the corallite cavity. Dissepiments abundant, about 13 to 5 mm.; they slope downward and inward. From reading the Pourtalès description quoted above, it will be evident that this is only a variety of *O. cavernosa* with crowded calices. The *Explanaria radiata* of Ehrenberg is the ordinary *Heliastraea cavernosa* as figured by Milne Edwards and Haime, except that the fourth cycle of septa may not always be complete.

Orbicella cavernosa var. *compacta* Vaughan (pl. 88, figs. 3, 3*a*, 3*b*) has solid exotheca, low mammillate corallites, and equal costae. Recent on the Brazilian coast; lat. 12° 48′ S., long. 38° W.; 27 fathoms.

Localities and geologic occurrence.—On the living and Pleistocene reefs of Florida, the West Indies, and the Caribbean side of Central America. There are beach worn or Pleistocene specimens from the Isthmus of Darien in the United States National Museum, collected by Dr. Van Patton.

6a. ORBICELLA CAVERNOSA var. ENDOTHECATA (Duncan).

Plate 89, figs. 1, 1*a*.

1863. *Astraea endothecata* Duncan, Geol. Soc. Lond. Quart. Journ., vol. 19, p. 434, pl. 15, figs. 7*a*, 7*b*.

1868. *Heliastraea endothecata* Duncan, Geol. Soc. London Quart. Journ., vol. 24, p. 24.

The corallite walls are thick; costae strongly alternating in size; the last cycle are small and thin, and there appear to be no septa corresponding to them; occasionally there is a rudimentary septum of the fourth cycle. The last cycle of septa may have been broken off; or the wall, because of subsequent thickening, may have included their inner ends; all other septa, with rare exceptions, extend to the large, well developed columella. Diameter of corallites from 8 to

10 mm. Type in the Geological Society of London; duplicate in the United States National Museum (No. 155276). The preceding remarks are based on the latter.

Localities and geologic occurrence.—Type said to come from the Nivajè shale of Santo Domingo.

Costa Rica, station 4269, Port Limon; collected by Doctor Wailes in a bed of reputed Pliocene age. The size of the calices, and the costae, wall, and columella of the Port Limon specimen are as in var. *endothecata;* but usually every other septum meets the columella; a cycle of small septa between the larger is clearly present. As it is probable that the last cycle of septa has been destroyed in the type of var. *endothecata,* the presence of small septa between the larger would not indicate specific difference. The strongly developed costae with small ones between them are the same in both the type and the Port Limon specimens.

The stratigraphic range of this variety, therefore, is from the Nivajè shale (lower Miocene) to probably Pliocene.

6b. ORBICELLA CAVERNOSA var. CYLINDRICA (Duncan).

Plate 89, fig. 2.

1863. *Astraea cylindrica* Duncan, Geol. Soc. London Quart. Journ., vol. 19, p. 434, pl. 15, fig. 8.

1868. *Heliastraea cylindrica* Duncan, Geol. Soc. London Quart. Journ., vol. 24, p. 24.

This variety closely resembles var. *endothecata.* It has smaller corallites, 5 to 6 mm. in diameter; fewer septa, 12 to 16 principal septa, with from 1 to 3 smaller intermediate septa. Between each pair of larger septa on the mural summits around the calices is an intermediate rudimentary septum; the total number of septa is about 38. The costae corresponding to the principal septa are strikingly prominent, while those corresponding to the rudimentary septa are very small or even obsolete. The calice is rather deep, about 2.5 mm.

This coral may be only a growth facies of *O. endothecata.*

Localities and geologic occurrence.—Duncan type, in the Geological Society of London, comes from "the tufaceous limestone" of Santo Domingo; duplicate specimen No. 155277, U.S.N.M. Miss C. J. Maury has recently collected the variety in Santo Domingo as follows:

Rio Gurabo, zone D, associated with *Stylophora affinis* Duncan, *Madracis decactis* (Lyman), *Pocillopora crassoramosa* Duncan, *Stephanocoenia intersepta* (Esper), *Orbicella limbata* (Duncan), *Orbicella cavernosa* (Linnaeus) var., *Syzygophyllia dentata* (Duncan), The single specimen collected is essentially typical, in fact it is a better specimen than Duncan's type. Cercado de Mao, without more specific information. The latter specimen has corallites with somewhat larger diameter, as much as 7.5, than those of typical specimens, diameter 4.5 to 5 mm., in that respect more closely resembling var. *endothecata*, but there are no or only a few small costae between the large ones, and the septal characters are more similar to those of var. *cylindrica*.

Costa Rica "Colline en démolition", Port Limon, No. 669, collection of H. Pittier. The specimens from Port Limon consist of two isolated corallites, which so closely resemble those of the type of var. *cylindrica* as not to need comment. Except in size, they are very similar to var. *endothecata*.

7. ORBICELLA APERTA (Verrill).

Plate 89, fig. 3.

1868. *Heliastraea aperta* Verrill, Conn. Acad. Arts and Sci. Trans., vol. 1, p. 356.
1902. *Orbicella aperta* Verrill, Conn. Acad. Arts and Sci. Trans., vol. 2, p. 103, pl. 33, figs. 1, 1*a*.

This species is especially characterized by having the principal septa, that is, those of the first, second, and third cycles, all of which ordinarily reach the columella, taller and thinner than is usual in *O. cavernosa*. At one time I was inclined to consider it only a variety of *Orbicella cavernosa*, but comparisons of large suites of *O. cavernosa* from Florida and the West Indies with a good suite of *O. aperta* from Brazil shows persistently recognizable differences.

Localities.—Abrolhos reefs, Bay of Bahia, and Island of Itaparica, Brazil.

8. ORBICELLA BAINBRIDGENSIS, new species.

Plate 90, figs. 1, 1*a*, 1*b*, 1*c*.

In growth form, general aspect of the corallum, and size of calices similar to *Orbicella cavernosa*.

Calices 6 to 7 mm. in diameter; walls slope from calicular margins to bottom of intercorallite areas; protuberant about 2 mm.; distance apart from 1.5 to 3.5 mm.

Costae subequal, relatively thick, rather low, beaded on the edges, correspond to all septa, meet in the intercorallite depression.

Septa in nearly four complete cycles, 10 to 12 septa, i. e., the primaries and most or all of the sceondaries are thicker than the other septa, these and in some calices a variable number of tertiaries extend to the columella. Usually the tertiary septa do not reach the columella, and the quaternaries are still shorter. The septa are distinctly of three sizes, even where the tertiaries reach the columella they are thinner than the members of the lower cycles. Septal margins dentate; distinct, rather wide, erect paliform lobes usual on the inner ends of the primaries and secondaries and in places on the tertiaries; on some septa instead of paliform lobes there are several teeth with rounded upper ends. The youngest septa are largely composed of ascending spines which are not completely fused.

Columella relatively large, composed of septal trabeculae, upper surface coarsely papillate.

Endothecal dissepiments highly developed, forming curved vesicles. Exotheca composed of successive, superposed but separated platforms extending between corallites (see pl. 90, fig. 1*c*).

Localities and geologic occurrence.—Georgia, stations 3881, Blue Spring, 4 miles below Bainbridge, and station 3883, Hales Landing, 7 miles below Bainbridge, Flint River, Decatur County, collected by T. W. Vaughan; in the basal part of the Chattahoochee formation, just above the contact with the Ocala limestone. In the base of one specimen from station 3383 there is a cast of the surface of *Cerithium vaughani* Dall, and there are several specimens of orbitoidal foraminifera, one of which is clearly a species of *Lepidocyclina*. Stations 6085, Withlacoochee River, a few hundred yards below the Valdosta Southern Railway bridge, and 6084, about 3 miles below the same bridge, Lowndes County, Georgia, collected by L. W. Stephenson.

Type.—No. 324881, U.S.N.M.

Santo Domingan specimens, representing a very closely related if not identical species, were obtained by Miss C. J. Maury, on Rio Cana, in what she refers to as zone H, in association with a fauna representing the Bowden horizon, namely, *Placocyathus* new species, *Stylophora granulata* Duncan, *Antillia bilobata* Duncan, *Orbicella limbata* (Duncan), *Solenastrea bournoni* M. Edwards and Haime, *Syzygophyllia gregorii* (Vaughan), and *Siderastrea siderea* (Ellis and Solander).

9. ORBICELLA COSTATA (Duncan).

Plate 91, figs. 1, 1*a*, 2, 3, 3*a*; plate 92, figs. 1, 2, 3; plate 93, figs. 1, 1*a*.

1863. *Astraea costata* Duncan, Geol. Soc. London Quart. Journ., vol. 19, p. 422, pl. 13, fig. 9.

1867. *Heliastraea costata* Duncan, Geol. Soc. London Quart. Journ., vol. 24, p. 24.

Original description.—"The specimens of this species which I have examined present polished longitudinal and transverse sections of corallites, but I have seen no calices. Corallites long, parallel, sometimes deformed, generally circular in transverse outline, not crowded, but close, varying in size. Intercorallite spaces very distinct. Walls thin, not thicker than the delicate septa. Costae large alternately, both sizes equally produced; wedge-shaped at the wall, pointed, and often bent at the free end. Septa all delicate and linear near the columella and in the middle; at the wall their base is narrower than that of the costae. They are arranged in six systems, the cycles being very irregular. In three systems there are three cycles, and in the rest an incomplete fourth; rarely there are two systems with four complete cycles; the fourth and fifth orders often curve toward the third order. Lamellae rather cribriform, joining the columella by oblique processes. Columella lax, small, and formed by dissepiments from the septa and a central spongy mass. Endotheca very abundant, vesicular, and horizontal, with four or five dissepiments in one-tenth inch [2.5 mm.]. Exotheca abundant, nearly equal to the endotheca. Reproduction by extra-calicular budding. Diameter of the corallites from three-tenths to seven-twentieths inch [7.5 to 8.25 mm.].

"This species is closely allied to the astraeans with great endothecal development, and especially to *Astraea vesiculosa* Edwards and Haime, from Dax, as well as to *A. antillarum* nob., and *A. endothecata* nob."

Locality.—"The Marl of Antigua."

Illustrations based on one of Duncan's original specimens, but not the type, are given on plate 91, figures 1, 1*a*.

This species is represented in the Antigua formation of Antigua, the Pepino formation of Porto Rico, the Culebra formation of the Canal Zone, and in the marls and limestone of Anguilla. The principal variation consists in the size of the calices. The minimum size of the calices in the Antiguan specimens (pl. 91, figs. 2, 3, 3*a*) is about 7 mm., which is about the average for the Porto Rican specimens (pl. 92, fig. 1), and the calices of the specimens from the Canal Zone (pl. 92, fig. 2) average slightly smaller than those from Porto Rico, but the two sets of specimens differ very little. In Anguilla (pl. 92, fig. 3; pl. 93, figs. 1, 1*a*) the large and small calicled forms are found in association.

The amount of the protuberance of the corallites varies greatly, but protuberant and low corallites are found on the same corallum. Usually where the corallites are low the alternation in size of the costae is not so pronounced as where the corallites are exsert; but some protuberant corallites of the specimen represented by plate 92, figure 3, have equal costae on at least one side.

There are pali before all except the last cycle of septa; they are moderately wide, erect, rounded above, form two crowns.

Localities and geologic occurrence.—Antigua, in the Antigua formation, at station 6881, Willoughby Bay, collected by T. W. Vaughan.

Porto Rico, in the Pepino formation, station 3191, 4 miles west of Lares, collected by R. T. Hill.

Canal Zone, in the Culebra formation, at station 6020*c* Las Cascadas, collected by Vaughan and MacDonald.

Anguilla, stations 6893, 6894, 6966, in the lower and the middle beds on the south and west sides of Crocus Bay; 6969*a*, bottom bed at Road Bay.

This species in its general aspect resembles *Cyathomorpha belli* Vaughan (see p. 459), but has thinner septa and costae and deeper calices. The lower surface is more or less invested with epitheca, and no synapticulae could be found.

10. ORBICELLA CANALIS, new species.

Plate 94, figs. 1, 1*a*, 2, 2*a*, 3, 3*a*; plate 97, figs. 4, 4*a*.

This species can best be characterized in terms of comparison with *O. costata.* The growth forms and the general facies of both are similar, except that the maximum size of the calices in *O. canalis* is nearly the minimum size in *O. costata;* range in calicular diameter of *O. canalis* from 5 to 9 mm., average about 6 or 6.5 mm.

The costae in *O. canalis* are alternately large and small or subequal around the calicular edge below which they may be subequal, alternately large and small, or the last cycle may disappear.

Septa in 4 or nearly 4 cycles; primaries notably larger than the secondaries except in occasional unusually large calices, and each bears a strong tooth on its inner end; secondaries thinner than the primaries, also with a tooth on the inner end, these and the primaries reach the columella; tertiaries shorter, but with a paliform thickening or a tooth on the inner end; quaternaries decidedly small. The septa usually are lanceolately thickened in the wall, in this character resembling typical *O. costata.*

The columella is formed by the fusion of the inner ends of the septa and is less developed than in *O. costata.*

Endothecal dissepiments well developed, thin, from 0.5 to 1.5 mm. apart. Exotheca consists of thick-walled blister-like, small vesicles, about 0.5 mm. high, and more or less wavy platforms which extend between the corallites.

Localities and geologic occurrence.—Canal Zone stations 6015 and 6016, quarries in the Emperador limestone, Empire, collected by T. W. Vaughan and D. F. MacDonald, also collected in Empire by Ralph Arnold.

Anguilla, stations 6894, lower bed; 6966, middle bed, between 50 and 75 feet above the base of the section; and 6967, upper bed, west side of Crocus Bay, collected by T. W. Vaughan.

Type.—No. 324862, U.S.N.M. (pl. 94, figs. 1, 1*a*).

Paratypes.—No. 324861, U.S.N.M. (pl. 94, figs. 2, 2*a;* pl. 97, figs. 4, 4*a*). The specimen represented by plate 94, fig. 3, 3*a* No. 324859, U.S.N.M. is a varietal form that appears referable to *O. canalis;* it is from Anguilla.

Orbicella canalis is so nearly related to a number of Antillean upper Oligocene species, that I have hesitated to apply a distinctive name, but as the large suite of specimens before me, 30 of those from Empire, Canal Zone, have been selected as the reserve series of the United States National Museum, shows characters by which they can be discriminated, it seems logical to recognize them as a species. *Stylangia panamensis* has a general resemblance to those specimens of *O. canalis* in which the corallites are small and the costae not very prominent; but the corallites of *O. canalis* are larger, and they have not the lamellate columella of *S. panamensis*. Small-calicled specimens with prominent, strongly alternating costae resemble *O. imperatoris*, and differ from the latter by their somewhat larger calices and more numerous septa. The calices of *O. costata* are larger, the primary and secondary septa are subequal, and the columella is more developed. In both *O. intermedia* and *O. costata* the secondary septa are more developed. Larger suites of specimens than are at present available may lead to the reduction of some of these names to subspecific or varietal rank.

11. ORBICELLA TAMPÄENSIS, new species.

Plate 95, figs. 1, 2, 2*a*, 3, 3*a*.

1915. *Orbicella cavernosa* var. *tampäensis* Vaughan, *nomen nudum*, U. S. Nat. Mus. Bull. 90, p. 18.

The corallum forms head-shaped masses up to the size of a man's fist.

Calices deep, decidedly elevated, up to 4 or 4.5 mm.; diameter from 6 to 10 mm. Costae prominent, distant; there are no or only rudimentary costae corresponding to the last cycle of septa.

Septa, distant, in four cycles, the fourth usually more or less incomplete. The primaries and some or all of the secondaries, occasionally a tertiary, reach the columella. Usually there are three or four different sizes. On the inner ends of the primaries are paliform teeth, below which the margins fall steeply to the bottom of the fossa. Margins of the primaries exert as much as 1.5 mm.; those of secondaries almost as prominent; those of the tertiaries less prominent; those of the quaternaries inconspicuous. Septa thickened in the wall.

Columella much looser than in the other related species.

Locality and geologic occurrence.—The "silex" bed of the Tampa formation, Tampa, Florida.

Type.—No. 324900, U.S.N.M. (pl. 95, figs. 2, 2*a*.)

Paratype.—No. 324901, U.S.N.M. (pl. 95, fig. 1.)

Paratype.—Wagner Free Institute of Science, Philadelphia (pl. 95, fig. 3).

11a. ORBICELLA TAMPÄENSIS var. SILECENSIS, new variety.

Plate 96.

1915. *Orbicella cavernosa* var. *silecensis* Vaughan, *nomen nudum*, U. S. Nat. Mus. Bull. 90, p. 18.

Corallum oblong, irregularly convex above; type about 16 cm. long, 11 cm. wide, and 9.5 cm. high.

Calices slightly elevated, the corallites somewhat swollen below the calicular edges. Diameter, 8.5 to 9.5 mm. Costae prominent; those corresponding to the primary and secondary septa subequal; tertiaries subequal to those of lower cycles or smaller; fourth cycle small but usually recognizable.

Septa in four cycles, usually differentiated in size according to cycle; primaries and secondaries and occasionally some tertiaries reach the columella. Margins of primaries, secondaries, and tertiaries exsert, up to as much as 1.5 mm., usually about 1 mm.; those of the quaternaries obvious but not prominent.

Columella rather well developed.

Locality and geologic occurrence.—The "silex" bed of the Tampa formation, Tampa, Florida.

Type.—Wagner Free Institute of Science, Philadelphia.

Paratype.—No. 324896, U.S.N.M.

This variety, which intergrades with the typical form of the species, is especially distinguished by its less prominent calices and the better developed last (quaternary) cycle of costae.

Orbicella tampäensis var. *silecensis* is near *Orbicella costata*, from which it is separable especially by the more exsert margins of the primary, secondary, and tertiary septa, and by the quaternary septa having much lower margins than those of the other cycles. The general resemblance of the Tampa specimens of *O. tampäensis* var. *silecensis* is so close to specimens of *O. costata* from Anguilla that at one time I thought them referable to the same species, but the differences in the characters of the costae and of the upper septal margins served to separate them. For a comparison of *O. tampäensis* with *O. irradians* (Milne Edwards and Haime) Vaughan see page 394 of this paper.

12. ORBICELLA BREVIS (Duncan).

Plate 97, fig. 1.

1864. *Astraea brevis* Duncan, Geol. Soc. London Quart. Journ., vol. 20, p. 37, pl. 4, figs. 3*a*, 3*b*.
1868. *Heliastraea brevis* Duncan, Geol. Soc. London Quart. Journ., vol. 24, p. 24.
1870. *Heliastraea brevis* Duchassaing, Rev. Zooph. et Spong. Ant., p. 30.

The following is Duncan's original description:

> Corallum small, irregularly convex above, and slightly concave below. Corallites short, irregularly distant, and radiating. Calices circular, tolerably elevated, their height varying; the margin is rather sharp, and the external wall is marked by very distinct costae. The septa are very slightly exsert, largest at the wall, arched, the radius of the curve being directed upwards and inwards, passing but a little way inwards before descending abruptly; they are dentate on the free margin. In six systems of three cycles, with a septum of a fourth in some half-systems; primary septa the largest, the tertiary being small. The laminae are perfect, join the columella by ascending processes, and are slightly granular. Costae well developed, passing downwards and outwards from the margin; the primary are equal to the secondary, and there is some variation in the size of the tertiary; they are dentate,

and appear to be covered with a fine epitheca, and their course is often in a curve. In transverse and vertical sections the costae are seen to project far from the wall, and to be marked by oblique and abundant exothecal dissepiments; the tertiary costae being much less projecting than the others. The columella is large, lax, and papillary. The fossa is deep. The endotheca is not well developed, but the dissepiments extend to close to the calice. Diameter of calices one-fifth inch [5 mm.]; height of the corallum 9.10 inches [22.5 mm.]. The costae are very marked in this species, and with the papillary columella and short calices distinguish it from its allies; it is related both to *Astraea cylindrica* nob., and to *Astraea cavernosa* Edwards & Haime.

From the Nivajè shale, San Domingo. Coll. Geol. Soc.

Duncan's remarks on the affinities of this coral are correct, and in a previous paper I referred it to the synonymy of *O. cavernosa*.[1] The type of the species is represented by plate 97, figure 1. The costae are similar to those of *O. costata*, but the calices are much smaller. It will be noted in the figure that around the calicular margins the costae are subequal and that lower down on the corallite limb those corresponding to the last cycle of septa become smaller while the alternate costae become more prominent and extend on to the intercorallite areas. The costal beading is rather coarse, therein resembling *O. tampaensis*, which has larger calices. As predictions as to the ultimate fate of coral-names are admittedly hazardous, I will only remark that it seems to me from the material available for study that *O. brevis* is a distinct species; but a specimen from the "silex" beds near Tampa, Florida, so nearly bridges the gap between *O. tampaensis* and *O. brevis* that doubt is cast on their specific distinctness. Should the two supposed species ultimately be combined under one name, of course *O. brevis*, it being the older name, would persist, and *O. tampaensis* would become either a synonym or would be reduced to varietal or subspecific rank.

13. ORBICELLA INSIGNIS (Duncan).

Plate 98, figs. 1, 2, 2*a*.

1867 *Heliastraea insignis* DUNCAN, Geol. Soc. London Quart. Journ., vol. 24, pp. 19, 24, pl. 1, fig. 4.

Original description.—"The corallum is large, and the corallites also; they are wide apart, are circular in transverse outline, and are very equal in size. The wall is stout as regards the septa and costae, but thin in comparison with the diameter of the corallites. The septa are delicate, wide apart, long, slightly thicker at the wall than elsewhere, straight, and the primary septa are hardly any broader than the tertiary. There are three cycles of septa in the six systems, and rarely a septum of the fourth cycle is noticed in half of a system. The primary and secondary septa are of equal length, and the tertiary extend far in towards the columella. The columella is small. The costae are long, slender, often bent, almost equal, and of about the

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[1] Geolog. Reichs. Mus. Leiden, ser. 2, vol. 2, pt. 1, p. 29, 1901.

same thickness as the septa; occasionally a rudimentary costa is seen, and is not represented by a septum. The exotheca is inclined and abundant. The endotheca is very abundant and inclined.

"Diameter of corallites (costae not included) four-tenths inch [10 mm.].

"*Loc.* Antiguan Tertiary deposits.

"The large size of the corallites, the low septal number, the long septa and costae, with the small columella and highly developed endotheca, distinguish this species."

One of Duncan's original specimens, in the Geological Society of London, is represented by plate 98, figure 1.

I did not obtain in Antigua any coral definitely referable to *O. insignis.*

Regarding the specimens from Serro Colorado, Arube, referred by me to *Orbicella cavernosa*,[1] the following notes will be made (see pl. 98, fig. 2, 2*a*):

The corallites are circular in cross section, and have a diameter of a centimeter, sometimes slightly greater. The distance between them is 3 mm. or even greater. Endotheca and exotheca are very richly developed. The septa are usually 24 in number, alternately larger and smaller, all of the larger reach the columella; occasional small quaternaries. They are thin, but are thickened at the wall sufficiently to form a so-called "pseudotheca." There are two specimens of this coral from Serro Colorado, one of which is completely silicified, and a large portion of the other has undergone silicification. The columella is lax, spongy, and fairly large, occupying about one-third of the diameter of the corallite cavity. These specimens closely resemble Duncan's *Astraea radiata* var. *intermedia,* but have larger corallites; they are very near *O. costata* (Duncan), from which they differ by having thicker and fewer septa and a larger columella; *O. antillarum* differs by its somewhat smaller corallites; I discover no difference from *O. insignis* Duncan.

14. ORBICELLA INTERMEDIA (Duncan).

Plate 97, fig. 2.

1863. *Astræa radiata* var. *intermedia* DUNCAN, Geol. Soc. London Quart. Journ., vol. 19, p. 421.

Astraea radiata var. *intermedia* Duncan is, according to its original description, characterized by "having the third cycle of septa complete, and a little excess of vesicular endotheca. * * * The variety forms a link between the great astraeans of the Miocene of the Antilles and the existing *Astraea radiata* of the Caribbean Sea, *Astraea antillarum* being closely allied to it." The type-specimen, No. 2943, Geological Society of London, is represented by plate 97, figure 2. The diameter of the corallites is about 5 mm., distance between corallites from 1 to 2 mm. There are in places indications

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[1] Geolog. Reichs. Mus. Leiden Samml., ser. 2, vol. 2, pp. 32–33, 1901.

of small costae between the larger ones, similar to those of *O. cavernosa* var. *endothecata,* and there are a few quaternary septa. Columella rather small.

I did not collect any specimen of this species in Antigua. The species to which I am applying the name *O. canalis* is very nearly related and may eventually become a synonym. However, the primary and secondary septa are more nearly equal in *O. intermedia* than in *O. canalis*. *O. costata* and *O. insignis* are both very similar to *O. canalis*. O. *costata* has more extended costae, and *O. insignis* has larger calices and, in comparison with the size of the calices, fewer septa. As suites of specimens adequate for a satisfactory study of variation are not available, at least temporarily, the three names, *O. intermedia, O. costata,* and *O. insignis* should be treated as valid.

Locality and geologic occurrence.—According to Duncan, "From the upper Parian of Trinidad (Wall and Sawkins coll.), and the marl-formation [Antigua formation] of Antigua." The specimen represented by plate 97, figure 2, is from Antigua.

15. ORBICELLA GABBI, new species.

Plate 108, figs. 1, 1*a*, 1*b*.

Corallum massive; corallites very large, from 20 to 25 mm. in diameter, by far the largest corallites of any species of the genus known from the American Tertiary formations. Intercorallite areas narrow or as much as 4.5 mm., perhaps more, across.

Septa very numerous, thin, crowded, 106 were counted in the corallite represented by plate 108, figure 1a. There are more than 5 complete cycles. Septal grouping obvious, usually every other or every fourth septum reaches the columella, but in places there are seven or eight shorter septa, forming a group, between two long septa.

Columella rather small, only about 2.5 mm. in diameter. Endothecal and exothecal dissepiments greatly developed, thin-walled.

Locality.—Santo Domingo (Gabb Collection).

Type.—Academy of Natural Sciences of Philadelphia.

16. ORBICELLA IRRADIANS (Milne Edwards and Haime) Vaughan.

Plate 97, figs. 3, 3*a*.

1848. *Phyllocoenia irradians* Milne Edwards and Haime, Comptes Rend., vol. 27, p. 469.

1860. *Phyllocoenia irradians* Milne Edwards and Haime, Hist. nat. Corall., vol. 2, p. 272.

1868. *Phyllocoenia irradians* Reuss, K. K. Akad. Wissensch. Wien, Math.-Naturw. Cl., Denkschr., vol. 28, p. 156, pl. 10, figs. 5–7; pl. 11, figs. 1–3.

This appears to be the species referred to by Fabiani in his "Il paleogene del Veneto"[1] as *Heliastraea irradians* Michelin. Michelin erroneously applied the name *Astrea radiata*[1] to this species.

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[1] R. Univ. Padova Inst. geolog. mem., vol. 3, pp. 225, 230, 231, 1915.

Figures of *Orbicella irradians* and some notes on it are introduced here, because of the close resemblance of *Orbicella tampäensis* to it. The beading of the costae in *O. tampäensis* appears coarser, and paliform lobes seem more specialized in *O. irradians.*

Locality and geologic occurrence.—Milne Edwards and Haime (1857) record it from Castel Gomberto and Chaine d'Hala (Sinde). Reuss[2] says it is the most abundant anthozoan of the Monte Grumi beds. He also records it from Castellaro, Monte Spiado, Monte del Carrioli, and Montecchio Maggiore.[3] D'Archiardi mentions it as occurring in what he designates as the Castel Gomberto, Montecchio Maggiore, and Monte Viale groups.[4] Fabiani refers *Heliastraea irradians,* by which I believe he means this species, to the Lutetian (Eocene) and to the Rupelian (middle Oligocene) of Castel Gomberto and San Giovanni Ilarione. The specimen in the United States National Museum (No. 164723) (see pl. 97, figs. 3, 3*a*), was received from Professor Parona of the University of Turin, and came from Monte Grumi di Castel Gomberto. Although apparently reported from the Lutetian Eocene of Veneto, it is most abundant in the Rupelian or middle Oligocene. Because of the close resemblance of *Orbicella tampäensis* to *O. irradians,* of the presence of *Antiguastrea cellulosa* in the "silex" bed at Tampa, and of the presence at Tampa of species of *Stylophora, Galaxea, Endopachys, Goniopora,* and *Alveopora,* all genera now extinct in the Atlantic Ocean, I believe that the fauna of the "silex" bed at Tampa surely is as old as upper Oligocene.

The generic name *Phyllocoenia,* genotype *P. irradians,* is a synonym of *Orbicella* Dana.

Genus SOLENASTREA Milne Edwards and Haime.

1848. *Solenastrea* Milne Edwards and Haime, Compt. Rend., vol. 27, p. 494.

1850. *Solenastrea* Milne Edwards and Haime, British fossil corals, Introduction, p. xl.

1917. *Solenastrea* Vaughan, U. S. Geol. Survey Prof. Pap. 98–T, p. 371.

Type-species.—*Astrea turonensis* Michelin.

SOLENASTREA HYADES (Dana).

1846. *A[straea] Orbicella hyades* Dana, U. S. Expl. Exped. Zoophytes, p 212, pl. 10, fig. 15.

1846. *A[straea] Orbicella excelsa* Dana, U. S. Expl. Exped. Zoophytes, p. 212, pl. 10, fig. 16.

1902. *Orbicella excelsa* Verrill, Conn. Acad. Arts and Sci. Trans., vol. 11, p. 98, pl. 15, figs. 4, 4*a*, 4*b*.

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[1] Icon. Zoophytol., p. 58, pl. 12, fig. 4, 1812.

[2] K. K. Akad. Wissensch. Wien, Math.-Natuwiss. Cl. Denkschr., vol. 28, p. 156, 1868.

[3] Idem, p. 135.

[4] Studio comparativo fra i coralli dei terreni terziari del Piemonte e dell' Alpi Venete, p. 46, Pisa, 1868.

1902. *Solenastrea hyades* VERRILL, Conn. Acad. Arts and Sci. Trans., vol. 11, p. 104, pl. 15, figs. 5, 5*a*, 5*b*.

1917. *Solenastrea hyades* VAUGHAN, U. S. Geological Survey Prof. Paper 98–T pp. 372, 373, pl. 98, figs. 1, 1*a*, 2, 2*a*, 3.

Professor Verrill has studied Dana's types of *Orbicella hyades* in the collection of the Boston Society of Natural History, and gives the following description:[1]

> Calicles circular, or nearly so, mostly 3 to 3.5 mm. in diameter; borders generally distinctly elevated above the exotheca, often to the height of 0.5 to 1 mm. Younger and smaller calicles, 1.5 to 2.5 in diameter, are scattered between the full-grown ones. In the middle of the convex summit the calicles are so crowded that the walls are in contact, and here they often become angular by crowding, and when not in contact their edges may not be elevated. On other parts they may be separated by intervals of 2 or 3 mm. or more. The walls are very thin. The costae are thickened and roughly minutely serrulate; they are very narrow and mostly confined to the wall, never extending across the exothecal spaces, when these occur. The surface of the exotheca is smooth or vesicular; in sections the exotheca is openly vesicular.
>
> Septa 20 to 24, mostly 24 in mature calicles; 12 extend to the columella; those of the third cycle are also wide, but thinner, and most of them bend toward and join the larger ones about midway between the wall and columella. The septa all become thin and curved toward the columella, but thickened at the wall; the summits are narrowed and rather prominent above the walls; inner edge irregularly and roughly serrulate, especially distally; sides roughly granulated. Paliform lobes small and thin. Columella usually rather small and loose; formed of small twisted processes from the inner edges of the septa, but variable in size.
>
> Thickness of the larger mass from St. Thomas, about 50 mm.; diameter 125 mm.; diameter of calicles, mostly 3 to 3.5 mm., rarely 4 mm.
>
> This species is found on the Florida Reefs and throughout the West Indies. It has not been found at the Bermudas. St. Thomas (coll. C. F. Hartt, Yale Mus.). In the American Museum, New York, there is a large turbinate mass, 12 to 14 inches in diameter and about 10 inches high, from Jamaica.

The same author gives the following description of *Orbicella excelsa* Dana:[2]

> Dana's type of this species, in the Boston Society of Natural History, was carefully studied by me a number of years ago, and descriptions were made at that time. The type is apparently slightly beach-worn, but so little that the natural surface of the coenenchyma and costae, and the summits of the septa are well preserved in most parts, and there is no evidence of post-mortem alteration by infiltration to account for the solidity of the coenenchyma, referred to by Dana, and which is, indeed, quite remarkable in most parts. The coral is very solid and heavy as contrasted with *O. annularis* or *Solenastraea hyades*.
>
> A fragment, apparently of the same specimen, and which appears to have been used by Dana in describing the details, is preserved in the Museum of Yale University. From this the accompanying photograph has been made (pl. 15, fig. 4). The coral grows in irregular, often upright, lobed or gibbous masses, up to 100 to 150 mm. or more high, but when young it must be encrusting. No. 1729.
>
> The type-specimen is so strongly lobed that the lobules in some places look like incipient branches. But these may possibly be due to the coral growing over the tubes of invading bivalves or annelids, though none can be seen without sections.

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[1] Conn. Acad. Arts and Sci. Trans., vol. 11, pp. 104, 105, 1902.

[2] Idem, vol. 11, pp. 98, 99, 1902.

The calicles are more closely crowded on the lobules, especially at the obtuse summits, where they become angular and are separated by thin walls and cellular exotheca. Elsewhere the calicles are nearly circular, scarcely elevated, and separated by exothecal spaces usually about equal to the radii of the calicles, but toward the base often equal to their diameters. The exotheca and walls are very solid in most parts.

The 24 costae are subequal, thickened, only slightly raised, faintly or almost microscopically granulated; those of adjacent calicles are usually separated at the surface by a slight intermediate groove, forming polygonal areas around the calicles. The exotheca is nearly level with the edges of the walls and costae, flat or slightly concave, minutely granulated or nearly smooth, sometimes slightly vesicular at the surface, but usually almost solid and blended with the costae and walls; near the tips costae unite and exotheca is cellular.

In a transverse section, near the surface, the entire partition between the calicles may be perfectly solid, whether thick or thin, but in many cases one or two rows of small, rounded or crescent-shaped vesicles can be seen, and sometimes, close to the surface, vesicular dissepiments are visible between the small costae, while close to the basal margin of the coral the exotheca may be decidedly vesicular, appearing almost like miniature honeycomb in transverse sections. But this basal portion is formed by the thin, down-growing margin, where the new calicles are very short, oblique, and far apart, as in many other corals that have a thin, proliferous margin.

The septa are generally 24, subequal, in three regular cycles; those of the first two cycles are nearly equal in height and thickness; those of the third cycle are thinner and narrower, and generally bend to the right and left in pairs to join the straight septa of the second cycle, usually at a point more than half way to the columella, and often very near it. The summits of all the septa are narrow and only slightly raised above the walls. The edges are irregularly serrulate, two to four of the basal teeth being the larger. The sides are distinctly granulated. The septa are all thin, but slightly thickened toward the wall, and all are narrowed above the base, so as to leave a cup-like calicular cavity. The columella is small, trabecular, papillose, and often nearly wanting. In transverse sections of some calicles it is solid, and formed by the union of the inner edges of the septa, but in most it is small, porous, trabecular.

Diameter of the calices 2.5 to 3 mm.; breadth of intercalicinal spaces, usually 1 to 2 mm., sometimes 3 to 4 mm. or more, near the base.

Origin uncertain, supposed to be West Indies. Several irregular gibbous masses of this species, 3 to 5 inches in thickness, in the American Museum, New York, were found near Osprey, West Florida, cast on the beach, after a storm, by R. P. Whitfield (No. 485). I have also seen specimens from Key West.

Verrill keeps *O. hyades* and *O. excelsa* separate, with the remark, however, that "they may eventually prove to be one species." The differences between the two consist in the latter possessing a much more solid exotheca and more developed costae. There is in the United States National Museum a moderate suite of specimens from the living Florida reefs, and a large number of fossil specimens. I feel convinced that the two forms are only variations of the same species, as in the same specimen the exotheca may be solid or vesicular; and the costae may be confined to the corallite periphery or extend from the periphery of one corallite to that of the next. Although Professor Verrill's descriptions are so comprehensive as to render a new one unnecessary, I should like to call attention to some features not considered in detail by him. The costae seen on the surface are not prolongations of the distal ends of the septa. They are only elevations on the exothecal surface corresponding in position with the septa. The exotheca is usually built up of more or less horizontal platforms, which when closely applied one above another give rise to a compact, or even a solid exotheca; if the platforms are separated, the intervening spaces contain vesicular dissepiments. In some instances the exothecal surface is formed by thin-walled vesicles. The septal trabeculae are directed upward at a low angle, and have their courses indicated by rather small and crowded granulations. The inner septal edges or trabeculae from the septal edges fuse to form a false columella. The septa usually are imperforate; however, in some instances perforations occur between the trabeculae near the columella, but never so abundantly as in *Orbicella annularis.*

Localities and geologic occurrence.—Recent specimens in the United States National Museum: Osprey and Caesars Creek, Florida, collected by T. Wayland Vaughan; southern Florida, collected by S. T. Walker; Caesars Creek, Florida, collected by Edw. Palmer; Cedar Keys, Florida, collected by Lieut. J. F. Moser, U. S. N.; reefs near Miami, Florida, collected by J. E. Benedict.

Pleistocene, Miami oolite and Key Largo limestone, Florida, collected by T. W. Vaughan.

In the Pliocene Caloosahatchee marl on Shell Creek and Caloosahatchee River, Florida, collected by numerous persons.

In the Miocene La Cruz marl at stations 3440 and 3443, in the northeast part of Santiago, Cuba; station 3445, crossing over the railroad of the highway from Santiago to the Morro, collected by T. W. Vaughan. At one time I thought these Santiago specimens might come from a deposit of Pliocene age, but the other associated fossils indicate that this is another species of considerable geologic antiquity. A specimen from station 3451, Cienaga railroad station, near Habana, collected by T. W. Vaughan, seems to belong to this species.

SOLENASTREA BOURNONI Milne Edwards and Haime.

1850. *Solenastrea bournoni* Milne Edwards and Haime, Ann. Sci. nat., ser. 3, Zool., vol. 12, p. 121.

1861. *Cyphastrea oblita* Duchassaing and Michelotti, Mém. Corall. Antilles, p. 77 (of reprint).

1861. *Plesiastrea carpinetti* Duchassaing and Michelotti, Mém. Corall. Antilles, p. 77 (of reprint).

1861. *Solenastrea ellisii* Duchassaing and Michelotti, Mém. Corall. Antilles, p. 77 (of reprint).

1861. *Solenastrea micans* Duchassaing and Micheloltti, Mém. Corall. Antilles, p. 77 (of reprint), pl. 9, figs. 10. 11.

1861. *Leptastrea caribaea* Duchassaing amd Michellotti, Mém. Corall. Antilles, p. 78 (of reprint).

1863. *Plesiastraea distans* Duncan, Geol. Soc. London Quart. Journ., vol. 20, p. 37, pl. 4, figs. 4*a*, 4*b*.

1863. *Plesiastraea globosa* Duncan, Geol. Soc. London Quart. Journ., vol. 20, p. 38, pl. 4, fig. 5.

1917. *Solenastrea bournoni* Vaughan, U. S. Geol. Survey Prof. Paper 98–T, pp. 372, 374, pl. 99, figs. 1, 1*a*, 1*b*, 2, 3, 3*a*; pl. 100, figs. 1, 2, 2*a*, 3, 3*a*, 3*b*.

The following description is based on specimens from the Pliocene Caloosohatchee marl of Florida:

Corallum forming spheroidal or dome-shaped masses, sometimes as much as a foot, or even more, in diameter; the outer surface uniformly rounded or with gibbosities.

The succeeding portion of the description is based upon a single head-shaped specimen, 15.3 cm. tall; greater diameter 12.8 cm., lesser, 11 cm.

The calices have very slightly elevated margins, and thin corallite walls. Diameter from 2 to 2.5 mm. Distance apart from 0.75 to about 2 mm.; usually about 1 mm., or half the diameter of the calices. The depth of the calicular fossae can not be determined with certainty, as the specimen is worn; where it is best preserved they are shallow. The corallite walls externally are costate, a costa corresponding to each septum; the costae, however, are short, those from one corallite not extending to those of the next. Between the corallites are thin-walled exothecal vesicles, which have a horizontally stratified arrangement. The outermost exothecal platform may show costal striations.

The septa are thin, somewhat thicker at the wall; uniformly in three complete cycles; primaries and secondaries equal and reaching the columella; tertiaries only about half as long; thinner, inner margins free. Rather wide, thin pali occur before the first and second cycles. The septal faces are finely granulate, with the courses of the trabeculae indicated; no perforations could be discovered. Thin endothecal dissepiments present. Columella poorly developed, rather small and lax.

VARIATION OF SOLENASTREA BOURNONI.

The United States National Museum possesses very large suites of specimens of this species, permitting a rather satisfactory study of its variation. The specimen already described shows within itself the limits of variation in the size and distance from one another of the calices. About 2 mm. is the average calicular diameter. The exotheca may be very light and delicate, or rather compact, even almost solid. The septa vary in thickness and the pali may be strongly or weakly developed; where strongly developed they are triangular in shape, the base of the triangle directed outward, and the tertiaries may fuse to the basal corners or to the sides of the pali before the secondaries. The thickened pali are correlated with the denser exotheca, the various skeletal elements seem to thicken together.

SYNONYMY OF SOLENASTREA BOURNONI.

Of the species described by Duchassaing and Michelotti, *Cyphastrea oblita, Plesiastrea carpinetti, Solenastrea ellisii, Solenastrea micans,* and *Leptastrea caribæa* can confidently be placed in this synonymy.

I examined in the Museum of Natural History in Turin a specimen labeled *Cyphastrea oblita* Duchassaing and Michelotti, but it is a small caliced corallum of *Orbicella annularis* (see p. 374 of this paper), and it does not accord with the original description of *C. oblita,* which is as follows: "Species rounded, with rounded calices, the margins of which are a little elevated; costae rare, almost confluent; the intercalicular areas are beset with granulations: columella, large and papillary."

In a note it is stated the septa of *C. oblita* bear small, subpaliform lobes. It seems to me more probable that the type is the specimen in the Muséum d'Histoire Naturelle, Paris, figured by me in United States Geological Survey Professional Paper 98–T, plate 99, figures 3, 3*a*.

The original description of *P. carpinetti* is as follows: "The form of the corallum is convex and lobed; the calices are small, and often slightly deformed with prominent margins, separated by distinct costae and vesicular tissue: the septa are finely denticulate and do not attain a length of one-third the radius of the calice because of the development of the pali. The last are thick, as strong as the septa, when examined with a lens they appear covered with granulations; the columella is formed by papillae similarly granulate."

Solenastrea ellisii, according to Duchassaing and Michelotti, "has for a synonym the *Astrea pleiades* figured in the work of Ellis and Solander, Nos. 1 and 4 of plate 53." There is a specimen, probably the type, in the Museum of Natural History at Turin, labeled *Solenastrea ellisii.* It has small calices, 2 mm. in diameter, and three cycles of septa, the members of the last cycle are very small.

The original description of *Solenastrea micans* is as follows: "Corallum orbicular, with crowded calices, circular, but often deformed, diameter about a line [2 mm.]; their upper margin is free, projecting above the rest of the surface; the septa are very echinulate and thicken outwardly; the columella is thick and vesiculate." St. Thomas.

The calices of the type are crowded; 2 to 3 mm. in diameter. Septa in two complete cycles, with a few tertiaries; primaries and secondaries of the same size

The original description of *Leptastrea caribaea* is as follows: "Species globular, with calices almost contiguous, circular, margins elevated; columella simple, septa alternately smaller." St. Thomas.

Calices of the type, 2 to 2.5 mm. in diameter; margins slightly elevated. Septa of the last cycle rarely fused to the sides of the secondaries; paliform lobes insignificant or absent. Columella with papillate upper surface.

Duncan's *Plesiastraea distans* and *P. globosa*, from the silt of the sandstone plain of Santo Domingo, belong in the same synonymy. The types of both species are preserved in the collection of the Geological Society of London, where I have studied them. A duplicate of the latter is in the United States National Museum. The difference between *P. distans* and *P. globosa* consists in the calices of the former being one-half or more than one-half their diameter apart, while in the latter the distance between them is usually less than one-half this diameter.

Cyphastrea hyades and *C. bournoni* are closely related species. The calices of *C. hyades*, however, are constantly larger than those of *C. bournoni*, and the tertiary septa, except in young coralla, constantly fuse to the sides of the secondaries. *C. bournoni* has smaller calices, and except when the pali are decidedly thickened, has the inner ends of the tertiary septa free. These differences are constant in the considerable suites of specimens that I have been able to study.

Localities and geologic occurrence.—Living at St. Thomas, Virgin Islands, whence Duchassaing had a number of specimens. Tortugas, Florida, in water between 8 and 9 fathoms deep.

Pliocene, in the Caloosahatchee marl of Florida, on Caloosahatchee River, collected by Frank Burns and others; and Shell Creek, Florida, collected by Frank Burns and by Doctor Griffith.

Miocene, Rio Cana, Zone H, Santo Domingo, collected by Miss C. J. Maury in association with an invertebrate fauna of the age of the Bowden marl of Jamaica.

Miocene, in the La Cruz marl, Santiago, Cuba, at stations 3436, 3437, 3446, collected by T. W. Vaughan, in association with an invertebrate fauna closely related to, but probably a little younger than that of the Bowden horizon.

ANTIGUASTREA, new genus.

Growth form massive; asexual reproduction by intercorallite budding; septal margins very obscurely dentate, subentire; corallites usually joined by thin costae; columella lamellar, usually well developed and prominent; exothecal and endothecal dissepiments highly developed.

Type-species.—*Astraea cellulosa* Duncan.

This genus is near *Orbicella*, from which it differs by its more obscurely dentate septa and its lamellar columella. The costae between corallites are thin and in some instances disappear on the surface of the exothecal vesicles.

Reis[1] proposed the name *Heterastraea* for the genus here named *Antiguastrea;* but, as R. F. Tomes had used *Heterastraea* for a genus of English Liassic corals in 1888,[2] Reis's name can not stand. Reis's account of the columella in his description of *Heterastraea* is contradictory. Regarding *Heterastraea tenuilamellosa* (Gümbel) Reis, he says, "zeigen ein verlängertes blattartiges bis papillöses Säulchen." The columella in that species, therefore, is lamellate.

This genus of corals is important in its bearing on the correllation of American and European Tertiary formations. At the end of his table of the corals from the Reiter Schichten, Reis says:[3] "Aus diesem Tabelle geht unzweifelhaft hervor, dass erstens die Reiter Korallenlager und die vom Hallthurm mit denen von Haering gänzlich stimmen, also keinen tieferem Horizont angehören können und dass zweitens dieser Horizont sowohl durch Haeringer Schichten als auch durch die deutlichsten Beziehungen zu den unter- bis mittel oligocänen Korallenlagern des Vicentins als solcher festgestellt ist." Reis reports species of *Heterastraea* from Reit, Castelgomberto, and Crosara.

There is in the United States National Museum (No. 155186) a specimen of *Heterastraea michelottina* (Catullo) Reis, received from Prof. K. A. von Zittel. This specimen has a distinct, short, thick, lamellar columella. It so closely resembles *Antiguastrea cellulosa* that specific distinction is difficult, perhaps even doubtful. *Isastrea elegans* Reuss is referable to *Antiguastrea*. It is described after *Antiguastrea cellulosa* (see p. 409, pl. 102, figs. 1, 1*a*). *Astrea alveolaris* Catullo[4] also belongs to *Antiguastrea*. Notes on it follow those on *A. elegans*.

ANTIGUASTREA CELLULOSA (Duncan).

Plate 98, figs. 3, 3*a*, 4, 4*a*; plate 99, figs. 1, 1*a*, 2, 2*a*, 3, 3*a*; plate 100, figs. 1, 2, 3, 3*a*, 4, 4*a*; plate 101, figs. 2, 2*a*.

1863. *Astraea cellulosa* DUNCAN, Geol. Soc. London Quart. Journ., vol. 19, pp. 417, 418, pl. 13, fig. 10.
1863. *Isastraea turbinata* DUNCAN, Geol. Soc. London Quart. Journ., vol. 19, p. 423, pl. 14, figs. 1*a*–1*c*.
1866. *Heliastraea cellulosa* DUCHASSAING and MICHELOTTI, Sup. Mém. Corall. Antilles, p. 86 (of reprint).
1866. *Isastraea turbinata* DUCHASSAING and MICHELOTTI, Sup. Mém. Corall. Antilles, p. 89 (of reprint).
1867. *Heliastraea cellulosa* DUNCAN, Geol. Soc. London Quart. Journ., vol. 24, p. 24.
1867. *Isastraea turbinata*, DUNCAN, Geol. Soc. London Quart. Journ., vol. 24, p. 25.
1870. *Heliastraea cellulosa* DUCHASSAING, Rev. Zooph. et Spong. Antilles, p. 30.

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[1] Korallen der Reiter Schichten, Bayerisch. geognost. Landesuntersuch, geognost. Jahreshefte, Jahrg. 2, pp. 150-152, 1889.

[2] Geol. Mag., Dec. 3, vol. 5, pp. 207-218, pl. 7, 1888.

[3] Korallen der Reiter Schichten, p. 91.

[4] Dei terreni di Sedimento superiore delle Venezie, e dei fossili byrozoari, antozoari, e spongiari. ai quali dannoricetto, p. 51, pl. 11, fig. 1. Padova, 1856.

1870. *Isastraea turbinata* DUCHASSAING, Rev. Zooph. et Spong. Antilles, p. 31.
1902. *Orbicella cellulosa* VAUGHAN, Geol. Soc. London Quart. Journ., vol. 52, p. 497.
1915. *Orbicella cellulosa* VAUGHAN, Carnegie Inst. Washington Yearbook, No. 13, p. 360.

Original description.—"Corallum tall, and, judging from the disposition of the corallites, subplane above. Corallites very numerous, tall, slender, crowded, but distinct; usually cylindrical, but sometimes more or less prismatic from mutual pressure; varying in size. The transverse section of the corallites is generally circular, now and then deformed. Septa crowded, linear; the primary are the largest, but often the secondary are nearly as large. The primary septa are of nearly the same thickness at the wall and throughout. There are six systems of four cycles; in imperfectly developed systems the fourth cycle is wanting, but the persistence of this cycle throughout all the systems is very generally decided. The fourth and fifth orders are very small, and when there are only three cycles, the third order is small; the septa are generally straight. Columella small and slightly developed. The wall appears to be stout. Costae attached to every septum, subequal, and not very greatly developed. Endotheca vesicular, greatly developed. There are often four dissepiments dividing each interseptal space. Exotheca cellular and highly developed; exothecal cells small, more rectangular and larger than the endothecal cells. The reproduction is by extracalicular gemmation; the smallest buds visible have three perfect cycles of septa.

"From the Conglomerate of Antigua. Coll. Geol. Soc.

"*Dimensions.*—Height of corallum several inches. Diameter of corallites from 1–2 lines [2 to 4.2 mm.]."

The type of the species was examined in the collections of the Geological Society of London, and the identification of the specimens I am referring to it was verified.

As this is an enormously variable species further discussion of it should begin with a clear statement of the characters of the typical form. These may be summarized as follows: Calices 2 to 4.2 mm. in diameter, crowded, but distinct; costae subequal, not greatly developed; wall stout. Septa in four cycles, primaries the largest and of the same thickness throughout; secondaries almost as large as the primaries; tertiaries and quaternaries smaller according to cycle. Columella said to be small and slightly developed. Endotheca and exotheca greatly developed. Plate 98, figures 3, 3*a* illustrate a typical specimen, which completely satisfies the requirements of Duncan's description, except that close inspection shows a small, well-developed, lamellate columella. Plate 100, figures 1, 2, are reproduced from photographs of thin sections of specimens and show the lamellar columella.

The first variant to be considered is represented by plate 99, figures 1, 1*a*. The corallites have free limbs as much as 1.25 mm. tall, and are separated by intercorallite areas usually about 1 mm. wide, range in width from 0.5 to 1.5 mm. The walls are thick; costae slightly developed, thin. Calicular diameter from 3 to 5 mm. Septa in 4 complete cycles; 6 thick primaries which reach the columella; secondaries stout, but thinner than primaries, reach to or almost to the angle formed at the inner ends of the adjacent primaries; tertiaries thin, their inner ends project just beyond a peripheral zone of dissepiments; quaternaries small and thin, their inner ends barely reach the inner side of the dissepimental zone. Columella a compressed axial tubercle or an axial lamella. Endotheca and exotheca well developed. This specimen, which differs only slightly from the typical form of the species, represents the extreme of variation in one direction.

One line of variation from the typical form of the species is by increase in the size of the calices, diameter from 7 to 9 mm., with consequent greater development of the higher cycles of septa, and the development of thin corallite walls which are separated by interspaces from 1 to 2 mm. wide. The intergradation between specimens with the large and small calices and thick and thin walled corallites is complete; in fact, the variations may be found on the same specimen. These larger calicled specimens belong to what Duncan designated var. *curvata*.

Specimens showing the variations so far discussed occur in Antigua at the southwestern foot of the limestone hills from Willoughby Bay practically to the intersection of the hills with the sea near Wetherell Point.

Other lines of variation may best be presented by describing a series of specially selected specimens.

Specimen No. 1, from Station 6866, opposite the Cathedral, St. John, Antigua (pl. 99, figs. 2, 2*a*).—Corallum broken on the base; 66 mm. long, 50 mm. wide, 34 mm. tall. There is one tuberose protuberance.

Corallites separated by narrow intercorallite areas, only 0.25 mm. wide, or by areas which range up to 3.5 mm. across, measured between the peripheries of neighboring calices. Where the calices are separated the intercorallite areas are depressed and are crossed by thin costae, which are confluent where they can be clearly seen, but in other areas they may alternate; about 15 costae to 5 mm., or the distance between summits of adjacent costae is about 0.3 mm.; the interspaces decidedly wider than the thickness of the costae.

The following table gives the size of eight calices.

Measurements in millimeters of calices of Antiguastrea cellulosa.

	1	2	3	4	5	6	7	8
Greater diameter	10.75	9.25	9	9.25	5	7.75	5	4.5
Lesser diameter	10.00	9.25	7.5	6.00	4	6.00	5	4.5

About half the calices on this specimen are 9 or more mm. long. The large calices are usually separated by narrow intercorallite areas, while most of the smaller calices are distant from 1.25 up to as much as 3.5 mm. The large calices are excavated, while the smaller are shallow and are tumid around their peripheries.

Septa thin, normally in four complete cycles; in some calices quinaries are present in a few quarter systems. The primaries are usually somewhat thicker, in a few calices conspicuously thicker than the members of the higher cycles, and extend to the columella; the secondaries also extend to the columella. The tertiaries may fuse to the secondaries near the columella; and the quaternaries may fuse to the tertiaries about halfway between the calicular periphery and the columella, or the inner septal ends may be free. Septal grouping not conspicuous. Septal margins with fine dentations, about 7 in 1.25 mm.; that is, a little less than 0.2 mm. from the top of one dentation to that of the next.

Columella small, in some calices represented by an axial lamella. The variant represented by this specimen is abundant about three-quarters of a mile south of the Cathedral in St. John, on the southwest side of the Otto estate, where I obtained 11 specimens.

Specimen No. 2, also from Station 6866, St. John, Antigua (pl. 99, figs. 3, 3*a*).—The corallum is of tuberose shape and has a maximum length of about 75 mm.

This specimen resembles in its characters that part of specimen No. 1 where the corallites and calices are smaller and more distant. The calices are tumid around their peripheries and are shallow. The usual calicular diameter, measured between the tops of the septal arches, is from 4.5 to 5 mm.; distance between calices, about 2.5 mm.

Other characters need not be described, except to say that the columella is either a compressed papilla or a short lamella.

Specimen No. 3, from Station 6856, Friars Hill, Antigua (pl. 100, figs. 3, 3*a*).—The corallum of this specimen is 85 mm. long, 70 mm. wide, about 75 mm. tall, and has a more or less tuberose form of growth.

The fully developed calices are 5 to 6 mm. in diameter, and are usually about 2 mm. apart, with depressed intercorallite areas, and slightly raised calicular rims, which project as much as 0.75 mm. The free part of the corallites in places rises perpendicularly above the intercorallite areas, but in other places the calicular peripheries are rounded in profile.

Septa in four complete cycles, with a few quinaries in some calices; primaries the thickest; secondaries nearly as thick as the primaries; tertiaries considerably thinner; quaternaries the thinnest, unless quinaries are present. There is grouping of the highest cycles around the secondaries, but it is not very striking.

Columella variable in development, represented by an axial papilla or by a distinct axial lamella.

Other specimens from Station 6866, St. John, Antigua.—There are in addition to those already described, from station 6866, two large specimens and fragments representing three others. The largest is 13 by 14 cm. in diameter and about 9 cm. tall. The calicular and septal characters are similar to those of specimen No. 2 of the foregoing descriptions. The primary septa in many calices are decidedly thick, the thickness of the other septa decreasing according to cycle. The columella, although it appears to be derived from the septa, is an axial lamella and in many cycles is decidedly thick.

The specimens described in the foregoing remarks are the ones that have given me the most trouble in identification. They grade directly into typical specimens, such as the one on which Duncan based his original description, and those described on pages 403, 404 of the present discussion.

The following is Duncan's original description of *Isastraea turbinata:*

> Corallum 7 inches high, subplane and irregularly convex above, broad and gibbous at the sides, small and conical at the base, whence the corallites radiate; upper surface ridged with the elevated margins of more or less polygonal, close calices. Corallites very long, slender, and prismatic, excessively crowded. Walls united, simple throughout. Calices very numerous, irregularly pentagonal, not deep, and not packed geometrically. Margins existing as sharp ridges, not marked by the septa, but faintly ragged; united, crowded, not deep. Septa small, not exsert, not arched, but slanting irregularly downwards and inwards, except the primary, which stand up in the fossa, and are easily seen. They are laminar, delicate, and crowded, slightly toothed near the internal end, ragged above, and granular on the sides. The primary septa sometimes meet by their inner ends; the secondary and tertiary are subequal when there are others. They are disposed in six systems. In fully developed calices there are four cycles in four systems and three in the rest; in other calices three cycles with an occasional fourth order. The fourth cycle is very small. Septa straight, not crenulate, but slightly ragged; no external spines. Endotheca tolerably developed. From the condition of the base, which has been rolled, no epitheca can be seen. Reproduction by submarginal (close to the wall) gemmation. Diameter of the calices from 2 lines to 3½ lines [4.2 to 7.3 mm.]. (From the Chert formation of Antigua Coll. Geol. Soc.)

A specimen that agrees with Duncan's descriptions and figures is represented by plate 100, figures 4, 4*a*. This coral puzzled me for some time but it is almost typical *Antiguastrea cellulosa,* in which the intercorallite tissues have been mineralogically changed so as to present the appearance of solid intercorallite walls; however, in a few places the calicular edges persist, showing separate calicular margins between which is a lower intercorallite area crossed by thin costae. The septal and columellar characters are precisely as in *A. cellulosa.* I failed to find Duncan's type of *Isastraea turbinata* in London, but I am convinced that it is a specimen of *Antiguastrea cellulosa* in which the intercorallite tissues are solidified by secondary mineral changes.

Localities and geologic occurrence.—This is one of the commonest corals in the Antigua formation of Antigua, where I collected and brought to Washington about 100 specimens. A list of the stations at which collected would be almost a list of the exposures of the Antigua formation examined. In Cuba, at station 7508, Ocujal Spring, altitude 200 feet a. t., near Guantanamo, collected by O. E. Meinzer. In Porto Rico, zone C, near Lares, collected by Bela Hubbard, of the New Academy Porto Rican Explorations. Serro Colorado, Arube, Dutch West Indies.

As a slight variant from the typical form, it is common in the base of the Chattahoochee formation along Flint River, near Bainbridge, Decatur County, Georgia, and it is well represented in the silex bed of the Tampa formation at Tampa, Florida.

It is also found in Anguilla, where I collected a single specimen at station 6893, on the south side of Crocus Bay.

In the State of Tamaulipas, Mexico, at the following localities: One mile east of Salitre; Cerro del Aire, 7 miles southeast of Refugio; 1 mile east of San José de las Rusias; hill 4 miles east of San Rafael (specimens submitted by Mr. E. T. Dumble).

A specimen sent to the United States National Museum by Mr. Philip Crutcher is reputed to come from Vicksburg, Mississippi; subsequently collected by O. B. Hopkins at station 7463 in the Byram calcareous marl, 4½ miles south of Vicksburg, Mississippi.

In general, the species is abundant in the three formations mentioned, and is important in indicating an Oligocene horizon. It has not yet been found in deposits younger than those of Tampa age.

Prof. K. Martin, director of the Geologisch-Reichs Museum, Leiden, submitted to me for determination some material from Serro Colorado, Arube, that I referred to *Orbicella tenuis* (Duncan), supposing at the time that Duncan's *Astraea tenuis* belonged to the genus *Orbicella*.[1] Subsequent study of additional collections has shown that Duncan's *Astraea tenuis* is in reality a fungid coral. The following are the notes I published on the Arube specimens in the paper referred to in the footnote:

> The corallites are long; are close together, only a millimeter apart, and usually are not round because of having been deformed by mutual pressure; the diameter of the corallites is from 4 to 5 mm. The septa are thin, and crowded; the usual arrangement being four complete cycles. The members of the first and second cycles reach the columella; those of the third cycle are not so long; and those of the fourth are still shorter. The members of the first and second cycles are of about the same thickness, no constant difference in thickness according to cycles is discernible. There is no marked difference in the thickness of any of the septa at the wall. The members of the third and fourth cycles are slightly thinner. Endotheca is well developed. The exotheca has been destroyed in the process of fossilization. The columella is poorly developed, being formed by the loose fusion of the principal septa in the axial space.

I also pointed out in the paper cited the close resemblance of the specimens described to "*Orbicella*" *cellulosa* (Duncan). I have

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[1] Geolog. Reichs Mus. Leiden Samml., ser. 2, vol. 2, p. 33, 1901.

carefully restudied the specimens, and, as I can find only dissepimental endo- and exotheca, they can not be identified as Duncan's *Astraea tenuis*. Because of silification and changes due to fossilization the columellar characters are obscured, but it is possible to recognize the presence of a lamellar columella. The species, therefore, is definitely *Antiguastrea cellulosa* (Duncan).

ANTIGUASTREA CELLULOSA var. CURVATA (Duncan)

Plate 98, figs. 4, 4*a*.

1863. *Astraea cellulosa* var. *curvata* Duncan, Geol. Soc. London Quart. Journ., vol. 19, p. 418.

Original description.—"Corallites slender, long, close, sometimes compressed; circular in transverse section, except when compressed. Walls thin and delicate. Costae delicate, unequal, narrow at the base, tapering externally. Septa well developed, in six systems of four complete cycles. The primary septa are large, toothed on either side, not larger at any one point than at another. The secondary septa are smaller than the primary, and have a tooth near the columella. The tertiary are smaller than the secondary, vary much in size, often extend nearly up to the columella, and curve there towards the latter; they have lateral teeth, and a larger tooth at the end; or they reach only halfway, being either straight or curved. The quaternary septa have wedge-shaped bases and spike-like prolongations, extend one-quarter the distance to the columella, and sometimes curve towards the tertiary. Columella lax and parietal. Endotheca greatly developed, subdividing the septal loculi by transverse bars. Exotheca distinct, cells small.

"*Dimensions.*—Diameter of the corallites one-fifth inch [5 mm.]; a bud 1 line [2 mm.] in diameter has three cycles.

"Chert-formation of Antugua. Coll. Geol. Soc. As a rule, this variety is curiously fossilized."

Plesiotype.—U.S.N.M. No. 324923 (pl. 98, fig. 4, 4*a*). This is actually more abundant in Antigua than the typical examples of the species. I doubt the presence of teeth on the primary and secondary septa. The appearance of their being present is probably due to changes resulting from fossilization.

ANTIGUASTREA CELLULOSA var. SILICENSIS, new variety.

Plate 101, figs. 1, 1*a*.

The two distinctive characters of this variety are, (1) the flat or domed upper surface; (2) the rather large calices, which are occasionally only 4 mm. in diameter, but usually 5 to 6.5 mm., sometimes the diameter may be as much as 11.5 mm. when the fifth cycle of septa is nearly complete.

Localities and geologic occurrence.—Basal part of the Chattahoochee formation, Blue Springs, Flint River, 4 miles below Bainbridge, and

Hales Landing, Flint River, about 7 miles below Bainbridge, Ga.; "silex" bed of the Tampa formation. Specimens obtained about three-quarters of a mile south of the Cathedral St. John, Antigua, and at station 6893, Crocus Bay, Anguilla, and one specimen from hill 4 miles south of San Rafael, Tamaulipas, Mexico, are referable to this variety.

Type.—No. 324936, U.S.N.M.

ANTIGUASTREA ELEGANS (Reuss) Vaughan.

Plate 102, figs. 1, 1*a*.

1874. *Isastraea elegans* Reuss, K. K. Akad. Wiss. Wien, Math.-Naturwiss. Cl., Denkschr., vol. 33, p. 36, pl. 53, figs. 3–5.

1915. *Isastraea elegans* Fabiani, R. Univ. Padova Inst. geolog. mem., vol. 3, p. 230.

Illustrations of and a few notes on this species are introduced for purposes of comparison with *Antiguastrea cellulosa.* The illustrations exhibit the calicular characters so well that a detailed description is not necessary. Specific distinction between it and *A. cellulosa* is exceedingly doubtful.

Localities and geologic occurrence.—Reuss originally described *Isastraea elegans* from Fontana della Bova di San Lorenzo, the locality at which the specimen here figured was obtained. Fabiani lists it as Rupelian Oligocene.

Plesiotype.—No. 156898, U.S.N.M.; specimen received in exchange from Prof. J. Felix of the University of Leipzig.

ANTIGUASTREA ALVEOLARIS (Catullo) Vaughan.

1856. *Astrea alveolaris* Catullo, Terr. sed. sup. Venezie, p. 54, pl. 11, fig. 1.

1874. *Phyllangia alveolaris* Reuss, K. K. Akad. Wiss. Wien, Math.-Naturwiss. Cl., Denkschr., vol. 33, p. 32, pl. 52, figs. 1*a*, 1*b*.

1868. *Phyllangia alveolaris* D'Achiardi, Stud. comparat. corall. terr. terz. Piemonte e Alpi Veneto, p. 20.

1915. *Phyllangia alveolaris* Fabiani, R. Univ. Padova Inst. geolog. mem., vol. 3, p. 231.

This coral is not a species of *Phyllangia*, the type-species of which is *Phyllangia americana* Milne Edwards and Haime,[1] from Florida and the West Indies. I dredged a particularly fine example of *P. americana* in water between 15 and 16 fathoms deep in Rebecca Channel, Florida, between Tortugas and Rebecca Light. The columella is composed of curled, flaky processes from the inner ends of the principal septa. The margins of the largest septa are faintly dentate, while on the septal faces there are small, sharp, distinct ridges with granulations along their courses.

Reuss's figures of an enlargement of the calices of *Phyllangia alveolaris* represent the columella as bluntly styliform. He says however, "Die rudimentäre Axe besteht nur aus 1–3 öfters etwas

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[1] Brit. foss. corals, Introduction, p. 44, 1850.

verlängerten Papillen." There are two specimens in the United States National Museum, as follows: (1) No. 156910 from Fontana della Bova di San Lorenzo, received from Prof. J. Felix; (2) No. 164726, from Monte Grumi, received from Professor Parona of the University of Turin. I believe there is no doubt as to the correctness of the identification of these specimens. The columella in both is lamellate; in No. 156918 a relatively thick, coarse lamella; in No. 164726 it is small and thinner but distinct. *Astrea alveolaris* Catullo, therefore, belongs to the genus *Antiguastrea*, and it closely resembles those variants of *A. cellulosa*, in which the calices are somewhat elevated and relatively remote one from another. Compare especially with the description of specimen No. 2 on page 405 of this paper.

Localities and geologic occurrence.—Catullo originally described the species from "Gambugliano nel Vicentino;" d'Achiardi records it from Dego, Torricelle, Castelgomberto, Monte Viale, Montecchio Maggiore, Crosara, and Veronese; Reuss cites it from Monte di Carlotta; the United States National Museum has it from Fontana della Bova di San Lorenzo and from Monte Grumi. Fabiani lists the species as of only Rupelian Oligocene age.

Genus STYLANGIA Reuss.

1874. *Stylangia* Reuss, K. K. Akad. Wiss. Wien, Math.-Naturwiss. Cl., Denkschr., vol. 33, p. 11.

Type-species.—*Stylangia elegans* Reuss (K. K. Akad. Wiss. Wien, Math-Naturwiss Cl., Denkschr., vol. 33, 1874, p. 11, pl. 42, figs. 1, 1*a*), from San Giovanni Ilarione. Horizon, Lutetian Eocene according to Fabiani.[1]

The species of coral next to be described does not precisely fit into any of the genera known to me. It has the general aspect of *Antiguastrea alveolaris* (Cat.) Vaughan, and as it has a compressed styloid or very narrow-lamellate columella, it appeared referable to *Antiguastrea*, but the columella is really more in the nature of a compressed style than a lamella. I should have no hesitancy in referring the species to *Stylangia*, if it were not for the very distinctly developed pali. However, as pali in this group of corals are usually not of generic value I am placing the species in *Stylangia*.

STYLANGIA PANAMENSIS, new species.

Plate 86, figs. 1, 1*a*.

The following is a description of the type, the only specimen of the species well enough preserved to show clearly the specific characters:

Corallum, a small mass, 29 mm. long and 26 mm. wide.

Corallites protuberant from 1.5 up to 3.5 mm., distance between the calicular margins from 2 to 4.5 mm. The diameter at the calice

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[1] R. Univ. Padova Inst. geolog. mem., vol. 3, p. 226, 1915.

of a corallite about 3 mm. tall is about 4 mm., at its base about 5 mm., showing that although the diameter at the base of the free corallite limbs is greater than it is at the calice, the increase in diameter toward the base is rather slight. The costae on the free limbs are low, subequal, closely crowded, between 40 and 48 in number, relatively thick, as thick as or thicker than the intercostal furrows, and closely beaded along the edges. The walls are thick.

Septa, 3 complete cycles and a variable number of quaternaries. The 6 primaries are larger than the other septa, extend to the columella, and bear paliform thickenings which are decidedly prominent in those calices where they have been preserved; the secondaries are somewhat shorter than the primaries; the tertiaries still shorter; and the quaternaries, which may be completely developed in some systems, are still smaller; in some systems in many calices the quaternaries are not distinguishable within the calices, but are represented by small costae.

Columella, a narrow, compressed style.

Endotheca and exotheca, details of their character not clear in the type.

Locality and geologic occurrence.—Canal Zone, station 6016, in the Emperador limestone, quarry, Empire, collected by T. W. Vaughan and D. F. MacDonald.

Type.—Cat. No. 324955, U.S.N.M.

Genus SEPTASTREA d'Orbigny.

1849. *Septastrea* D'Orbigny, Notes sur Polyp., p. 9.
1849. *Septastrea* Milne Edwards and Haime, Ann. Sci. nat., ser. 3, Zool., vol. 12, p. 163.
1857. *Septastraea* Milne Edwards and Haime, Hist. nat. Corall., vol. 2, p. 449.
18—. *Septastraea* (part) de Fromentel, Intr. Étude Polyp. foss., p. 174.
1884. *Septastraea* (part) Duncan, Linn. Soc. London Journ., Zoology, vol. 18, p. 103.
1887. *Glyphastraea* Duncan, Geol. Soc. London Quart. Journ., vol. 43, pp. 24–32, pls. 1–3.
1888. *Septastraea* Hinde, Geol. Soc. London Quart. Journ., vol. 44, pp. 200–227, pl. 9.
1900. *Septastraea* Gane, U. S. Nat. Mus., Proc. vol. 22, p. 194.
1904. *Septastrea* Vaughan, Maryland Geological Survey Miocene, p. 444.

Type-species.—*Septastrea subramosa* d'Orbigny, 1849 = *S. forbesi* Milne Edwards and Haime, 1849 = *Astrea marylandica* Conrad, 1841 = *Septastrea marylandica* (Conrad) Vaughan, 1904.

SEPTASTREA MATSONI, new species.

Plate 86, figs. 6, 6a.

Corallum incrusting surfaces of shells. The type incrusts part of the surface of a *Turritella* shell. It is probable that the fully grown corallum may be massive or ramose.

Calices irregular in form, subpolygonal or more or less elliptical in outline; slightly excavated. Diameter from 3 to 4.5 mm.; depth about 1 mm. Intervening walls narrow, acute.

Septa in two complete cycles. The primaries are rather thick and reach the calicular center; in fully developed calices all or nearly all of the secondaries also extend to the center, tertiary septa absent or very rudimentary. Margins not exsert; within the calices straight or slightly concave upward. There are no recognizable dentations. but on the septal edges and faces there are many rather large granulations. Interseptal loculi wide and open.

Columella false, formed by the fusion of the thickened inner ends of the principal septa. There are no trabecular septal processes.

Asexual reproduction by intercorallite budding.

Locality and geologic occurrence.—Republic of Colombia, station 7873, Gatun formation, about 0.5 km. west of Usiacuri, collected by G. C. Matson.

Type.—No. 324956, U.S.N.M.

Septastrea matsoni closely resembles young coralla of *S. marylandica* (Conrad) Vaughan, from the St. Marys and Yorktown formations in Virginia.[1] It is interesting to find in Colombia a species of *Septastrea* that is doubtfully distinguishable from a species in the Miocene of Virginia. The fossiliferous marl that almost surrounds Usiacuri appears to be the same formation as the Gatun formation, or to be a part of the Gatun formation. Although the evidence supplied by this coral is not great, it is at least indicative of the late Miocene age of a part if not all of the Gatun formation.

Family FAVIIDAE Gregory.

Genus FAVIA Oken.

1815. *Favia* Oken, Lehrb. Naturgesch., Th. 3, Abth. 1, p. 67.
1857. *Favia* Milne Edwards and Haime, Hist. nat. Corall, vol. 2, p. 426.
1902. *Favia* Verrill, Conn. Acad. Arts and Sci. Trans., vol. 11, p. 88.
1917. *Favia* Vaughan, Carnegie Inst. Washington Pub. 213, p. 100.

Type-species.—*Madrepora fragum* Esper.

FAVIA FRAGUM (Esper).

1795. *Madrepora fragum* Esper, Pflanzenth., Fortsetz., p. 79., pl. 64, figs. 1, 2.
1901. *Favia fragum* Vaughan, Geol. Reichs Mus. Leiden Samml., ser. 2, vol. 2, p. 34 (with synonomy).
1901. *Favia fragum* Vaughan, U. S. Fish Com. Bull. for 1900, vol. 2, p. 303, pl. 3.
1902. *Favia fragum* Verrill, Conn. Acad. Arts and Sci. Trans., vol. 11, p. 90, pl. 13, figs. 1, 2.
1915. *Favia fragum* Vaughan, Washington Acad. Sci. Journ., vol. 5, p. 596.
1916. *Favia fragum* Vaughan, Carnegie Inst. Washington Yearbook No. 14, pp. 224, 227.

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[1] See Vaughan, T. W., Anthozoa, Maryland Geol. Survey, Miocene, pp. 444-447, pl. 126, figs. 1*a*, 1*b*, 2; pl. 127, figs. 1-3; pl. 128, figs. 1, 2; pl. 129, 1904.

This species is common in Pleistocene deposits near Colon, Canal Zone.

Localities and geologic occurrence.—Canal Zone stations 5850 and 6037; Pleistocene, Mount Hope, collected by D. F. MacDonald. Throughout the West Indies, in Florida, and on the Atlantic side of Central America, where there are elevated Pleistocene reefs. Now living throughout the same area, in the Bermudas, the Azores (Quelch), and St. Vincent (collected by Mr. Cyril Crossland, specimens donated to the United States National Museum by Prof. J. Stanley Gardiner).

FAVIA MACDONALDI, new species.

Plate 102, fig. 2; plate 103, fig. 1.

Corallum massive, with a rounded upper surface (for general aspect of the upper surface (see pl. 102, fig. 2).

Calices large, oblong, elliptical or subquadrangular in outline; separated by intercorallite areas from 2 to 5 mm. across. Cavities slightly excavated. Walls thin on the upper edge, in places entirely composed of dissepiments; deeper down fairly thick.

Measurements, in millimeters, of calices of Favia macdonaldi.

Calice	1	2	3	4	5	6	7	8
Greater diameter	11.5	9.75	10.5	15.5	14.5	13	13.5	11
Lesser diameter	11.5	8.5	9.5	8	11.5	12	12	9

The number of septa in calice No. 4 of the table is about 38, of which 12 or 13 extend to the columella. A few rudimentary septa may have been broken so as not to be distinguishable now. In calice No. 5, 36 septa were counted, of which about 12 extend to the columella. On a polished cross section, in which every septum is clearly visible, there are 31 septa in a corallite having calicular diameters of 12.5 and 8.5 mm.; of the septa about 12 reach the columella—that is, usually every alternate or every third septum extends to the columella. In the calice the septa are thin and distant, but deeper down they are rather thick. The inner ends of the long septa are slightly thickened, suggesting that paliform lobes were present.

Costae correspond to all septa, greatly developed, long; those from one corallite extending to meet those from the adjacent corallite; members of the different cycles subequal in thickness; thicker in the wall, gradually thinning distally.

Columella composed of the fused inner ends of the septa; fairly well developed; some papillae on upper surface.

Thin endothecal and exothecal dissepiments well developed.

No clear instance of asexual reproduction was observed, but that it is by fission seems an inference warranted by the configuration of the corallites.

Locality and geologic occurrence.—Station 6587, in limestone and iron bearing sandstone, Tonosi, Panama, collected by D. F. Macdonald. This deposit is of Oligocene age (for fuller discussion, see pages 207, 555, 582). Station 6881, Antigua formation, Willoughby Bay, Antigua, collected by T. W. Vaughan.

Type.—Cat. No. 324993, U.S.N.M.

The only American fossil species at all nearly related to *Favia macdonaldi* is one from the Oligocene or Miocene of Santo Domingo, not yet described in print. It has smaller corallites and relatively more numerous septa than *F. macdonaldi.* These two species are Indo-Pacific in their affinities, there being no nearly related species in the Atlantic Ocean, with the possible exception of *F. leptophylla* Verrill, of which I have no specimen for comparison. It gives me pleasure to attach the name of Doctor Macdonald to this really handsome species of coral, which was discovered by him.

Genus FAVITES Link.

1807. *Favites* Link, Beschreib. Nat. Samml. Rostock, pt. 3, p. 162.
1901. *Favites* Vaughan, Geolog. Reichs Mus. Leiden Samml., ser. 2, vol. 2, p. 21.
1902. *Favites* Verrill, Conn. Acad. Arts and Sci. Trans., vol. 11, p. 92.
1917. *Favites* Vaughan, Carnegie Inst. Washington Pub. 213, p. 109.

Type-species.—*Madrepora abdita* Ellis and Solander.

FAVITES MEXICANA, new species.

Plate 103, figs. 2, 2*a*.

Corallum massive, with more or less rounded or flattish upper surface. Type a small broken specimen, 54 by 61 mm. in horizontal diameter and 27 mm. thick.

Corallites polygonal, separated by narrow intercorallite walls which are barely 0.5 mm. thick. Diameter of corallites as follows:

Diameter, in millimeters, of corallites of Favites mexicana.

Corallite	1	2	3	4	5	6	7	8
Greater diameter	9	11	8.5	8.5	9	7.5	11.5	9
Lesser diameter	7.5	7.5	8	7.5	7.5	6.5	9	8.5

Calices damaged so that their depth can not be definitely ascertained, but apparently they were shallow.

There are 46 septa in a corallite 7.5 by 6.5 mm. in diameter; of these, 14 reach the columella and 23 are small or rudimentary. Usually three sizes of septa are recognizable; the tertiaries fuse to the side of the secondaries, as a rule. Even the large septa are relatively thin, not so thick as the width of the interseptal loculi. The inner ends of the principal septa are somewhat thickened and paliform lobes may have been present.

Columella trabecular, false, fairly well developed.

Thin endothecal dissepiments abundant.

Asexual reproduction by marginal fission.

Locality and geologic occurrence.—Mexico, hill 4 miles east of San Rafael Ranch, State of Tamaulipas, collected by W. F. Cummins and J. M. Sands in the Oligocene San Rafael formation of Dumble,[1] in association with *Antiguastrea cellulosa* (Duncan) Vaughan.

Type.—Cat. No. 324995, U.S.N.M.

This specimen closely resembles *Astroria antiguensis* Duncan.[2] I have a photograph (see pl. 131, fig. 4) of Duncan's type (No. 12936, Coll. Geol. Soc. London), and because of the resemblance, I furnished Mr. Dumble the name *Goniastrea* (*?*) *antiguensis* (Duncan), as given in his papers cited. Subsequent study of the photograph and further comparisons with specimens from Antigua lead me to believe that *Astroria antiguensis* is in reality a fungid coral, and is probably based on a silicified specimen of *Cyathomorpha antiguensis* (Duncan) Vaughan in which the corallites are deformed by crowding. That adjacent corallites are separated by costate intercorallites areas is clear on most of this photograph; and apparently there are both intercostal and mural synapticulae. For additional notes on *Astroria antiguensis* see page 466 of this paper.

FAVITES POLYGONALIS (Duncan).

1863. *Astroria polygonalis* DUNCAN, Geol. Soc. London Quart. Journ., vol. 19, p. 424, pl. 14, fig. 6, 1863.

Besides *F. mexicana*, the only other definitely known species of *Favites* in the American older Tertiary formations is *F. polygonalis* (Duncan) Vaughan, which is very abundant in Antigua. The calices of *F. polygonalis* are much larger than in *F. mexicana*, the smallest size usually being 15 mm., rarely as little as 14 mm. in diameter; range in diameter from the size just stated up to 23 mm. wide by 35 mm. long, an extraordinarily large calice. The lesser diameter of a calice is usually between 15 and 20 mm. The calices are excavated, depth 8 to 10 mm., separated by acute walls. Septa in 4 or 5 sizes, thin, rather distant, about 8 within 1 cm. In many specimens there is a more or less flattened zone around the columellar fossa, which is bounded by the rather steep inner ends of the septa. In *F. mexicana*, 9 septa were counted within a linear distance of 5 mm., being twice as many within the same distance as there are in *F. polygonalis*. Cooke and Mansfield collected in the base of the Chattahoochee formation, station 7078, 8 miles below Bainbridge, Georgia, a species of *Favites* that seems to be the same as the Antiguan specimens of *F. polygonalis* with small calices.

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[1] See p. 206 for additional notes.

[2] Geol. Soc. London Quart. Journ., vol. 19, p. 425, 1863.

Genus GONIASTREA Milne Edwards and Haime.

1848. *Goniastrea* MILNE EDWARDS and HAIME, Comptes Rend., vol. 27, p. 495.

Type-species.—Astrea retiformis Lamarck.

GONIASTREA CANALIS, new species.

Plate 91, fig. 4.

Corallum massive, rounded or flattened on the upper surface, forms masses 15 cm. or more in diameter.

Calices joined directly by their walls, shallow, polygonal deformed; lesser diameter of adult calices about 3.5 mm., greater diameter from 3.5 mm. up to 5.5 mm.

Septa about 42, in a calice 3.5 mm. wide by 4 mm. long; of these 11 extend to the columella, and there are about 21 small (rather rudimentary) septa. The inner ends of the smallest septa are usually free; but the septa of the intermediate size fuse to the sides of the members of lower cycles, and in places a small septum fuses to the side of a member of a lower cycle. As is normally the case in corals reproducing by fission, the septal arrangement is not definite. About 10 septa, alternately larger and smaller, were counted in a space of 2.25 mm. along the wall. At the wall the interseptal spaces are about as wide as the thickness of the larger septa. Septal faces with some granulations. Septal margins too badly damaged to permit a study of their characters.

Columella false, fairly well developed, formed by the fusion of the inner end of the long septa.

Asexual reproduction by fission, either equal or unequal, equal fission seems more common.

Locality and geologic occurrence.—Canal Zone, station 6016, quarry, Empire, in the Emperador limestone collected by T. W. Vaughan and D. F. MacDonald.

Type.—No. 324996 U.S.N.M.

Of the species of *Goniastrea* previously described from the American Tertiaries, *G. variabilis* Duncan[1] from the upper Eocene St. Bartholomew limestone, French West Indies, has larger calices, about 5 mm. wide, and as it has about 40 septa to a calice, the septa in it are less crowded than in *G. canalis*. I collected in the Oligocene of Antigua, in the Antigua formation, a species of *Goniastrea*, that is evidently the same as *Stephanocoenia reussi* Duncan.[2] This differs from *G. canalis* only by the absence of rudimentary septa between the larger septa. The two forms, although closely related, seem to represent distinct species.

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[1] Geol. Soc. London Quart. Journ., vol. 29, p. 557, pl. 21, fig. 11, 1873.

[2] Idem, vol. 24, p. 19, pl. 2, fig. 1, 1867. I have excellent photographs of Duncan's type, which is No. 5011, Brit. Mus. Nat. Hist.

Genus MAEANDRA Oken.

1815. *Maeandra* Oken (part), Lehrb. Naturg., Th. 3, Abth. 1, p. 70.
1902. *Maeandra* Verrill, Conn. Acad. Arts and Sci. Trans., vol. 11, p. 66.
1917. *Maeandra* Vaughan, Carnegie Inst. Washington Pub. 213, p. 119.

Type-species.—*Madrepora labyrinthiformis* Linnaeus.

MAEANDRA ANTIGUENSIS, new species.

Plate 103, figs. 3, 4, 4*a*.

The general habit of the corallum is similar to that of *Maeandra clivosa* (Ellis and Solander), that is, the upper surface is more or less lobulate, not rather uniformly rounded or domed as *M. strigosa* (Dana). A view of the upper surface of each cotype is shown on plate 103, figures 3, 4. Valleys sinuous, relatively long, as much as or more than 26 mm. in length; width from 3.5 to 5.5 mm., about 4.25 mm. usual; depth about 2 mm. Collines with narrow, acute or subacute summits, the septa sloping away at an angle of about 45°. Adjacent valleys are usually separated by simple walls; in places separate mural edges are distinguishable, but in such instances the distance between the walls is less than 0.5 mm.

Septa decidedly crowded, 8 or 9 long septa and as many intermediate short septa within 5 mm., that is, from 32 to 36 septa, alternately short and long, within 1 cm. The long septa extends to edge of the columellar fossa; the intermediate septa are about half as long. Septal margins finely dentate, about 10 small teeth on the long septa; slope downward and inward at an angle of about 45°, as previously stated. Inner ends of long septa more or less thickened, some appear to bear paliform lobes, fused by lateral expansions and processes at the edge of the columellar fossa.

Columella composed of axial septal processes, which are usually more or less flattened and curled. Calicinal centers indistinct.

Thin, crowded, endothecal dissepiments abundant.

Localities and geologic occurrence.—Antigua, station 6881, Antigua formation, Willoughby Bay, cotypes, 2 specimens, collected by T. W. Vaughan.

Panama, station 6587, Tonosi, a broken specimen, collected by D. F. MacDonald.

Cotypes.—No. 325003, U.S.N.M.

Maeandra antiguensis is very close to *M. clivosa.* The principal differences seem to be the steeper margins and the thicker intercorallite walls, and the slightly wider and deeper valleys of *M. clivosa.* The cotypes of *M. antiguensis* were compared with 33 small specimens of *M. clivosa* and the differential characters indicated appear valid.

The specimen obtained by Doctor MacDonald is only a fragment, but as the cross-section of the corallites and walls and the septal characters agree with *M. antiguensis*, there is no reasonable doubt as to its belonging to that species.

MAEANDRA PORTORICENSIS, new species.

Plate 107, figs. 1, 1*a*.

Corallum massive, composed of long valleys, from 5.5 to 9 mm. wide, and about 3.5 mm. deep, separated by acute collines. Walls in the collines, rather thick but simple.

Septa, rather thick, crowded, about 10 in 5 mm., or 20 to the centimeter. As a rule alternately shorter and longer, but in some places they are equal. At the wall usually equal in thickness. The inner ends of some septa are enlarged, and there are indications that such septa bear upright paliform teeth. Margins dentate. Calicinal centers indistinct.

Columella absent.

Locality and geologic occurrence.—Four miles west of Lares, Porto Rico, Pepino formation, collected by R. T. Hill.

Type.—No. 325004, U.S.N.M.

Remarks.—*Maeandra portoricensis* is very close to an undescribed species from the St. Bartholomew Eocene, to which Duncan erroneously applied the name *Manicina areolata* (Linnaeus). The difference seems to lie in the former having straighter valleys (a character of very little value), and thicker septa and walls.

MAEANDRA DUMBLEI, new species.

Plate 104, figs. 1, 1*a*.

Corallum massive, upper surface gradually curved, without gibbosities. The type, a segment of a head, is 63 mm. long, 57 mm. wide, and 45 mm. thick.

Valleys straight or curved; length from 5 mm., the diameter of a solitary calice, up to 30 mm. or even more; width from 3 to 5 mm.; depth 1.5 mm. or less, the valleys are very shallow, almost superficial Collines flat or furrowed along the top; width from 1.5 to 2.5 mm. Each of two adjacent series usually with its own separate wall, the walls separated on top by a slight depression which is crossed by costae. The colline characters are those characteristic of *Diploria*, which is typical *Maeandra*.

Septa rather distant, 9 within 5 mm. or 18 to 1 cm.; subequal or alternately longer and shorter, the shorter usually almost reaching the columella; no rudimentary septa except in young calices; outer septal ends thick. Septal margins broken in the type, but the trabeculae indicate fairly large dentations, about 5 on a long septum outside the distinct, thickened, palar lobe.

Columella composed of septal processes, only slightly developed. Calicinal centers distinct or obscure.

Locality and geologic occurrence.—Mexico, hill one mile east of San Jose de las Rusias ranch, State of Tamaulipas, collected by W. F. Cummins and J. M. Sands, in the Oligocene formation to which Mr. E. T. Dumble[1] applied the name "San Fernando beds," later changed to San Rafael beds. *Antiguastrea cellulosa* (Duncan) Vaughan was also collected at this locality.

Type.—No. 325005, U.S.N.M., presented by Mr. E. T. Dumble.

This species groups with the living West Indian *Maeandra labyrinthiformis* (Linnaeus), the genotype, which has far more crowded septa, and with *M. bowersi* Vaughan, from Carrizo Creek, California, which has wider intercorallite areas, deeper valleys, and fewer long septa to the centimeter.

MAEANDRA AREOLATA (Linnaeus).

1758. *Madrepora areolata* LINNAEUS, Syst. Nat., ed. 10, p. 795.
1901. *Manicina areolata* VAUGHAN, U. S. Fish Com. Bull. for 1900, vol. 2, p. 305, pl. 4, figs. 2, 3.
1902. *Maeandra areolata* VERRILL, Conn. Acad. Arts and Sci. Trans., vol. 11, p. 81, pl. 11, figs. 1, 2; pl. 12, figs, 1, 2, 3.
1915. *Maeandra areolata* VAUGHAN, Washington Acad. Sci. Journ., vol. 5, p. 596.
1916. *Maeandra areolata* VAUGHAN, Carnegie Inst. Washington Yearbook No. 14, pp. 225, 227.

Common in the Pleistocene marl of Mount Hope near Colon, Canal Zone.

Locality and geologic occurrence.—Canal Zone, stations 5850 and 6039, Mount Hope, collected by D. F. MacDonald.

This species is a common fossil in the Pleistocene coralliferous deposits and in areas of living reefs in the Caribbean region and Florida. *M. areolata* is not a true reef coral. It thrives best on the flats behind the reefs or in water 10 to 12 fathoms deep off the reefs proper. As it has no firm basal attachment, it can not resist the impact of the waves of rough seas.

MAEANDRA CLIVOSA (Ellis and Solander).

1786. *Madrepora clivosa* ELLIS and SOLANDER, Nat. Hist. Zooph., p. 163.
1901. *Platygyra clivosa* VAUGHAN, Geolog. Reichs. Mus. Leiden Samml., ser. 2, vol. 2, p. 57. (With synonymy.)
1902. *Maeandra clivosa* VERRILL, Conn. Acad. Arts and Sci. Trans., vol. 11, p. 78.
1902. *Maeandra agassizi* VERRILL, Conn. Acad. Arts and Sci. Trans., vol. 11, p. 80, pl. 14, figs. 1, 1*a*.
1915. *Maeandra clivosa* VAUGHAN, Washington Acad. Sci. Journ., vol. 5, pp. 596, 597.
1916. *Maeandra clivosa* VAUGHAN, Carnegie Inst. Washington Yearbook No. 14, p. 227.

Locality and geologic occurrence.—Costa Rica, station 6251, Monkey Point, in a slightly elevated Pleistocene reef, collected by D. F. Mac-

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[1] Dumble, E. T., Some events in the Eogene history of the present coastal area of the Gulf of Mexico in Texas and Mexico, Journ. Geol., vol. 23, pp. 481, 498, 1915 (see pp. 495–496); Tertiary deposits of northeastern Mexico, Calif. Acad. Sci. Proc., vol. 5, pp. 163–193, pls. 16–19, Dec., 1915 (see pp. 189–190).

Donald. This species is general in the elevated Pleistocene reefs and in the areas of living reefs in the Caribbean region and in Florida. It is one of the most abundant species on the living Bahamian reefs, but appears not to occur in the Bermudas.

MAEANDRA STRIGOSA (Dana).

1846. *Meandrina strigosa* DANA, U. S. Expl. Exped. Zooph., p. 257, pl. 14, figs. 4*a*, 4*b*.
1901. *Platygyra viridis* VAUGHAN, Geolog. Reichs. Mus. Leiden, ser. 2, vol. 2, p. 51. (With synonymy.)
1901. *Platygyra viridis* VAUGHAN, U. S. Fish Com. Bull. for 1900, vol. 2, p. 306, pls. 9, 10, 11, 12, 13.
1902. *Maeandra cerebrum* VERRILL, Conn. Acad. Arts and Sci. Trans., vol. 11, p. 74, pl. 10, fig. 4; pl. 12, fig. 4; pl. 14, figs. 4, 5.
1902. *Maeandra viridis* VAUGHAN, Biol. Soc. Washington Proc., vol. 15, p. 55.
1907. *Maeandra cerebrum* VERRILL, Conn. Acad. Arts and Sci. Trans., vol. 12, p. 169.
1915. *Maeandra strigosa* VAUGHAN, Washington Acad. Sci. Journ., vol. 5, p. 596.
1917. *Maeandra strigosa* VAUGHAN, Carnegie Inst. Washington Yearbook No. 14, p. 227.

I can not at all agree with Professor Verrill's application of Ellis and Solander's name "*cerebrum*" to this species. There are three large, massive species of *Maeandra* in the West Indies and Florida, namely, *M. labyrinthiformis* (Linnaeus), *M. clivosa* (Ellis and Solander), and *M. strigosa* (Dana). I applied to *M. strigosa* a varietal name proposed by Le Sueur, but Professor Verrill expressed doubt as to Le Sueur's having meant the species under consideration. There is good evidence that Ellis and Solander did not intend *Madrepora cerebrum* for this species, for they applied the name *Madrepora labyrinthica* to it and figured it. As they applied names to two of the identifiable species, it is probable that they intended *Madrepora cerebrum* for the third species, that is, for *Madrepora labyrinthiformis*, of which *Diploria cerebriformis* (Lamarck) M. Edwards and Haime is a synonym.

Under these circumstances, the proper course to pursue evidently is to take the first name concerning which there is no doubt. Choice then fall on *Meandrina strigosa* Dana, the type of which is in the United States National Museum.

Locality and geologic occurrence.—Costa Rica, station 6251, Monkey Point, in the slightly elevated Pleistocene reef, collected by D. F. MacDonald. This species is general in the Pleistocene and living coral reefs of the Caribbean region, Florida, and the Bahamas, and is found living in the Bermudas. It is one of the two most important massive reef-building species in Florida and the West Indies; the other of the most important species is *Orbicella annularis* (Ellis and Solander).

Genus LEPTORIA Milne Edwards and Haime.

1848. *Leptoria* Milne Edwards and Haime, Comptes Rend., vol. 27, p. 493.
1917. *Leptoria* Vaughan, Carnegie Inst. Washington Pub. 213, p. 117.

Type-species.—Meandrina phrygia Lamarck = *Madrepora phrygia* Ellis and Solander.

LEPTORIA SPENCERI, new species.

Plate 109, figs. 2, 2*a*, 3.

1863. *Maeandrina* species Duncan, Geol. Soc. London Quart. Journ., vol. 19, p. 424.

Corallum more or less explanate, with a flatish, undulate upper surface.

Valleys long and sinuous, shallow, from 3.25 to 5 mm. wide, separated by narrow, but strong colline walls.

There are 8 or 9 long septa within 5 mm., 18 to 19 within 1 cm. These are rather stout and extend from the wall to the columellar fossa; somewhat thickened in the wall and on their inner ends, where there appear to be paliform knots or lobes. Usually between each pair of larger septa is a very thin septum, which is either short or long.

The columella is stout and lamelliform.

Locality and geologic occurrence.—Cuba, station 3473, Rio Canapu, crossing of Manassas trail, Oriente Province, Cuba, collected by Dr. Arthur C. Spencer, for whom the species is named. *Cyathomorpha tenuis* (Duncan) was obtained at the same place. The geologic horizon, therefore, seems to be that of the Antigua formation of Antigua; but Dr. J. A. Cushman reports *Orthophragmina* from the same station, and suggests that the formation exposed there is of upper Eocene age.

The specimen from Antigua referred to by Duncan as "*Maeandrina* sp." seems to belong to *L. spenceri*, according to two photographs I have of Duncan's original specimen, No. 12946, coll. Geol. Soc. London. Duncan's specimen has a distinctly lamellate columella.

Type.—No. 324968*a*, U.S.N.M. (pl. 109, figs. 2, 2*a*).

Paratype.—No. 324968*b*, U.S.N.M. (pl. 109, fig. 3).

There is no other known species from the West Indies to which *L. spenceri* is nearly related. It has closer affinities with the Indo-Pacific species *L. phrygia* and *L. gracilis*. *L. spenceri* has about the same number of septa to the centimeter as *Maeandra antiguensis*, but it differs from *M. antiguensis* in having shallower valleys, stouter interserial walls, and its columella is distinctly lamelliform.

Genus MANICINA Ehrenberg.

1834. *Manicina* Ehrenberg, Corallenth. Roth. Meer., p. 101 (of reprint).
1848. *Colpophyllia* Milne Edwards and Haime, Comptes Rend., vol. 27, p. 492.
1902. *Manicina* Verrill, Conn. Acad. Arts and Sci. Trans., vol. 11, p. 84.

Type-species.—Madrepora gyrosa Ellis and Solander.

MANICINA GYROSA (Ellis and Solander).

1786. *Madrepora gyrosa* Ellis and Solander, Nat. Hist. Zooph., p. 163, pl. 51, figs. 1, 2.
1901. *Colpophyllia gyrosa* Vaughan, Geolog. Reichs-Mus. Leiden, ser. 2, vol. 2, p. 41 (With synonymy, except *Mussa fragilis* Dana).
1902. *Manicina gyrosa* Verrill, Conn. Acad. Arts and Sci. Trans., vol. 11, p. 85.
1915. *Manicina gyrosa* Vaughan, Washington Acad. Sci. Journ., vol. 5, p. 596.
1916. *Manicina gyrosa* Vaughan, Carnegie Inst. Washington Year Book, No. 14 p. 227.

Locality and geologic occurrence.—Canal Zone, station 5850, Pleistocene, Mount Hope, collected by D. F. MacDonald.

Costa Rica, station 5884*b*, probably Pleistocene, Moin Hill, collected by D. F. MacDonald.

This species is general in the elevated Pleistocene and on the living coral reefs of the Caribbean area and in Florida. Usually specimens are not abundant, but can nearly always be found in both the Pleistocene and living reefs.

There is in the Antigua formation of Antigua a very handsome species of *Manicina*, which is of interest in showing the presence of the genus in American Tertiary deposits of middle Oligocene age.

MANICINA WILLOUGHBIENSIS, new species.

Plate 104, figs. 2, 2*a*; plate 105.

Corallum attached by a more or less centrally placed basal peduncle, from which the lower surface slopes upward and outward, upper surface curved or flattish. Common wall thrown into rounded corrugations, which are narrow at the lower end, but widen with outward growth until they may be 15 mm. across, height as much as 7 mm. Besides the corrugations, the lower surface is costate; large, low rounded costae about 1 mm. apart, with an intermediate smaller costa between each pair of larger. There is no vestige of epitheca. (There are only occasional shreds of epitheca on the lower surface of *M. gyrosa*.)

Valleys long and sinuous; from 7 to 16 mm. wide, between 10 and 11 mm. usual; depth 8 to 10 mm. Colline submits narrow, usually from 1 to 1.5 mm. wide, but the walls of adjacent series are nearly always distinct, being separated by a narrow furrow, against the sides of which the outer ends of the septa terminate.

Septa from 19 to 22 to 1 cm., one-half of which are small and rudimentary; the larger septa are thin and are arranged in 2, 3, or 4 sizes. Near the top of the wall all septa are narrow and steep through a distance of about 3 mm., below which the larger septa widen by a slope of about 45°; their inner edges fall steeply, in places perpendicularly, to the bottom of the axial furrow. There are no definitely developed paliform lobes, but in places the septal margins rise upward just outside the steep fall into the axial fossa. Dentations on the septal margins small and serrate, not prominant. Septal faces with small granulations.

Columella very poorly developed or absent; calicinal centers as a rule fairly distinct, range from 9 to 21 mm. apart.

Thin endothecal dissepiments well developed.

Locality and geologic occurrence.—Antigua, station 6881, Willoughby Bay, (cotypes), and at other localities in the Antigua formation, Antigua, collected by T. W. Vaughan,

Type.—No. 325006*a*, U.S.N.M.

Paratype.—Cat. No. 325006*b*, U.S.N.M.

This species is closely related to the living *Manicina gyrosa* of the Caribbean and Floridian regions. It has narrower collines, because the septa are narrow in their upper part; it has much more numerous septa; and the septa of *M. gyrosa* have far more exsert-margins.

The only European species, known to me, with which comparison will be made is *Diploria intermedia* Michellotti from the Oligocene of Sassello, Liguria (specimen so labelled, received from the Museum of Natural History at Turin, No. 156300, U.S.N.M.). This specimen, although it has the aspect of *Diploria* (precise synonym of typical *Maeandra*), is in my opinion really a species of *Manicina*, for the lower surface is corrugate and there is no epitheca, while there is a complete, concentrically striate epitheca on the base *Maeandra* ("*Diploria*") *labyrinthiformis*. The costae on the base of *Diploria intermedia* are similar to those of *Manicina*. Besides the characters already mentioned, the calicinal centers in *D. intermedia* are more distinct than in the type-species of *Diploria*. I will therefore designate Michelotti's species *Manicina intermedia* (Michellotti). This species has narrower (3.5 to 7 mm. wide), shallower (2.5 to 3 mm. deep), valleys, and thicker septa than *M. willoughbiensis*, and there are distinct, thickish paliform lobes on many long septa. Although the two species are distinct, the genus to which they belong was coincident in the Oligocene of southern Europe and of the West Indies. D'Achiardi has described two species of this genus as *Colpophyllia taramellii* and *C. flexuosa* from the Eocene of Friuli.

Genus THYSANUS Duncan.

1863. *Thysanus* DUNCAN, Geol. Soc. London Quart. Journ., vol. 19, pp. 430, 439, pl. 15, figs. 3*a*, 3*b*, pl. 16, figs. 6*a*, 6*b*.

1863. *Teleiophyllia* DUNCAN, Geol. Soc. London Quart. Journ., vol. 20, p. 34.

1864. *Thysanus* DUNCAN, Geol. Soc. London Quart. Journ., vol. 21, p. 10.

1884. *Thysanus* DUNCAN, Linn. Soc. London Journ. (Zoology), vol. 18. p. 15.

1884. *Teleiophyllia* DUNCAN, Linn. Soc. London Journ. (Zoology), vol. 18, p. 85.

Type-species.—Thysanus excentricus Duncan (Geol. Soc. London Quart. Journ., vol. 19, p. 439, pl. 16, figs. 6*a*, 6*b*).

Duncan included two species in this genus at the time he described it, designating neither one as the type. *Thysanus corbicula* occurs first in the paper, but as specimens of it are not accessible for study, I have selected as the genotype the second species, *Thysanus excentricus*, of which I have seen nearly 700 specimens.

THYSANUS aff. T. EXCENTRICUS Duncan.

1863. *Thysanus excentricus* DUNCAN, Geol. Soc. London Quart. Journ., vol. 19, p. 439, pl. 16, figs. 3*a*, 3*c*.

Apparently the tall variant of *T. excentricus* is represented by casts in material from Cuba.

Locality and geologic occurrence.—Cuba, station 3439, in the La Cruz marl, first railroad cutting east of La Cruz, near Santiago, collected by T. W. Vaughan.

THYSANUS HAYESI, new species.

Plate 77, figs. 3, 3*a*, 3*b*.

The type is much damaged, but the three views on plate 77, figures 3, 3*a*, 3*b*, give an idea of its form. The corallum, which was about 21 mm. long, 12 mm. tall, and 13 mm. in maximum diameter, is relatively wide, and is unilateral.

The costae are decidedly prominent, 1 mm. or more tall at the mural edge, and are distant, about 2 mm. between the summits of adjacent costae. Their edges are coarsely and irregularly dentate, the dentations compressed transversely to the septal planes, and secondarily spinulose. Toward the base of the corallum the costae become less prominent and are obsolete on the base. There are no distinct secondary costae.

Nearly all of the septa extend to the columella, they are distant and rather thin; intermediate small septa are rare. Margins dentate. Faces with sharp ridges and coarse granulations.

Columella trabecular and obscurely lamellate.

Endothecal dissepiments abundant, thin.

Locality and geologic occurrence.—Cuba, station 3461, Gorge of Yumuri River, Matanzas, lower Miocene, collected by T. W. Vaughan.

Type.—No. 324994, U.S.N.M.

This species, which I am naming for Dr. C. W. Hayes, is most nearly related to *Thysanus corbicula* Duncan, but differs in its more distant, more prominent, and coarser costae.

Family MUSSIDAE Verrill.

Genus SYZYGOPHYLLIA Reuss.

1860. *Syzygophyllia* REUSS, K. K. Akad. Wiss. Wien, Mat., Natur. Cl., Sitzungber, vol. 39, p. 216, pl. 1, figs. 10–12; pl. 2, fig. 10.

Type-species.—Syzygophyllia brevis Reuss.

SYZYGOPHYLLIA HAYESI, new species.

Plate 106, figs. 1, 1*a*, 1*b*.

Corallum compressed-turbinate in form. Greater diameter 75 mm.; lesser diameter 59 mm.; height 40 mm. +. The tip of the base and the upper part of the calice of the type are broken. Wall strong, moderately thick; with coarsely dentate costae just below the calicular edge, lower down covered by thick, finely wrinkled epitheca.

The number of septa could not be counted with certainty, there are about 200, or approximately 6 cycles. The primaries, secondaries, and tertiaries extend to the columella and are very thick, 1 mm. usual and 2 mm. occasional. The quaternaries are shorter and thinner; and the members of the fifth and sixth cycles shorter and thinner than the quaternaries according to cycle. The very thick principal septa with shorter and thinner intermediate septa constitute one of the most striking characteristics of the species. The septal margins are broken but their character can be inferred from the plan of the broken cross section. There are alternate swollen and thinner areas, showing that the septa are composed of compound trabeculae, and had coarsely dentate margins. The bases of some of the teeth were probably as much as 3 mm. in width, but a more usual width was probably between 2 and 2.5 mm.

The columella is relatively small, it appears to be entirely composed of the fused inner ends of the septa.

Locality and geologic occurrence.—Nicaragua, Brito formation (upper Eocene), on or near the Pacific coast; collected by C. W. Hayes, for whom the species is named.

Type.—No. 325009, U.S.N.M.

Two other species of *Syzygophyllia* are known from middle America, *Syzygophyllia gregorii* (Vaughan) and *S. dentata* (Duncan). *S. gregorii* was first described from the Bowden marl of Bowden, Jamaica, but also occurs in beds of equivalent age in Santo Domingo. *S. dentata*, which was described from the Nivajè shale of Santo Domingo, occurs stratigraphically above *S. gregorii*, but in deposits paleontologically closely related to the Bowden marl. Of the two species *S. hayesi* is more like *S. gregorii*, but its principal septa are thicker and its columella is less developed. Probably the most nearly related species is one collected in the Eocene St. Bartholomew limestone by Prof. P. T. Cleve, but the specimen that I have seen of this is not good enough for positive identification.

MADREPORARIA FUNGIDA.

Family AGARICIIDAE Verrill.

Genus TROCHOSERIS Milne Edwards and Haime.

1849. *Trochoseris* Milne Edwards and Haime, Comptes Rend., vol. 29, p. 72.
1905. *Trochoseris* Vaughan, U. S. Nat. Mus. Proc., vol. 28, p. 384.

Type-species.—*Anthophyllum distortum* Michelin.

The columella in the type-species is very small, false, and more or less papillary.

TROCHOSERIS MEINZERI, new species.

Plate 106, figs. 2, 2*a*, 2*b*.

Corallum trochoid, attached by a basal peduncle. Greater diameter of calice, 59.5 mm.; lesser diameter, 41 mm.; height, 38.5 mm.; wall solid, finely and closely costate; costae low, equal or alternating in size, about 13 in 5 mm. or 26 in 10 mm. Calice, flaring, shallow, slightly excavated.

Septa very numerous and crowded, about 16 in 5 mm., 32 in 10 mm; at the calicular edge, thicker than the width of the interseptal spaces. Of the septa about every eighth seems to extend to the axial fossa, and 35 were counted around the fossa, but the number of septa probably exceeds 280. The margins are obscurely, very finely, dentate, subentire. Synapticulae small, numerous, crowded.

Columella very small, 2 mm. in diameter, in a small fossa; a few papillae are recognizable.

Locality and geologic occurrence.—Cuba, station 7522, Mogote Peak, 0.5 mile east of east boundary of United States Naval Reservation, Guantanamo, south side of peak, altitude about 375 feet a. t., collected by O. E. Meinzer (type).

Panama, station 6587, Tonosi, collected by D. F. MacDonald.

Type.—No. 325228, U.S.N.M.

The only other species of *Trochoseris* described from the American Tertiary formations is *T. catadupensis* Vaughan [1] from the Eocene at Catadupa, Jamaica. This is a much smaller species than *T. meinzeri* and does not appear closely related.

The specimen obtained by Doctor MacDonald at Tonosi, Panama, is broken and poor, but the identification of it with the Cuban specimen seems certain.

Genus AGARICIA Lamarck.

1801. *Agaricia* Lamarck, Syst. Anim. sans Vert., p. 373.
1905. *Agaricia* Vaughan, Science, n. s., vol. 21, p. 984.
1917. *Agaricia* Vaughan, Carnegie Inst. Washington Pub. 213, p. 140.

Type-species.—*Madrepora undata* Ellis and Solander.

AGARICIA AGARICITES (Linnaeus).

1758. *Madrepora agaricites* Linnaeus, Syst. Nat., ed. 10, p. 795.
1901. *Agaricia agaricites* Vaughan, Geol. Reichs. Mus. Leiden Samml., ser. 2 vol. 2, p. 64.
1902. *Agaricia agarcites* Verrill, Conn. Acad. Arts and Sci. Trans., vol. 11, p. 146, pl. 26, figs. 2, 3; pl. 27, figs. 1, 2, 2*a*, 3, 3*a*, 5, 6, 6*a*, 7, 7*a*.
1915. *Agaricia agaricites* Vaughan, Washington Acad. Sci. Journ., vol. 5, p. 596.
1916. *Agaricia agaricites* Vaughan, Carnegie Inst. Washington Yearbook No. 14, p. 228.

Locality and geologic occurrence.—Canal Zone, station 6039, Pleistocene, Mount Hope, collected by D. F. MacDonald, abundant.

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[1] Mus. Comp. Zool. Bull., vol. 34, p. 242, pl. 39, figs. 5, 6, 1899.

This species in its typical form is generally present on the living West Indian and Floridian reefs, and is usual in the Pleistocene reefs of the same region.

AGARICIA AGARICITES var. PURPUREA Le Sueur.

1820. *Agaricia purpurea* LE SUEUR, Mus. Hist. nat. Paris Mém., vol. 6, p. 276, pl. 15, figs. 3a, 3*b*, 3*c*.
1902. *Agaricia purpurea* VERRILL, Conn. Acad. Arts and Sci. Trans., vol. 11, p. 149, pl. 27, figs. 4, 4*a*, 4*b*.
1902. *Agaricia agaricites* var. *gibbosa* VERRILL, Conn. Acad. Arts and Sci. Trans., vol. 11, p. 148, pl. 27, figs. 1, 1*a*.
1912. *Agaricia crassa* VAUGHAN, Carnegie Inst. Washington Yearbook, No. 10, p. 153.
1912. *Agaricia fragilis* var. VAUGHAN, Carnegie Inst. Washington Yearbook No. 10, pp. 153–154.
1915. *Agaricia purpurea* VAUGHAN, Washington Acad. Sci. Journ., vol. 5, p. 596.
1915. *Agaricia purpurea* VAUGHAN, Carnegie Inst. Washington Yearbook, No. 14, p. 228.

Locality and geologic occurrence.—Canal Zone, station Nos. 5849 and 6039 Pleistocene, Mount Hope, collected by D. F. MacDonald, abundant. This variety is widespread on the living reefs in the West Indies and Florida.

Agaricia agaricites var. *purpurea* is one of the corals on which I made many experiments at Tortugas, Florida. The following is an account of one experiment:[1]

> The result of one experiment with *Agaricia* gave unexpectedly important information on the influence of environment on variation. On the piers of the Fort Jefferson dock a thin, unifacial, subcircular, or reniform *Agaricia*, attached by the center of the lower surfaces, is rather abundant. This seems to be a variety of *Agaricia fragilis* (Dana). On the reefs off Loggerhead Key an *Agaricia* of massive form, several inches in diameter and of somewhat less height, is abundant. This appears to be the same as *Agaricia crassa* Verrill. One specimen of the thin *Agaricia fragilis* form attached to a tile in June, 1910, had by June, 1911, assumed the *Agaricia crassa* growth-form. This specimen was attached by its entire lower surface and seems to have had its growth-form influenced by the wide basal attachment. It is evident that there is here one species of *Agaricia* that under different conditions assumes different growth-forms. In very quiet water it is thin, orbicular, or reniform, with a slight basal attachment at its center, while on the reefs it is more strongly attached and has a more massive growth-form. But, in the quiet waters, the massive growth-form may be produced by giving the normally thin form a wide base of attachment, or there is a reaction to contact. On the reefs, when the water is strongly agitated, there is probably a clinging of the peripheral polyps to the basal support; this causes the basal attachment to cover a larger area than in the more quiet waters; then upward growth from this wide base would produce the massive form.

AGARICIA AGARICITES var. CRASSA Verrill.

1902. *Agaricia crassa* VERRILL, Conn. Acad. Arts and Sci. Trans., vol. 11, p. 145, pl. 30, fig. 6; pl. 34, fig. 2.
1915. *Agaricia crassa* VAUGHAN, Washington Acad. Sci. Journ., vol. 5. p. 596.
1916. *Agaricia crassa* VAUGHAN, Carnegie Inst. Washington Yearbook, No. 14, p. 228.

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[1] Carnegie Inst. Washington Yearbook No. 10, pp. 153–154, 1912.

Locality and geologic occurrence.—Limon, Costa Rica, Moin Hill, "Niveau *a*," collected by H. Pittier, probably Pleistocene.

As has been stated this is in reality only a vegetative growth form of *Agaricia agaricites* var. *purpurea*. It is especially abundant on the reefs off the west side of Andros Island, Bahamas.

AGARICIA AGARICITES var. PUSILLA Verrill.

1902. *Agaricia agaricites* var. *pusilla* Verrill, Conn. Acad. Arts and Sci. Trans., vol. 11, p. 148, pl. 27, figs. 3. 3*a*.

Locality and geologic occurrence.—Canal Zone, station 6039, Pleistocene, Mount Hope, collected by D. F. MacDonald, moderately abundant. This variety was originally based on specimens from Colon, Panama.

AGARICIA ANGUILLENSIS, new species.

Plate 108, figs. 2, 3, 4.

Corallum rather low, consisting of crispate, divided, and lobed fronds. Height or extension from the center, 44 + mm. Thickness, 3 to 4 mm; thinner on the edges.

Calices unifacial, subconcentrically arranged, mother calice excentric. In the type-specimen, the distance from the mother calice to the edge of the frond is 35 mm., with five rows of calices, the outermost calice 6 mm. from the margin, making 7 mm. the average distance between the rows, the distance varies from 5 or 6 to 9 mm. *The lower side of the rows is very slightly swollen; the ridges are almost suppressed.* Transverse diameter of calices 3 to 7 mm. On the upper side the septo-costae are directly continuous without elevation to the next series. Under side of frond finely striate.

The septa vary in number from 15 to 38, alternately larger and smaller, arranged in three cycles; 6 to 12 septa are decidedly larger and thicker than the others. The septo-costae are solid and coarse, alternately larger and smaller. Synapticulae abundant.

Calicular fossa shallow. Columella stout, composed of two or three large papillæ that fuse to form an axial tubercle or an axial lamella.

Localities.—Island of Anguilla, West Indies; collected by P. T. Cleve.

Type.—University of Upsala; duplicates in the United States National Museum (Cat. No. 324971).

One of the striking characters of this species is the slight tumidity of the lower side of the calices; otherwise it closely resembles *Agaricia dominicensis*, the species next to be described.

AGARICIA DOMINICENSIS, new species.

Plate 109, figs. 1, 1*a*.

The type is a fragment of a frond, 27.5 mm. long, 23 mm. wide, and from 1 to 2.5 mm. thick on the lower edge, exclusive of the calicular protuberances. The width of the frond as given is the true width, for the specimen is not broken on its lateral edges. Common wall solid, naked. Calices are confined to one surface. The outer surface is longitudinally finely costate; 16 costae, alternating in size, were counted within 5 mm. in two areas. The costae are low, triangular in profile, their bases meeting or with an exceedingly fine costal thread between them. These costal threads are not included in the count of costae within 5 mm. as given above. A row of small granulations along each costal edge.

Calices swallow-nest-like, tend to be arranged in concentric rows and series; *lower side protuberant about 3 mm.* Distance between calicular series 4 to 7 mm. In the same series adjacent calices confluent but with separate centers; isolated calices may form part of the same row. Transverse diameter of isolated calices from 2.5 to 4 mm.

Septa in largest isolated calices 24 in number, 10 of which extend to the columella; as a rule alternately longer and shorter, and alternately more and less exsert. Septal margins over the edges of the protuberant side of the calices steeply arched but not pointed.

Septo-costae with very thin edges, as a rule alternately taller and lower; 16 within a linear distance of 5 mm. The septo-costae from the upper side of a lower calice or calicular series extend as septo-costae to the next higher calice or calicular series and continue as the septa of the higher calice or series. Synapticulae are highly developed.

Columella a wide, thin, prominent, axial plate.

Locality and geologic occurrence.—Santo Domingo, station No. 7778, Rio Gurabo, zone G, collected by Miss C. J. Maury (type), associated with *Placocyathus variabilis* Duncan.

Cuba, station 3461, gorge of Yumuri River, Matanzas, collected by T. W. Vaughan.

Type.—No. 324973, U.S.N.M., presented by Miss C. J. Maury.

Agaricia dominicensis differs from *A. anguillensis* by the greater tumidity and prominence of the lower lips of the calices or calicular series; in fact, the lower edge of the calices in *A. dominicensis* is carried upward so that usually it is as high as or higher than the upper side of the calicular aperture. It also differs from *A. anguillensis* in its thin, prominent, platelike columella.

The living *Agaricia nobilis* Verrill,[1] found in Florida, Turks Island (West Indies), and Porto Rico, is near *A. dominicensis*. *A. nobilis* has still a more prominent calicular lip, and more prominent and strongly alternating septa and septo-costae.

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[1] Conn. Acad. Arts and Sci. Trans., vol. 11, p. 150, pl. 28, figs. 1, 2, 1902. See also *Agaricia elephantotus* Vaughan, U. S. Fish Com. Bull. for 1900, vol. 1, p. 310, pl. 17, fig. 1.

The three species, naming them in geologically ascending series, *A. anguillensis*, *A. dominicensis*, and *A. nobilis*, seem to form an evolutionary series, the lower side of the calices becoming progressively more produced and more prominent, while the alternation in the size of the septa and the septo-costae increases.

Genus **PAVONA** Lamarck.

1801. *Pavona* Lamarck, Syst. Anim. sans. Vert., p. 372.
1917. *Pavona* Vaughan, Carnegie Inst. Washington Pub. 213, p. 132.

Type-species.—Pavona cristata Lamarck = *Madrepora cristata* Ellis and Solander = *Madrepora cactus* Forskål.

PAVONA PANAMENSIS, new species.

Plate 110, figs. 1, 1*a*, 1*b*, 2, 2*a*, 3, 3*a*.

This species is so variable that formal descriptions of the two extremes will be presented.

The first specimen to be described (pl. 110, figs. 1, 1*a*, 1*b*) is from station 6016, Empire, Canal Zone.

Corallum massive or forming thick plates, maximum thickness of type 37 mm.

Calices in more or less definite series; diameter, about 4 mm.; distance between series as much as 3.5 mm. Intercalicular areas arched or flat.

Septa strongly alternating in size; about 10 prominent, tall septa reach the columella; between each pair of these is a lower, smaller septum, occasionally three small between two larger septa; edges of the larger septa steep around the columella fossa.

Septo-costae continuous from calice to calice, strongly alternating or in places subequal in size; synapticulae visible between them.

Columella formed by the fusion of the inner ends of the large septa; in some calices it appears to be a central tubercle.

Dissepiments well developed; 7 within 4 mm.

The next specimen (pl. 110, figs. 2, 2*a*) is from station 6015, also in Empire, Canal Zone.[1]

Corallum forming nodular masses or encrusting dead coral or other such objects. The size and form are shown by plate 110, figures 2, 2*a*. Another specimen has an attached base and flat upper surface.

Calices irregularly distributed or in short, indistinct series; diameter of the apertures usually range between 2 and 3 mm., as the outline in plan is subelliptical or oval the two diameters at right angles are rarely equal in the same calice; depth about 1.5 mm.; distance apart ranges from a mere dividing wall up to 2.5 mm., about 1 mm. usual. Intercalicular areas flat between fully developed calices.

Septa, number in fully grown calices 24 to 26; of these about half or more than half extend to the columella; around the calicular edge,

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[1] Compare the illustrations of this specimen with the figures of D'Aehiardi's *Reussastraea granulosa*, Corall. eocen. Fruli, p. 67, pl. 13, figs. 2*a*, 2*b*, 2*c*, 1875. *Reussastraea* is a synonym of *Pavona*.

they are thick and subequal, within the calice there is indefinite alternation in size, and there may be irregular grouping, but usually the small septa do not fuse to the sides of the larger. The septal margins within the calices fall steeply to the bottom of the relatively large fossa.

Septo-costae continuous from one calice to the next; they are low, subequal, and synapticulae are visible between them.

Columella formed by the fusion of the inner ends of the long septa; it is styliform in many calices, and in some it is distinctly compressed.

A specimen from station 6016, represented by plate 110, figures 3, 3*a*, is intermediate in its septal and septo-costal characters between the two other specimens above described.

Localities and geologic occurrence.—Canal Zone, stations 6015 and 6016, in the Emperador limestone, quarry, Empire, collected by T. W. Vaughan and D. F. MacDonald.

Cotypes.—Nos. 325232, 325334, 325335, U.S.N.M.

This species has its nearest relative in the living *P. clivosa*, from Pearl Island, Bay of Panama.

Genus LEPTOSERIS Milne Edwards and Haime.

1849. *Leptoseris* Milne Edwards and Haime, Comptes Rend., vol. 29, p. 72.

Type-species.—*Leptoseris fragilis* Milne Edwards and Haime.

LEPTOSERIS PORTORICENSIS, new species.

Plate 107, figs. 2, 2*a*, 2*b*.

Corallum forming a rather thick unifacial frond. The type-specimen is a fragment and does not give a definite idea of the size to which the corallum grew. It is 45 mm. long, of the same width, and 5.5 mm. thick. The back is without calices; it is naked and finely costate, about 23 costae to 1 cm. The costae are subequal in size, alternately larger and smaller, or every fourth may be slightly larger than those intervening. The costal edges are narrower than the bases and are finely beaded. Intercostal furrows of about the same width as the costae.

Calices not very definitely arranged, occurring in clusters or in irregular transverse series. Considerable areas are without calices. Each calice is surrounded by from 6 to 9 prominent septo-costae, as tall as 2 mm., and 1 mm. thick. Between these on the upper (distal) side often there are smaller ones. New calices may originate by budding from the costate area. Diameter of fully developed calices, about 4 mm. The septo-costae in the noncaliculate areas are coarse, prominent, and equal. Number to the centimeter, 10; height as much as 1 mm.; thickness of base, as much as 0.7 mm. Edges rather acute and beaded. Intercostal furrows usually narrower than the costae. Synapticulae present.

Columella absent, or slightly developed and false.

Locality and geologic occurrence.—Porto Rico, station 3191, 4 miles west of Lares, in the Pepino formation, collected by R. T. Hill.

Type.—No. 325231, U.S.N.M.

It is possible that this species may ultimately be referred to the genus *Mycedium*, to which it is very close.

Genus **PIRONASTRAEA** D'Achiardi.

1875. *Pironastraea* D'Achiardi, Corall. eocen. del Friuli, p. 76, pl. 15, figs. 2*a*, 2*b*, 3*a*, 3*b*, 3*c*, 3*d*.

Type-species.—*Pironastraea discoides* D'Achiardi,from the Eocene at Brazzano, Russitz, Cormons, and Rosazzo, Italy.

The species described below as *Pironastraea anguillensis* is essentially typical of the genus except that the basal epitheca is incomplete, occurring only as shreds in both the type-specimens from Anguilla and in a specimen from Porto Rico, collected by Mr. Bela Hubbard, of the New York Academy of Sciences Porto Rico expedition. The columella of *P. discoides*, according to D'Achiardi, is a single papilla.

The following generic diagnosis is based on the two West Indian species, *P. anguillensis* and *P. antiguensis*, descriptions of which are subsequently given:

Corallum more or less massive or forming thick undulating plates which expand from a subcentral basal attachment. Lower surface mostly naked, a few epithecal shreds are present, finely costate; common wall synapticular in origin, but in places it is almost or quite solid. Upper surface caliculate.

Calices usually form subconcentric series, some are circumscribed. In the series calicinal centers either distinct, or indistinct as in *Pachyseris*. Separated by rounded collines, of equal slopes on both the peripheral and proximal sides; no interserial walls.

Septa lamellate, with few or no perforations; apparently some perforations near the columella, where the trabecular fusion is incomplete. Septal margins with obtuse, crowded dentations, which are compressed transversely to the septal planes, and are more conspicuous around the axial fossa, where the calicinal centers are distinct, or along the bottom of the valley where the calicinal centers are indistinct. Columella false, in places a few papillae may be recognized. Septo-costae equal in size, directly confluent across the collines.

Synapticulae greatly developed, small, crowded.

Geologic occurrences.—Oligocene of Anguilla, Antigua, Cuba, and Porto Rico.

There seems to be only one genus of corals with which comparisons need to be made. Milne Edwards and Haime[1] proposed *Oroseris*[2] for

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[1] Polyp. foss. Terr. paléozoïques, p. 130, 1851.

[2] A synonym of *Comoseris* D'Orbigny, according to Gregory, Juras. Cor. Cutch., pp. 154-156, 1900.

a genus, designating as the type-species *O. plana* M. Edwards and Haime, which is a new name for *Agaricia sommeringii* Michelin[1] (*not* Goldfuss), from the middle Oolite of Mecrin and Hannonville (Meuse). A part of the description of *O. plana* is as follows: "Quelques collines minces et peu saillantes entre lesquelles on voit souvent plusieurs séries de centres calicinaux. Ceux-ci sont bien distincts et peu profonds."

The multiple series of calices between collines and the very distinct calicinal centers appear to be valid generic differences. Furthermore in the distinct calices of *Pironastraea* the columella is false but clearly papillary, whereas in *Oroseris* the columella is rudimentary. There may be additional differences in septal structure not ascertainable from the short description of the type-species of *Oroseris*.

Pironastraea differs from *Pachyseris* by its more distinct calicinal centers; but apparently it is the ancestor of the latter genus.

PIRONASTRAEA ANGUILLENSIS, new species.

Plate 111, figs. 1, 1*a*, 1*b*; plate 112, figs. 1, 1*a*.

Corallum forming plates as much as nearly 5 cm. thick, and more than 12 cm. across. Width of valleys measured between collines summits from 2.5 to 5.5 mm., about 4 mm. usual; height of collines above the bottom of the axial furrow or of the columella pit about 3 mm. Distance between distinct calicinal centers ranges from 3 to 4 mm.

Septa numerous, from 38 to 45 in fully developed calices, most of them extend to the axis, some grouping in 3's at the calicular ends. On a septum 2 mm. long about 10 crowded, knot like dentations. Septo-costae equal, crowded, 18 were counted within 5 mm.

The columella fossa, where the calicinal centers are distinct, is a small pit, less than 0.5 mm. in diameter.

Synapticulae abundant, crowded, 7 or more to an interseptal loculus.

Locality and occurrence.—Anguilla, stations 6893, 6894, 6966, Crocus Bay, T. W. Vaughan collector. A specimen from station 6966 was obtained in place between 30 and 50 feet above the base of the bluff on the west side of Crocus Bay.

Porto Rico, Lares Road, zone C, collected by Mr. Bela Hubbard of the New York Academy of Sciences Porto Rico Expedition.

Type.—*No.* 325174, U.S.N.M., pl. 111, figs. 1, 1*a*, 1*b*.

Paratype.—No. 325175 U.S.N.M., pl. 112, figs. 1, 1*a*.

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[1] Iconograph zoophytol., p. 105, pl. 23, fig. 2, 1843.

PIRONASTRAEA ANTIGUENSIS, new species.

Plate 112, figs. 2, 2*a*; plate 113, figs. 1, 1*a*.

Corallum massive. Type a small specimen, 48 mm. long, 32 mm. wide, and about 30 mm. thick. Subsequently two larger specimens, apparently referable to this species, will be described.

Width of calicinal series, measured between colline summits 5.5 mm. to 7.5 mm. Valleys shallow, about 1.5 mm. deep. Collines with broader bases than in *P. anguillensis*, some colline-profiles are more triangular than in the latter species. Distance between calicinal centers in the same series about 4.5 mm.

Septa numerous, about 48 in a calice 6 mm. in diameter, between 12 and 14 extend to the axis, other septa shorter, irregularly fused in pairs or in groups of three. Around the calicular edges all septa are subequal; their thickness about the same as or slightly less than the width of the interseptal loculi. The septal margins with bluntish, crowded dentations, 20 were counted in a length of 3.4 mm.

Septo-costae subequal, crowded, each of three counts in different places gave 22 to 5 mm. of linear distance. Synapticulae numerous, crowded, 9 were counted in a distance of 2.5 mm. along the course of a septum.

Columella false, papillary, not sunken in a definite pit.

Locality and occurrence.—Antigua. Type (pl. 112, figs. 2, 2*a*) from the Antigua formation, station 6854, Rifle Butts, T. W. Vaughan collector; and station 6880, west side of Otto's estate, T. W. Vaughan collector. The last-mentioned specimen is silicified and broken, but as it presents the general aspect of the type of *P. antiguensis*, and has from 18 to 22 septo-costae to 5 mm., the specific identity of the two specimens appears certain.

Cuba, station 7514, about 5 miles nearly due east of monument H 4 on the east boundary of the United States Naval Reservation, Guantanamo, altitude about 400 feet a. t., collected by O. E. Meinzer. The latter specimen is represented by plate 113, figures 1, 1*a*.

Type.—No. 325177, U.S.N.M.

Paratype.—No. 325179, U.S.N.M.

P. antiguensis differs from *P. anguillensis* in its more massive growth form, wider valleys, lower collines, more numerous septo-costae, and the absence of a columella pit. The calicinal centers in the specimen from station 7514, near Guantanamo, Cuba, are usually joined by an axial septum extending from one to the next center, producing the appearance of an axial lamella. The lamella, however, is not a columella, for the calicinal centers are usually recognizable, and when they are distinct there are a few papillae in the columellar area. It appears that the well-developed axial lamella is one of the specific characters, but the suite of specimens, three in all, is too small to be sure of this.

Genus **SIDERASTREA** de Blainville.

1801. *Astrea* (part) Lamarck, Anim. sans Vert., p. 371 (not *Astraea* Bolten, Mus. Boltenianum, p. 79, 1798).
1815. *Astraea* Oken, Lehrb. der Naturg., Th. 3, Abth. 1, p. 75.
1830. *Siderastrea* De Blainville, Dict. Sci. nat., vol. 60, p. 335.
1846. *Siderina* Dana, U. S. Expl. Exp. Zoophytes, p. 218.
1848. *Siderastrea* Milne Edwards and Haime, Comptes Rend., vol. 27, p. 495.
1857. *Astraea* Milne Edwards and Haime, Hist. nat. Corall., vol. 2, p. 505.
1861. *Astrea* De Fromentel, Introd. à l'Ètude des Polyp. foss., p. 235.
1886. *Siderastraea* Quelch, Challenger Exp. Reef Corals, p. 133.
1890. *Siderastraea* Verrill, In Dana's Corals and Coral Islands, ed. 3, p. 424.
1895. *Astraea* Gregory, Geol. Soc. Lond. Quart. Journ., vol. 51, p. 278.
1900. *Siderastrea* Vaughn, U. S. Geol. Survey Mon. 39, p. 154.
1907. *Siderastrea* Vaughan, U. S. Nat. Mus. Bull. 59, p. 136.

Type-species.—Madrepora radians Pallas.

In the last publication cited in the synonymy given above I said in discussing the genus *Pavona:* Two of these species [of *Pavona*], *P. clavus* Dana and *Siderastrea maldivensis* Gardiner, have been referred to the genus *Siderastrea,* type species *Madrepora radians* Pallas; and they superficially resemble that genus. Upon closer scrutiny an additional resemblance is found in the distinct, continuous corallite walls, but there are important differences. The septal margins of the species [of *Pavona*] discussed in the foregoing remarks are entire or microscopically dentate, and the septal lamellae are absolutely solid. In the 5 or 6 species, specimens of which I have studied, there is persistently a lamellate columella or a compressed styliform columella. *The septal margins of Siderastrea are pronouncedly dentate,* the dentations rounded, one dentation corresponding to each septal trabecula. *The younger septa are distinctly perforate, the perforations not being confined to the inner edges.*"

It would seem that this clear statement of certain characters of *Siderastrea* should have stopped the erroneous reference to it of such species of *Pavona* as *P. clavus* Dana and *P. maldivensis* (Gardiner) Vaughan,[1] yet Felix in his Die fossilen Anthozoen aus der Umgegend von Trinil (Java)[2] persists in the erroneous reference to it of species belonging to another genus or other genera. He places in *Siderastraea* (misspelling the generic name) *S. blanckenhorni,* new species, which from his figures[3] and his descripition,[4] is certainly not *Siderastrea, S. columnaris,* new species, *S. maldivensis* Gardiner, and *S. micrommata,* new species, no one of which belongs to *Siderastrea.*

This is not the only misuse or misunderstanding of the generic names of corals by Felix in the paper cited. In others of his publi-

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[1] For a discussion of the known living species of *Pavona,* see Vaughan, Some shoal-water corals from Murray Island (Australia), Cocos-Keeling Islands, and Fanning Island, Carnegie Inst. Washington Pub. 213, pp. 132–139, 1918. Notes on *P. maldivensis* (Gardiner) Vaughan are given on page 138, and it is illustrated by plate 56, figs. 3, 3*a*, 3*b*.

[2] Palaeontographica, vol. 60, pp. 311–365, pls. 24–27, 1913.

[3] Idem, plate 27, figs. 6, 6*a*.

[4] Idem, p. 333.

cations, he does not follow the accepted canons of systematic zoology, an instance being in his application[1] of *Parastraea*,[2] originally named by Milne Edwards and Haime, to a species, *Parastraea grandiflora*, erroneously referred to *Parastraea* by Reuss. There are in the United States National Museum specimens of this species received from Professor Felix; they belong to a genus of fungid corals related to *Diploastrea* Matthai, but I am not decided as to their generic identification. However, they most emphatically do not belong to *Parastrea*. Other instances of similar errors in Felix's work might be mentioned.

In order to present properly the systematic affinities of the species of *Siderastrea* that need to be considered in this paper, it is desirable to discuss all Oligocene and later species known from the West Indies, Central America, and the southeastern United States. *S. stellata* Verrill from Brazil is also included.

Siderastrea is represented in the living Caribbean and Floridian fauna by *S. radians* (Pallas) and *S. siderea* (Ellis and Solander). The fossil species hitherto described from the West Indies are as follows:

S. conferta (Duncan)[3] (as *Isastraea*) from Antigua.

S. crenulata var. *antillarum* Duncan [4] from Santo Domingo.

S. grandis Duncan [5] (syn. of *S. siderea*) from Jamaica.

S. pariana (Duncan)[6] (as *Astraea*) from St. Croix, Trinidad.

S. confusa (Duncan)[7] (as *Isastraea*) from St. Croix, Trinidad.

S. hexagonalis Vaughan[8] from the Eocene Clayton limestone, Prairie Creek, Alabama.

S. clarki Nomland [9] from the Oligocene *Agasoma gravidum* zone, Contra Costa County, California.

S. mendenhalli Vaughan,[10] Pliocene, Carrizo Creek, California.

S. californica Vaughan,[11] Pliocene, Carrizo Creek, California.

Neither the Californian species nor the Eocene *S. hexagonalis* will be specially considered here.

Duncan's *S. crenulata* var. *antillarum* is probably a synonym of *S. siderea;* his *S. grandis* is certainly a synonym of *S. siderea*. Addi-

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[1] Palaeontographica, vol. 49, p. 181, 1903.

[2] *Parastrea* Milne Edwards and Haime, Comptes. Rend., vol. 27, p. 495, 1848; examples *Astrea rotulosa* and *A. ananas* Lamarck. Placed in the synonymy of *Favia* by Milne and Haime, Hist. nat. Corall., vol. 2, p. 426.

[3] Geol. Soc. London Quart. Journ., vol. 19, p. 422, pl. 14, fig. 2, 1863.

[4] Idem, p. 435.

[5] Idem, p. 441, pl. 16, figs. 5*a*, 5*b*.

[6] Geol. Soc. London Quart. Journ., vol. 24, p. 14, 1867

[7] Idem, p. 14, pl. 2, fig. 6.

[8] U. S. Geol. Survey Mon. 39, p. 155, pl. 18, figs. 1–4, 1900.

[9] Univ. Calif. Pub., Bull. Dept. Geology, vol. 9, p. 65, pl. 5, figs. 3, 4, 1916.

[10] U. S. Geol. Survey Prof. Pap. 98–T, p. 374, pl. 101, figs. 3, 3*a*, 4, and var. *minor*, Idem, p. 375, pl. 102, fig. 1, 1917.

[11] Idem, p. 375, pl. 102, figs. 2, 2*a*, 3, 4.

tional specimens of *S. pariana* and *S. confusa* from St. Croix, Trinidad, are needed before those species can be adequately characterized, but the original descriptions of them are included. Therefore, the following old names are adopted in the discussion here given:

S. radians (Pallas), living.

S. siderea (Ellis and Solander), living; fossil in the Miocene Bowden marl of Jamaica and in deposits of similar age in Santo Domingo and Cuba.

S. stellata Verrill, living.

S. conferta (Duncan), fossil.

S. pariana (Duncan), fossil.

S. confusa (Duncan), fossil.

I am describing as new five species and one variety as follows:

S. pourtalesi, upper Oligocene or lower Miocene of Santo Domingo.

S. pliocenica, Pliocene Caloosahatchee marl, Florida.

S. hillboroensis, lower Miocene Alum Bluff formation, Florida; Oligocene Chattahoochee formation.

S. silecensis, Oligocene Tampa formation, Florida, and Chattahoochee formation, Florida and Georgia; lower Miocene, Alum Bluff formation, Florida.

S. dalli, Pliocene Caloosahatchee marl, Florida.

These species may be divided into five groups on the basis of the number of septa. The first group has only three cycles of septa and contains one species; the second group has the fourth cycle of septa incomplete; the third normally has four complete cycles and occasionally a few quinaries; the fourth has uniformly a few quinaries in fully developed calices; the fifth has from 12 to 43 quinary septa in fully developed calices. The following synopsis of some striking characters may aid in recognizing the different species:

SYNOPSIS OF CHARACTERS OF SPECIES OF SIDERASTREA.

Only 3 cycles of septa.. 1. *S. pariana* (Duncan).
Fourth cycle of septa incomplete.
Columellar fossa a pronounced pit.
Calices rarely 4 mm. in diameter.
Columella composed of from 1 to 3 fused papillæ. 2. *S. radians* (Pallas).
Calices deformed, lesser diameter 2 to 3 mm., length as much as 6.5 mm., or more.
Columella finely papillary.......................... 3. *S. stellata* Verrill.
Columellar fossa only moderately deep.
Calices 2.5 to 5 mm. in diameter.
Columella false.................................. 4. *S. confusa* (Duncan).
Columellar fossa shallow, calices shallow and open.
Wall delicate, interseptal loculi relatively open. 5. *S. pourtalesi*, new species.
Wall stout, interseptal loculi narrow, largely closed by granulations and syapticulae (fourth cycle complete in some large calices).
6. *S. pliocenica*, new species.

Fourth cycle of septa normally complete, a few quinaries in large calices.

Columellar fossa not very deep; lesser diameter of calices from 4 to 6 mm.; tertiary septa fuse to secondary distinctly back from the columella; about 4 septal teeth to 1 mm. (fourth cycle of septa incomplete in some calices).
7. *S. hillsboroensis*, new species.

Columellar fossa deep, rather narrow at the bottom; calices 3 to 5 mm. in diameter; tertiary septa normally fuse to secondaries distinctly back from the columella; 6 to 8 septal teeth to 1 mm.... 8.[1] *S. siderea* (Ellis and Solander).

Four complete cycles and normally some quinaries septa.

Columellar fossa rather deep and wide bottomed; calices 5 to 7, even 8 mm. in diameter; tertiary septa fuse to secondaries near or at the columella; septa and septal teeth less numerous than in No. 11; septal teeth not transversely compressed and frosted as in No. 10.................... 9. *S. silicensis*, new species.

Columellar fossa shallow, calices widely open; calices 5 to 6.5, even 8, mm. in maximum diameter; tertiary septa fuse to secondaries near the columella; septal teeth numerous, crowded, transversely compressed, finely frosted.
10. *S. dalli*, new species.

Four complete cycles of septa and many quinaries.

Columellar fossa shallow or rather deep and narrow; calices from 4.25 to 6, up to 8.5 mm. in maximum diameter; septa numerous, up to 91 in large calices, thin crowded; septal teeth small, crowded.............. 11. *S. conferta* (Duncan).

The foregoing is intended to aid in the preliminary placing of a species with reference to the other members of the genus, and is not a complete summary of characters. The details of the mural characters, the relative thickness and crowding or remoteness of the septa, the septal trabeculae, the dentation of the septal margins, the distribution and size of the synapticulae, and the details of the columella, all need to be considered. For these additional details the descriptions and the rather elaborate illustrations must be consulted.

1. SIDERASTREA PARIANA (Duncan).

1867. *Astraea pariana* DUNCAN, Geol. Soc. London Quart. Journ., vol. 24, pp. 14, 24.

Original description.—"The corallum is massive and rather tall and its upper surface is flat. The corallites are slender, tall, crowded, and equal. The calices are small, and the fossa is rather deep. The columella presents one rounded process. The septa are in six systems and there are three cycles; they are alternately large and small, and the smallest usually unite to the large septa; they are faintly dentate. The laminae present on their sides sets of granules in horizontal but wavy lines. The endotheca is rare. The diameter of the calices is one-twelfth inch [2 mm.]."

Locality.—St. Croix, Trinidad.

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[1] *S. siderea* var. *dominicensis*, new variety, is like *S. siderea* except that it has larger calices and correspondingly a number of quinary septa.

2. SIDERASTREA RADIANS (Pallas).

Plate 114, fig. 1.

1766. *Madrepora radians* PALLAS, Elench. Zooph., p. 322.
1767. *Madrepora astroites* LINNAEUS, Syst. Nat., ed. 12, p. 1276 (not Pallas, 1766).
1786. *Madrepora galaxea* ELLIS and SOLANDER, Nat. Hist. Zooph., p. 168, pl. 48, fig. 7.
1801. *Astrea galaxea* LAMARCK, Syst. Anim. s. Vert., p. 371.
1815. *Astraea radians* seu *astroites* OKEN, Lehrb. Naturgesch., Th. 3, Abth 1, p. 65.
1830. *Astrea* (*Siderastrea*) *galaxea* DE BLAINVILLE, Dict. Sci. nat., vol. 60, p. 335.
1834. *Astraea astroites* EHRENBERG, Cor. Roth. Meer., p. 95 (of separate). (Not *Explanaria galaxea* Ehrenberg=*Cyphastraea savignyi* Milne Edwards and Haime.)
1846. *Siderina galaxea* DANA, U. S. Expl. Exped. Zooph., p. 218, pl. 10, figs. 12, 12b, 12c (*not* figs. 12*a*, 12*d*).
1880. *Siderastraea galaxea* POURTALÈS, Mus. Comp. Zool. Mem., vol. 7, pt. 1, pl. 11, figs. 14–31; pl. 15, figs. 1–12.
1895. *Astraea radians* GREGORY, Geol. Soc. Lond. Quart. Journ., vol. 51, p. 277.
1901. *Siderastrea radians* VAUGHAN, Geolog. Reichs. Mus. Leiden Samml., ser. 2, vol. 2, p. 61.
1901. *Siderastrea radians* VAUGHAN, U. S. Fish Com. Bull. for 1900, vol. 2, p. 309, pl. 15, pl. 16, fig. 2.
1902. *Siderastraea radians* VERRILL, Conn. Acad. Arts and Sci. Trans., vol. 11, p. 153. pl. 30, fig. 1.
1904. *Siderastrea radians* DUERDEN, Carnegie Inst. Washington Pub. No. 20, pp. 1–130, 11 plates.
1915. *Siderastrea radians* VAUGHAN, Washington Acad. Sci. Journ., vol. 5, p. 597.
1916. *Siderastrea radians* VAUGHAN, Nat. Acad. Sci. Proc., vol. 2, pp. 95 *et passim*.
1916. *Siderastrea radians* VAUGHAN, Carnegie Inst. Washington Yearbook No. 14, p. 228.

This is one of the best known species of Antillean corals. Its most important characters may be summarized as follows: Calices more or less deformed or subhexagonal; diameter from 2 to 4 mm.; septa in 3 complete cycles; fourth cycle normally incomplete. Outer part of septal margins flattened above, inner part falls steeply, almost perpendicularly, to the bottom of the columellar fossa; septal dentations relatively coarse, 12 to 14 on long septa. Columella usually composed of two or three solidly fused papillae. All of these characters are shown on plate 35, figure 1.

Locality and geologic occurrence.—Canal Zone, stations 5850 and 6039, Pleistocene, Mount Hope, collected by D. F. MacDonald. Common on the living and Pleistocene reefs and reef flats of eastern Central America, the West Indies, and Florida; on the living reefs and reef flats of the Bermudas.

3. SIDERASTREA STELLATA Verrill.

Plate 115, figs. 2, 2*a*, 2*b*.

1868. *Siderastraea stellata* VERRILL, Conn. Acad. Arts and Sci. Trans., vol. 1, p. 352.
1901. *Siderastrea stellata* VAUGHAN, Geolog. Reichs. Mus. Leiden Samml., ser. 2, vol. 2, p. 62.
1902. *Siderastraea stellata* VERRILL, Conn. Acad. Arts and Sci. Trans., vol. 11, p. 155, pl. 30, figs. 4, 5.

This species resembles *S. radians* in usually having the fourth cycle of septa incomplete, in the flattened outer margins and very steep inner margins of the septa, and a deep columellar fossa. It differs, as a comparison of the figures shows, by having deeper calices, which may be meandriform, by its more coarsely dentate septa, and by its much less developed, finely papillate columella. It is a very distinct species and is not a synonym of *S. siderea*, as Gregory supposed.[1] The specimen figured (pl. 115, figs. 2, 2*a*, 2*b*) is No. 36859, U.S.N.M.

Locality and geologic occurrence.—"It is widely distributed on the coast of Brazil; Bahia, Abrolhos reefs, etc.;" living.[2]

4. SIDERASTREA CONFUSA (Duncan).

1867. *Isastraea confusa* DUNCAN, Geol. Soc. London Quart. Journ., vol. 24, pp. 14, 24, pl. 2, fig. 6.

Original description.—"The corallum is short, and covers much space. The corallites are very irregular in size, and the calices also. The fossa is moderately deep, and presents a false columella. The septa are thick, and unite laterally in sets of three, four, or six. The free margin is faintly dentate. The largest calices have four cycles of septa in six systems; but usually only three cycles are found in smaller calices. The diameter of the calices is from one-tenth to four-tenths inch 2.5 to 10 mm."

Locality.—St. Croix, Trinidad.

5. SIDERASTREA POURTALESI, new species.

Plate 115, figs. 1, 1*a*.

1875. *Siderastraea galaxea* POURTALÈS, Geol. Mag., new ser., dec. 2, vol. 2, p. 545.

The specimen identified by Pourtalès as *Siderastrea galaxea* (Ellis and Solander) = *Siderastrea radians* (Pallas), the older name, is not that species, but as it is closely related the following is a comparative diagnosis.

In growth, form, size of calices, and septal arrangement, *Siderastrea pourtalesi* is similar to *S. radians*, but the wall is very thin, even interrupted, zigzagging between the thick outer ends of the wedge-shaped septa. The interseptal spaces are relatively wide and are

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[1] Geol. Soc. London Quart. Journ., vol. 51, p. 279, 1895.

[2] Verrill, Conn. Acad. Arts and Sci. Trans., vol. 11, p. 155, 1902.

conspicuously open. Synapticulae are present, but they are rather scarce, and are delicate. The delicate wall and synapticulae and the relative openness of the interseptal loculi constitute striking differences from the appearance presented by *S. radians*.

Locality.—Santo Domingo, collected by W. M. Gabb.

Type.—Museum of Comparative Zoology.

6. SIDERASTREA PLIOCENICA, new species.

Plate 118, figs. 2, *2a*, *2b*, 3.

Twelve specimens, all of them excellent, serve as the basis of the following specific diagnosis. One is designated as the type in the collection.

The corallum usually forms a rather small rounded head, but a few are elongate, and one is flattish, sublamellate. The heads attain a diameter of between 45 and 50 mm. About a third of the specimens show signs of having been attached or have not calices uniformly distributed over the whole outer surface of the corallum.

The corallites are rather large, and are rather uniformly hexagonal or pentagonal; usual diameter is 4.5 to 5 mm.; intercorallite wall distinct and zigzag in plan. The calices are shallow or superficial.

Septa thick, usually in almost four complete cycles, the fourth cycle is as a rule absent in one or two systems. Septal margins dentate, each dentation rounded, corresponding to the upper termination of a septal trabecula, the number of dentations on a septum of the first cycle varies from 8 or 9 to 13. The length of such a septum is almost 2.5 mm. Septal grouping is as usual in the genus, the members of the first cycle are continued directly to the columellar space and do not form parts of septal groups; the members of the second cycle, also, are continued directly to the columellar space, but each member of this cycle is the middle of a septal group, the members of the third cycle bend toward it, and the members of the fourth bend toward the included member of the third. Along the course of each trabecula is a regular row of granulations, which are compressed in a plane transverse to the longitudinal course of the trabecula. Septal perforations are frequent near the inner margins of the septa, usually occurring in the intertrabecular spaces, but in places a large perforation interrupts a trabecular course. The perforations become rarer as the wall is approached. Completely imperforate septa are very rare or do not exist at all.

Both synapticulate and dissepimental endotheca is present. In places as many as four or five vertical rows of synapticulae can be distinguished. Very thin dissepiments are abundant. The wall is formed by synapticulae that are so elongated in a vertical row that they fuse and produce a continuous wall with only an occasional perforation.

The columella is papillary, about two papillae being larger than the others. In worn specimens it is very prominent, appearing compressed styliform.

Locality and geologic occurrence.—Florida, Caloosahatchee River, collected by W. H. Dall; Shell Creek, Florida, collected by Doctor Griffith; Pliocene.

Type.—No. 325184, U.S.N.M.

Paratype.—No. 325185, U.S.N.M.

The most striking differences between *S. pliocenica* and *S. radians*, to which it probably has the greatest affinity, are its larger and much shallower calices. *S. californica* Vaughan from the Pliocene of Carizo Creek, California, is a nearly related species.

7. SIDERASTREA HILLSBOROENSIS, new species.

Plate 117, fig. 2.

Description of the type.—Corallum massive, composed of long, prismatic corallites. No entire corallum is available for description, but the height may certainly exceed 10 cm.

Diameter of a large corallite, 5.5 mm.; of a smaller one, 4 mm. The two measurements indicate the range in diameter.

Septa normally in 4 cycles, the fourth cycle complete or almost complete, arranged as follows: The six primaries extend directly to the columella and are free from fusion with other septa; the secondaries also extend to the columella, near which the tertiaries fuse to sides of the included secondaries; the quaternaries fuse to the sides of the included tertiary system about halfway between the wall and the columella. The fourth cycle is incomplete in a few quarter systems of some calices. The primaries and secondaries are of about equal thickness; the tertiaries slightly thinner, and quaternaries still thinner. The number of dentations on the septal margins was estimated from the number of septal trabeculae, as the septal margins are not preserved; it is 9 or 10.

Synapticulae well developed; in each interseptal loculus; three or four are usually conspicuous between the wall and halfway from it to the columella. Although the upper septal margins are not preserved, it seems probable that there is a flattened area between adjacent calicular fossae in perfect specimens.

Columella false, but strongly developed by the axial fusion of the inner ends of the primary and secondary septa.

Localities and geologic occurrence.—Station No. 4890, Tampa brickyard, 5 miles northeast of Tampa, Florida, in the Alum Bluff formation, G. C. Matson collector, the type; in the Alum Bluff formation at station No. 3836, near Alachua, Florida, T. W. Vaughan collector;

and at White Springs, Florida, T. W. Vaughan and L. W. Stephenson, collectors. Station 7076, in the Chattahoochee formation, 12 miles below Bainbridge, Georgia, on the east bank of Flint River, collected by C. W. Cooke and W. C. Mansfield.

Type.—No. 325183, U.S.N.M.

Paratype.—No. 325155, U.S.N.M., the specimen described below.

The diagnosis of *S. hillsboroensis* was written and the figures made to illustrate it before an interesting specimen from 12 miles below Bainbridge came to my notice. This specimen, which is a subcycilindrical segment of a more or less columnar corallum, has a maximum horizontal diameter of 160 mm., and a vertical thickness of 75 mm. The entire corallum was rather large. The septal margins over considerable areas are somewhat elevated around the calicular fossae and the rims are separated by depressed interspaces that in places are as much as 2 mm. across. Adjacent corallites, however, are separated by simple common-walls. The number of septa in fully developed calices ranges from a few less than to about four complete cycles, grouped as in the types of the species. The septal dentations are strikingly large. The following table gives the dimensions of several corallites, the number of septa, the number of septal teeth within 1 mm., and the character of the columella:

Dimensions of corallites, etc., in Siderastrea hillsboroensis.

Corallite No.	Diameter corallites.	Number of septa.	Septal teeth.	Columella.
1	5 by 7.5 mm	50		
2	4.5 by 6.6 mm			
3	5.5 by 6 mm			
4	6 by 6.75 mm	48		Weak.
5	5.25 by 7 mm	50		Do.
6	4.5 by 6.5 mm	48		Do.
7			4 in 1 mm	
8			do	
9			5 in 1.5 mm	
10			6 in 1.5 mm	
11			do	

S. hillsboroensis has some corallites of nearly the same size as those of *S. silecensis*, but they average smaller; it has thicker and relatively fewer septa, which fuse into groups farther from the columella; and the septal teeth are distinctly coarser.

8. SIDERASTREA SIDEREA (Ellis and Solander).

Plate 114, figs. 2, 3; plate 122, figs. 1, 2, 2*a*, 2*b*, 3, 3*a*.

1786. *Madrepora siderea* Ellis and Solander, Nat. Hist. Zooph., p. 168, pl. 49, fig. 2.
1816. *Astrea siderea* Lamarck, Hist. nat. Anim. s. Vert., vol. 2, p. 267.
1830. *Astrea* (*Siderastrea*) *siderea* De Blainville, Dict. Sci. nat., vol. 60, p. 335.
1834. *Astraea tricophylla* Ehrenberg, Cor. Roth. Meer., p. 95 (of separate) (*fide* Milne Edwards and Haime).

1846. *Pavonia siderea* Dana, U. S. Expl. Exped. Zooph., p. 331.
1850. *Siderastrea siderea* Milne Edwards and Haime, Ann. Sci. nat., ser. 3, Zool., vol. 12, p. 141.
1857. *Astraea siderea* Milne Edwards and Haime, Hist. nat. Corall., vol. 2, p. 509, pl. D7, fig. 2.
1863. *Siderastraea grandis* Duncan, Geol. Soc. London Quart. Journ., vol. 19, p. 441, pl. 16, figs. 5*a*, 5*b*.
1871. *Siderastraea siderea* Pourtalès, Mus. Comp. Zool. Ill. Cat. No. 4, p. 81.
1895. *Astraea siderea* Gregory, Geol. Soc. London Quart. Journ., vol. 51, p. 278.
1901. *Siderastrea siderea* Vaughan, Geolog. Reichs-Mus. Leiden Samml., ser. 2, vol. 2, p. 62.
1901. *Siderastrea siderea* Vaughan, U. S. Fish. Com. Bull. for 1900, vol. 2, p. 309, pl. 14, figs. 1, 2; pl. 16, fig. 1.
1902. *Siderastraea siderea* Verrill, Conn. Acad. Arts and Sci. Trans., vol. 11, p. 151, pl. 30, figs. 2, 3.
1903. *Siderastraea siderea* Duerden, Nat. Acad. Sci. Mem., vol. 8, p. 588, pls. 22–24, figs. 150–160.
1915. *Siderastrea siderea* Vaughan. Washington Acad. Sci. Journ., vol. 5, p. 597.
1916. *Siderastrea siderea* Vaughan, Carnegie Inst. Washington Yearbook No. 14, p. 228.

This species forms much larger masses than *S. radians*, the other abundant living species of *Siderastrea* in the West Indies and Florida, and is a common exposed-reef coral. The calices average larger than in *S. radians*, usually 4 to 5 mm. in diameter, occasionally smaller, 3 to 3.5 mm. in diameter. The intercorallite walls are more acute and the septal margins are more sloping; but, as is shown on plate 114, figure 3, on some areas the corallite wall may occur in a slight depression (pl. 114, fig. 2). The septa are normally in four complete cycles, arranged as in figure 3, on plate 114. The tertiary septa fuse to the secondaries, and the quaternaries to the tertiaries nearer the wall than in *S. silecensis*, the next species to be described. The septal margins are more finely dentate than in *S. radians*, and usually the columella is distinctly, finely papillate.

The foregoing notes are on shallow-water specimens, and apply to specimens ranging in locality from Barbados to the Bahamas in the West Indies, from Central America, and from Florida. About one-half mile south of Loggerhead buoy, Tortugas, in water between 8 and 9 fathoms, I dredged three specimens of *S. siderea* that show very interesting variation. The size and shape of the calices, the character of the wall, the number of septa, and the axial fossae are as usual in the species; but the septa are thicker, the septal pectinations are more conspicuous, and the columellar papillae are solidly fused or there is a single, stout, compressed axial tubercle. A group of calices is shown on plate 122, figure 1. These specimens agree in all essential particulars with a specimen from the Bowden marl of Jamaica, a description of which follows:

Description of specimen from Bowden, Jamaica (pl. 122, figs. 3, 3*a*).—Corallum with a rounded upper surface and a flattish base; epithecate around the edge. Transverse diameters, 36 by 38 mm.; height 26 mm.

Calices irregularly polygonal, excavated on top of the corallum, but shallow near its edges. Length of largest calices, 5.5 mm.; width of largest calices, 3.5 to 4 mm.; 4 to 4.5 mm. about the usual diameter; depth between 2 and 2.25 mm. The area between adjacent calicular depressions is relatively acute, the wall usually traceable along the summit as a slightly raised zigzag or straight line.

Septa thicker than the width of the interseptal loculi; four complete cycles and in the larger calices some quinaries; primaries and secondaries extend to the columella, subequal, or the primaries slightly larger; tertiaries fuse to the included secondary about two-thirds the distance from the wall to the center of the calice or very near the columella; quaternaries fuse to the included tertiary about one-third or one-half the distance from the wall to the calicular center; quinaries where present fuse to the included quaternary.

Septal margins slope gently from the wall to about half the distance toward the calicular center and then incline steeply to the outer edge of the columella. The dentations are small, crowded, and bluntish or rather acute, more pointed near the columella, compressed in planes transverse to the septal planes; 15 were counted on a septum 2.5 mm. long; in other words, 6 within 1 mm.

Synapticulae crowded near the wall, 3 within 1 mm. measured down the septal slope from the wall edge.

Columella small, false, papillary; a central, styliform papilla noticeable in many calices.

Description of a specimen collected by Miss C. J. Maury in Santo Domingo, Rio Cana, zone H (pl. 122, figs. 2, 2*a*, 2*b*).—Corallum a small mass, with a flattish base and a rounded upper surface. Diameter, 26 by 28 mm.; height, 15 mm.

Calices shallow, polygonal, usually one diameter longer than the other, separated by narrow, straight, or zigzag walls. Diameter of largest calice, 6 mm.; about 4 mm. a usual measure of the diameter.

In the largest calice (6 mm. in diameter) there are 52 septa, which, according to the usual practice of assigning septa to cycles, would represent 4 complete cycles and 4 quinary septa. Fifteen septa, 6 primaries, 6 secondaries, and 3 tertiaries, extend to the columella, and 2 other tertiaries fuse to the included secondary almost at the periphery of the columella. Where quinary septa are present it is difficult to distinguish between primaries and secondaries, and between the elongate tertiaries and the secondaries. In a calice 4 mm. in diameter the septal arrangement is more definite; there are 46 septa, the quaternaries not being developed in one quarter system. The tertiaries fuse to the secondaries either rather near the columella and the quaternaries to the tertiaries about halfway between the wall and the columella, or somewhat nearer the columella. At the wall the thickness of the septa and the width of the interseptal loculi are nearly the same, but farther within the calice the septa are thinner and the loculi are wider.

Next the wall the septal margins are usually flattened from above, producing a flat area ranging from about 0.5 to about 1 mm. wide, its inner edge marked by a ring of synapticulae, and the wall forms a more or less median slightly raised ridge. From this area the margins slope slightly to the bottom of the calicular fossa. The peripheral flat zone is not present in all calices; in many there is a gradual slope or a gently convex curve from the wall to the bottom of the calice. On the septal margins are fine, crowded, bluntish dentations, which in many instances are compressed transversely to the septal plane. About 16 were counted on a septum 2 mm. long; 12 were counted on another septum 1.5 mm. long. The number, therefore, is between 8 and 9 for a distance of 1 mm. The septal faces are closely beset with blunt granulations. Synapticulae well developed near the wall.

Columella rather small, with a delicately papillate upper surface in the best-preserved calices.

This Santo Domingan specimen has greatly puzzled me, perhaps partly because it is immature. The calices are shallow, not having a distinct axial fossa, as in typical *S. siderea*, and the septal dentations are more numerous than is usual in *S. siderea*. As the calices of the Bowden specimen are excavated on the top of the corallum and superficial near the lower edge, the shallowness of the calices of the Santo Domingan specimen does not seem a sufficient basis for referring it to a different species. Although the septal dentations are finer than the average in *S. siderea*, they are not finer than the dentations on the outer prolongations on some of the septa of the specimens represented by plate 35, figures 2, 3, in which there are 8 or 9 fine teeth within 1 mm. outside the calicular fossa. For these reasons it seems to me that the Santo Domingan fossil should be referred to *S. siderea;* and I believe that the coral designated as *Siderastraea crenulata* var. *antillarum* [1] by Duncan should also be referred to *S. siderea*. Duncan says that his variety *antillarum* is near *S. siderea*. I examined Duncan's type in the collection of the Geological Society of London. It is a flattened mass, rounded above. Calices irregularly polygonal or hexagonal, separated by sharp walls; diameter 4 to 5 mm. Septa in four complete cycles, margins beaded. Columella papillary, in some calices terminated by several stout knobs.

Fossil specimens obtained by me at station 3446, in the La Cruz marl, first deep cutting east of La Cruz, near Santiago, Cuba, differ

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[1] Geol. Soc. London Quart. Journ., vol. 19, p. 435, 1863.

in no noteworthy character from typical *S. siderea*. One specimen from this locality is 187 mm. across.

Localities and geologic occurrence.—Miocene: Jamaica, Bowden marl, received from Hon. T. H. Aldrich. Santo Domingo, Rio Cana, Zone H, collected by Miss C. J. Maury. Cuba, La Cruz marl, station 3446, near Santiago, collected by T. W. Vaughan.

Pleistocene: Canal Zone, at station 5849, Mount Hope; and Costa Rica, station 6251, Monkey Point, collected by D. F. MacDonald; Moin Hill, Costa Rica, collected by H. Pittier.

This species is general in the Pleistocene and living reefs of the West Indies, eastern Central America, and Florida.

The stratigraphic range of *S. siderea* is from the horizon of the Bowden marl to the present.

8a. SIDERASTREA SIDEREA var. DOMINICENSIS, new variety.

Plate 114, figs. 4, 4*a*.

This variety differs from typical *S. siderea* by having much larger calices, which are as much as 6 mm. in diameter in a nearly hexagonal calice, and 4.5 by 8 mm. in diameter in a much deformed calice; and corresponding to the greater size of the calices, there are many quinary septa. Otherwise there seems to be no important difference, for the septal slopes, the septal dentations, the columellar pit, and the papillary columella are about normal.

S. siderea var. *dominicensis* resembles *S. conferta* (Duncan) in possessing more than 4 cycles of septa, but according to the size of the calices the septa of *S. conferta* are more numerous, more crowded, and have more finely dentate septal edges; and the calices of *S. conferta* are shallower and more open.

Locality and geologic occurrence.—Haiti, living, collected by Langston, no more definite information.

Type.—No. 36909, U.S.N.M.

9. SIDERASTREA SILECENSIS, new species.

Plate 116, figs. 1, 1*a*, 2, 3; plate 117, figs. 1, 1*a*, 1*b*; plate 118, figs. 1, 1*a*.

1915. *Siderastrea silecensis* VAUGHAN, *nomen. nudum*, U. S. Nat. Mus. Bull. 90, p. 18.

The following is a description of the type of the species (pl. 116, figs. 1, 1*a*):

Corallum massive, with domed upper surface. Greater diameter of specimen 170 mm.; lesser diameter 140 mm.; thickness, originally more than 85 mm.

Calices polygonal, separating wall usually slightly raised. The peripheral part of the septal margins is flattened, producing between adjacent calicular fossae a flat area which ranges from 0.5 to 1.5 mm. in width. Diameter of an adult calice, measured between the thecal summits, 5 mm.; some oblong calices are as much as 7 mm. long and 5 mm. wide. Depth of calices, 1.5 mm.

Septa, number in a calice 5 mm. in diameter, 50—i. e., 4 complete cycles and 2 quinaries; in a calice 6 mm. long and 4.5 mm. wide, the number is 48, precisely 4 cycles. The usual number of septa is 4 complete cycles, with a few quinaries in large calices. Around the calicular margins the septa are subequal in size, the outer ends of the quaternaries being only slightly smaller than those of the members of the lower cycles. The interseptal spaces average slightly wider than the thickness of the septa. Within the calices the primaries and secondaries are only faintly larger than the tertiaries. There is the usual septal fusion of tertiaries to secondaries and quaternaries to tertiaries, but the tertiaries may almost or actually reach the columella area while the quaternaries extend more than half way from the wall to the columella.

The upper flattened part of the septal margins is beaded; within a distance of 1 mm., 5 rounded dentations were counted; between the place where the septa drop downward in the calicular fossa and the columella the number of dentations on the long septa is between 8 and 10; the total number on the large septa is, therefore, between 13 and 15. Synapticulae well developed, rather coarse, as would be expected from the relatively coarse septal trabeculae.

Columella weakly developed; upper surface papillary, but in many instances crossed by directive septa which meet in the corallite axis.

Locality and occurrence of type specimen.—Station 3694, pine woods, Waukulla, Florida, T. W. Vaughan collector; Chattahoochee formation.

Type.—No. 325187, U.S.N.M.

The following is a description of a young, encrusting corallum without a locality label, but almost certainly from the "silex" bed at Tampa, Florida. (See pl. 116, fig. 3.)

The calicular cavities are slightly excavated, between 0.75 and 1 mm. deep; separated by intervening flattish areas which are from 1.5 to a little more than 2 mm. across and are faintly furrowed where adjacent corallites meet. The corallite wall may usually be recognized as a raised thread-like ridge in the intercorallite furrow. Corallite diameter from 5 to 6.5 mm.

Septa in 4 complete cycles with 6 or a few more quinaries in the larger calices. The septal dentations are serrate or rounded, about 13 on the long septa.

Columella with a papillary upper surface, but some calices show considerable stereoplasmic deposit around the papillae with tendency toward the formation of a compact columella.

A specimen from the "silex" bed at Ballast Point, Tampa, collected by C. W. Cooke, has some calices that duplicate those of the specimen just described, but in other calices the septa and columella are thickened, the columella in some calices being a more or less papillate compressed axial plug. The variation from the normal is similar to the variation exhibited by the specimens of *S. siderea* from a depth of about 9 fathoms south of Tortugas, described on page 444.

Another specimen from Ballast Point has calices up to as large as 5 by 6.5 mm. in diameter. A large calice has 64 speta. Except in having rather large calices and correspondingly more septa, this specimen does not seem to differ in any important particular from the type of the species.

Plate 117, figures 1, 1*a*, 1*b*, illustrates a variant from Coronet Phosphate Mine, station No. 6043, G. C. Matson collector. The calices in it are from 7 to a little more than 8 mm. in diameter. A calice, 6.5 by 8 mm. in diameter, of this specimen has 66 septa.

A specimen from station 6084, Withlacoochee River, 3 miles below Valdosta, Lowndes County, Georgia, has in a calice 6 by 7 mm. in diameter 64 septa and in a calice 5.5 by 7 mm. in diameter 72 septa. This specimen very closely approaches *S. conferta* (Duncan), but appears to have on the average fewer septa than *S. conferta*. Perhaps these specimens that have over 60 septa should be separated from *S. silecensis* and either referred to a new species or to *S. conferta*. At one time I referred them to *S. conferta*, but their average fewer septa according to the size of calices as compared with *S. conferta*, led me to consider them and the specimen next to be described as belonging to a different species.

Description of a specimen from station 3381, Flint River, 4 miles below Bainbridge, Georgia (pl. 118, figs. 1, 1*a*).—Corallum subdiscoid in form. Its greater transverse, diameter 45 mm.; lesser transverse diameter, about 38 mm.; thickness, 14 mm. Upper and lower surface, subplane, somewhat undulated.

Calices irregularly hexagonal or pentagonal in shape, fairly large, range in diameter from 4 to 6.5 mm.; rather shallow or superficial.

Septa numerous, in one calice 6.5 mm. long by 4.5 mm. wide 58 were counted. There are, applying the ordinary method of distributing septa into cycles according to the number, four complete cycles and a fair number of members of a fifth. The various cycles are not distinctly marked. The septal margins in places slope from an acute ridge to the bottom of a moderately deep calice; in other places the calices are shallow, superficial, the septal margins flattened from above, no ridge being present. The dentations on the septal margins are rounded; there are about 10 within 2 mm. Some septa are perforated between the trabeculae, but it seems probable that these perforations are of secondary origin, resulting from the solution of the septa in the thinnest places during fossilization.

Synapticulae are very abundant, especially well developed in several, at least two or three, vertical series near the outer boundary of the corallites. The boundary between adjoining calices is formed by a vertical row of synapticulae, considerably larger than the others.

Columella papillary, fairly well developed.

Localities and geologic occurrence.—Chattahooche formation, basal part, station 3381, Little Horse Shoe Bend, Flint River, 4 miles below Bainbridge, Georgia, collected by T. W Vaughan; Chattahoochee formation, probably near the base, station 6084, Withlacoochee River, 3 miles below Valdosta, Lowndes County, Georgia, collected by L. W. Stephenson; Chattahoochee formation, upper part (stratigraphically the same as the Tampa formation), station 3694, Waukulla, Florida, collected by T. W. Vaughan.

Tampa formation, the "silex" bed, Ballast Point, Tampa, stations 2115, collected by F. Burns; station 7754, an excellent specimen collected by C. W. Cooke.

Alum Bluff formation, station 6043 Coronet Phosphate Mine, near Plant City, Florida, collected by G. C. Matson.

Specimens of this species have been obtained at other localities in Georgia and Florida in the Chattahoochee and Alum Bluff formations. It is abundant around Alachua, Florida.

Siderastrea silecensis so closely resemble *S. conferta* (Duncan) that for some time I referred the specimens of it to that species, but in calices of the same size the septa in *S. conferta* are more numerous, more crowded, and thinner, and have more finely dentate margins. In a calice, 4.5 by 8.5 mm. in diameter, of a specimen of *S. conferta* from Antigua there are about 80 septa, a larger number than was counted in any calice of *S. silecensis.*

10. SIDERASTREA DALLI, new species.

Plate 119, figs. 1, 1*a*, 2.

Corallum forming a mass rounded above. The type has a length of about 122 mm. and is 75 by 82 mm. in diameter in its median part.

The corallites are large, hexagonal or pentagonal in shape. The usual diameter is from 5 to 6.5 mm.; a large corallite is 5.75 by 8 mm. in diameter. Wall between the corallites usually distinct, thin. Calices, shallow.

Septa, rather thin, or fairly thick, very crowded. There are four complete cycles and a fair number of the members of a fifth cycle. The large calice, 5.75 by 8 mm. in diameter, has 68 septa. The septal grouping need not be described, as it is that common for the genus. Septal dentations fine, compressed transversely to the septal planes, finely frosted, from seventeen to twenty or more teeth on the members of the first cycle. No compound or double dentations were seen. The septal faces, closely granulate; perforations similar to those in *S. pliocenica.*

Synapticulae in three or four vertical rows—in the outer portion of the interseptal loculi, there may be even more. Very thin, nearly horizontal dissepiments present. The wall is similar to that of *S. pliocenica*, but thinner.

Columella, papillary. The papillae are fine, more delicate than in *S. pliocenica.*

Locality and geologic occurrence.—Florida, station No. 3300, Shell Creek, collected by F. Burns (type); station 2094, Caloosahatchee River, Florida, collected by W. H. Dall; Pliocene.

Type.—No. 325196, U.S.N.M. (pl. 119, figs. 1, 1*a*).

Paratype.—No. 325195, U.S.N.M.

This species is separated from *S. pliocenica* by its generally more delicate structure, more numerous septal dentations, and more numerous septa. It differs from *S. siderea* (Ellis and Solander) by its larger and shallower calices and its more numerous septa.

The closely crowded, transversely compressed, and finely frosted septal dentations of *S. dalli* give it an appearance very different from any other American species of *Siderastrea.* The number of septa is in corallites of the same diameter about the same as in specimens of *S. silecensis.*

11. SIDERASTREA CONFERTA (Duncan).

Plate 117, fig. 3; plate 120, figs. 1, 2, 2*a*, 3, 4; plate 121, figs. 1, 1*a*, 2, 2*a*.

1863. *Isastraea conferta* Duncan, Geol. Soc. London Quart. Journ., vol. 19, p. 422, pl. 14, fig. 2.

1867. *Isastraea conferta* Duncan, Geol. Soc. London Quart. Journ., vol. 24, p. 25.

The original description of *Isastraea conferta* is as follows: "Corallites very close, tall, slender, straight, and prismatic; a transverse section shows the wall to be very thin. The breadth of the corallites varies from three-tenths to one-tenth inch [=7.5 to 2.5 mm.]. Septa very numerous; linear; the primary extend to the centre of the corallite, the secondary less so, and the others join the larger septa at a very acute angle; all are very slender and excessively crowded. There are eighty-two septa in the larger corallites, sixty in the smaller. The septa of one corallite do not join those of the next, but end sharply at the wall. Endotheca plainly exists, linear, appearing, in transverse section, to divide the interseptal loculi into several cells. The reproduction is by submarginal budding. The sclerenchyma has been replaced by dark homogeneous silica, and the interspaces by porcellanous and opaline silica.

"From the Chert-formation of Antigua. Coll. Geol. Soc.

"This is a very remarkable form. Unfortunately no calices exist; but the transverse view of the corallites is excellent. If the specimen had been found in Oolitic rocks, it would have passed for a small variety of *Isastraea tenuistriata*."

I examined the type of this species in the Geological Society of London collection (No. 12,929), and it is represented by plate 120, figure 1. It belongs to the genus *Siderastrea*. There are more than four cycles of septa. The septal trabeculae are narrow, and produce fine dentations on the septal margins. The estimated number of teeth on the margins of the longer septa is about 20; the synapticulae are fine and are crowded in two or three rings near the wall, which is narrow and continuous. The columella is weakly developed and evidently had a finely papillary upper surface.

I collected in Antigua, station 6888, one-half mile north of McKinnon's mill, in the Antigua formation, one satisfactory specimen of this species. It is of massive, subcolumnar growth form, is about 105 mm. tall, and is 82 by 92 mm. in diameter near the top. The basal part is appreciably narrower than near the summit. The calices are shallow; corallite walls thin. A calice 4.5 by 8.25 in diameter has about 80 septa. Septa composed of small trabeculae and correspondingly have finely dentate margins. Synapticulae delicate and crowded.

This species is very abundant in the Oligocene deposits of the West Indies and the Canal Zone. Description of or notes on specimens from the different localities follow. The next specimen to be described is essentially typical, and as it is in a better state of preservation than the one from Antigua, it is more satisfactory for purposes of illustration.

Description of a specimen from near Lares, Porto Rico (pl. 120, fig. 2, 2*a*).—Corallum massive, rounded above, basal portion somewhat expanded. Greater diameter of base, 106 mm.; lesser diameter of base, about 65 mm.; height, 65 mm.

Calices polygonal, rather large, diameter (measured from summit to summit of wall) from 4.7 to 7.4 mm., 5 to 6 mm. the usual diameter. Near the edges the calices are shallow, higher up on the corallum they are excavated and moderately deep. The outer ends of the septa are arched on the upper part of the corallum, may be somewhat flattened near the wall; lower down they may be depressed across a wide area, with a very shallow calicular cavity; in a few instances a depression corresponds in position to the upper edge of the wall. Wall usually distinct, narrow, zigzag.

Septa very crowded, thin and numerous, 70 in a calice 4.6 by 7.4 mm. in diameter, 76 in one 5.75 by 7.6 mm., 74 in one 5.5 by 6.3 mm. in diameter. They are so crowded that it is difficult to make out the cycles. The primaries appear to be free, the other septa form groups around the secondaries. Septal margins finely beaded; about 26 dentations on a large septum, an actual count for an entire septal length could not be made, but 6 teeth within 0.7 mm. were counted on the outer part of a septum. This would be more than 8 teeth to 1 mm. Synapticulae abundant.

Columella not greatly developed; upper surface finely papillary.

I collected at Crocus Bay, Anguilla, a suite of 22 specimens very closely similar to the Porto Rican specimen. Several of these are illustrated by plate 117, figure 3; plate 120, figures 3, 4; and plate 121, figures 2, 2*a*. The calice represented by plate 117, figure 3, is 4.25 by 6.6 mm. in diameter, and has 68 septa; the larger calice illustrated by plate 120, figure 3, is 7 by 9.5 mm. in diameter, and has 91 septa; the calice illustrated by plate 120, figure 4, is 5.5 by 7.3 mm. in diameter, and has 64 septa; and one of those figured on plate 121, figure 2*a*, is 4.5 by 6.3 mm. in diameter, and has 75 septa.

Specimens of what seem undoubtedly to belong to the same species were collected in the Culebra formation, station 6020*c*, near Las Cascadas, by Doctor MacDonald and me. Some specimens are as much as 14 inches (about 36 cm.) tall, and over 12 inches (about 31 cm.) thick. A part of the surface and an enlarged view of the calices are represented by plate 121, figures 1, 1*a*. A calice 4 by 5.7 mm. in diameter has about 72 septa.

A specimen collected by Gabb in Santo Domingo and identified by Pourtalès as *Siderastraea siderea*[1] belongs to this species. The specimen has numerous thin, crowded septa; there are about 82 septa in a calice 4.5 mm. wide and 6.5 mm. long. It is the property of the Museum of Comparative Zoology, Harvard University.

Localities and geologic occurrence.—Island of Antigua, Antigua formation, Duncan's type; station 6888, one-half mile north of McKinnon's Mills, collected by T. W. Vaughan.

Porto Rico, Pepino formation, station 3191, 4 miles west of Lares, collected by R. T. Hill.

Canal Zone, Culebra formation, station 6020*c*, at Las Cascadas, collected by T. W. Vaughan and D. F. MacDonald.

Island of Anguilla, Anguilla formation, stations 6893, 6894, 6966, lower and middle beds, south and west sides of Crocus Bay, collected by T. W. Vaughan.

As has been remarked, *S. silecensis* Vaughan from Georgia and Florida is very close to *S. conferta*. In calices of the same size there are more septa and the septa are more finely dentate in *S. conferta* than in *S. silecensis*.

Family OULASTREIDAE, new family.

Fungid corals with the superficial aspect of the genera belonging to the family Orbicellidae. Corallites with distinct margins, usually separated by intercorallite areas that are crossed by confluent or

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[1] Geol. Mag., new ser., dec. 2, vol. 2, p. 545, 1875.

alternating septo-costae. Septa lamellate but irregularly more or less perforate. Both synapticulae and dissepiments present. Columella trabecular. Asexual reproduction by intercalicular gemmation.

The coral genera represented by *Oulastrea* Milne Edwards and Haime, *Diploastrea* Matthai, and *Cyathomorpha* Reuss appear to me to deserve recognition as a group of family value. The latter two of these genera have been confused with *Orbicella*, as will be made evident in subsequent remarks. It is unfortunate that the validity of neither *Cyathomorpha* nor of *Diploastrea* can be established at present. The reasons for the uncertainty will appear in·discussions to follow.

Oulastrea crispata (Lamarck) Milne Edwards and Haime, the type species of *Oulastrea*[1] is represented in the United States National Museum by 30 specimens from Puerto Princesa, Palawan, collected by J. B. Steere, and from near Mariveles, Luzon, collected by Albert M. Reese, Philippine Islands. The description and figures given by Milne Edwards and Haime are really excellent, but they did not recognize that the genus belongs to the Madreporaria Fungida. The septa are mostly solid, but there are some perforations, especially in the smaller septa. The walls of the corallites are synapticulate and perforate around the periphery of the corallum, but those of the interior corallites are continuous, with few or no obvious perforations. There are synapticulae between the peripheral septo-costae; within the corallite cavities synapticulae mostly occur near the inner edges of the septa, but some occur between the wall and the inner septal edges. Thin dissepiments are abundant. The septal teeth usually make two fairly definite, in some very definite, palar crowns that stand a little higher than the columellar papillae. These specimens are stained black and do not bleach when boiled with caustic potash.

As *Oulastrea* is the only genus referred to the family of the validity of whose name I can be reasonably certain, notes on the generic characters are given in some detail.

Genus CYATHOMORPHA Reuss.

1868. *Cyathomorpha* Reuss, K. K. Akad. Wiss. Wien., Mat.-Naturwiss. Cl., Denkschr., vol. 28, p. 142, pl. 2, figs. 6*a*, 6*b*, 6*c*.

1884. *Cyathomorpha* Duncan, Linn. Soc. Lond. Journ. (Zool), vol. 18, p. 105.

1889. *Cyathomorpha* Reis, Bayer. geognost. Landesuntersuch. Geognost. Jahresh., Jahrg. 2, p. 147, pl. 3, figs. 17–19.

Type-species.—*Cyathomorpha conglobata* (Reuss) Reuss = *Astrea rochettina* Michelin = *Cyathomorpha rochettina* (Michelin) Reis, *fide* Reis.[2]

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[1] Comptes Rend., vol. 27, p. 495, 1848; Ann. Sci. nat., ser. 3, Zool., vol. 10, pl. 9, figs. 4, 4*a*, 1848; Idem vol. 12, p. 116, 1849.

[2] Bayer. geognost. Landesuntersueh. Geognost. Jahresh., Jahrg. 2, p. 147.

As the validity of this genus name is in doubt the following remarks will be made on genera that appear to be either closely related or synonymous.

Brachyphyllia Reuss: *type-species, B. dormitzeri* Reuss.

In the first of the publications cited in the footnote [1] below Reuss described and referred the following species to *Brachyphyllia: B. depressa, B. dormitzeri*, and *B. glomerata*. In the second paper [2] cited Reuss proposed the name *Agathiphyllia*, referred *Brachyphyllia depressa* to it, and said "der Typus der Gattung *Brachyphyllia* bleibt mithin fortan *Br. dormitzeri* Rss. * * * Sie wird durch die viel kleineren Zellensterne, die dünneren, am obern Rande gleichmässig fein gezähnelten Radiallamellen und die wenig entwickelte, sehr feinkörnige Axe charakterisirt."

Agathiphyllia Reuss: *type-species, A. explanata* Reuss.

Reuss originally referred three species to *Agathiphyllia:*[2] *A. depressa* (Reuss) Reuss (first placed in *Brachyphyllia*), *A. conglobata* Reuss, and *A. explanata* Reuss. In 1868,[3] *A. conglobata* and one specimen previously referred to *A. explanata* are combined under *A. conglobata*, and made the type-species of a new genus, *Cyathomorpha*, which is separated from *Agathiphyllia* by possessing a conspicuous palar crown. This procedure left two species, *A. depressa* (Reuss) and *A. explanata* Reuss, in *Agathiphyllia*. Reuss does not actually designate a type-species for *Agathiphyllia*, but, as he says, "Die Gattung *Agathiphyllia* dürfte sich daher auf die l.c.[4], Tab. 2, Fig. 8, 9 abgebildete *A. explanata* beschränken," I take *A. explanata* as the genotype, excluding the misidentified specimen of *A. conglobata*.

In an endeavor to ascertain the generic characters of *Brachyphyllia*, of course, *B. dormitzeri* must be studied. As there is no specimen of that species in the United States National Museum, Reuss's original description and the later one by Felix [5] were consulted, but neither are the details of the structure and mode of formation of the wall or of the septa, nor is the character of the endotheca given. At present it is not known whether *Brachyphyllia* is an imperforate coral belonging to the family Orbicellidae, or whether it is a fungid coral, related to or the same as *Cyathomorpha*.

Duncan [6] refers *Agathiphyllia* to the synonymy of *Cyathomorpha* without giving any reason for adopting the later instead of the earlier name. The type-species of *Agathiphyllia, A. explanata* Reuss, is from Oberburg, Styria. According to the figures, *Agathiphyllia* has not the wide paliform lobes of *Cyathomorpha;* but critical study of

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[1] K. K. Akad. Wiss. Wien., Mat.-Naturwiss. Cl., Denkschr., vol. 7, p. 103, 1854.

[2] Idem. vol. 23, p. 14, 1864.

[3] Idem. vol. 28, p. 143, 1868.

[4] Idem. vol. 23, p. 15, 1864.

[5] Palaeontographica, vol. 49, p. 260, 1903.

[6] Linn. Soc. London Journ. (Zool.), vol. 18, p. 105, 1884.

authentic specimens of the type-species is needed to ascertain whether the genus is or is not a fungid coral.

At present neither *Brachyphyllia* nor *Agathiphyllia* can be identified.

Cyathomorpha is a fungid genus that has the general appearance of *Orbicella*, with which it has been confused.

The next description is of the genotype.

CYATHOMORPHA ROCHETTINA (Michelin) Reis.

Plate 123, figs. 1, 1*a*, 1*b*, 1*c*, 1*d*, 1*e*.

1840-1847. *Astrea rochettina* Michelin, Icongraph. Zoophytol., p. 58, pl. 12, fig. 2.

1889. *Cyathomorpha rochettina* Reis, Bayer. geognost. Landesuntersuch. Geognost. Jahresh., Jahrg. 2, p. 147, pl. 3, figs. 17, 19. (With synonymy.)

There is in the United States National Museum one young specimen (No. 156900), from Crosara, Italy, received from the K. K. Museum für Naturkunde, Berlin. Plate 123, figures 1, 1*a*, 1*b*, presents a view each of the upper surface, of the side, and of the lower surface of this specimen, natural size.

On the base and in places on the sides of the corallum the edges of superposed layers are clearly seen, the lower edge of the outer layer often flaring somewhat. There are prominent, steep-sided, distant costae, crossed by transverse carinae; distance between costal crests usually ranges from about 0.75 to 1.5 mm. In places the courses of these costae are interrupted by what morphologically corresponds to septal perforations. Between the larger are small costae, which for the most part are represented by rows of spines. Exothecal dissepiments are present. The walls in general appear solid, but near the upper edges synapticulae and intercostal pits or perforations are distinguishable. The spines, trabeculae, of the small costae in places are joined to the large costae by synapticulae.

The larger septa are imperforate, at least for the most part, but the last two or three cycles are clearly perforate, composed of imperfectly fused trabeculae. Faces of large septa with carinae; synapticulae well developed, especially near the columella.

Columella large, trabecular; upper surface papillary.

The foregoing notes are not intended as a description of the species; their object is to emphasize the fact that *Cyathomorpha* is a fungid coral and to indicate its important generic characters. Reis[1] recognized the presence of synapticulae in this species but did not refer it to Madreporaria Fungida.

Localities and geologic occurrence.—Castel Gomberto, Crosara, and Sassello, Italy; Reit-im-Winkel, Bavaria; lower to middle Oligocene.[2]

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[1] Bayer geognost. Landesuntersuch. Geognost. Jahresh., Jahrg. 2, p. 147, 1889.

[2] Idem., pp. 93, 94.

CYATHOMORPHA HILLI, new species.

Plate 124, figs. 1, 1*a*; plate 125, figs. 1, 1*a*, 1*b*, 1*c*, 1*d*, 2, 2*a*.

Corallum with a small base, above which it increased in diameter; upper surface rounded; calices confined to the upper curvature; base and sides below the level of the calices naked, not even shreds of epitheca were observed. Below the calices, the sides of the corallum grow outward by the superposition of costate layers, each outer layer resting on the costae of the next inner layer, except at the lower edge where it may flare outward. The layers range in thickness from 0.5 and 1.5 mm.; usually they are imperforate, but in places perforations and synapticulae can be clearly recognized. The costae are narrow, steep-sided, fairly prominent, acute or rounded on the edges; distance between costal summits from 0.75 to 1.5 mm. The type is 112 mm. in horizontal diameter and 80 mm. tall.

Corallites protuberant from 1.5 up to more than 10 mm., average 5 or 6 mm.; distance between thecal summits of neighboring corallites from 3 to 10 mm., or even more. Corallite walls with a rather sharp upper edge; mostly imperforate. Some perforations and synapticulae, especially near the upper edges. Septo-costae low, subequal, wide, flattish or rounded in profile.

Calices subcircular, broadly elliptical, or compressed elliptical in outline. A large subcircular calice on the type is 18 mm. in diameter; a small, but apparently fully developed calice, on the same specimen, is 10 by 13 mm. in diameter; the shorter diameter of young calices is only 8 mm. The calices of the type are larger than those of the other specimens of the species. In paratype No. 1 (pl. 125, fig. 1), the largest calice is 11.5 by 13.5 mm. in diameter; the smallest is 8 by 13 mm. in diameter. In paratype No. 2 (pl. 125, fig. 2), the largest calice is 13.5 by 16.5 mm.; the smallest, 10 mm. in diameter. Unless the calices are young or stunted the average of the two diameters is rarely below 10 mm. Depth of calices slight, about 4 mm. a maximum; columellar fossa not deep.

The number of septa in the calice represented by plate 125, fig. 1*c*, paratype No. 1, is 70. This calice is 11.5 by 13.5 mm. in diameter, and is of the size about normal for the species. It has four complete cycles of septa and 22 quinaries. About 8 of the septa are thicker than the others, and bear thick paliform lobes which are fully half the width of the septa. These 8 septa and about 15 thinner septa extend to the columella; the thinner septa also bear wide paliform lobes. In general in a half or quarter system the septa of the penultimate cycle fuse to the sides of the included member of the next lower cycle, while the members of the last cycle are small. All except the smallest septa bear paliform lobes. Septal margins low over the wall, subentire; within the calice the thicker septa have subentire margins, the thinner septa have decidedly dentate edges. Larger septa solid; the thinner ones, especially those next to the last cycle, considerably perforate; septal faces granulate.

Synapticulae well developed, especially near the wall and near the columella; very obvious near the inner fusion of the septal groups. Some thin dissepiments present.

Columella rather coarsely trabecular, well developed, approximately one-third the diameter of a calice; upper surface sunken in a shallow central fossa.

Asexual reproduction by intercalicular budding.

Locality and geologic occurrence.—Antigua, in the Antigua formation, at stations 6881, Willoughby Bay (type and paratypes); 6854, Rifle Butts; 6856, south side of Friar's hill; 6888, one-half mile north of McKinnon's mill, collected by T. W. Vaughan.

Type.—No. 325204, U.S.N.M.

Paratypes.—No. 325205, U.S.N.M. (2 specimens).

That *Cyathomorpha hilli* is very nearly related to *Cyathomorpha rochettina* (Michelin) Reis, is shown by a comparison of the descriptions and figures here presented. *C. browni*, the next species to be described, differs from *C. hilli* by its prominent, acute costae, and by its septa higher than the second cycle being more strongly differentiated according to cycles.

It gives me pleasure to attach the name of Mr. Robert T. Hill to this handsome species.

CYATHOMORPHA BROWNI, new species.

Plate 126, figs. 1, *1a*, *1b*.

This species is similar to *Cyathomorpha hilli* in the general aspect of the corallum. It differs principally in having prominent, acute costae corresponding to all except the last cycle of septa, to which the corresponding costae are either very small or obsolete.

The calices range from about 8 to 13 mm. in diameter; average size smaller than in *C. hilli*.

In a calice 12.5 mm. in diameter there are 4 cycles of septa and in some systems the fifth is complete but it is represented by small, thin, rudimentary septa. Primaries and secondaries subequal; tertiaries and quaternaries shorter and thinner according to cycles. All septa except the last cycle bear thickened paliform lobes. The septa are thinner and the interseptal spaces relatively wider than in *C. hilli*.

Synapticulae present near the wall and near the inner ends of the septa. Apparently some thin dissepiments present.

Locality and geologic occurrence.—Antigua, in the Antigua formation, stations 6888, one-half mile north of McKinnon's mill (type, and three other specimens); 6868, Pope's Saddle, collected by T. W. Vaughan.

Type.—No. 325211, U.S.N.M.

This coral may ultimately be shown to intergrade with *Cyathomorpha hilli.* but according to the specimens available for study they are distinct.

Cyathomorpha browni is named for Prof. Amos P. Brown who paid considerable attention to the paleontology of the Central American and West Indian Tertiary formations.

CYATHOMORPHA BELLI, new species.

Plate 128, figs. 1, 1*a*, 1*b*.

Corallum more or less explanate, rounded above and flattish below; base without epitheca, similar in this character to *C. rochettina.*

Calices large, 11.5 mm. a usual measure of the diameter, range in diameter from 7.5 mm. (a small calice) to 12.5 mm.; distance apart from 3.5 to 10.5 mm.; calicular rims elevated up to as much as 5 mm., usually lower on the distal than on the proximal side. Calicular cavities relatively shallow in comparison with the diameter, depth about 2.5 mm. Corallite walls with few or no perforations except at the upper edge; appear to be originally synapticulate and subsequently compacted.

Costae at the calicular edge subequal or slightly alternating in size, corresponding to all septa; but just below the calicular edge the costae corresponding to the last cycle of septa tend to decrease in size and usually disappear at the base of the free corallite limb, while the costae corresponding to the lower cycles of septa tend to increase in height and extend as rather prominent plates on to or even across the intercorallite areas. Costal edges with low beading.

The septa in a calice 10 mm. in diameter are only 46 in number; in another calice 9.25 by 13 mm. in diameter there are 48 septa. Therefore, in comparison with the size of the calices, there are relatively few septa, barely four cycles. In general the following is the septal arrangement: primaries and secondaries extend to the columella, and have a circle of single or double paliform lobes; tertiaries extend to or almost to the columella, but are thinner than the primaries and secondaries, and many bear a paliform lobe near the columella; the quaternaries are shorter and thinner, some of these bear pali. Over the mural summit the margins of all septa are subequally slightly exsert, about 0.6 mm. is a maximum, average between 0.25 and 0.5 mm. Large septa solid; higher cycles with perforations. Septal arch a gradual curve. Margins with some dentations.

Columella large, about 3 mm. in diameter or nearly one-third the diameter of the calice, trabecular, more or less whorled.

Synapticulae present, especially near the columella. Endothecal dissepiments highly developed and vesicular.

Locality and geologic occurrence.—Antigua, station 6854, Rifle butts, Antigua formation, collected by T. W. Vaughan.

Type.—No. 325218, U.S.N.M.

This species is dedicated to His Excellency Sir H. Hesketh Bell, Governor of the Leeward Islands at the time I collected in Antigua and other Leeward Islands. It was to his helpfulness that the success of my work was largely due.

On page 389 of this paper attention is directed to the resemblance between *Orbicella costata* (Duncan) and *Cyathomorpha belli.*

CYATHOMORPHA SPLENDENS, new species.

Plate 128, figs. 2, 2*a*, 2*b*.

Corallum unifacial, calices on the upper surface; base naked, with wide, low costae. Maximum thickness of type 24.5 mm.; thickness to base of corallite 15 mm.

Calices shallow, but excavated; diameter, 17.5 by 20 mm.; margin elevated 4 mm. on one side, 9 mm. on the other side. Strong subequal costae correspond to all septa except those that are rudimentary.

Septa 54 in number, the quinaries rudimentary; primaries and secondaries larger than the septa of higher cycles.

Columella large, 8 mm. in diameter, surface coarsely papillate.

Dissepiments greatly developed; synapticulae present.

Locality and geologic occurrence.—Antigua, station 6854, in the Antigua formation, Rifle Butts, collected by T. W. Vaughan.

Type.—No. 325219, U.S.N.M.

The description of this species is brief, because a more elaborate one would be largely a repetition of what has been said under the four preceding descriptions. The most nearly related species is *C. belli,* from which it differs by the wider and lower costae of its lower surface, its much larger calices, and, in comparison with the size of the calices, its fewer septa.

CYATHOMORPHA ANGUILLENSIS, new species.

Plate 127, figs. 1, 2, 3, 4, 5.

This species is usually characterized by its large, distant, and prominent calices.

Dimension of calices of Cyathomorpha anguillensis.

	1	2	3	4	5	6	7
	mm.	*mm.*	*mm.*	*mm.*	*mm.*	*mm.*	*mm.*
Greater diameter	18.5	15	12	14.5	15	14	11
Lesser diameter	14.5	14.5	12	12.5	14	12.5	9.5

The young calices, of course, are smaller.

Distance apart 7 to 20 mm. Isolated calices may be decidedly prominent, 5 mm. or more in height. Depth, moderate.

The corallites externally are strongly costate; large, tall, thin costae alternate with much smaller ones. The intercostal spaces wider than the costae. Wall mostly dissepimental, but there are some synapticulae with intervening perforations similar to those in *C. rochettina*.

Septa in the larger calices between 70 and 80, the various systems and cycles are not distinctly differentiated, about 24 reach the columella. Within the wall the septa are thin, in the thecal ring they are thicker; the costae are thicker than the inner portions of the septa. Pali before the members of the first three cycles of septa. Both synapticulae and dissepiments present.

Columella large, composed of twisted, interlacing, fused inner ends of septa. Its diameter about one-third the diameter of the calice.

Localities and geologic occurrence.—Island of Anguilla, West Indies, collected by P. T. Cleve; station 6969*a*, bottom bed, Road Bay, Anguilla, collected by T. W. Vaughan.

A specimen from station 7509, west of Ocujal Spring, conglomerate boulder on hill of limestone conglomerate, near Guantanamo, Cuba, collected by O. E. Meinzer, seems to be referable to this species; it is a large caliced species of *Cyathomorpha*, and I have found no differences between it and *C. anguillensis*.

Type.—University of Upsala (pl. 127, fig. 1); 4 specimens in the United States National Museum.

Three specimens belonging to the University of Upsala collection are typical, although they show some variation. Four other specimens show gradual decrease in both the size and prominence of the calice. These four specimens are figures on plate 127, figures 2, 3, 4, 5. With them before one it does not seem possible to separate sharply the large and prominent caliced specimens from those with smaller (7 mm. diameter) and only slightly prominent calices.

The specimens with smaller, less prominent calices closely resemble the specimens described below under the name *C. roxboroughi*.

CYATHOMORPHA ROXBOROUGHI, new species.

Plate 129, figs. 1, 1*a*, 1*b*.

Corallum massive, usually rather broadly and obtusely conical in shape. Type—greater diameter of base, 111 mm.; lesser diameter of base, 73 mm.; height, 103 mm. The rather large difference in the basal diameters is probably in part due to compression. A paratype has a greater basal diameter of 121 mm.; lesser basal diameter, 108 mm.; height, 96 mm. Base without calices; apparently some shreds of epitheca. Costae of base, low, rather crowded, subequal, with clearly visible synapticulae between them.

Calices very shallow, quite or almost superficial, with margins ranging from flush with the intercorallite areas up to 3.5 mm. or more in height. In some corallites the free limb on the lower side is from 6.5 to 9 mm. long, while the margin of the upper side is only slightly elevated. The calicular outline is subcircular or broadly elliptical; the diameter ranges from 6 to 10 mm., 8 to 9 mm. usual for fully developed calices. Distance between calicular rims ranges from 4 to 13 mm. Intercalicular area flattish except near the peripheries of the calices where they slope upward rather steeply if the calices are elevated. Septo-costae correspond to all septa and are subequal at the calicular margins; lower down they are either subequal, low, broad, and with flattish or rounded summits, or they alternate in prominence; where there is such alternation the edges are usually acute. Transversely compressed granulations on some septo-costae, but usually the margins are almost smooth. The septo-costae are confluent between adjacent corallites or meet at a sharp angle; outer limits of corallites usually marked by a circumscribing ridge that joins adjacent septo-costae. Synapticulae distinct between the septo-costae, in both transverse and longitudinal sections. Walls with synapticulae near the upper edge.

Septa thick, lanceolate, in the wall, rapidly thinning within the calicular cavity. In a calice 8 mm. in diameter there are 38 septa, every other one of which extends to the columella. There are strongly developed, thick, prominent pali on the inner ends of all unbroken long septa, obscurely arranged in two crowns. Unless decidedly small the septa of the last cycle fuse to the sides of the septa of the next lower cycle; in some systems tertiaries fuse to secondaries and quarternaries to tertiaries. Septal margins subentire or obscurely dentate. Usually the lamellae are solid, but broken transverse sections of the corallites of a specimen not the type show some perforations. Synapticulae well developed.

Columella large, coarsely trabecular, in the center of the shallow flat-bottomed calice.

Asexual reproduction by intercalicular gemmation.

Locality and geologic occurrence.—Anguilla, at the following stations: 6962, 1 mile northeast of Boat Harbor (type); 6893, Crocus Bay, on roadside from Valley Post Office down the bluff (7 specimens); 6894, west side of Crocus Bay, probably from the lower part of the exposure (paratype); 6963, west side of Sandy Hill (2 specimens), collected by T. W. Vaughan. Professor Cleve obtained at least one and I obtained 11 identifiable specimens of this species in Anguilla.

Type.—No. 325250, U.S.N.M.

Paratype.—No. 325248, U.S.N.M.

This is the species to which I referred as *Diploastrea* from the lowest horizon of the exposure at Crocus Bay, Anguilla, in discussing the genus *Diploastrea* in my paper entitled: Some shoal-water corals from Murray Island (Australia), Cocos-Keeling Islands, and Fanning Island.[1] My remarks particularly applied to the paratype from station 6894.

Cyathomorpha roxboroughi closely resembles those specimens of *C. anguillensis* with smaller calices.

C. roxboroughi is named for His Honor T. L. Roxborough, who was administrator of St. Christopher while I was there and to whom I am indebted for many acts of courtesy and kindness.

CYATHOMORPHA ANTIGUENSIS (Duncan) Vaughan.

Plate 129, fig. 2; plate 130, figs. 1, 1*a*, 2, 2*a*, 3; plate 131, figs. 1, 1*a*, 1*b*, 2, 3, 4; plate 132, figs. 1, 2, 2*a*, 2*b*; plate 133, fig. 1.

1863. *Astraea antiguensis* Duncan, Geol. Soc. London Quart. Journ., vol. 19, p. 419, pl. 13, fig. 8.

1863. ?*Astroria affinis* Duncan, Geol. Soc. London Quart. Journ., vol. 19, p. 425.

1863. *Astroria antiguensis* Duncan, Geol. Soc. London Quart. Journ., vol. 19, p. 425.

1866. ?*Astroria affinis* Duchassaing and Michelotti, Sup. Corall. Antilles, p. 83 (of reprint).

1866. *Astroria antiguensis* Duchassaing and Michelotti, Sup. Corall. Antilles, p. 83 (of reprint).

1866. *Heliastraea antiguensis* Duchassaing and Michelotti, Sup. Corall. Antilles, p. 86 (of reprint).

1867. ?*Astroria affinis* Duncan, Geol. Soc. London Quart. Journ., vol. 24, p. 24.

1867. *Astroria antiguensis* Duncan, Geol. Soc. London Quart. Journ., vol. 24, p 24.

1867. *Heliastraea antiguensis* Duncan, Geol. Soc. London Quart. Journ., vol. 24, p. 24.

1870. ?*Astroria affinis* Duchassaing, Rev. Zooph. Antilles, p. 30.

1870. *Heliastraea antiguensis* Duchassaing, Rev. Zooph. Antilles, p. 30.

1870. *Astroria antiguensis* Duchassaing, Rev. Zooph. Antilles, p. 30.

This species was referred by me doubtfully to the synonymy of *Orbicella cavernosa* (Linnaeus) in my Fossil Corals from the Elevated Reefs of Curacao, Arube and Bonaire,[2] not having recognized at that time that the species is one of the Madreporaria Fungida.

Original description.—"Corallum large, turbinate, convex and gibbous above, with a very small base. Corallites long, close, rather crowded, but distinct and radiating from the narrow base. Walls well developed, moderately thick. Costae moderately developed, projecting more than the width of their base; they are plain where seen superficially, very nearly equal, and are not spined or toothed. In some corallites the fourth cycle of costae is wanting, but not in those that are fully developed. Calices circular, slightly raised,

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[1] Carnegie Inst. Washington Pub. 213, p. 142, 1918.

[2] Geologisch. Reichs. Museum Leiden Samml., ser. 2, vol. 2, p. 28, 1901.

appearing as truncated cones, sometimes compressed (at the side of the corallum they are distorted), unequal in size; margins thin. Fossa not deep, but variable. Columella well developed, projecting at the bottom of the fossa; its component tissue is laminar and folded, and it is rounded above. Septa straight, very slightly exsert, delicate throughout, not larger at any point decidedly; but the largest are more delicate midway between the walls and the columella; they are arranged in six systems of four cycles. The primary and secondary septa are equal; the tertiary a little smaller; those of the fourth order are very small, and barely developed in some calices, but they exist in all. The primary and secondary septa have a tooth near the columella. Endotheca tolerably developed. Exotheca well developed, forming large and small cells, both square, though often divided by dissepiments. Reproduction by extracalicular gemmation. There is no epitheca.

"*Dimensions.*—Height of corallum several inches; diameter of calices from a little less than 3 lines to 4 [6.25 to 8.3 mm.]; thickness of septa one-sixtieth inch [0.4 mm.]. The dimensions of the elliptical calices are—length, 3½ lines [7.3 mm.]; breadth, 2½ lines [5.2 mm.]; depth of fossa, two-thirds of a line [1.4 mm.]. Exothecal cells from one-fourth to one-half line [0.5 to 1 mm.]. The lateral calices are very irregular, and the younger corallites have three cycles of septa.

"*Fossillization.*—Calices, as a rule, not filled up. Sclerenchyma light-brown in color, opaque, and siliceous, the central portions of the corallum evidently consisting of dark homogeneous flint, the sclerenchyma having been destroyed in the process of silicification.

"From the Marl-formation of Antigua. Coll. Geol. Soc."

Plate 130, figures 2, 2*a*, presents illustrations of Duncan's type (No. 12942, collection of the Geological Society of London). Duncan was of the opinion that this species belonged to the genus *Heliastraea* Milne Edwards and Haime, which is a synonym of *Orbicella* Dana. It was my belief that the species was referable to *Orbicella* until I obtained a number of remarkably good specimens in Antigua. A selected series of these will be described in the following remarks:

The corallum forms rounded or discoid masses, the two largest I collected having the following dimensions: No. 1, horizontal diameter, 225 by 305 mm.; height, 155 mm. No. 2, horizontal diameter, 322 by 400 mm.; height, 131 mm. Specimen No. 1 has a more arched upper surface than No. 2 which is more discoid in shape.

On the lower surface of the corallum there is very little epitheca—only shreds in places. Costae are well-developed, subequal, interrupted here and there; intercostal furrows perforate, many synapticulae present, joining the outer ends of adjacent septa (see pl. 130, figs. 1, 1*a*).

The series of figures (pl. 131, figs. 1, 2, 3), shows the range in size, shape, depth, and distance apart of the calices. Except very young calices, which may be only 3 mm. in diameter, the range in diameter of these on the specimen represented by plate 129, figure 2, is from 5.5 to 10 mm.; on the specimen represented by plate 130, figure 3, one calice is 12.5 mm. in diameter. In shape the calices are subcircular, elliptical, deformed elliptical, or, where crowded, polygonal. The depth ranges from superficial to as much as 4.5 mm. or a little more, but on most specimens the calices are rather shallow. The distance apart ranges from 0.75 mm. to nearly 10 mm. Plate 131, figure 3, shows polygonal crowded calices and distant circular calices on the same specimen. Costae subequal or slightly alternating, correspond to all septa. Their margins, where perfectly preserved, are beaded, in places interrupted. Unless the calices are very crowded, synapticulae are obvious between the costae. The corallite walls are synapticulate and very perforate (see pl. 131, fig. 1*a*).

The septa are usually thin, in about 4 cycles, as many as 58 in large calices. Primaries and secondaries subequal, extend to the columella; tertiaries rather long but usually do not reach the columella; quaternaries, and quinaries where present, are shorter. In many calices some tertiaries fuse to the sides of the secondaries, and the quaternaries may fuse to the sides of the tertiaries; but there is much variation, in some systems there are no septal groups by fusion. The septal arches may be rather wide, the septal edges gradually curving over the calicular rim; or the arches may be narrow, the septal edges falling steeply to near the level of calicular bottom—both of these conditions occur on the same specimen. Primary and secondary septa appear imperforate, should there be perforations they are rare; higher cycles perforate. Septal faces with carinae and granulations. Margins of larger septa finely beaded; margins of members of higher cycles more conspicuously dentate. Prominent, rather wide, thickish, paliform lobes before the primary and secondary septa; an outer palar crown before the tertiary septa.

Columella fairly well developed, trabecular; upper surface papillary in the best preserved calices.

Synapticulae abundant within the corallite cavities. Endothecal dissepiments also present.

Asexual reproduction by intercalicular budding.

Localities and geologic occurrence.—Antigua, in the Antigua formation, at stations 6854, Friar's Hill; 6856, Rifle Butts; 6881, Willoughby Bay; 6888, one-half mile north of McKinnon's Mill, collected by T. W. Vaughan, a total of about 35 specimens.

Porto Rico, in the Pepino formation, station 3191, 4 miles west of Lares, Porto Rico, collected by Robert T. Hill.

Cuba, station 7514, 5 miles east of monument H4 of U. S. Naval Reservation, Guatanamo, altitude 400 feet a. t., collected by O. E. Meinzer.

Mexico, in the San Rafael formation, 4 miles east of Salitre Ranch, State of Tamaulipas, collected by W. F. Cummins and J. M. Sands.

The foregoing description, except the measurements of the large specimens, is based entirely on the five specimens represented by plate 129, figure 2; plate 130, figures 1, 1*a*, 3; plate 131, figures 1, 1*a*, 1*b*, 2, 3. Two of these specimens, plate 129, figure 2 and plate 130, figures 1, 1*a*, 3, are from station 6881, Willoughby Bay; and three, plate 131, figures 1, 1*a*, 1*b*, 2, 3, are from station 6854, Rifle Butts Antigua. The specimen from Salitre Ranch, Tamaulipas, Mexico, is so completely typical that no further notes on it are necessary. Two of the specimens from Porto Rico, plate 132, figures 1, 2, 2*a*, 2*b*, have thicker primary and secondary septa, and the costae corresponding to the last cycle of septa seem usually to be small or even obsolete in places. The rear side of the specimen, general view, plate 132, figure 2, has calices and costae so nearly typical that it can scarcely be regarded as more than a variant of *C. antiguensis.*

The specimen from station 7514, near Guatanamo, represents the same variant as the Porto Rico specimens.

Duncan's *Astroria affinis*, I believe, is based on a specimen of *Cyathomorpha antiguensis* that has crowded, polygonal corallites. Plate 133, figure 1, represents the type (No. 12938, Coll. Geol. Soc., London), and the following is the original description: "Corallites crowded. Walls very thin indeed. Transverse section of corallites polygonal, rarely forming short series. Columella slightly but decidedly developed. Septa alternately large and very small, linear, a little larger externally, with at least four cycles in six systems. Breadth of the calices four lines [8.4 mm.]; five septa to one line [2.1 mm.]. Endotheca abundant.

"From the Chert-formation of Antigua. Coll. Geol. Soc."

In my notes on the type, I say that *A. affinis* is undoubtedly the same as Duncan's *Astroria antiguensis* type (No. 12936, Coll. Geol. Soc. London), illustrated by plate 131, figure 4 of this paper; but I am not certain that it is different from *C. tenuis*, the species to be considered next. The original description is as follows:

"Corallites not crowded, but close, tall. Walls rather thin. The transverse section of the corallites is in many cases circular, in others obscurely polygonal; some present short series, but rarely. Columella very indistinct. Septa alternately large and small, in six systems of four cycles, the fourth being occasionally deficient in two systems. Breadth of the corallites, from 2 to 3½ lines [4.2 to 7.3 mm.]. Length of the series, 6 lines [12.7 mm.]: five septa to a line [2.1 mm.]. Endotheca abundant.

"Fossilization like that of the other Astrorians, and rendering the details indistinct. It is closely allied to the other species of *Astroria* from Antigua.

"From the Chert-formation of Antigua. Coll. Geol. Soc."

CYATHOMORPHA TENUIS (Duncan) Vaughan.

Plate 132, figs. 3, 3*a*; Plate 133, figs. 2, 3, 3*a*, 3*b*.

1863. *Astraea tenuis* Duncan, Geol. Soc. London Quart. Journ., vol. 19, p. 421, pl. 13, fig. 11.

1867. *Heliastraea tenuis* Duncan, Geol. Soc. London Quart. Journ., vol. 24, p. 24.

1901. *Orbicella tenuis* Vaughan (*part*), Geolog. Reichs Mus. Leiden Samml., ser. 2, vol. 2, p. 33.

This species, as well as *Astraea antiguensis* Duncan, was erroneously confused with *Orbicella* Dana. I obtained excellent material in Antigua, which shows that both the common corallum wall and the corallite walls are synapticulate. Three views of one of these species are given on plate 133, figures 3, 3*a*, 3*b*. Plate 133, figure 3, is a general view of the upper surface of the corallum; figure 3*b* shows the synapticulate character of the common wall; and figure 3*a* illustrates the costae and the synapticulae between them.

The following description is based upon four specimens collected by Mr. Robert T. Hill at a locality 4 inches west of Lares, Porto. They satisfy in all particulars Duncan's description of *C. tenuis* and differ in no important particulars from the Antiguan specimens.

The corallum is pulvinate, with the calices confined to the upper surface and sides.

Dimensions of specimens of Cyathomorpha tenuis (Duncan).

Specimen No.	Greater diameter.	Lesser diameter.	Height.	
	mm.	*mm.*	*mm.*	
1[1]	69	52	55	Specimen apparently somewhat crushed.
2	87	70	58	
3[1]	100	100	45	Specimen subquadrangular in shape.
4	126	97	64	

[1] Specimens figured.

The calices of specimen No. 1 (pl. 132, figs. 3, 3*a*) are described, although those along the top have been somewhat deformed through lateral compression of the corallum. The calices on the upper part of the surface have slightly elevated margins; 0.75 mm. is the maximum height. Some calices are rather deep, about 2 mm.; the diameter of the most nearly circular ones ranges from 3.5 to very slightly more than 4 mm.; the distance between adjacent calices is from a mere dividing ridge to 2 mm.; the calicular edges, however, are usually distinct. Around each calice and joining adjacent ones are equal, acute costae, between which are synapticulae. On the sides, near the lower edges, the calices flatten, become larger and more distant, and are either circular or faintly hexagonal in outline. Diameter from 4.5 to 5 mm.; distance apart, from 0.5 to 2 mm.; the range in the distance apart is the same as on the top, but the calices are more uniformly separated. The costae are distinct, low, and equal, with numerous intervening synapticulae.

The number of septa to a calice is the same for both the top and sides, ranging from 26 to a few over 30. They are relatively thin; that is, not so thick as the width of the interseptal loculi, except that they are thickened at the wall and the principals are thickened on their inner ends, bearing distinct paliform lobes. The primaries and secondaries are subequal, extend to the columella, and are paliferous; tertiaries shorter and thinner within the calice; quaternaries, where present, still smaller. The wall is composed of peripheral synapticulae.

Columella only slightly developed.

The preceding description is based on a single specimen—No. 1 of the table. The principal variation shown by the other specimens is in the distance apart and size of the calices and the number of septa. In specimen No. 3 (see pl. 133, fig. 2) the calices are usually about 0.75 mm. apart; their diameter ranges from 3.5 to 5.7 mm., and, as would be expected, the calicular outlines are polygonal; there are in the larger calices as many as 40 septa, the fourth cycle, however, in these calices seems never to be complete, but it is complete in some large calices of the Antiguan specimens. Palar thickenings can be seen on the larger septa; columella poorly developed.

Localities and geologic occurrence.—Island of Antigua at numerous localities in the Antigua formation, collected by T. W. Vaughan.

Porto Rico, station 3191, in the Pepino formation, 4 miles west of Lares, collected by Robert T. Hill.

Cuba, station 3467, Canapu River, Manasas trail, collected by Arthur C. Spencer. Station 7511, between Ocujal and Palma, altitude about 500 feet a. t., near Guantanamo, Cuba, collected by O. E. Meinzer. Station 7514, 5 miles east of monument H4 of U. S. Naval Reservation, Guantanamo, Cuba, altitude 400 feet a. t., collected by O. E. Meinzer.

Prof. K. Martin, director of the Geologisch Reichs Museum, Leiden, submitted to me for determination some material from Serro Colorado, Arube, that I thought referable to this species.[1] At the time I studied these specimens I was of the opinion the species belonged to the genus *Orbicella*. The specimens referred to *O. tenuis* in the paper cited are referred in the present paper to *Antiguastrea cellulosa* (Duncan) Vaughan (see p. 407).

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[1] Geolog. Reichs Mus. Leiden Samml., ser. 2, vol. 2, p. 33.

Cyathomorpha tenuis in some of its characters is very similar to *Oulastrea*. In fact I have vacillated between referring it to *Cyathomorpha* or to *Oulastrea*, particularly as there is in the New York Academy Porto Rican collection a species that resembles *C. tenuis*, but is more appropriately referable to *Oulastrea* than to *Cyathomorpha*, and a specimen, poorly preserved but apparently the same species, was obtained by Mr. Meinzer at Mogote Peak, east of the U. S. Naval Reservation, near Guantanamo, Cuba, in beds of the same age as those in which the Porto Rican specimen was collected. As the Cuban material is not good enough for an accurate description, the discussion of this interesting species must be deferred.

Genus **DIPLOASTREA** Matthai.

1914. *Diploastrea* Matthai, Linn. Soc. London Trans., ser. 2, Zool., vol. 17, p. 72.
1917. *Diploastrea* Vaughan, Carnegie Inst. Washington Pub. 213, p. 142.

Type-species.—*Astrea heliopora* Lamarck.

In my paper cited in the synonymy I wrote "*Diploastrea* is one of the most important genera of Oligocene corals in the southeastern United States and in the West Indies. *Astraea crassolamellata* Duncan, from Antigua belongs to it. It is also found in the lowest horizon at Crocus Bay, Anguilla; in Cuba at numerous localities; along Flint River near Bainbridge, Georgia; and in eastern Mexico."

I also remarked that *Diploastrea* might ultimately become a synonym of *Cyathomorpha*. I am referring the Crocus Bay specimen to *Cyathomorpha roxboroughi* Vaughan, new species (see page 461 of this paper), and am referring the Mexican specimen to *Cyathomorpha antiguensis* (Duncan) Vaughan (p. 466 of this paper). *Diploastrea*, *Cyathomorpha*, and *Oulastrea* are closely related genera. All are fungid corals that resemble in habit the genus *Orbicella*, and all have been confused with it. *Diploastrea* has more coarsely dentate and more perforate septa than *Cyathomorpha*, and it lacks the prominent, wide pali of *Cyathomorpha;* but the inner septal teeth of *Diploastrea* in many instances simulate pali. For the present at least it is desirable to treat each as a valid genus. According to Reuss (see p. 455 of this paper), *Agathiphyllia* differs from *Cyathomorpha* in not having pali; therefore, *Diploastrea* may be a synonym of *Agathiphyllia*.

Before discussing the species here referred to *Diploastrea*, mention will be made of two species—*Brachyphyllia eckeli* [1] and *Brachyphyllia irregularis* [2] described by Duncan from St. Croix, Trinidad. These, according to the figures, are fungid corals, and probably are referable to *Diploastrea*. The costae of the type-species of *Diploastrea* are either confluent or notched in the intercorallite areas. *Brachyphyllia*, until the type-species, *B. dormitzeri*, has been studied and

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[1] Geol. Soc. London Quart. Journ., vol. 24, p. 13, pl. 2, fig. 4, 1867.
[2] Idem, p. 13, pl. 2, fig. 5.

described in more detail is an unidentifiable genus (see pp. 455, 456 of this paper).

DIPLOASTREA HELIOPORA (Lamarck) Matthai.

Plate 134, figs. 1, 1*a*, 1*b*, 1*c*.

1816. *Astrea heliopora* LAMARCK, Hist. nat. Anim. sans Vert., vol. 2, p. 265.
1914. *Diploastrea heliopora* MATTHAI, Linn. Soc. London Trans., ser. 2, Zool., vol. 17, p. 72, pl. 20, figs. 7, 8; pl. 34, fig. 9.
1917. *Diploastrea heliopora* VAUGHAN, Carnegie Inst. Washington Pub. 213, p. 143, pl. 59, figs. 5, 5*a*.

Figures 1, 1*a*, 1*b*, 1*c*, plate 134, are intended to illustrate the generic characters of the genotype. Plate 134, figure 1, is a natural size view of the calices; figure 1*b* is a view of the calices enlarged four times. These figures illustrate the imperfect, synapticulate wall as seen from above, the dentate septal margins, and the trabecular columella. It should be noted here that the septal margins are not so prominent nor are they so coarsely dentate in all specimens. Plate 134, figure 1*a*, illustrates the costae of the edge of the lower part of the corallum, four times enlarged, and shows that the common wall originally is synapticulate and perforate. Plate 134, figure 1*c*, is a longitudinal section of the corallites, four times natural size, to illustrate the interrupted corallited walls, the perforate character of the septa, and the synapticulae and dissepiments on the septal faces.

Geographic distribution.—*Diploastrea heliopora* is found on the living coral reefs of the Indo-Pacific from the east coast of Africa, French Somaliland, eastward at least as far as the Fiji Islands. The specimen here figured is from Djibouti, French Somaliland, collected by Dr. Charles Gravier.

DIPLOASTREA CRASSOLAMELLATA (Duncan) Vaughan.

Plate 135, figs. 1, 2, 3, 4, 4*a*, 5, 5*a*, 5*b*; plate 136, figs. 1, 1*a*, 1*b*; plate 137, figs. 1, 2, 3, 4, 4*a*, 5.

1863. *Astraea crassolamellata* DUNCAN, Geol. Soc. London Quart. Journ., vol. 19, pp. 412–417, pl. 13, figs. 1–7.
1866. *Heliastraea crassolamellata* DUCHASSAING and MICHELOTTI, Sup. Corall. Antilles, p. 86 (of reprint).
1857. *Heliastraea crassolamellata* DUNCAN, Geol. Soc. London Quart. Journ., vol. 24, p. 24.
1870. *Heliastraea crassolamellata* DUCHASSAING, Rev. Zooph. Antilles, p. 30.
1902. *Orbicella crassolamellata* and *Brachyphyllia* sp. VAUGHAN, Geol. Soc. London Quart. Journ., vol. 57, p. 497.

The following are Duncan's original descriptions of the general characters of this species and of the typical form, and his synopsis of the seven varieties into which he subdivided it:

General description.—"A group of forms from the Marl presents the following structural characteristics: Corallum very massive and large, with an irregular upper surface, which is convex in some parts, almost flat in others, and more or less largely gibbous in all; intercalicular groove very decided. Corallites usually very large, and never very small. Wall very delicate and indistinct; costae small; columella large. Septa variable in cyclical arrangement, the larger excessively developed at the wall and linear within. Endotheca abundant, but not in excess, vesicular. Exotheca not well developed, but decided and plentiful. Calices invariably found as casts. Impressions prove them to have been shallow. Coenenchyma well developed.

"These characters, common to many forms, are more or less varied in intensity in different specimens. The septal number varies in individuals of the same corallum, in one series of forms to a remarkable extent, although the corallites thus differing are nearly equal in diameter, and are nearly, if not quite, as advanced in development. In other forms it is fixed to four cycles in six systems; whilst in some there are three cycles in some systems, and only two in others, the corallum being large.

"The form which I consider typical of the species has four perfect cycles in six systems; but in some corallites the rudimentary sixth and seventh orders of a fifth cycle exist. The specific characteristics—the thick and great development of the septal laminae at their wall end, and the more or less linear, but entire, conditions of their internal parts—are seen in all these forms, in the primary, secondary, and tertiary septa, according to the relative septal arrangements. In some corallites with a low septal number, the primary septa alone are thus characterized; and as the higher cycles are seen, so the secondary and tertiary septa become enlarged and resemble the primary. The septa of the higher orders are either linear throughout or slightly enlarged at the wall; and as they approach the tertiary or quaternary, as the case may be, they are seen to become more equal to them in size. In examining these forms allowance must be made for their fossil condition; and attention must be given, in examining transverse sections of corallites, that they are quite at right angles to the corallite, for any obliquity will, of course, diminish the peculiar spear-shape or mace-shape of the septa, and render them more like a paddle, or a leaf with the stalk attached.

"The tendency of the higher orders of septa to become linear throughout, or to be less decidedly large at one end and thin elsewhere—that is, more or less uniformly thick, but in a less degree than is usual at the wall—is seen throughout the species; and in a gigantic variety, where the fully developed corallites have 12 or 14 septa in every system, the whole of the septa are less decidedly thick at the wall, and are either more or less so throughout, or present the usual form of the septa in a modified degree.

"This species is found throughout the great Marl formation, and presents every variety of siliceous fossilization, from that characterized by silicification of the sclerenchyma and infiltration of the interspaces by granular carbonate of lime, to that where all is siliceous and capable of polish. Destructive silicification almost invariably exists in a greater or less degree; and as the sections preserved were made, as a rule, for ornament or amusement, I have seldom seen accurately transverse and longitudinal views of the corallites.

"All the specimens, with the specific peculiarities mentioned, may be ranged in several groups; that which contains the detailed characters in their greatest intensity, generally, may be considered the typical form.

"*a. Astraea crassolamellata,* typical form.

"Corallum large, irregularly convex above. Corallites tall, large, crowded here and there, but not so much so higher up or at the surface. Calices circular, but more or less elliptical when on an irregularity of the surface; very large, and separated from each other by well-marked, furrow-shaped, polygonal tracts; tracts marked by costal elevations and by granules.[1] Calices crateriform, not much elevated above the surface. Wall thin, and rendered insignificant by the great development of the septa at the margin. Fossa not deep. Costae numerous, and, considering the diameter of the septa at the wall, very small; they project but little, and are, as a rule, alternately large and small, not dentate, and often incline one to the other at their free edge. The larger costae present regular enlargements where the cross-tissue (dissepiments) of the exotheca joins them, when there are more than four cylces of septa, the smaller costae are irregular as regards their appearance and development. Columella large, of lax laminae, parietal; it does not project much at the bottom of the fossa, and occupies a large space in the corallite. Septa numerous, generally characterized by great enlargement at the wall, and linear appearance in the rest of their course, the higher orders being nearly linear at the wall also. The number of cycles varies with the stage of development of the corallite.

Analysis of the species.

	Intercalicular furrow.	Septa.	Cycles.	Diameter of corallites.
a. Astraea crassolamellata (type).	Well marked....	Very thick at wall..	4, in some 5..	19 to 20 mm.
b. ———var. *magnetica*......	.....do..........	.....do..............	4............	12.7 mm.
c. ———var. *pulchella*........	Less well marked	.....do..............	Variable....	8 to 12.7 mm.
d. ———var. *nobilis*..........	.....do..........	Very large at wall...	.....do......	Variable.
e. ———var. *minor*...........	.....do..........	Very thick at wall..	2 and 3......	Small, variable.
f. ——— var. *nugenti*.........	Less marked....	.....do..............	.....do......	Do.
g. ———var. *magnifica*.......	Well marked....	Less thick, more linear.	4 to 6........	8 to 25 mm. and more.

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[1] As none of the specimens exhibit, perfect calices many of these characters have, of necessity, been taken from casts.

"In young corallites there are six systems of three cycles. As growth proceeds the other orders of the fourth and sometimes of the fifth cycle are gradually added. Some systems are defective in certain orders, while others possess them. The largest corallites have four perfect cycles, and a fifth in two or three systems; the ninth order being usually wanting. It is difficult, in the larger corallites, to distinguish the systems on account of the resemblance of the primary, secondary, and tertiary septa to each other.

"The primary septa are very thick externally, but delicate and linear elsewhere; the linear part joins the rest suddenly, like the staff of a big-headed spear; at the junction the thick corners of the enlargement give off a lateral spine, like a piece of endotheca; near the costal end of the septa there are delicate lateral spines. The space between the sets of lateral spines is more or less square. The secondary septa are very like the primary.

"When there are more orders in the system than five—that is, when there are six, seven, eight, and nine—the tertiary septa equal the primary and secondary, the blunt end terminating in the linear portion a little nearer the wall. When there are four cycles, the tertiary septa are smaller than the primary and secondary; and when there are only three cycles, as in young corallites, the tertiary septa are linear throughout. The quaternary septa are linear and very slightly developed; when there are more septa than those of the fourth cycle, the quaternary resemble small tertiary septa. The remaining septa are very small and linear, and reach a very little way from the wall; they are apt to curve towards the septa nearest them. In examining the shape of the septa in this and in all the allied forms, particular attention must be paid that the section is quite transverse, as any obliquity will more or less alter the shape of the larger end.

"As regards the endotheca, the dissepiments are frequent and delicate, and not very much developed. The exotheca is tolerably well developed, but not in proportion to the size of the corallites. Its dissepiments form square cells. The free surface between the costae and calices has a few granules. Increase by extracalicular gemmation.

"Marl formation of Antigua. Coll. Geol. Soc.

"*Measurements.*—Diameter of the calices in six specimens $\frac{3}{4}$ inch [19 mm.], in seven others $\frac{4}{5}$ inch [20 mm.], and in some from $\frac{1}{2}$ to $\frac{1}{4}$ inch [12.5 to 6.25 mm.]. The elliptical calices (situated on the sides of the corallum) are about $1\frac{1}{10}$ inch [27.5 mm.] in longest diameter. The greatest thickness of the septa at the wall is $\frac{1}{10}$ inch [2.5 mm.]. Columella $\frac{1}{5}$ inch [5 mm.] in diameter."

It is obvious that Duncan had no really good specimens on which to base his original description of this species. I was fortunate in obtaining more than 60 specimens in Antigua, and have selected 14 of these as the basis of the following notes. Of Duncan's varieties, it seems to me that *magnetica, pulchella,* and *nobilis* should be combined with the typical form of the species; that his varieties *minor* and *nugenti* should be combined under one name, *nugenti,* preferred by me as it is desirable to preserve the record of the part Doctor Nugent played in making known the fossil corals of Antigua; and that variety *magnificea* should be retained without any important change.

DIPLOASTREA CRASSOLAMELLATA (Duncan) Vaughan, typical.

Plate 135, figs. 1, 2, 3, 4, 4*a*, 5, 5*a*, 5*b;* plate 136, figs. 1, 1*a*, 1*b*; plate 137, figs. 1, 2, 3, 4, 4*a*, 5.

Plate 135, figure 1, illustrates, natural size, a polished surface of a typical specimen in Duncan's original sense; and plate 135, figure 2, illustrates natural size, a polished surface of Duncan's variety *nobilis.* Duncan did not recognize that the septa in such specimens are perforate and that synapticulae are abundant. These two figures will serve to validate the identifications here made, as reference to Duncan's original figures will show.

As I collected a series of specimens ranging from a solitary corallite to a fully developed corallum, the development of the corallum will be described.

Specimen No. 1.—The only solitary corallite I collected (pl. 135, fig. 3) is inversely sub-conical in shape, the apex broken. It is 28.5 mm. tall, and is 16 by 18 mm. in maximum diameter. The older calice was damaged and a smaller calice has formed above the older. On the outer surface is an incomplete, finely striate pellicular epitheca; subequal or alternately larger and smaller, more or less interrupted, beaded costae are seen in the areas not covered by the epitheca. The costal ends are joined by synapticulae, between which are perforations. The wall originally is synapticulate. Septal margins coarsely beaded. Primary and secondary septa solid for the most part; tertiaries more perforate; quaternaries decidedly perforate. Columella well developed; surface coarsely papillary; fossa shallow. As the structural characters of this specimen are essentially identical for all other typical specimen of the species, descriptions of the epitheca, costae, and intercostal synapticulae need not be repeated.

Specimen No. 2.—In this specimen the primary corallite has given rise to one lateral bud (pl. 135, figs. 4, 4*a*), between which and the parent corallite is a slightly depressed intercorallite area. Diameter of parent corallite, 24 mm. Septo-costae more or less confluent and continuous, interrupted with perforations, joined to one another by synapticulae; margins coarsely, rather irregularly beaded.

Specimen No. 3.—There are seven corallites, separated by wide intercorallite grooves, in this specimen. Five corallites are shown on plate 135, figure 5. The lesser diameter of the three larger corallites is 19 mm.; the greater diameter ranges from 21 to about 23 mm. The calices of this specimen are shallow. In the calice represented by plate 135, figure 5*b*, it will be seen that the primary and secondary septa are subequal and are thicker than the members of the higher cycles. There are about 86 septa in this calice—that is, there are 4 complete cycles and 38 quinaries. The primaries and secondaries are solid for the most part; the tertiaries are somewhat thinner and near the columella they are represented by only partially fused septal tabeculae. The quaternaries are thinner and more perforate than the tertiaries, to which they fuse by their inner ends rather near the columella. The quinary septa are still thinner and very perforate; they tend to fuse to the sides of the included quaternary. On the inner part of the largest septa are indefinite lobes or teeth, some of which simulate partially developed paliform lobes. Synapticulae are greatly developed, between both the costae and the septa; and there are endothecal dissepiments.

Specimen No. 4.—This specimen is composed of seven corrallites, plate 137, figure 1. It differs from specimen No. 3 principally by having deeper calices and on some of the large septa there are fairly well-developed paliform lobes.

Specimen No. 5.—Plate 136, figures 1, 1*b*, are two views, natural size, of a specimen that is essentially typical variety *nobilis* of Duncan. It differs from the typical form of the species by having somewhat smaller corrallites and consequently less numerous septa. Specimens bridging the slight gap between specimens Nos. 4 and 5 might be described, but to do so seems unnecessary.

The foregoing descriptions apply to the typical form of the species; some variants will now be considered.

Specimen No. 6.—Plate 137, figure 3, represents a calice and inter calicular areas in a specimen that differs from specimen No. 3 chiefly by the nonexsert calicular margins.

Specimen No. 7.—The calices represented by plate 137, figures 4, 4*a*, are of a specimen that practically intergrades with specimen No. 6. The calices illustrated are smaller and the septo-costae coarser than in specimen No. 6. Plate 137, figure 5, illustrates a closely similar specimen from the base of the Chattahoochee formation, on Flint River, about 4 miles below Bainbridge, Georgia. The calices of the Bainbridge specimens are excavated, thereby differing from specimen No. 7.

Specimen No. 8.—This specimen, plate 137, figure 2, has corallites that are more prominent and more isolated than in the other specimens described, and the costâe on the free corallite limbs are mostly subequal.

Localities and geologic occurrence.—Island of Antigua, in the Antigua formation, at stations 6854, Rifle Butts; 6856, Friar's hill; 6881, Willoughby Bay; 6888, one-half mile north of McKinnon's Mill, collected by T. W. Vaughan. Previously collected by Robert T. Hill and by J. W. Spencer, in addition to the material originally studied by Duncan.

Island of Porto Rico, Lares road, associated with corals, representing the Pepino formation of Hill, collected by Bela Hubbard of the New York Academy Scientific Survey of Porto Rico.

Cuba, station 3481, Rio Canapu, Manassas trail, collected by Arthur C. Spencer. Station 7506 west side of Ocujal Spring, near Guantanamo, Cuba, altitude between 200 and 250 feet, at contact with underlying conglomerate, collected by O. E. Meinzer. Fragments from station 7522, Mogote Peak, one-half mile east of east boundary of United States Naval Reservation, Guantanamo, elevation about 375 feet, a. t., collected by O. E. Meinzer, probably should be referred to variety *magnifica* (Duncan).

Georgia station 3381, 4 miles below Bainbridge, Flint River, in the base of the Chattahoochee formation, collected by T. W. Vaughan.

Panama, station 6587, Tonosi River, collected by D. F. MacDonald. A poorly preserved specimen from this locality seems referable to this species.

This is stratigraphically one of the most important coral species of the American Oligocene, for it seems to occupy almost the identical horizon everywhere it has as yet been found. Its stratigraphic position, as at present known, is middle Oligocene; but the possibility of some specimens being upper Eocene needs to be borne in mind (see page 206).

DIPLOASTREA CRASSOLAMELLATA var. MAGNIFICA (Duncan) Vaughan.

Plate 138, figs. 1, 2, 2*a*.

1863. *Astraea crassolamellata* var. *magnifica* DUNCAN, Geol. Soc. London, Quart. Journ., vol. 19, p. 417, pl. 13, fig. 3.

The following is Duncan's original description: "In the smaller corallites of this variety the spear-shaped septa are seen; but in the larger, where there are from twelve to fourteen septa in a system, the primary, secondary, and tertiary orders are nearly equal in size. They have lost the extreme relative thickness between their extremities, and, although still very thin at the columella, they are not greatly developed at the wall. In some corallites the septa, in transverse view, are not straight, but form curving radii; and in all, the relation which the septa bear to the interseptal spaces and to the wall is very much exaggerated.

"Corallites circular in transverse section; they vary much in diameter, and are now and then crowded, but generally have much coenenchyma between them. The diameters of five corallites are as follows: $\frac{5}{6}$ inch [21 mm.], $\frac{2}{3}$ inch [17 mm.], 1 inch [25 mm.], $1\frac{1}{10}$ inches [27.5 mm.] $\frac{1}{2}$ inch [12.5 mm.]. Walls very indistinct. Costae small, and appearing to be appended to all the septa. Exotheca is present and connects the costae. Septa numerous, especially in large corallites, where the cycles, which are small and rudimentary in the lesser, become well developed. In the smallest corallites there are six systems of four cycles, the fourth and eighth orders being very small. In medium-sized corallites there are six systems, four cycles in five systems, and in the sixth there are the rudimentary sixth, seventh, and eighth orders. The first, second, and third orders are nearly equal in size. In the largest there are six systems, and from twelve to fourteen septa in every system. Lateral teeth exist on all the primary septa at the place of greatest width. The higher orders in every system are very linear. Endotheca abundant, but not in excess. Columella large, well developed, and spongy. Coenenchyma formed of cells produced by the costae and the exothecal dissepiments."

Except that Duncan failed to recognize that this is a fungid coral his description is good.

I am introducing on plate 138 figures of two specimens of this variety, one specimen from Antigua (fig. 1); the other from Flint River, near Bainbridge, Georgia, (figs. 2, 2*a*).

Localities and geologic occurrence.—Antigua, in the Antigua formation, station 6881, Willoughby Bay, collected by T. W. Vaughan.

Porto Rico, Lares road, associated with corals representing the Pepino formation of Hill, collected by Bela Hubbard of the New York Academy Scientific Survey of Porto Rico.

Cuba, station 7522, collected by O. E. Meinzer. It was stated on page 476, that the fragments obtained by Mr. Meinzer on Mogote Peak near Guantanamo seem referable to this variety.

Georgia, station 3381, 4 miles below Bainbridge, Flint River, in the base of the Chattahoochee formation, collected by T. W. Vaughan.

This variety has the same stratigraphic significance as the typical form of the species.

DIPLOASTREA CRASSOLAMELLATA var. NUGENTI (Duncan) Vaughan.

Plate 138, fig. 3, 3*a*.

1863. *Astraea crassolamellata* var. *minor* DUNCAN, Geol. Soc. London Quart. Journ., vol. 19, pp. 414, 416, pl. 13, fig. 6.

1863. *Astraea crassolamellata* var. *nugenti* DUNCAN, Geol. Soc., London Quart. Journ., vol. 19, pp. 414, 416, pl. 13, fig. 5.

Duncan's original description of variety *nugenti* is as follows: "The specimen upon which this variety is founded has no calices but the transverse views of the corallites are very distinct. Corallites one-third inch [8.3 mm.] in diameter, not crowded. Septa in six systems, two cycles in four systems and three in the other two. The tertiary orders are small, and often join the secondary near the columella. The primary septa are square and large at the wall, and not very linear, but staff-shaped within; their width at the margin is one-fifteenth [1.7 mm.] inch. The secondary septa are very much smaller and thinner than the primary, but nearly as large when the tertiary orders are present. Costae wide apart. Exothecal cells scalariform, wider than high; from one-thirtieth to one-sixtieth [0.8 to 0.4 mm.] inch high, and one-fifteenth inch [1.7 mm.] long. Endotheca abundant.

"This form has squarer headed septa, longer exothecal cells, costae wider apart, and a lower septal number than many of the forms of the species; and differs from the forms with three more or less incomplete septal cycles in the greater thickness of the inner part of the septal laminae, the broad exothecal cells, and in the disposition of the tertiary septa to join the secondary."

The original description of var. *minor* is as follows:

"Corallites tall, slender, crowded, distinct; walls circular, not thick. Calices circular, somewhat variable in size; the largest is three-tenths inch [7.5 mm.] in diameter. The larger septa are spear-shaped, the smaller linear; they are in six systems of two cycles; rarely three cycles in two systems in some corallites. Primary septa much larger than the secondary, but nearly equaling them when there is a third cycle. Columella large.

"The alternate large and small, spear-shaped and linear septa are very well seen in this form. The same details as in this form are found in several specimens with larger corallites."

It seems to me that varieties *nugenti* and *minor* should not be separated, and I am using *nugenti* as the varietal name. This variety is principally characterized by its small (diameter about 7 mm.) and relatively distant calices. The specimen represented by plate 138, figures 3, 3*a*, apparently has more compact structures than specimens more typical of the species. The compact appearance I believe is in large part due to secondary mineral changes, and to the surface having been worn, for some septal perforations are recognizable and synapticulae are distinct. An unfigured specimen referred to var. *nugenti* has perforate corallite walls and perforate septa, but the septa of a worn lateral corallite are mostly solid. As it is usual for the skeletal structures of stunted corals to be denser than those of specimens living under more favorable conditions, it is probable that *nugenti* is only a vegetational variant of typical *D. crassolamellata*.

Localities and geologic occurrence.—Antigua, in the Antigua formation at station 6881, Willoughby Bay (figured specimen), and 6854, Rifle Butts, collected by T. W. Vaughan.

MADREPORARIA PERFORATA.

Family EUPSAMMIIDAE Milne Edwards and Haime.

Genus BALANOPHYLLIA Searles Wood.

1844. *Balanophyllia* Searles Wood, Ann. and Mag. Nat. Hist., vol. 13, p. 11.

Type-species.—*Balanophyllia calyculus* Searles Wood.

BALANOPHYLLIA PITTIERI, new species.

Plate 139, figs. 1, 1*a*, 1*b*, 2, 2*a*.

Corallum compressed-cornute in form. The smaller of the two cotypes is 32 mm. long; greater diameter of calice, 4 mm.; lesser diameter of calice, 8.5 mm. (See pl. 139, figs. 1, 1*a*, 1*b*.) The larger cotype has both the lower and upper ends broken. It is 41 mm. long; greater diameter of lower end, 9.5 mm.; lesser diameter, about 7 mm.; greater diameter of upper end, 20.5 mm.; lesser diameter, 13 mm. (See pl. 139, figs. 2, 2*a*.)

Wall perforate between the costae, less perforate along the costae; becomes secondarily thickened; the interseptal loculi near the base are almost solidly filled. There is some pellicular epitheca, which may reach to within 3 mm. of the calicular edge. Costae relatively wide, with narrow interspaces, subequal, every fourth may be somewhat the more prominent where there are four cycles of septa; in general the costae corresponding to the primary and secondary septa are the more conspicuous. In profile they are flat or faintly carinate; about three ill-defined rows of granulations along them, or there are irregularly scattered granulations; where the costae are slightly carinate the median row is the more prominent.

Septa with typical balanophylliid arrangement; in the smaller cotype four complete cycles and a few quinaries; in the larger cotype, four complete cycles and many quinaries, a total of about 78 septa. Paliform lobes appear well developed before the secondaries.

Columella well developed, elongate, vesicular, protuberant in the bottom of the calice.

Locality and geologic occurrence.—Costa Rica, "Colline en démolition," Limon, No. 618, H. Pittier collection. Station 6249, Hospital Point, Bocas del Toro, collected by D. F. MacDonald. The horizon is about that of the Bowden marl.

Cotypes.—Nos. 325014, U.S.N.M.

Family ACROPORIDAE Verrill.

Genus ACROPORA Oken.

1815. *Acropora* Oken (part), Lehrb. Naturg., Th. 3, Abth. 1, p. 66.
1902. *Acropora* Verrill, Conn. Acad. Arts and Sci. Trans., vol. 11, pp. 164, 208 (with synonymy).
1918. *Acropora* Vaughan, Carnegie Inst. Washington Pub. 213, p. 159.

Type-species.— *Millepora muricata* Linnaeus, s. s. = *Madrepora cervicornis* Lamarck.

ACROPORA PANAMENSIS, new species.

Plate 141, figs. 1, 1*a*, 1*b*, 2.

Corallum composed of rather thick branches, apices bluntish, or at least not acuminate. The specimen (the holotype) represented by plate 141, figure 1, is 58 mm. long; the diameter of its lower end is 13 mm.; upper end broken, compressed, 20 mm. wide, lesser diameter of fracture 8 mm.; diameter of end of a new lateral branch not yet fully formed about 4.5 mm. The diameter of the lower end of the specimen (paratype) represented by plate 141, figure 2, is 15 mm.

As the axial corallites are broken their characters are not known. Radial corallites of two kinds, protuberant and immersed or subimmersed. Protuberant corallites ascending, appressed, tubular, slightly compressed. Length as much as 4 mm., about 2.5 mm. probably an average; all intermediate lengths down to the immersed corallites. Greater diameter ranges from 2 up to 3.5 mm.; lesser diameter from 2 to 2.5 mm. Distance apart in vertical rows or spiral from 1 to 2.5 mm.; in horizontal plane, from 1.5 to 3 mm. Lower wall better developed than the upper, texture rather loose, of moderate thickness, outside strongly costulate with synapticulae clearly visible between the costules; upper edge not rounded or incurved in the cotypes. Upper wall short but traceable. Apertures with margins which slope downward and outward from the upper wall or they are short labiate, no nariform or dimidiate apertures were observed. Two well-developed cycles of septa, primaries larger than the secondaries, upper directive more prominent than the lower; in some calices apparently there may be a few tertiaries. Immersed and subimmersed corallites smaller and with less developed septa than the protuberant corallites

Coenenchyma porous, granulate, reticulate, costulate, and somewhat flaky.

Locality and geologic occurrence.—Canal Zone, station 2024*b*, crossing of Panama Railroad over Rio Agua Salud, between Bohio Ridge and New Frijoles, in the Emperador limestone, collected by T. W. Vaughan and D. F. MacDonald.

Antigua, station 6854, Rifle Butts, in the Antigua formation, collected by T. W. Vaughan.

Type.—No. 325042*a*, U.S.N.M.

Paratype.—No. 325042*b*, U.S.N.M.

This species belongs to the subgenus to which Brook applied the name *Eumadrepora*, that is, *Acropora* s. s., but it is not closely related to *Acropora muricata* (Linnaeus) and its relatives, *A. prolifera* (Lamarck) and *A. palmata* (Lamarck), of the Floridian and West Indian region.

ACROPORA SALUDENSIS, new species.

Plate 141, figs. 3, 3*a*, 4, 4*a*.

Corallum composed of relatively slender branches. The dimensions of the two cotypes which are branch segments are as follows:

Dimensions of branches of Acropora saludensis.

Branch No.	Length.	Diameter of lower end.	Diameter of upper end.
	mm.	*mm.*	*mm.*
1	28	10 by 11	9 by 11
2	34	10.5 by 12	8 by 11.5

The diameters are given for the stem proper, exclusive of the corallite protuberances. The relatively greater width of the upper end of No. 2 is due to its apparently being at the base of a bifurcation. The form of the corallum was probably arborescent.

The characters of the axial corallites not distinguishable in the cotypes. The radial corallites, although not all of equal size, are nearly all protuberant, a few subimmersed but no immersed corallites were seen; however, immersed corallites might be present on the basal part of the corallum. The form is ascending appressed tubular; length measured along lower side, 2.5 to 3.5 mm.; lesser diameter 1.5 to 2.5 mm.; greater diameter 1.75 to 2.5 mm.; lateral compression relatively slight but apparent. Lower and side walls well developed, thick, rather dense, outer surface usually strongly costulate; upper edge of lower wall more or less rounded, somewhat uncinate in some corallites. Upper wall only slightly protuberant or obsolete. Apertures nariform or dimidiate. Primary septa well developed; secondaries recognizable in many calices, appear to be usually present.

Coenenchyma relatively dense, surface closely beset with coarse, somewhat elongate, more or less vermiculate granules, no well-defined costules.

Localities and geologic occurrence.—Canal Zone, Emperador limestone, at station 6024*b*, crossing of Panama Railroad over Rio Agua Salud between Bohio Ridge and New Frijoles (cotypes); and at station 6016, quarry, Empire, collected by T. W. Vaughan and D. F. MacDonald.

Antigua, station 6854, Rifle Butts, in the Antigua formation, collected by T. W. Vaughan.

Cotypes.—No. 325043, U.S.N.M. (2 specimens.)

This species belong in the same group of *Acropora* as *A. squarrosa* (Ehrenberg), *A. rosaria* (Dana), and *A. murrayensis* Vaughan,[1] and is referrable to the subgenus *Rhabdocyathus* of Brook.

ACROPORA MURICATA (Linnaeus).

1758. *Millepora muricata* LINNAEUS (*part*), Syst., Nat., ed. 10, p. 792.
1767. *Madrepora muricata* LINNAEUS (*part*), Syst., Nat., ed. 12, p. 1279.

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[1] Vaughan, T. W., Some shoal-water corals from Murray Island (Australia), Cocos-Keeling, and Fanning Islands, Carnegie Institution, Washington Pub. 213, pp. 183–184, 1918.

1893. *Madrepora muricata* forma *cervicornis* BROOK, Brit. Mus. (Nat. Hist.) Cat. Madrep. corals, gen. Madrepora, p. 27.

1900. *Madrepora cervicornis* GREGORY, Ann. and Mag. Nat. Hist., ser. 7, vol. 6, p. 30.

1901. *Isopora muricata* s. s. VAUGHAN, U. S. Fish. Com. Bull. for 1900, vol. 2, p. 313, pl. 21, pl. 22, fig. 2.

1902. *Acropora muricata* var. *cervicornis* VERRILL, Conn. Acad. Arts and Sci. Trans., vol. 11, p. 167.

1903. *Madrepora muricata* DUERDEN (*part*), Nat. Acad. Sci. Mem., vol. 8, p. 543. pls. 1 to 3, figs. 1 to 27.

1915. *Acropora cervicornis* VAUGHAN, Washington Acad. Sci. Journ., vol. 5, p. 597.

1916. *Acropora cervicornis* VAUGHAN, Carnegie Inst. Washington Yearbook No. 14, p. 228.

The nomenclature of the living West Indian and Floridian species of *Acropora* is, in some respects, amusing. Brook in 1893, after studying the considerable collections in the British Museum of Natural History, reached the conclusion that the three previously recognized species from Florida and the West Indies, *A. cervicornis* *A. prolifera*, and *A. palmata*, really represented only forms of one species, to which he applied the specific name *muricata* of Linnaeus. Gregory in 1895 [1] adopted the opinion of Brook, but in 1899 he visited the West Indian coral reefs and decided that all three supposed species were valid (see reference for 1900 in the foregoing synonymy). I studied a large suite of specimens and concurred with Brooks (reference for 1901 in synonymy), and Verrill in his paper for 1902 followed the same course. From 1908 to 1915 (inclusive) I had extensive field experience with the living coral reefs of Florida, the Bahamas, and some of the Lesser Antilles, and am convinced that Gregory's opinion, based on field acquaintance with these corals, is correct. Very rarely indeed does one find a specimen that can not be instantly referred to its proper species. In some of my papers on the ecology and growth rate of Floridian and Bahaman corals,[2] I have referred to this species as *Acropora cervicornis*, because *cervicornis* is a rather generally known name for it.

Localities and geologic occurrence.—Pleistocene at stations 5850, Mount Hope, and 6554, mud flat, 1 foot above ordinary high-tide level, Colon, Canal Zone; station 6251, Monkey Point, Costa Rica, collected by D. F. MacDonald; and Moin Hill, Limon, Costa Rica, "Niveau A.," collection of H. Pittier.

This species is general in the West Indian and eastern Central American Pleistocene reefs, where they were not exposed to the beat of the heavy surf. Recent; eastern Central America, the West Indies, and Florida.

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[1] Geol. Soc. London Quart. Journ., vol. 51, p. 281, 1895.

[2] Mostly in Yearbooks Nos. 9 to 14 of the Carnegie Institution of Washington.

ACROPORA PALMATA (Lamarck).

1816. *Madrepora palmata* LAMARCK, Hist. nat. Anim. sans Vert., vol. 2, p. 279.
1893. *Madrepora muricata* forma *palmata* BROOK, Brit. Mus. (Nat. Hist.) Cat. Madrep. corals, gen. Madrepora, p. 25.
1900. *Madrepora palmata* GREGORY, Ann. and Mag. Nat. Hist., ser. 7, vol. 6, p. 29.
1901. *Isopora muricata* forma *palmata* VAUGHAN, U. S. Fish Com. Bull. for 1900, vol. 2, p. 313, pls. 26 and 27.
1902. *Acropora muricata* var. *palmata* VERRILL, Conn. Acad. Arts and Sci. Trans., vol. 11, p. 166.
1915. *Acropora palmata* VAUGHAN, Washington Acad. Sci. Journ., vol. 5, pp. 597, 598.
1916. *Acropora palmata* VAUGHAN, Nat. Acad. Sci. Proc., vol. 2, pp. 95, 100.
1916. *Acropora palmata* VAUGHAN, Carnegie Inst. Washington Yearbook No. 14, pp. 227, 228, 229, 230.

Localities and geologic occurrence.—Costa Rica, Pleistocene at station 6251, Monkey Point, collected by D. F. MacDonald. Also in the slightly elevated reefs around Colon Bay.

Acropora palmata is of general occurrence in the elevated Pleistocene coral reefs of eastern Central America and the West Indies; and is present on the living reefs of the same region and in Florida. In places, as in the Bahamas, it is one of the most important reef-forming corals, its strong skeleton enabling it to withstand the pounding of breakers.

Genus ASTREOPORA de Blainville.

1896. *Astraeopora* BERNARD, Brit. Mus. Cat. Madreporaria, vol. 2, pp. 77–99.
1918. *Astreopora* VAUGHAN, Carnegie Inst. Washington Pub. 213, p. 145.

Type-species.—Astrea myriophthalma Lamarck.

ASTREOPORA GOETHALSI, new species.

Plate 140, figs. 3, 4, 4*a*.

Corallum composed of rather large, subterete, subelliptical, or much compressed branches. The following are measurements of four broken branches:

Measurements of branches of Astreopora goethalsi.

Branch No.	Length.	Diameters of lower end.	Diameters of upper end.
	mm.	*mm.*	*mm.*
1	85	27 by 56	26 by 71 [1]
2	134	42 by 52	28 by 55
3	154	32 by 44	28 by 65
4	186	16 (thick)	25 by 94

[1] Width at bifurcation 22 mm. below upper end.

Calices subcircular or more or less distorted. Diameter ranges from 1 mm. in young, to 2 mm. in large calices, usual diameter from 1.5 to 2 mm. Distance apart from 1 to 1.5 mm. Calicular rims slightly elevated, not quite 0.5 mm., due to the projection of the corallite walls beyond the coenenchymal surface. Distinct costae correspond to most, if not all, of the septa; irregular in size, but those corresponding to the primaries are usually the larger.

Septa in two complete cycles, with a variable number of tertiaries. Primaries usually well differentiated from the other septa, thicker, longer, and somewhat taller; in many calices a larger primary marks the plane of symmetry; secondaries and tertiaries small.

Columella poorly developed, in some calices a false columella formed by the fusion of the inner end of the primary septa is recognizable.

Coenenchyma with a flattish surface between corallites, vermiculately costate, with perforations between the costae in areas not covered by glassy-looking basal deposit, which in the cross-sections of some branches is solid, in the cross-sections of others there are platforms one above another.

Locality and geologic occurrence.—Canal Zone, stations 6015 and 6016, in the Emperador limestone, quarries, in the town of Empire, collected by T. W. Vaughan and D. F. MacDonald. The same or a very closely related species occurs at stations 3381 and 3383, respectively, 4 and 7 miles below Bainbridge, Georgia, in the base of the Chattahoochee formation, collected by T. W. Vaughan.

Cotypes.—No. 325036, U.S.N.M. (2 specimens).

Paratypes.—No. 325043, U.S.N.M. (4 specimens).

ASTREOPORA ANTIGUENSIS, new species.

Plate 139, figs. 3, 3*a*; plate 140, fig. 1.

Corallum forming large thick branches that may be more or less palmate. Plate 139, figure 3, represents a branch one-half natural size.

The calices are moderately deep, more or less irregular in outline, often subelliptical, the diameter ranges from 2 to 4 mm. Their margins elevated about 1 mm., and are distant from one another from 1.5 to 2.5 mm. Somewhat swollen around the base. Free limbs of corallites more or less distinctly costate.

The septal arrangement appears often to be irregular, sometimes two complete cycles and an incomplete third, in many calices the third cycle is complete, and occasionally a few members of the fourth cycle may be present. The absence of the smallest septa undoubtedly is often due to their destruction in fossilization.

Columella very poorly developed, in fact there may be none at all.

Coenenchymal surface usually formed by a compact basal deposit, but in places perforations may be recognized between costae.

Locality and geologic occurrence.—Antigua, Morris Looby's Hill, in the Antigua formation, collected by R. T. Hill.

Georgia, station No. 3381, Russell Spring, Flint River, Decatur County, Georgia, collected by T. W. Vaughan, in the base of the Chattahoochee formation.

Canal Zone, station No. 6026, 2 miles south of Monte Lirio, collected by T. W. Vaughan and D. F. MacDonald in the Culebra formation.

Type.—Museum of Comparative Zoology.

Paratype.—Ho. 325609, U.S.N.M.; also other specimens.

Comparison of the specimens from near Bainbridge, Georgia, with the smaller specimens from Antigua, fails to reveal any difference whatever between the specimens; and no noteworthy difference is seen between the other specimens and the best one from near Monte Lirio.

ASTREOPORA PORTORICENSIS, new species.

Plate 140, figs. 2, 2*a*.

Corallum ramose, branches subcircular or elliptical in cross-section. Length of type, 56 mm.; greater diameter of lower end, 16 mm., lesser, 13 mm.; width of upper end (which is bifurcating) about 30 mm.

Calices moderately deep, usually deformed, one diameter longer than the other. A small calice has a greater diameter of 1.7 mm., lesser, 1.3 mm.; a rather large calice has diameters measuring 2.3 and 1.6 mm., respectively. The distance apart of the calices varies from 1.3 to slightly more than 2 mm. Calicular margins scarcely elevated; there is really no distinctly elevated rim.

Septa, in the larger calices, in three cycles, the last very small; their outer ends thick, the inner portions thin. Upper margins very slightly exsert.

Columella, poorly developed.

Coenenchymal surface usually coated by basal deposit, but in places costae with intervening perforations are obvious.

Locality and geologic occurrence.—Porto Rico, station 3191, 4 miles west of Lares, Pepino formation, collected by R. T. Hill.

Type.—No. 325306, U.S.N.M.

This species is very near *Astreopora antiguensis;* in fact, I am by no means sure that they are really distinct. The type of *A. portoricensis* has smaller and less prominent calices; but some of the specimens of *A. antiguensis* from Bainbridge, Georgia, have small calices. The critical difference, therefore, consists in the low, nonprotuberant calices of *A. portoricensis*, a difference which, according to the available material, is valid.

Genus ACTINACIS d'Orbigny.

1849. *Actinacis* D'ORBIGNY, Notes sur des Polyp. foss., p. 11.
1860. *Actinacis* MILNE EDWARDS, Hist. nat. Corall., vol. 3, p. 170.

Type-species.—Actinacis martiniana d'Orbigny.

I have not been able to study the type-species of this genus, but judging from Reuss's figures of *A. martiniana* [1] it is probable that the corals here referred to are correctly determined.

Besides the species described here, there is another species of *Actinacis* in the West Indies Tertiary formations, namely, the coral from the Eocene St. Bartholomew limestone, to which Duncan applied the name *Astreopora panicea*.[2] It will be considered in another paper.

The species to which Duncan applied the names *Heliastraea exsculpta* [3] (not *Astraea exsculpta* Reuss [4]) and *Heliastraea cyathiformis*,[5] and which I made under the latter name, the type species of *Multicolumnastraea*,[6] deserves mention here. The intercorallite costae in Duncan's *Heliastraea cyathiformis* are more or less vermiculate and are joined one to another by synapticulae, between which there are openings. This species is very close to *Actinacis*, but the coarse columellar tubercles or pillars may warrant generic separation. The species, according to the stratigraphic data supplied by Mr. R. T. Hill, occurs in his Blue Mountain Series, of Cretaceous age, and his Catadupa beds, of Eocene age.[7] It seems to me that the Catadupa beds are probably of Cretaceous age, for they contain no species of corals in common with the Richmond and Cambridge formations, while two of the five species recorded from them are common to the Blue Mountain Cretaceous.

ACTINACIS ALABAMIENSIS (Vaughan).

Plate 149, figs. 3, 3*a*.

1900. *Turbinaria* (?) *alabamiensis* VAUGHAN, U. S. Geol. Survey Mon. 39, p. 194, pl. 23, figs. 1, 2, 3; pl. 24.

The type-specimen (Cat. No. 158482) and the paratypes (Cat. Nos. 158480 and 158481, U.S.N.M.) clearly belong to the genus *Actinacis*, to which I suggested they might belong in the original account of the species. The following is the original description:

"Corallum massive, the masses may be more than 20 cm. across and 7 cm. thick, upper surface apparently convex or concave. Gen-

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[1] Beiträge zur Charakteristik der Kreideschichten in den ostalpen, K. K. Akad. Wiss. Wien. Math.-Naturw.-Cl., vol. 7, pl. 24, figs. 12-15, 1854.

[2] Geol. Soc. London Quart. Journ., vol. 29, p. 561, 1873.

[3] Idem, vol. 21, pp. 7, 8, 11, 1865.

[4] K. K. Akad. Wissensch. Wien. Math.-Naturw. Cl., Denkshr. vol. 7, p. 114.

[5] Geol. Soc. London Quart. Journ., vol. 21, pp. 7, 8, pl. 1, figs. 1*a*, 1*b*, 1865.

[6] Mus. Comp. Zool. Bull., vol. 34, pp. 235-237, pl. 37, figs. 5, 6, 7; pl. 38, fig. 1, 1899.

[7] Vaughan, T. W., Mus. Comp. Zool., vol. 34, p. 231, 1899.

eral appearance of the corallum is as if composed of superimposed laminae. Calices shallow (?), crowded; diameter, 1.5 mm.; distance apart, quite constantly 1 mm. Coenenchyma, of superimposed irregularly perforate laminae. Wall, perforate. Septa, perforate, in three complete cycles; 12 septa reach the columnella; the members of the third cycles usually fuse by pairs to the sides of an included septum (the first and second cycles can not be distinguished from each other, and therefore it can not be known whether the septa of the third fuse to the sides of the first or second). Sides granulate. Pali are probably present, but no detail could be made out. Columella very well developed, spongy.

"*Locality.*—Salt Mountain, 6 miles south of Jackson, Alabama.

"*Geologic horizon.*—'Coral limestone,' above Vicksburg beds."

"I have not been able to decide positively whether this is an Actinacis or a Turbinaria. It probably belongs to the latter genus."

The following is a description of a species of *Actinacis*, referred to *A. alabamiensis*, from Flint River, near Bainbridge, Georgia:

Corallum forming large explanate masses, a foot or more across and 70 to 75 mm. thick. The perpendicular section shows a thinly lamellate structure.

Calices small, 1.3 to 1.5 mm. in diameter, usually separated by less than their own diameter of coenenchyma. The coenenchyma is composed of flexuous, perforate, granulated costae, which are fused into a reticulum by abundant synapticulae. The calices are distinctly differentiated from the coenenchyma, but a definite wall is only poorly developed; where it is present, it appears to be due to a zone of peripherally disposed synapticulae. The costae often lead directly across the coenenchyma from one calice to the next, thus joining the septa of adjacent calices.

Septa slightly less in thickness than the interseptal loculi. The usual number is about 20, the third cycle as a rule is incomplete, arranged with reference to a plane of symmetry. The presence of a directive plane and the grouping of the septa into pairs or groups of threes is characteristic. Pali occur at the junctions of the inner ends of the septa—it seems that the full number is 12. The interseptal loculi are conspicuously open; if any synapticulae are present, they are rare.

Columella well developed, composed of septal processes.

A species of *Actinacis*, apparently the same as *A. alabamiensis*, was collected by me in Antigua. It is represented by a small piece 61 mm. long, 33 mm. wide, and 25 mm. in maximum thickness. The upper surface is nodose; calices from 1.25 to 1.5 mm. in diameter; coenenchyma composed of a fine trabecular mesh work. This specimen seems to me to belong to the same species as the specimens from near Bainbridge, Georgia, that I am identifying as *A. alabamiensis*.

Localities and geologic occurrence.—Alabama, Salt Mountain, 6 miles south of Jackson, in the "coral limestone" above the top of the Vicksburg group, collected by T. W. Vaughan (the type).

Georgia, station 3381 and 3383, on Flint River, respectively 4 and 7 miles below Bainbridge, in the base of the Chattahoochee formation, collected by T. W. Vaughan.

Antigua, West Indies, station 6854, Antigua formation at Rifle Butts, collected by T. W. Vaughan.

This species is of a high order of importance in the correlation of American Oligocene deposits.

The septal arrangement in *A. alabamiensis* is similar to that of *Porites* in the presence of a plane of symmetry and the tendency of the septa to fuse by their inner ends in pairs. The septa themselves, however, are very different, being lamellate, almost imperforate, and sharply differentiated from the surrounding coenenchyma.

Professor Felix in his Anthozoen der Gosauschichten in den Ostalpen[1] has redescribed and figured *A. haueri* Reuss and *A. martiniana* d'Orbigny. He does not speak of the bilateral symmetry of the calices but both of his figures indicate such a condition, as in each there are two opposite elongate septa that connect with each other through the columella. I take it, then, that the calices of *A. martiniana* are bilaterally symmetrical with the septa grouped not very definitely in two's, three's, four's, or five's on each side of the median plane.

It seems probable that *Actinacis* may be intermediate in character between the families *Acroporidae* and *Poritidae*. These notes and suggestions are made in the hope that some one with the requisite material may make a more careful study of the Cretaceous species of the genus to determine the relations of those two families.

Family PORITIDAE Dana.

Genus GONIOPORA Quoy and Gaimard.

1833. *Goniopora* Quoy and Gaimard, Voyage de l'*Astrolabe*, Zool., vol. 4, p. 218.

Type-species.—*Goniopora penduncculata* Quoy and Gaimard.

GONIOPORA HILLI, new species.

Plate 142, figs. 1, 1*a*.

Corallum composed of flattish plates, which may be more than 20 cm. wide and 4 cm. thick and appear to have grown in a subhorizontal position.

The calices are polygonal, from 3 to 4 mm. in diameter, from 1 to 1.5 mm. deep, separated by walls from 0.75 to 1.25 mm. thick. The walls are crossed by rather low costae, and in places there is some

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[1] Palaeontographica, vol. 49, pp. 176-178, figs. 2, 3, 1903.

intercalicular reticulum, but it usually does not well up and form peaks, ridges, and crests between the calices.

Septa of the normal gonioporid number and arrangement, outer parts thick and subequal, all relatively narrow in their upper parts, and either fall steeply or slope to the level of the large columella tangle, which is joined by the primaries and secondaries and the tertiaries fuse to the secondaries near it. Usually 3 or 4 teeth on the margins. Paliform lobes not greatly developed.

Columella tangle large, about 1.5 mm. in diameter, more than one-third the diameter of the calice; its upper surface forms the flattish or gently concave bottom of the calices.

Localities and geologic horizon.—Canal Zone, stations 6015 and 6016, quarries in the Emperador limestone, Empire, T. W. Vaughan and D. F. MacDonald, collectors.

Type.—Figured specimen No. 325058, U.S.N.M.

Paratypes.—No. 325057, U.S.N.M.

GONIOPORA PANAMENSIS, new species.

Plate 142, figs. 2, 2*a*, 2*b*.

Corallum forms thick plates, which may be more than 17 cm. wide and as much as 5 cm. thick in the center, thin on the edges. Growth form similar to that of *Goniopora hilli*.

Calices large, but irregular in size and distribution, because of the large development of intercorallite reticulum, which in some areas wells upward and forms nipple-shaped peaks in the angles between the entirely circumscribed calices or forms ridges with calices on each side. The diameter of the calices ranges from 2.5 to 3.5 mm.; the intervening walls or ridges range up to 2.5 mm. thick, their length ranges up to 13 mm., where as many as three calices occur in a single valley, their height ranges up to 2 mm. Costae can be traced across the intercorallite walls and the ridges between calicinal series.

Septa rather thick, about 24, arrangement indefinite, but according to the gonioporid plan; they slope to the bottom of the calice or their outer part is narrow and falls steeply to the level or the columella tangle, to which the primaries and secondaries extend. Three or four dentations on the margin of each large septum. Paliform knots present, but lobes are not conspicuous.

Columella tangle well developed, but not so large as in *G. hilli*.

Localities and geologic horizon.—Canal Zone, stations 6015 and 6016, quarries in the Emperador limestone, Empire, collected by T. W. Vaughan and D. F. MacDonald.

Anguilla, station 6894, Crocus Bay, collected by T. W. Vaughan.

Type.—Figured specimen, No. 325053, U.S.N.M.

Paratypes.—No. 325054, U.S.N.M.

GONIOPORA DECATURENSIS, new species.

Plate 143, figs. 1, 1*a*.

Corallum lamelliform, the lateral expansion far exceeding its thickness. The specimen selected as the type is a portion of a corallum, 90 mm. across and about 23 mm. thick. Another specimen is 49 mm. long, 35 mm. wide, and 7.5 mm. thick. The upper surface is plane or undulate. When the corallum is foliaceous, it may be irregularly flexed.

Calices polygonal, shallow, superficial or only slightly excavated. Usual diameter 2.5 to 3 mm. The wall, when somewhat worn, usually has a membraniform appearance, being almost continuous, interrupted in places, but forming a quite distinct boundary between adjacent calices. In other instances there may be no well-defined boundary to the calices. Two rows of synapticulae frequently reinforce the wall in the peripheral portion of the interseptal loculi

Septa of variable thickness on the same specimen, usually moderately stout; on the thinner lamellae they are thick. The thickness of the septa seems to be correlated with the thickness of the colony. When the corallum is thick the septa are thin and *vice versa*. The normal number is 24, although there are in some places a few less, in others a few more. The usual arrangement is six primaries extending directly to the axis, with a triplet group of a secondary and two tertiaries between each pair. A directive plane could be observed in some calices, but the septa are too much damaged to permit discovering all the details of the arrangement. The margins are dentate, five to seven dentations on each longer septum. The faces with the usual granulations. Synapticulae rather abundant, but not greatly crowded, variable in thickness.

Columella tangle well developed.

The texture of the corallum is of variable firmness, depending upon the thickness of the septal trabeculae, the synapticulae, etc., however, it seems never to be especially dense.

Localities and geologic occurrence.—Georgia, station 3381, Blue Springs, 4 miles below Bainbridge; and station 3383, Hale's Landing, 7 miles below Bainbridge, Flint River, Decatur County, in the base of the Chattahoochee formation, collected by T. W. Vaughan.

Cuba, station 7523, Mogote Peak, 250 feet a. t., ½ mile east of U. S. Naval Reservation, Guantanamo, Cuba, collected by O. E. Meinzer.

Type.—No. 325031, U.S.N.M.

Besides the lot of specimens referred to the species in the foregoing description, three other types or kinds of *Goniopora* occur on Flint River at Blue Springs and Hale's Landing. It is impossible with the material at hand to decide whether they are distinct species or only varieties or forms of *G. decaturensis*. However, as it seems very probable that two of these are only varieties of *G. decaturensis,* they are named and described as such.

GONIOPORA DECATURENSIS var. SILICENSIS, new variety.

Plate 143, figs. 2, 2*a*.

This is a specimen 113 mm. long, 54 mm. wide, and 20 mm. thick. The upper surface is slightly undulated, there is one deep depression, but it may have been caused by a burrowing animal or the surface may have been corroded.

Calices 2.5 to 4 mm. in diameter, larger than in typical *G. decaturensis.* Septa decidedly thin; texture light and fragile.

Locality and geologic occurrence.—Georgia, station 3381, Flint River, Blue Springs, 4 miles below Bainbridge, in the base of the Chattahoochee formation, collected by T. W. Vaughan.

Type.—No. 325026, U.S.N.M.

GONIOPORA DECATURENSIS var. BAINBRIDGENSIS, new variety.

Plate 143, figs. 3, 3*a*.

Two small, inflated, rounded specimens are referred to this variety. No. 1, length 26.5 mm., width 25 mm., thickness 13.5 mm.; No. 2 (type), length 33 mm., width 24 mm., thickness 19 mm.

Calices superficial, about 3 mm. in diameter.

Septa moderately thick.

These specimens are separated from typical *G. decaturensis* solely on the growth form.

Locality and geologic occurrence.—Georgia, station 3381, Flint River, Blue Springs, 4 miles below Bainbridge, in the base of the Chattahoochee formation, collected by T. W. Vaughan.

Type.—No. 325029, U.S.N.M.

GONIOPORA REGULARIS (Duncan).

1863. *Alveopora daedalaea* var. *regularis* DUNCAN, Geol. Soc. London Quart. Journ., vol. 19, p. 426, pl. 14, figs. 4*a*, 4*c*.
1867. *Alveopora daedalaea* DUNCAN, Geol. Soc. London Quart. Journ., vol. 24, p. 25.
1901. *Alveopora regularis* VAUGHAN, Geolog. Reichs. Mus. Leiden Samml., ser. 2, vol. 2, p. 71.

Duncan's material of this coral is very poor, consisting of casts and mineral replacements of the original skeleton; and, as I pointed out in my paper cited in the synonomy, he incorrectly gave the dimensions of the corallites. The diameter is not "½ line" [=about 1 mm.] as stated by Duncan, but is usually 2 mm., with a range from 1.5 to 2.5 mm. I have three photographs of Duncan's type (No. 12949, Coll. Geol. Soc. London), and after having made a large collection in Antigua identify with certainty the species represented by Duncan's poor specimen. It is a species of *Goniopora* and is one of the commonest corals in Antigue, where I obtained about 30 good specimens.

The corallum is usually more or less turbinate in shape, rising from a narrow base, expanding upward, with a lobulate, but somewhat flattish upper surface. The dimensions of the largest specimen are as follows: Least diameter of fracture on basal surface, 5 cm.; height 18.5 cm.; diameter of upper surface 22 by 25.5 cm. Some specimens are more or less columniform; others are glomerate.

The calices are from 2 to 2.5 mm. in diameter and are separated by distinct, straight walls, or there is some costate intercorallite reticulum.

The septal formula is normal for *Goniopora,* but the septa are more distinctly lamellate than is usual. There is a wide, detached, septal granule, that is usually compressed in the septal plane and is plate-like. Pali well developed; plate-like in many calices.

This species will be described in detail and figured in a forthcoming report.

Localities and geologic occurrence.—Antigua, at nearly every exposure of the coral reef in the Antigua formation, collected by T. W. Vaughan.

Porto Rico, zone C, near Lares, collected by Bela Hubbard, of the New York Academy Porto Rico investigations.

Arube, Serro Colorado.

GONIOPORA REGULARIS var. MICROSCOPICA (Duncan).

1863. *Alveopora microscopica* DUNCAN, Geol. Soc. London Quart. Journ., vol. 19, p. 426, pl. 14, fig. 5.

1867. *Alveopora microscopica* DUNCAN, Geol. Soc. London Quart. Journ., vol. 24, p. 25.

Duncan based *Alveopora microscopica* on a silicified specimen (No. 12951, Coll. Geol. Soc. London), of which I have a photograph. This is a small calicled species of *Goniopora,* with rather strikingly lamellate septa. I obtained in Antigua three specimens that I identify with Duncan's species, which probably is only a variant of *Goniopora regularis. G. microscopica* has a more regularly rounded corrallum and smaller calices, 1.25 to 1.5 mm. in diameter; otherwise I detect no important differences.

Locality and geologic occurrence.—Antigua, stations 6856, Friar's Hill, and 6881, Willoughby Bay, Antigua formation, collected by T. W. Vaughan.

GONIOPORA JACOBIANA, new species.

Plate 144, figs. 1, 1*a*, 2, 2*a*, 3, 3*a*.

A description of the type (pl. 144, figs. 1, 1*a*), is as follows: Corallum obtuse, columniform. Horizontal diameter 160 by 165 mm.; height 133 mm. +, top damaged, when perfect probably about 210 mm. tall. Successive shells of skeletal substance are recognizable.

Calices shallow, polygonal in outline, usual diameter slightly more than 3.5 mm. Intercorallite walls rather narrow, with some reticulum, septa traceable through it, in places about 1 mm. wide.

Septa thin, formula complete, arrangement typical. Margins with an average of 5 or 6 delicate teeth between the columella and the wall, 8 teeth were counted on each of a few septa. There is no conspicuous palar crown.

Columella tangle weakly developed; apparently a central tubercle was present in a number of the calices.

Locality and geologic occurrence.—Cuba, station 3446, La Cruz marl, first deep cutting east of La Cruz near Santiago, collected by T. W. Vaughan (type).

Florida, station 6775, White Springs, Alum Bluff formation, collected by T. W. Vaughan and C. W. Cooke.

Type.—No. 325077, U.S.N.M.

There are two undescribed species of *Goniopora* that are nearly related to *G. jacobiana.* One of them is from the Chipola marl member of Alum Bluff formation, Chipola River, Florida. Its calices are of the same size and its septa are fragile as in *G. jacobiana,* but the intercorallite reticulum is a more curly mesh-work in which the radial skeletal elements are obscure or are less conspicuous than in *G. jacobiana.* This difference in the reticulum seems to constitute a valid specific distinction. The other closely related species is from the Bowden marl, Bowden, Jamaica. As the calices of the Bowden specimen average about 2.3 mm. in diameter, they are distinctly smaller than in *G. jacobiana.* The radial elements are obvious in the intercorallite reticulum, but it is somewhat flaky. The Bowden specimen may belong to *G. jacobiana,* but with the small amount of material for comparison, it must, for the present be considered distinct.

In addition to the two species mentioned, there is a somewhat similar species found abundantly in the calcareous marl of Anguilla, where I collected about 50 specimens of it. This species forms columniform or gibbous masses, composed of successive caps. It is not so massive as *G. jacobiana,* the columns are more slender, and its calices are more excavated.

The only observed difference between the type of *G. jacobiana* and the specimen from White Springs, Florida, identified with that species, is that the calices of the White Springs specimen may be somewhat deeper. To refer specimens so simllar in habit and structural detail to different species appears unjustifiable.

GONIOPORA IMPERATORIS, new species.

Plate 142, figs. 3, 3*a*.

Growth form as a compressed, lobate column, 54 mm. tall, 22 mm. thick, 37 mm. wide (excluding a lateral lobe which is about 13 mm. long).

Calices sunken between a rather regular mural network, diameter of calicular openings 1.5 to 2.5 mm., diameter measured between mural summits 2.5 to 3.5 mm., depth about 0.75 mm., separating walls from 0.75 to 1.25 mm. wide. The walls are rather flat-topped and are composed of costal prolongations of the septa joined together by synapticulae. In places there is considerable intercorallite reticulum, but it does not form protuberances between the calices; where the surface is well preserved, subequal costae extend across the walls.

Septa of normal gonioporid arrangement, in the typical formula; above the bottom of the calices they are narrow, extending down the insides of the walls as short ribs, which bear about three inwardly projecting dentations; at the bottom of the calice they widen and the primaries and secondaries extend to the columellar tangle. Well developed paliform lobes occur just inside the junction of the tertiaries with the secondaries and form a crown around the periphery of the columellar tangle. Width of interseptal loculi less than the thickness of the septa.

Columellar tangle well developed, large, forms a flattish bottom to the calices, width about one-half the calicular diameter.

Locality and geologic occurrence.—Canal Zone, station 6016, quarry, in the Emperador limestone, Empire, collected by T. W. Vaughan and D. F. MacDonald.

Anguilla, stations 6893, 6894, 6966, 6967, all coralliferous beds at Crocus Bay; station 6969*a*, bottom bed, Road Bay, collected by T. W. Vaughan.

Type.—No. 325049, U.S.N.M.

This species really should have been based on the Anguillan material, of which I collected 34 identifiable specimens. In fully developed colonies the branches are subcircular or elliptical in cross section, and range from 30 to 55 mm. in diameter. The distance between mural summits ranges up to 4.5 mm. but is usually less.

GONIOPORA CANALIS, new species.

Plate 146, figs. 1, 2, 3.

Corallum composed of compressed branches. The following are measurements:

Dimensions of branches of Goniopora canalis.

Branch No.	Length.	Greater diameter of lower end.	Lesser diameter of lower end.	Maximum width.
	mm.	*mm.*	*mm.*	*mm.*
1	41	20	6.5	30
2	41	20	12	28
3		22	8	35
4			7.5	20+

The lower end of each specimen and the tops of Nos. 3 and 4 are broken. Some coralla are evidently formed of rather thin, branching plates.

Calices polygonal, usual diameter 3 mm., young calices about 2 mm. in diameter, an occasional large one as much as 4 mm.; depth from 1 to 1.25 mm.; separated by walls from 0.75 to 1.25 mm. thick. The walls are crossed by costae and usually form a fairly regular network around the calicular cavities, but in places there is considerable intercalicular reticulum. In places there are low, rather indefinite ridges which may extend the length of as many as four calices. The tops of the walls are rounded or subacute.

The septa are normal gonioporid in number and arrangement; they are thick at the wall, becomes thinner toward the center; their upper part narrow, gradually sloping to the columella tangle, which is joined by the primaries and secondaries; margins with about 6 fine dentations.

Columella tangle not very conspicuous.

Locality and geologic horizon.—Canal Zone, station 6016, quarry in the Emperador limestone, Empire, collected by T. W. Vaughan and D. F. MacDonald.

Anguilla, station 6966, middle bed, Crocus Bay, collected by T. W. Vaughan.

Cotypes.—Nos. 325052, U.S.N.M. (3 specimens).

I am not certain the *G. canalis* is really different from *G. imperatoris.*

GONIOPORA PORTORICENSIS, new species.

Plate 146, figs. 4, 5.

Corallum ramous, branches rounded in cross section or very compressed, a branch of the latter form is 34 mm. wide with a maximum thickness of about 9 mm.

Calices polygonal, shallow, usual diameter 2 mm. The outer ends of the septa are flattened and fused together, separating the calicular depressions by a wall about 0.5 mm. thick.

Septa delicate, very perforate, in three complete cycles. Margins finely and delicately denticulate; about five small thin teeth on a long septum. Pali appear to be poorly developed, not specially differentiated from the ordinary septal dentations.

Columella weakly developed.

Locality and geologic occurrence.—Porto Rico, station 3191, 4 miles west of Lares, Pepino formation, collected by R. T. Hill.

Antigua, stations 6854, Rifle Butts; 6881, Willoughby Bay, in the Antigua formation, collected by T. W. Vaughan.

Type.—No. 325061, U.S.N.M.

Paratype.—No. 325060, U.S.N.M.

This species resembles compressed specimens of *Goniopora clevei* Vaughan, from which it is distinguishable by its thin septa, with delicately dentate margins.

GONIOPORA CLEVEI, new species.

Plate 145, figs. 1, 2, 2*a*, 3, 4, 5, 5*a*, 6, 6*a*.

Corallum branching. The type (pl. 145, figs. 2, 2*a*) is an irregularly shaped portion of a branch, selected because it permits the septal arrangement to be definitely determined. It is 44 mm. long; greater diameter of lower end, 12 mm.; of bulged portion, 15.5 mm. Probably some of the irregularity of form may be caused by erosion. Another broken specimen, a paratype, is represented by plate 145, figure 1.

Calices shallow, circular, or subcircular, 2 to 2.4 mm. in diameter. They may be close together or separated by reticulate and costate coenenchyma, as much as 1 mm. across; usually in the type, which is worn, they appear distinctly separated from the bounding coenenchyma and sharply defined by a peripheral zone of synapticulae.

There are 12 large lamellate septa with typical poritid arrangement, solitary directive, four lateral pairs, and a directive triplet; the inner ends of the laterals in the triplet are directed toward, but not actually fused, to the inner end of the principal directive. The outer ends of these larger are often bifurcated, or costae (these are to be considered rudimentary septa) exist between them, in some instances bringing the number up to 24. Pali well developed, six in number.

Columella tangle rather dense, with an axial tubercle.

Locality and geologic occurrence.—Island of Anguilla, West Indies, P. T. Cleve, collector (type); stations 6893, 6894, 6966, Crocus Bay, and 6970, 130 to 140 feet above sea level, east end of Road Bay, Anguilla, collected by T. W. Vaughan.

Canal Zone, station 6016, in the Emperador limestone, collected by T. W. Vaughan and D. F. MacDonald.

Antigua, station 6854, Rifle Butts, Antigua formation, collected by T. W. Vaughan.

Type.—University of Upsala.

Paratype.—University of Upsala.

Paratypes.—Nos. 325111 (3 specimens), 325115 (1 specimen), U.S.N.M.

It was decidedly difficult to decide whether this species should be referred to *Porites* or *Goniopora*. Bernard says: "These fossils with 12 central rays might almost be considered as transition forms toward *Porites* having to all appearance only 12 septa; but whenever it can be distinctly seen that a certain number of these septa fork before they reach the wall, I assume that the forking is the vestige of the fusion of the septa characteristic of *Goniopora*, and that therefore there are more than 12."[1]

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[1] Brit. Mus., Cat. Madrep. Corals, vol. 4, Gen. Goniopora, p. 21.

While in Anguilla in 1914 I collected about 40 identifiable specimens of this species, and am illustrating a series on plate 145, figures 3, 4, 5, 5*a*. The branches are thickish and blunt-ended, having some resemblance in growth form to the thicker-branched forms of *Porites porites*, such as are common on the reefs on the east side of Andros Island, Bahamas. The calices of these specimens are not perfectly preserved, but in many a third cycle of septa is clearly recognizable. I therefore am convinced that the species is referable to *Goniopora.*

Doctor MacDonald and I collected in the quarries at Empire, Canal Zone, a number of specimens that seem completely to agree with the Anguillan specimens. One of these is represented by plate 145, figures 6, 6*a*.

Flattened specimens of *G. clevei* resemble specimen of *G. portoricensis*, but the latter has thinner and more delicately dentate septa, and in it the tertiary septa are more developed.

GONIOPORA CASCADENSIS, new species.

Plate 146, figs. 6, 6*a*, 6*b*, 7, 8, 9.

Corallum composed of relatively slender, subterete branches. A branch segment 40 mm. long is 9 by 10 mm. in diameter at the lower end and 8 by 9 mm. in diameter at the upper end, showing 1 mm. decrease in diameter for 40 mm. in length; but branches may be thicker, up to as much as 15 mm. in diameter.

Calices slightly excavated, polygonal, from 1.75 to 2.5 mm. in diameter, separated by more or less discontinuous walls, in some places a straight or zigzag wall ridge is traceable, but in other places there seems to be none. Where there is a wall ridge, rather coarse mural denticles corresponding to the outer ends of the septa are present. In places mural reticulum is present and coarse radial skeletal structures are clearly traceable through it.

There are 12 large septa which extend to the columellar tangle, and about 12 small septa which fuse in pairs to the sides of an included septum (assumed to a secondary) about halfway between the wall and the columellar tangle. The septal granules seem to be arranged according to the following scheme: A ring of outer granules which are adherent to or only slightly detached from the wall, a ring of intermediate granules which correspond in position to the place of fusion of the small (tertiary) septa to the sides of the secondaries, and an inner ring of granules which form paliform knots around the periphery of the columella tangle. The intermediate and inner rings seem constantly recognizable, but the outer ring is not always definitely developed. The interseptal loculi are about as wide as the thickness of the septa.

Columella tangle well developed; width more than one-third the diameter of the calice. In some calice a central styliform process is distinguishable.

Locality and geologic occurrence.—Canal Zone, station 6020*c*, in the Culebra formation at Las Cascadas, collected by T. W. Vaughan and D. F. MacDonald.

Anguilla, station 6967, Crocus Bay, collected by T. W. Vaughan.

Antigua, station 6854, Rifle Butts, Antigua formation, collected by T. W. Vaughan.

Type.—No. 325072, U.S.N.M. (pl. 146, figs. 6, 6*a*, 6*b*).

Paratypes.—No. 335074, U.S.N.M. (3 specimens).

This species is one of those that is intermediate between *Porites* and *Goniopora*. As there are short tertiary septa within the wall, according to Bernard's treatment of such forms, it is referred to *Goniopora.*

The types are from Las Cascadas, Canal Zone. The calices of the specimens from Anguilla are not so well preserved as those of the cotypes, but the identifications seem reasonably certain, as there is agreement in all general characters and in the observed detail.

Genus PORITES Link.

1807. *Porites* LINK, Beschreibungen der Naturaliens Sammlungen, Rostock, p. 162.
1918. *Porites* VAUGHAN, Carnegie Inst. Washington Pub. 213, p. 138.

Type-species.—*Madrepora porites* Pallas.

PORITES PORITES (Pallas).

1766. *Madrepora porites* PALLAS (part), Elench. Zooph., p. 324.
1901. *Porites porites* forma *clavaria* VAUGHAN, U. S. Fish Com. Bull. for 1900, vol. 2, p. 316, pl. 29; pl. 31, fig. 2.
1902. *Porites porites* VAUGHAN, Biol. Soc. Washington Proc., vol. 15, pp. 56–58 (with references to literature and history of the name).
1909. *Porites porites* var., VAUGHAN, Carnegie Inst. Washington Yearbook No. 7, p. 135.
1912. *Porites clavaria* VAUGHAN, Carnegie Inst. Washington Yearbook No. 10, pp. 148, 152, 156, pl. 4, fig. 4*c*; pl. 6, figs. 3, 4.
1915. *Porites clavaria* VAUGHAN, Washington Acad. Sci. Journ., vol. 5, p. 597.
1916. *Porites clavaria* VAUGHAN, Nat. Acad. Sci. Proc., vol. 2, pp. 95, 98.
1916. *Porites clavaria* VAUGHAN, Carnegie Inst. Washington Yearbook No. 14, p. 228.

This is one of the species of corals to which most attention was given during my studies of the Floridian and Bahamian reef corals, and it is referred to in most of my reports in Yearbooks No. 7–14, inclusive, of the Carnegie Institution of Washington, usually as *Porites clavaria*, because that is the more generally known name.

Localities and geologic occurrence.—Recent throughout the coral-reef areas of the West Indies, the eastern side of Central America, Florida, and the Bermudas.

Pleistocene, in the elevated West Indian reefs.

Miocene, Santiago, Cuba, in the La Cruz marl, at station 3441, east of La Cruz, near crossing of the road from Santiago to the Morro over the railroad, collected by T. W. Vaughan. As these specimens agree in all details that I can discover, with the thicker-branched forms of *P. porites*, I am referring them to that species. This adds another to the considerable list of living species recognized in the La Cruz marl.

PORITES FURCATA Lamarck.

1816. *Porites furcata* LAMARCK, Hist. nat. Anim. sans Vert., vol. 2, p. 271.
1887. *Porites furcata* RATHBUN, U. S. Nat. Mus. Proc., vol. 10, p. 361, pl. 15, figs. 1–3; pl. 17, fig. 1.
1901. *Porites porites* forma *furcata* VAUGHAN, U. S. Fish Com. Bull. for 1900, vol. 2, p. 316, pl. 30; pl. 31, fig. 1.
1902. *Porites polymorpha* VERRILL (part), Conn. Acad. Arts and Sci. Trans., vol. 11, p. 158.
1913. *Porites furcata* VAUGHAN, Carnegie Inst. Washington Yearbook No. 10, p. 156, pl. 5, figs. 5*c*, 6*c*, 7, 8; pl. 6, figs. 1*a*, 1*b*, 2*a*, 2*b*.
1915. *Porites furcata* VAUGHAN, Washington Acad. Sci. Journ., vol. 5, p. 597.
1916. *Porites furcata* VAUGHAN, Nat. Acad. Sci. Proc., vol. 2, p. 95.
1916. *Porites furcata* VAUGHAN, Carnegie Inst. Washington Yearbook No. 14, p. 228.

Localities and geologic occurrence.—Canal Zone, Pleistocene at stations 5850 and 6039, Mount Hope, and 6554, dug out of mud flat, about 1 foot above ordinary high-tide level, Colon, collected by D. F. MacDonald.

Costa Rica, Moin Hill, Niveau *a*, H. Pittier collection.

Porites furcata is a common Pleistocene species. It is usual in the material behind elevated, sea-front reefs of the West Indies and eastern Central America, and it is one of the most abundant corals on the flats inside the living coral reefs in the same region and Florida. It has not been found in Bermudas.[1]

PORITES BARACOÄENSIS, new species.

Plate 147, figs. 1, 1*a*.

Corallum composed of slender branches. The type, a fragment of a branch, is 26 mm. long; lower end, subcircular in cross section, 6.25 mm. in diameter; 8.5 below upper end, the diameter is 6 by 8 mm., showing some flattening just below a bifurcation.

Calices polygonal, excavated but rather shallow; diameter from 1.25 to 2.25 mm., about 1.75 mm. usual. Wall straight, acute or with rather coarse knots corresponding to the outer ends of the septa; a distinct mural shelf is present in all or nearly all calices.

Septa arranged into a solitary directive, four lateral pairs, and a ventral triplet. There is a circle of septal granules detached from the wall and fused by their bases, forming a mural shelf on the inner margin of which the granules stand up as compressed knots or as

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[1] See Verrill, Conn. Acad. Arts and Sci. Trans., vol. 11, p. 158, 1902.

plates. Usually there are six pali; that is, normally there are pali before the lateral pairs, the solitary directive, and the triplet. In a few calices there is a palus before each member of the triplet, making eight pali in all; and in a few calices there is no recognizable palus before the solitary directive, the total number of pali being only five. The pali are solidly fused in the bottom of the calice one to another and to the columella tangle. No columellar tubercle was seen in any calice.

Locality and geologic occurrence.—Miocene, Cuba, station 3476, marl, Baracoa, collected by T. W. Vaughan (type).

Miocene, Jamaica, Bowden marl, Bowden, received from Hon. T. H. Aldrich.

Type.—No. 325069, U.S.N.M.

There is no other previously described species of *Porites*, fossil or living, in tropical or subtropical America closely resenbling *P. baracoäensis*. Superficially it looks like the living *P. furcata* Lamark or *P. divaricata* Le Sueur; but the definite mural shelf, above which the wall stands at its distal edge and the special granules on its inner edge, is distinctive.

PORITES BARACOÄENSIS var. MATANZASENSIS, new variety.

Plate 147, figs. 2, 2*a*, 3, 4.

Corallum composed of attenuate branches of small diameter. A fragment 15 mm. long is 3 mm. in diameter at one end and 3.25 mm. in diameter at the other. The maximum diameter of a branch seems to be about 3.75 mm., except where there is some flattening just below a bifurcation. The length of branches exceeds 20 mm., and probably is as much as 40 to 50 mm., or even more.

Calices polygonal, very shallow or even surficial; diameter from 2 to 2.75 mm. Wall slightly elevated, continuous and acute or with knots corresponding to the outer ends of the septa. Usually there is a distinct mural shelf.

The septal characters are the same as those of *P. baracoäensis*, except that the pali are less conspicuous and the septa in the upper half of the calice are usually elongated and have between three and five teeth on their margins between the wall and the columella tangle. But in some calices the upper septa are not produced, and in these the septal characters are the same as in typical *P. baracoäensis*. Because of the presence of calices presenting the same characters as those of typical *P. baraocoäensis*, a varietal designation seems all that is justifiable.

Locality and geologic occurrence.—Miocene, Cuba, station 3461, marl, gorge of Yumurí River, Matanzas, collected by T. W. Vaughan.

Type.—No. 325067*a*, U.S.N.M. (pl. 147, figs. 2, 2*a*.).

Paratypes.—Nos. 325067*b*, U.S.N.M.

Apparently the specimens from Yumurí gorge lived in deeper or quieter water than those from Baracoa, for the differences are of the kind incident to such differences in ecologic conditions. The specimens of *Stylophora granulata* from the Yumurí gorge are decidedly more attenuate than those from Baracoa; and the specimens referred to *Madracis mirabilis* are very slender and fragile.

PORITES DOUVILLEI, new species.

Plate 149, figs. 2, 2*a*; plate 151, figs. 1, 1*a*.

Corallum composed of compressed, more or less coalescent branches. Plate 151, figure 1, represents a part of a corallum 66 mm. long, 15 mm. in maximum thickness, and 40 mm. wide; the specimen, represented by figure 2 of plate 149, is 35.5 mm. long and 11 mm. in maximum thickness.

Calices shallow, polygonal, 1.25 to 2 mm. in diameter, 1.5 mm. probably about an average; separated by usually continuous, straight, membraniform walls, along the top of which are a few mural denticles corresponding to the outer ends of the septa; where the septa are distally forked there may be a denticle for each fork.

Septa forming four lateral pairs, two on each side of the plane of symmetry, a solitary directive, and a ventral triplet with the inner ends of its members free from each other. A ring of thickish septal granules is detached from the wall, standing about half way between it and the palar ring; the outer ends of a number of septa fork between the septal granule and the wall. Pali well-developed, formula complete or suppressed on one or more members of the triplets, suggestions of trident formation in some calices. Synapticulae in two rings, the outer corresponds in position with the septal granules and is usually incomplete, the inner is the palar synapticular ring and normally is complete.

Columella tangle consists of a central tubercle joined by radii to the pali.

Locality and geologic occurrence.—Canal Zone, station 6016, quarry in the Emperador limestone, Empire, collected by T. W. Vaughan and D. F. MacDonald.

Cotypes.—Cat. No. 325106 (2 specimens), U.S.N.M.

PORITES TOULAI, new species.

Plate 150, figs. 1, 1*a*, 2, 3, 4.

Corallum composed of elongate, rather slender, subterete, or only slightly compressed branches. The following measurements of broken branches indicate the shape and size.

Measurements of branches of Porites toulai.

Specimen No.	Length.	Diameter of lower end.	Diameter of upper end.
	mm.	*mm.*	*mm.*
1	40.5	7 by 8	6.75 by 7.5
2	46	13.5 by 14	12 by 14
3	74	11 by 17	8 by 10.5

Specimen No. 3 has been somewhat compressed by pressure.

Calices shallow, diameter about 1.75 mm., a few large calices have a greater diameter of as much as 2.5 mm. There is a pronounced tendency for the calices to occur in rather short, longitudinal series. One series is 5.5 mm. long and contains 4 calices, one of which is immature; another series, which is slightly curved, is 7.5 mm. long and contains 5 calices. The calices within a series are separated by indistinct walls; in fact, between some no definite wall is recognizable, the distal ends of septa from one calicinal center being continuous with the distal ends of the septa belonging to the next center. Such series are formed by fission. The walls between adjacent series are definite; a wall-ridge is usually but not invariably recognizable, it is interrupted and straight or somewhat zigzag. There is in places a considerable development of intercalicular or interserial reticulum, in which the radial (costal) skeletal elements are conspicuous.

The septal arrangement is irregular as would be expected in a coral in which asexual reproduction is largely by fission. Groups of calices from two specimens are shown on plate 150, figures 1*a*, 4. The scheme where complete seems to be a solitary directive, two lateral pairs on each side of the plane of symmetry, and a ventral triplet in which the inner ends of the lateral members converge toward the included directive and join it by synapticulae, but such a schematic arrangement is rarely recognizable. There are usually from 10 to 14 septa fusing in pairs or in threes, with a solitary septum, the directive plane being indicated in many calices by an elongate septum, to the inner end of which the columellar tubercle may be attached. Usually coarse septal granules slightly detached from the wall form a ring, and the pali form a ring surrounding the columellar tangle. There is indefiniteness and irregularity in the pali as there is in the septa; the normal number seems to be five or six. There are an outer ring of synapticulae, more or less fused to or detached from the wall, and an inner palar ring.

There is a well developed, rather prominent columellar tubercle, which is joined by radii to the inner ends of the septa.

Locality and geologic occurrence.—Canal Zone, station 6016, quarry in the Emperador limestone, Empire, collected by T. W. Vaughan and D. F. MacDonald.

Type.—Cat. No. 325105*a*, U.S.N.M. pl. 150, figs. 1, 1*a*.

Paratypes.—Cat. No. 325105*b*, U.S.N.M. (3 specimens).

PORITES ASTREOIDES Lamarck.

1816. *Porites astreoides* LAMARCK, Hist. nat. Anim. sans Vert., vol. 2, p. 269.
1887. *Porites astreoides* RATHBUN, U. S. Nat. Mus. Proc., vol. 10, p. 354.
1901. *Porites astreoides* VAUGHAN, U. S. Fish Com. Bull. for 1900, vol. 2, p. 317, pl. 32; pl. 33; pl. 34, figs. 1, 2.
1902. *Porites astreoides* VERRILL, Conn. Acad. Arts and Sci. Trans., vol. 11, p. 160, pl. 31, fig. 4.
1902. *Porites verrilli* VERRILL, Conn. Acad. Arts and Sci. Trans., vol. 11, p. 161, pl. 31, fig. 5.
1903. *Porites astraeoides* DUERDEN, Nat. Acad. Sci. Mem., vol. 8, p. 550, pls. 3–5, figs. 28–42.
1912. *Porites astreoides* VAUGHAN, Carnegie Inst. Washington Yearbook No. 10, pp. 148–156, pl. 4, figs. 3*a*, 3*d*, 3*e*; pl. 5, figs. 5*b*, pl. 6, figs. 1*c*, 2*e*.
1915. *Porites astreoides* VAUGHAN, Washington Acad. Sci. Journ., vol. 5, p. 597.
1916. *Porites astreoides* VAUGHAN, Nat. Acad. Sci. Proc., vol. 2, p. 98.
1916. *Porites astreoides* VAUGHAN, Carnegie Inst. Washington Yearbook No. 12, pp. 226, 227, 228, 231.

This is one of the coral species to which I devoted much attention during my field studies in Florida and the Bahamas. The results of my observations and experiments have mostly been published in Yearbook Nos. 7 to 14, inclusive, of the Carnegie Institution of Washington.

Localities and geologic occurrence.—Canal Zone, Pleistocene, station 6039, Mount Hope, collected by D. F. MacDonald. This species is general in both the living and the Pleistocene coral reefs of the Caribbean region and Florida. It is also found living both in the Bermudas and on the Brazilian reefs.[1]

I collected in the Miocene La Cruz marl in and near Santiago, Cuba, a number of specimens of a massive species of *Porites* that I can not distinguish from *P. astreoides.* The station numbers are 3436 and 3438, south side of the city along the trocha; 3446, first deep cutting east of La Cruz, along the railroad.

PORITES PANAMENSIS, new species.

Plate 148, figs. 1, 2, 3, 3*a*.

The type is the upper part of a plate, which is 90 mm. tall, 75 mm. wide, and 28 mm. in maximum thickness near the lower end. One side is nearly flat, while on the other there are two low gibbosities. (See pl. 148, fig. 3.)

Calices excavated but not very deep, circumscribed, 1.5 to 2 mm. in diameter, or confluent in short series of about three calices. Wall coarse, rather ragged in appearance, forms a considerably interrupted, usually straight, occasionally zigzag, elevated ridge with coarse knots along its top. As asexual reproduction is largely by fission, there are no definite walls between many calicinal centers.

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[1] Verrill, Conn. Acad. Arts and Sci. Trans., vol. 11, p. 161, 1902.

There is irregularity in the number and arrangement of the septa resulting from the formation of new calices by fission. They are usually rather thick and in many calices are bent in an irregular way. In fully developed calices there are 12 septa with the usual solitary directive, four lateral pairs, and a directive triplet. The laterals of the triplet are more or less free from the directive of the group, but usually appear to converge toward its inner end. Septal granules irregular in development, rarely forming a definite, clear-cut ring, more or less attached to the wall. Pali from six to eight in number, irregular in development. No definite outer synapticular ring, but a few synapticulae correspond in position to the septal granules; palar synapticular ring better developed.

There is a columellar tubercle rising in the middle of an irregular columellar tangle.

Locality and geologic occurrence.—Canal Zone, stations 6015 and 6016, quarries in the Emperador limestone, Empire, collected by T. W. Vaughan and D. F. Macdonald.

Type.—No. 325063, U.S.N.M.

Paratypes.—Nos. 325064, U.S.N.M. (2 specimens).

The type and three other specimens are plates with undulations or low gibbosities on the sides. This growth-form grades into nodose columns (see pl. 148, fig. 1, for growth habit, and fig. 2 for an enlarged view of the calices of another specimen of similar growth-form). As the good suite of specimens shows that these are only intergrading growth-forms of the same species and as they occur together at station 6016, separate nomenclatorial designation appears unnecessary.

PORITES ANGUILLENSIS, new species.

Plate 149, figs. 1, 1*a*, 1*b* (type); plate 150, fig. 5.

The following is a description of the type: Corallum composed of thin, more or less undulate, separate laminae, resting one on another. The underside epithecate to the edge, the epitheca minutely, regularly, and concentrically striate. The type-specimen consists of two such laminae, both broken. The greatest thickness of the two is about 15 mm., the greatest width 58 mm. One lamina is 5 mm. thick in its thickest portion, the edge is thinner.

The calices are shallow, subcircular, 1.7 to 2.3 mm. in diameter, separated by flat coenenchymal walls, 0.8 to 1 mm. across. The coenenchyma is perforate, but rather compact and costate.

Septa rather thick, normal number 12, with solitary directive, four lateral pairs, and the laterals on the sides of the principal directive loosely fused to it or continued to the columella tangle. Pali, usually six in number, before the lateral pairs, on the ends of the solitary and principal directives. As a rule, there is a prominent dentation at the inner edge of the wall. Synapticulae well developed, three rows in the wall, and a ring of thick ones, coinciding with the palar ring, around the axis of each corallite. Trabeculae of columellar tangle coarse; axial tubercle present. In longitudinal section there are in 3.5 mm. about 11 synapticulae; in the same distance about 10 vertical rods. The spaces of approximately the same thickness as the solid parts, except that the median portion of a synapticula is thinner than its ends.

Locality and geologic occurrence.—Island of Anguilla, West Indies, collected by P. T. Cleve; Crocus Bay, Anguilla, collected by T. W. Vaughan.

Canal Zone, station 6016, in the Emperador limestone, Empire, collected by T. W. Vaughan and D. F. MacDonald.

Type.—University of Upsala.

Duplicate specimen from the Cleve collection and other specimens in the United States National Museum.

This is an abundant species at Crocus Bay, Anguilla, where I collected it in both the lower and the upper part of the exposure on the south side of the bay. The epitheca is not always distinct on the lower surface, but I can not be sure whether it has been worn off or was not developed.

One of the two specimens from Empire, Canal Zone, is represented by plate 150, figure 5. The calicular characters are obscure but they seem to be the same as those of *P. anguillensis*. The general facies of the specimens is identical with that of *P. anguillensis*.

Subgenus SYNARAEA Verrill.

1864. *Synaraea* VERRILL, Mus. Comp. Zool. Bull., vol. 1, p. 42.

Type-species.—None was designated by Verrill; therefore I select as the type-species *Porites erosa* Dana, the first species in Verrill's list of those referred by him to *Synaraea.*

PORITES (SYNARAEA) HOWEI, new species.

Plate 151, figs. 2, 2*a*, 3, 3*a*, 4.

Corallum composed of rather small, slightly or greatly compressed, even subpalmate, branches, on some of which longitudinal carinae are well developed. Plate 151, figures 2, 3, 3*a*, are natural size illustrations of two specimens. The thickness of the lower end of the specimen represented by figure 2 is 6 mm., of the upper end of the same specimen about 5.5 mm.; the width and length of the specimen are indicated by the figure.

The calices are small, about 1 mm. in diameter, and occur more or less in series from 5 to 18 mm. long between reticular coenenchymal ridges, that range in thickness from a merely dividing partition up to 2 mm. wide, and in height up to a maximum of about 1 mm.

Septa small, 12 in number, with the usual poritid arrangement. The laterals of the triplet converge toward the inner end of the directive and fuse to it at the periphery of the columellar tangle. A circle of fairly prominent septal granules distinguishable just within and more or less attached to the wall. Pali small, but distinct and relatively prominent, usually six in number, on the inner ends of the two directives and before the lateral pairs. The synapticular rings are very clearly distinguishable, apparently there are two, the outer of irregular development.

Columellar tangle well developed, with a small, erect central tubercle.

Locality and geologic occurrence.—Canal Zone, station 6016, quarry in the Emperador limestone, Empire, collected by T. W. Vaughan and D. F. MacDonald.

Cotypes.—No. 325113, U.S.N.M. (3 specimens).

PORITES (SYNARAEA) MACDONALDI, new species.

Plate 152, figs. 1, 2, 3, 3*a*, 4, 5, 5*a*.

Corallum begins growth as an explanate plate with humps and gibbosities on its upper surface, by continued growth the protuberances rise into crests and compressed columiform lobes. The series of illustrations on plate 152, figures 1, 2, 3, 4, 5, indicate the growth-forms.

Calices of moderate size, average about 1.5 mm. in diameter, occur separately or in series, usually in series which range in length from the diameter of two or three calices up to 18 mm. long with 11 calices. Within the series, although the calicinal centers are clearly demarked, the walls between adjacent calices are only slightly developed, but the series are separated by distinct fairly continuous walls, which are costate on top, or by coarsely reticular coenenchyma. In many places the reticulum rises upward between calices, especially at their corners, and forms papillae, similar to those in the papillate species of *Montipora*. Such papillae may be single, with a basal diameter of about 1 mm. and a height also of about 1 mm., or they may fuse and form ridges as much as 7 mm. long and 1.5 mm. thick at the base. The reticulum composing the papillae is of coarse texture.

As new calices are largely formed by fission, the septal arrangement is not definitely schematic. Where it appears possible to recognize a ventral directive, the laterals of the triplet are joined to it by synapticulae at the periphery of the columellar tangle. There is a ring of septal granules slightly detached from the wall, and corresponding to it in position is an incomplete ring of synapticulae; pali are present, but usually indefinite in development, in one calice there appear to be eight; palar synapticulae indefinite.

Columellar tangle composed of indefinite, confused processes from the inner ends of the septa among which an axial plate is recognizable in a few calices.

Locality and geologic occurrence.—Canal Zone, station 6016, quarry in the Emperador limestone, Empire, collected by T. W. Vaughan and D. F. MacDonald.

Anguilla, station 6893, Crocus Bay, collected by T. W. Vaughan.

Cotypes.—No. 325046*a*, U.S.N.M. (4 specimens.)

The identification of the specimen represented by plate 152, figures 5, 5*a* (No. 325046*b*, U.S.N.M.), is not positive.

Class HYDROZOA.

Order HYDROCORALLINAE Moseley.[1]

Family MILLEPORIDAE L. Aggassiz.

Genus MILLEPORA Linnaeus.

MILLEPORA ALCICORNIS Linnaeus.

1758. *Millepora alcicornis* LINNAEUS, Syst. Nat., ed. 10, p. 791.
1898. *Millepora alcicornis* HICKSON, Zool. Soc. London Proc. for 1898, p. 256.
1901. *Millepora alcicornis* VAUGHAN, U. S. Fish Com. Bull. for 1900, vol 2, p. 318, pls. 35–38.

Locality and geologic occurrence.—Canal Zone, Pleistocene, stations 5850 and 6039, Mount Hope, collected by D. F. MacDonald. One of the two specimens is partly incrusted by *Polytrema mineaceum* (Linnaeus). *Millepora alcicornis* is found living on the West Indian and Floridian coral reefs nearly everywhere there are such reefs and in the Bermudas. According to Hickson, there is only one living species, which is Indo-Pacific as well as Atlantic in its distribution.

EXPLANATIONS OF PLATES.

PLATE 68.

West Indian Shore Lines.

	Page.
A. Five Islands Harbor, Antigua	273
B. Spencer Bay, Antigua	273
C. Publiken Bay, St. Bartholomew	275
D. St. Jean Bay, St. Bartholomew	275

PLATE 69.

West Indian Shore Lines.

A. Pointe Blanche, St. Martin	276
B. East side of Crocus Bay, north side of Anguilla	276
C. Calls Pond, Anguilla	277
D. Shore, south side of Anguilla, looking toward St. Martin	276

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[1] These organisms are not corals, but, as they are usually associated with corals and contribute calcium carbonate to reefs, accounts of them are frequently included in discussion of Madreporia.

PLATE 70.

West Indian Shore Lines.

PLATE 71.

West Indian Shore Lines.

PLATE 72.

Views of Isle of Pines, Cuba.

PLATE 73.

PLATE 74.

Stylophora imperatoris, new species.

PLATE 75.

PLATE 76.

	Page.
FIGS. 1, 1*a*. *Stylophora portobellensis*, new species, two views of the type.	
1. Corallum, natural size	338
1*a*. Calices, × 3	338
2, 2*a*. *Stylophora canalis*, new species, two views of the type.	
2. Corallum, natural size	341
2*a*. Calices, × 8	341
3, 3*a*, 3*b*. *Pocillopora arnoldi*, new species, three views of the type.	
3, 3*a*. Branch, natural size	343
3*b*. Calices, × 8	343
4, 4*a*. *Astrocoenia portoricensis*, new species, two views of the type.	
4. Corallum, natural size	350
4*a*. Calices, × 5	350

PLATE 77.

FIGS. 1, 1*a*. *Pocillopora baracoäensis*, new species.	
1. Branch, natural size	344
1*a*. Calices, × 5	344
2, 2*a*. *Pocillopora guantanamensis*, new species.	
2. Corallum, natural size	344
2*a*. Calices, × 5	344
3, 3*a*, 3*b*. *Thysanus hayesi*, new species.	
3. Calicular surface, × 2	424
3*a*. Base, × 2	424
3*b*. Side, × 2	424

PLATE 78.

FIGS. 1, 1*a*. *Astrocoenia portoricensis*, new species, two views of form with subterete branches.	
1. Branch, natural size	351
1*a*. Calices, × 5	351
2, 2*a*. *Astrocoenia d'achiardii* Duncan.	
2. Branch, natural size	346
2*a*. Calices, × 5	346
3, 3*a*, 4, 4*a*. *Astrocoenia decaturensis*, new species.	
3. View, natural size, of the corallum; 3*a*, calices, × 5, of the type from near Bainbridge, Ga	348
4. View, natural size, of the corallum; 4*a*, calices, × 5, of a specimen from Antigua	348

PLATE 79.

FIGS. 1, 1*a*, 2. *Astrocoenia guantanamensis*, new species.	
1. Corallum, natural size; 1*a*, calices, × 5, of type, from Guantanamo, Cuba	347
2. Specimen from Tonosi, Panama; calices, × 5	347
3, 3*a*. *Astrocoenia meinzeri*, new species.	
3. Corallum, natural size	349
3*a*. Calices, × 5	349
4, 4*a*, 4*b*. *Dichocoenia tuberosa* Duncan.	
4. Corallum, natural size	360
4*a*. Costae, × 4	360
4*b*. Calices, × 3	360

PLATE 80.

FIGS. 1, 1*a*, 1*b*, 2, 3. *Archohelia limonensis*, new genus and species. Page.
1. Corallum, natural size; 1*a*, calice, × 4; 1*b*, axial corallite, × 4, of the type ... 353
2, 3. Views, natural size, of two paratypes ... 353
4, 5, 6, 6*a*. *Asterosmilia hilli*, new species.
4. Corallum, × 2 ... 355
5. Corallum, × 2½ ... 355
6. Corallum, × 2½, 6*a*, calice, × 3, of the same specimen ... 355
7, 7*a*, 7*b*. *Orbicella annularis* (Ellis and Solander), three views of the specimen identified by Milne Edwards and Haime as *Heliastraea stellulata* (Ellis and Solander).
7. Corallum, five-sixths natural size ... 373
7*a*. Calices, × 3⅓ ... 373
7*b*. Longitudinal section of corallites, × 3⅓ ... 373

PLATE 81.

Orbicella annularis (Ellis and Solander).

FIGS. 1, 1*a*. Two views of a typical specimen from Tortugas, Florida.
1. Corallum, natural size ... 366
1*a*. Calices, × 3 ... 366
2. Variant with nodular surface, × ½, from Tortugas, Florida ... 367

PLATE 82.

Orbicella annularis (Ellis and Solander).

FIGS. 1, 1*a*. Variant from Mayaguez, Porto Rico.
1. Corallum, × ½ ... 368
1*a*. Calices, × 3 ... 368
2. Variant, discoidal in form, ×½, from Fort Taylor, Key West, Florida ... 368

PLATE 83.

Orbicella annularis (Ellis and Solander).

FIG. 1. Calices of Verrill's type of *Orbicella hispidula*, ×3 ... 368
2. Calices, ×3, of a specimen from Port Castries, Saint Lucia ... 369
3, 3*a*. Two views of a specimen of *Orbicella hispidula* Verrill, from the reef east of Cocoanut Point, Andros Island, Bahamas.
3. Corallum, ×½ ... 368
3*a*. Part of the surface, natural size ... 368

PLATE 84.

Orbicella annularis (Ellis and Solander).

FIG. 1. Calices of the type of *Echinopora franksi* Gregory, ×3 ... 371
2. Corallum of columnar growth-form from Tortugas, Florida, natural size. 367
3, 3*a*. Two views of a variant with columnar growth-form from Westpunt, Curaçao.
3. Corallum, natural size ... 371
3*a*. Calices, ×3 ... 371

PLATE 85.

Orbicella limbata (Duncan).

	Page.
FIGS. 1, 1*a*. Two views of an original specimen of Duncan's *Plesiastraea ramea*.	
1. Corallum, natural size	376
1*a*. Calices, ×3	376
2, 2*a*, 2*b*. Three views of the same specimen in the Museum of Comparative Zoology.	
2. Longitudinal section, natural size	377
2*a*. Longitudinal section, ×5	377
2*b*. Calices, ×3	377
3. Calices, ×3, of another specimen	377
4, 4*a*. Two views of one of the original specimens referred to by Duncan as *Phyllocoenia sculpta* var. *tegula*.	
4. Surface of corallum, natural size	377
4*a*. Calices, ×3	377

PLATE 86.

FIGS. 1, 1*a*. *Stylangia panamensis*, new species.	
1. Corallum, natural size	410
1*a*. Costæ, ×4	410
2, 3, 4, 5. *Orbicella imperatoris*, new species.	
2. Calices of a cotype, ×3⅓	378
3. Calices of a second cotype, ×3⅓	378
4. Longitudinal section of the corallites of a cotype, natural size	378
5. Calices of a specimen from Ciénaga, Cuba, ×3⅓	378
6, 6*a*. *Septastrea matsoni*, new species.	
6. Corallum, natural size	411
6*a*. Calices, ×4	411

PLATE 87.

Orbicella cavernosa (Linnaeus).

Four views of the same specimen.

FIGS. 1. Calices of one end, natural size. Corallites protuberant; costae low, thick, equal or subequal	381
1*a*. Calices of the other end, natural size. Corallites low; last cycle of costae very small or obsolete, costae of lower cycles tall and thin.	382
1*b*. Longitudinal section of corallite, ×2	381
1*c*. Exothecal cells, ×2	381

PLATE 88.

Orbicella cavernosa (Linnaeus).

FIG. 1. Marginal calices, natural size, of a specimen from 9 miles northwest of Key West, Florida	380
2. Calices natural size of a specimen from Tortugas, Florida	380
3, 3*a*, 3*b*. Three views of the specimen labeled *Orbicella compacta* Rathbun, from Brazil (lat. 12° 48′ S.; long. 38° W.). This is probably a valid variety of *O. cavernosa*.	
3. Upper surface of corallum, natural size	384
3*a*. A group of calices, ×2	384
3*b*. Longitudinal section of corallites, ×2	384

PLATE 89.

Figs. 1, 1*a*. *Orbicella cavernosa* var. *endothecata* (Duncan); two views of one of Duncan's original specimens. Page.
- 1. Outer surface; 1*a*, longitudinal section of corallites, each natural size. 384
- 2. *Orbicella cavernosa* var. *cylindrica* (Duncan); calices, natural size, of one of Duncan's original specimens.......... 385
- 3. *Orbicella aperta* (Verrill). Calices natural size.......... 386

PLATE 90.

Orbicella bainbridgensis, new species.

Four views of the type.

Figs. 1. Upper surface of the corallum, natural size.......... 386
- 1*a*. Calices, ×4.......... 386
- 1*b*. Longitudinal section of a corallite, ×4.......... 386
- 1*c*. Exotheca, ×4.......... 386

PLATE 91.

Figs. 1, 1*a*. *Orbicella costata* (Duncan). Cross-section of corallites of one of Duncan's original specimen. Figure 1, natural size; figure 1*a*, ×3.......... 388
- 2. *Orbicella costata* (Duncan). View natural size of a specimen from Antigua.......... 388
- 3, 3*a*. *Orbicella costata* (Duncan). Two views, each natural size of another specimen from Antigua.......... 388
- 4. *Goniastrea canalis*, new species. Calices of the type, ×3½.......... 416

PLATE 92.

Orbicella costata (Duncan).

Fig. 1. Specimen from 4 miles west of Lares, Porto Rico, natural size.......... 388
- 2. Specimen from Culebra formation, Las Cascadas, Canal Zone; calices, ×4.......... 388
- 3. Specimen from Anguilla, natural size.......... 388

PLATE 93.

Orbicella costata (Duncan).

Two views of the same specimen from Anguilla.

Fig. 1. Calices, ×4.......... 388
- 1*a*. Corallum, natural size.......... 388

PLATE 94.

Orbicella canalis, new species.

Figs. 1, 1*a*. Two views of the type.
- 1. Corallum, natural size.......... 389
- 1*a*. Calices, ×4.......... 389

2, 2*a*. Two views of a paratype from the Canal Zone.
- 2. Corallum, natural size.......... 389
- 2*a*. Calices, ×4.......... 389

3, 3*a*. Two views of a varietal form from Anguilla.
- 3. Corallum, natural size.......... 389
- 3*a*. Calices, ×4.......... 389

PLATE 95.

Orbicella tampäensis, new species.

Page.
Fig. 1. Corallum, natural size, of the type 390
2, 2*a*. Two views of the same paratype.
  2. Corallum, natural size 390
  2*a*. Calices and costæ, ×2 390
3, 3*a*. Two views of another paratype, Wagner Free Institute of Science.
  3. Corallum, natural size 390
  3*a*. Calices and costæ, ×2 390

PLATE 96.

Orbicella tampäensis var. *silecensis*, new variety.

General view of the type, natural size, Wagner Free Institute of Science. 390

PLATE 97.

Fig. 1. *Orbicella brevis* (Duncan). View, natural size, of the type, Geological Society of London 391
2. *Orbicella intermedia* (Duncan). View, natural size, of the type, Geological Society of London 393
3, 3*a*. *Orbicella irradians* (Milne Edwards and Haime). Two views of the same specimen.
  3. Corallum, natural size 395
  3*a*. Calices and costae, ×2 395
4, 4*a*. *Orbicella canalis*, new species. Two views of the same specimen.
  4. Calice and costae, ×4 389
  4*a*. Corallum, natural size 389

PLATE 98.

Figs. 1, 2, 2*a*. *Orbicella insignis* (Duncan).
  1. Cross-section of corallites of one of Duncan's original specimen, ×2, Geological Society of London 393
  2. Cross-section of corallites; 2*a*, longitudinal section, showing endotheca and exotheca of a specimen from Serro Colorado, Arube. Both figures ×2 393
3, 3*a*. *Antiguastrea cellulosa* (Duncan).
  3. Corallum, natural size; 3*a*, calices, ×2, of a typical specimen, from Antigua 403
4, 4*a*. *Antiguastrea cellulosa* var. *curvata* (Duncan).
  4. Corallum, natural size; 4*a*, calices, ×2, of the same specimen from Antigua 408

PLATE 99.

Antiguastrea cellulosa (Duncan).

Figs. 1, 1*a*. Two views of a specimen with protuberant, separate corallite limbs, from Willoughby Bay, Antigua.
  1. Corallum, natural size 403
  1*a*. Calices, ×4 403
2, 2*a*. Two views of a specimen from Cathedral, St. John, Antigua. Calices on one end excavated; on the other end shallow, tumid around the margins.
  2. Corallum, natural size 404
  2*a*. Calice, ×6 404
3, 3*a*. Two views of a second specimen from Cathedral, St. John, Antigua. Calices shallow, distant, tumid around the margins.
  3. Corallum, natural size 405
  3*a*. Calices, ×6 405

Plate 100.

Antiguastrea cellulosa (Duncan).

Page.

Fig. 1. Photograph of thin cross-section of corallites, ×6; shows the large, lamellar columella. Specimen from Cathedral, St. John, Antigua.. 405
- 2. Photograph of thin cross-section of corallites, ×6; columella not so wide as in figure 1. Specimen from Cathedral, St. John, Antigua.......... 405
- 3, 3*a*. Two views of a specimen from station 6856, Friar's Hill, Antigua.
  - 3. Corallum, natural size 405
  - 3*a*. Calices, ×6 405
- 4, 4*a*. Two views of a specimen of the kind designated *Isastræa turbinata* by Duncan.
  - 4. Corallum, natural size 406
  - 4*a*. Calices, ×4 406

Plate 101.

Figs. 1, 1*a*. *Antiguastrea cellulosa* var. *silecensis*, new variety. Two views of the type, from Flint River near Bainbridge, Georgia.
- 1. Upper surface of the corallum, natural size 408
- 1*a*. Calices, ×3 408

2, 2*a*. *Antiguastrea cellulosa* (Duncan). Two views of the same specimen, from the Byram calcareous marl, Vicksburg, Miss.
- 2. Part of upper surface of the corallum, natural size 407
- 2*a*. Calices, ×4 407

Plate 102.

Figs. 1, 1*a*. *Antiguastrea elegans* (Reuss) Vaughan. Two views of a specimen from Fontana della Bova di San Lorenzo, Italy, out of beds of Rupelian (middle Oligocene) age.
- 1. Upper surface, natural size 409
- 1*a*. Calices, ×4 409

2. *Favia macdonaldi*, new species. Corallum, upper surface, natural size. Enlarged view of cross-section of corallites shown on plate 103, fig. 1........ 413

Plate 103.

Fig. 1. *Favia macdonaldi*, new species. Cross-section of corallites, ×2. General view of corallum, plate 102, fig. 2........ 413

2, 2*a*. *Favites mexicana*, new species. Two views of the same specimen.
- 2. Corallum, natural size 414
- 2*a*. Calices, ×4 414

3, 4, 4*a*. *Maeandra antiguensis*, new species.
- 3. Upper surface of a cotype, natural size 417
- 4. Upper surface of the second cotype, natural size; 4*a*, part of surface of the same, ×4........ 417

Plate 104.

Figs. 1, 1*a*. *Maeandra dumblei*, new species. Two views of the type.
- 1. Upper surface, natural size 418
- 1*a*. Part of surface, ×4 418

2, 2*a*. *Manicina willoughbiensis*, new species.
- 2. Lower surface, natural size, of the type. Upper surface, illustrated by plate 105 422
- 2*a*. Part of lower surface of a paratype, ×2 422

Plate 105.

Page.

Manicina willoughbiensis, new species. Upper surface, natural size. Lower surface illustrated by plate 104, figure 2 422

Plate 106.

Figs. 1, 1*a*, 1*b*. *Syzygophyllia hayesi*, new species. Three views of the type.
  1. Calicular surface, natural size 424
  1*a*. Side view, natural size 424
  1*b*. Epitheca, ×5. Specimen photographed in horizontal position; the top toward the right 424
 2, 2*a*, 2*b*. *Trochoseris meinzeri*, new species. Three views of the type.
  2. Corallum, side view, natural size 426
  2*a*. Calice, natural size 426
  2*b*. Septa, ×5 426

Plate 107.

Figs. 1, 1*a*. *Maeandra portoricensis*, new species. Two views of the type.
  1. Upper surface, natural size 418
  1*a*. Part of upper surface, ×2 418
 2, 2*a*, 2*b*. *Leptoseris portoricensis*, new species. Three views of the type.
  2. Calicular surface, natural size 431
  2*a*. Outer surface, natural size 431
  2*b*. Costae of outer surface, ×4 431

Plate 108.

Figs. 1, 1*a*, 1*b*. *Orbicella gabbi*, new species. Three views of the holotype, Philadelphia Academy of Natural Sciences.
  1. Cross section of corallites, natural size 394
  1*a*. Cross section of a corallite, ×2 394
  1*b*. Endotheca and exotheca, ×4 394
 2, 3, 4. *Agaricia anguillensis*, new species. A view, natural size, of each of three cotypes, University of Upsala 428

Plate 109.

Figs. 1, 1*a*. *Agaricia dominicensis*, new species. Two views of the type.
  1. Calicular surface, ×2 428
  1*a*. Lower surface, ×2 428
 2, 2*a*, 3. *Leptoria spenceri*, new species.
  2, 2*a*. Two views of the upper surface of the holotype; figure 2, natural size; figure 2*a*, ×2 421
  3. Upper surface, natural size, a worn paratype 421

Plate 110.

Pavona panamensis, new species.

Figs. 1, 1*a*, 1*b*. Three views of a cotype in which the septa strongly alternate in prominence around the calices, but the septo-costae in places are subequal.
  1. Calicular surface, natural size 430
  1*a*. Calices, ×4 430
  1*b*. Calices, ×4 430

Page.

FIGS. 2, 2*a*. Two views of a cotype in which the septa are subequal in prominence around the calices.
  2. General view of the corallum, natural size 430
  2*a*. Calices and septocostae, ×4 430
3, 3*a*. Two views of a specimen intermediate in its septal and septo-costal characters between the preceding specimens.
  3. View, natural size 431
  3*a*. Calices and septo-costae, ×4 431

PLATE 111.

Pironastraea anguillensis, new species.

FIGS. 1, 1*a*, 1*b*. Three views of the holotype.
  1. Part of upper surface, natural size 433
  1*a*. Part of lower surface, natural size 433
  1*b*. Valleys and collines, ×5 433

PLATE 112.

FIGS. 1, 1*a*. *Pironastraea anguillensis*, new species. Two views of paratype.
  1. Part of upper surface, natural size 433
  1*a*. Valleys and collines, ×5 433
2, 2*a*. *Pironastraea antiguensis*, new species. Two views of the holotype, from Antigua.
  2. Upper surface, natural size 434
  2*a*. Part of upper surface, ×5 434

PLATE 113.

Pironastraea antiguensis, new species.

FIGS. 1, 1*a*. Two views of a specimen from near Guantanamo, Cuba.
  1. Part of upper surface, natural size 434
  1*a*. Part of upper surface, ×5 434

PLATE 114.

FIGS. 1. *Siderastrea radians* (Pallas). Calices, ×6, of a specimen from off Cocoanut Point, Andros Island, Bahamas 439
2, 3. *Siderastrea siderea* (Ellis and Solander).
  2. Calices, ×6, of a specimen from Guanica Centrale, Porto Rico 444
  3. Calices, ×6, of another specimen, the usual form of the species, also from Guanica Centrale, Porto Rico 444
4, 4*a*. *Siderastrea siderea* var. *dominicensis*, new variety. Two views of the type.
  4. Corallum, natural size 447
  4*a*. Calices, ×6 447

PLATE 115.

FIGS. 1, 1*a*. *Siderastrea pourtalesi*, new species. Two views of the type.
  1. Corallum, natural size 440
  1*a*. Calices, × 6 440
2, 2*a*, 2*b*. *Siderastrea stellata* Verrill. Three views of the same specimen.
  2. Corallum, one-half natural size 440
  2*a*. Part of surface above the lower edge, × 2 440
  2*b*. Summit calices, × 6 440

PLATE 116.

Siderastrea silecensis, new species.

Page.

FIGS. 1, 1*a*. Two views of the type.
  1. Corallum, one-half natural size 447
  1*a*. Calices, × 6 447
2. Photograph of thin section of corallites of specimen from the same locality as the type, × 6 447
3. Calices, × 6, of a specimen supposed to come from the "silex" bed at Tampa, Florida 448

PLATE 117.

FIGS. 1, 1*a*, 1*b*. *Siderastrea silecensis*, new species. Three views of a specimen from Coronet Phosphate Mine, Florida.
  1. Weathered cross section of corallites, × 6 449
  1*a*. Longitudinal section of a corallite, × 6 449
  1*b*. Thin section of corallites, × 6 449
2. *Siderastrea hillsboroensis*, new species. Weathered cross section of corallites of holotype, × 6 442
3. *Siderastrea conferta* (Duncan). Calices, × 6, of a specimen from station 6893, the middle or the upper horizon at Crocus Bay, Anguilla.. 453

PLATE 118.

FIGS. 1, 1*a*. *Siderastrea silecensis*, new species. Two views, each × 6, of the calices of a specimen from near Bainbridge, Georgia 449
2, 2*a*, 2*b*, 3. *Siderastrea pliocenica*, new species.
  2, 2*a*, 2*b*. Three views of the type. 2, corallum, natural size; 2*a*, calices, × 4; 2*b*, calices, × 6 441
  3. Worn calices of another specimen, × 6 441

PLATE 119.

Siderastrea dalli, new species.

1, 1*a*. Two views of the type.
  1. Corallum, natural size 450
  1*a*. A group of calices, × 4 450
2. Calices of another specimen, × 6 450

PLATE 120.

Siderastrea conferta (Duncan).

FIG. 1. Cross section, × 3, of corallites of Duncan's type, Geological Society of London 451
2, 2*a*. Two views of a specimen from the Pepino formation, 4 miles west of Lares, Porto Rico.
  2. Corallum, natural size 452
  2*a*. Calices, × 6 452
3, 4. Specimens from Anguilla.
  3. Calices, × 6 453
  4. Calices of another specimen, × 6 453

PLATE 121.

Siderastrea conferta (Duncan).

FIGS. 1, 1*a*. Two views of a specimen from the Culebra formation, Canal Zone.
  1. Upper surface, natural size 453
  1*a*. Calices, × 6 453
2, 2*a*. Two views of a specimen from Anguilla.
  2. Upper surface, natural size 453
  2*a*. Calices, × 6 453

PLATE 122.

Siderastrea siderea (Ellis Solander).

Page.

Fig. 1. Calices, × 6, of a specimen from Tortugas, Florida, water 8 to 9 fathoms deep 444

2, 2*a*, 2*b*. Three views of a specimen, apparently referable to this species from zone H, Rio Gurabo, Santo Domingo.

- 2. Corallum, natural size 445
- 2*a*, 2*b*. Calices, × 6 445

3, 3*a*. Two views of a specimen from the Bowden marl, Jamaica.

- 3. Corallum, natural size 444
- 3*a*. Calices, × 6 444

PLATE 123.

Cyathomorpha rochettina (Michelin) Reis.

Six views of the same specimen, from Crosara, Italy.

Fig. 1. Side view, natural size 456

1*a*. Calicular view, natural size 456

1*b*. Basal view, natural size 456

1*c*. Coarse costae, × 2 456

1*d*. Costae at calicular edge, × 4. Shows perforations near the calicular margin 456

1*e*. Calice, × 4. Shows some synapticulae and that the higher cycles of septa are perforate 456

PLATE 124.

Cyathomorpha hilli, new species.

Two views of the type.

Fig. 1. Upper surface, natural size 457

1*a*. Lower surface, natural size 457

PLATE 125.

Cyathomorpha hilli, new species.

Figs. 1, 1*a*, 1*b*, 1*c*, 1*d*. Five views of a paratype.

- 1. Upper surface, natural size 457
- 1*a*. Side view, natural size 457
- 1*b*. Costae, × 2 457
- 1*c*. Calice, × 2 457
- 1*d*. Another calice, × 2 457

2, 2*a*. Two views of a second paratype

- 2. Side view, natural size 457
- 2*a*. Upper surface, natural size 457

PLATE 126.

Cyathomorpha browni, new species.

Three views of the type.

Fig. 1. Upper surface, natural size 458

1*a*. Lower surface, natural size 458

1*b*. Calices and costae, × 2 458

PLATE 127.

Cyathomorpha anguillensis, new species. All figures natural size.

Page.

FIG. 1. Upper surface of type 461
2. Upper surface of a paratype with corallites somewhat smaller than those of the type 461
3. A specimen with very prominent corallites 461
4, 5. Specimens with small corallites. The specimen represented by figure 4 suggests intergradation with *Cyathomorpha roxboroughi*, new species 461
(All of these specimens are in the collection of the University of Upsala, Sweden.)

PLATE 128.

FIGS. 1, 1*a*, 1*b*. *Cyathomorpha belli*, new species. Three views of the type.
1. Upper surface, natural size 459
1*a*. Costae, × 4 459
1*b*. Calice, × 4 459
2, 2*a*, 2*b*. *Cyathomorpha splendens*, new species. Three views of the type.
2. Upper surface, natural size 460
2*a*. Lower surface, natural size 460
2*b*. Costae, × 2 460

PLATE 129.

FIGS. 1, 1*a*, 1*b*. *Cyathomorpha roxboroughi*, new species. Three views of the type.
1. Corallum, side view, natural size 461
1*a*, 1*b*. Groups of calices, each × 2 461
2. *Cyathomorpha antiguensis* (Duncan) Vaughan. Part of the upper surface of a specimen, natural size. Two other views of this specimen on plate 130, figures 1*a*, 1*b* 465

PLATE 130.

Cyathomorpha antiguensis (Duncan) Vaughan.

FIGS. 1, 1*a*. Two views of the same specimen. Upper surface illustrated by plate 129, figure 2.
1. View of outer surface of corallum to show synapticulae between the costal ends of the septa, × 4 464
1*a*. View of wall as seen looking across a corallite, one side of which is broken away, to show synapticulae between the peripheral ends of the septa, × 4 464
2, 2*a*. Two views of Duncan's type of *Astraea antiguensis*, Geological Society of London.
2. Upper surface, natural size 464
2*a*. Calices, × 2 464
3. View, natural size, of a specimen with large, distant, subcircular calices 465

PLATE 131.

Cyathomorpha antiguensis (Duncan) Vaughan.

FIGS. 1, 1*a*, 1*b*. Three views of the same specimen.
1. Upper surface, natural size. Calices more crowded than on plate 130, figure 3 465
1*a*. Costae of outer surface, × 2 465
1*b*. A calice, × 4, to show the prominent pali 465

Page.

FIGS. 2. A specimen, natural size, with both crowded and rather remote calices, on the same corallum ... 465

3. A specimen, natural size, most of the calices crowded, intercorallite areas very narrow, except at lower left-hand corner, where there is a distant, circular calice ... 465

4. Duncan type of *Astroria antiguensis*, natural size, Geological Society of London. Compare with figure 2 of this plate ... 466

PLATE 132.

FIGS. 1, 2, 2*a*, 2*b*. *Cyathomorpha antiguensis* (Duncan) Vaughan, from Porto Rico.

1. Calices, natural size ... 466

2, 2*a*, 2*b*. Three views of the same specimen. 2, corallum, natural size 2*a*, 2*b*, calices, × 4 ... 466

3, 3*a*. *Cyathomorpha tenuis* (Duncan) Vaughan. Two views of a specimen from Porto Rico.

3. Corallum, natural size ... 467

3*a*. Calices, × 4 ... 467

PLATE 133.

FIG. 1. Duncan's type of *Astroria affinis*, natural size, Geological Society of London. Probably a synonym of *Cyathomorpha antiguensis* (Duncan) ... 466

Cyathomorpha tenuis (Duncan) Vaughan.

2. Calices, × 2, of a specimen, with crowded calices, from Porto Rico ... 467

3, 3*a*, 3*b*. Three views of a specimen from Willoughby Bay, Antigua.

3. Upper surface of corallum, natural size ... 467

3*a*. Part of upper surface, × 4, to show synapticulae between the costae 467

3*b*. Costae with intervening synapticulae on lower surface, × 4 ... 467

PLATE 134.

Diploastrea heliopora (Lamarck) Matthai.

Four views of the same specimen.

FIG. 1. Upper surface, natural size ... 470

1*a*. Costae and intervening synapticulae of lower surface, × 4 ... 470

1*b*. Calices, × 4, to show synapticulae between the distal ends of the septa ... 470

1*c*. Longitudinal section of a corallite, × 4, to show septal perforations, synapticulae, and dissepiments ... 470

PLATE 135.

Diploastrea crassolamellata (Duncan) Vaughan.

FIG. 1. Cross-section of the corallites of a typical specimen, natural size. Most of the septal lamellae appear dark in the figure ... 474

2. Cross section of the corallites of a specimen representing Duncan's variety *nobilis* ... 474

3. A young, simple corallite, side view, natural size ... 474

4, 4*a*. Two views of the same specimen.

4. Side view, natural size ... 474

4*a*. Calicular view, natural size ... 474

5, 5*a*, 5*b*. Three views of the same specimen.

5. Calicular view, natural size ... 475

5*a*. Side view, natural size ... 475

5*b*. A calice, × 2 ... 475

PLATE 136.

Diploastrea crassolamellata (Duncan) Vaughan.

Three views of the same specimen.

Page.

FIG. 1. Side view of corallum, natural size 475
1*a*. Costae of side, × 2 475
1*b*. Calices, natural size 475

PLATE 137.

Diploastrea crassolamellata (Duncan) Vaughan.

FIG. 1. Specimen with excavated calices, natural size 475
2. Specimen with protuberant divergent corallites, natural size 475
3. Specimen with low corallites, × 2. Note the reticulate intercorallite area 475
4, 4*a*. Calices of the same specimen, × 2.
4. With some intercorallite reticulation 475
4*a*. Mostly without any intercorallite reticulation 475
5. Calices, natural size, of a specimen from the base of the Chattahoochee formation near Bainbridge, Georgia. All other specimens illustrated on this plate are from Antigua 475

PLATE 138.

FIGS. 1, 2, 2*a*. *Diploastrea crassolamellata* var. *magnifica* (Duncan) Vaughan.
1. Corallites, natural size, of a specimen from Antigua 477
2. Corallites, natural size; 2*a*, a smaller area, × 2, of a specimen from the base of the Chattahoochee formation near Bainbridge, Georgia. 477
3, 3*a*. *Diploastrea crassolamellata* var. *nugenti* (Duncan) Vaughan. Two views of the same specimen.
3. Corallum, natural size 478
3*a*. Calices, × 2 478

PLATE 139.

FIGS. 1, 1*a*, 1*b*, 2, 2*a*. *Balanophyllia pittieri*, new species.
1. Corallum, natural size; 1*a*, costae, × 4; 1*b*, calice, × 3, of the holotype. 479
2. Corallum, natural size; 2*a*, calice, × 3, of a paratype 479
3, 3*a*. *Astreopora antiguensis*, new species. Two views of the type. Enlarged calices of paratype on plate 140, figure 1.
3. Corallum, one-half natural size 484
3*a*. Part of cross-section of lower end, × 3 484

PLATE 140.

FIG. 1. *Astreopora antiguensis*, new species. Calices of paratype, × 6. For other views see plate 139, figures 3, 3*a* 484
2, 2*a*. *Astreopora portoricensis*, new species. Two views of the type.
2. Corallum, natural size 485
2*a*. Calices, × 6 485
3, 4, 4*a*. *Astreopora goethalsi*, new species.
3. Corallum of a cotype, one-half natural size 483
4. Corallum, one-half natural size; 4*a*, calices, × 6, of the second cotype. 483

PLATE 141.

FIGS. 1, 1*a*, 1*b*, 2. *Acropora panamensis*, new species. **Page.**
  1, 1*a*, 1*b*. Three views of the type. 1, branch, natural size; 1*a*, part of branch, × 3; 1*b*, calice, × 8 480
  2. View of a paratype, natural size 480
 3, 3*a*, 4, 4*a*. *Acropora saludensis*, new species.
  3. Branch, cotype, natural size; 3*a*, part of the same branch, × 3 481
  4. Branch, cotype, natural size; 4*a*, part of the same branch, × 3 481

PLATE 142.

FIGS. 1, 1*a*. *Goniopora hilli*, new species. Two views of the type.
  1. Surface of corallum, natural size 489
  1*a*. Calices, × 6 489
 2, 2*a*, 2*b*. *Goniopora panamensis*, new species. Three views of the type.
  2. One surface, natural size 489
  2*a*. The other surface, natural size 489
  2*b*. A part of the surface represented by figure 2*a*, × 3 489
 3, 3*a*. *Goniopora imperatoris*, new species. Two views of the type.
  3. Corallum, natural size 493
  3*a*. Calices, × 6 493

PLATE 143.

FIGS. 1, 1*a*. *Goniopora decaturensis*, new species. Two views of the type.
  1. Upper surface, natural size 490
  1*a*. Calices, × 3 490
 2, 2*a*. *Goniopora decaturensis* var. *silecensis*, new variety. Two views of the type.
  2. Corallum, natural size 491
  2*a*. Calices, × 3 491
 3, 3*a*. *Goniopora decaturensis* var. *bainbridgensis*, new variety. Two views of the type.
  3. Corallum, natural size 491
  3*a*. Calices, × 3 491

PLATE 144.

Goniopora jacobiana, new species.

FIG. 1, 1*a*. Two views of type.
  1. Corallum, one-half natural size 492
  1*a*. Calices, × 6. The thick, white radii represent interseptal filling; the septa have been dissolved and are represented by the black spaces 492
 2, 2*a*, 3, 3*a*. Four views of two fragments of the same specimen from White Springs, Florida.
  2. Upper surface, natural size; 2*a*, calices, × 6, of the same fragment .. 493
  3. Upper surface, natural size; 3*a*, calices, × 4, of the same fragment .. 493

PLATE 145.

Goniopora clevei, new species.

FIG. 1. Paratype, natural size, University of Upsala 496
 2, 2*a*. Two views the type, also University of Upsala.
  2. Branch, natural size 496
  2*a*. Calices, × 5 496
 3. Paratype, natural size. An elongate branch, tip rounded 497
 4. Paratype, natural size. A thicker branch; tips of branchlets obtusely rounded 497

	Page.
FIGS. 5, 5*a*. Two views of a specimen somewhat flattened by pressure.	
5. Natural size	497
5*a*. Calices, × 6	497
(Originals of figures 1–5*a* from Anguilla.)	
6, 6*a*. Two views of a specimen somewhat flattened by pressure, from Empire, Canal Zone.	
6. Natural size	497
6*a*. Calices, × 6	497

PLATE 146.

FIGS. 1, 2, 3. *Goniopora canalis*, new species.	
1. Cotype, corallum, natural size	494
2. Second cotype, corallum, natural size	494
3. Third cotype, calices, × 6	494
4, 5. *Goniopora portoricensis*, new species.	
4. Type, corallum, natural size	495
5. Calices, × 6, of a paratype	495
6, 6*a*, 6*b*, 7, 8, 9. *Goniopora cascadensis*, new species.	
6. Type, natural size; 6*a* and 6*b*, calices, × 6	497
7. Paratype, natural size	497
8. Paratype, natural size	497
9. Calices of a third paratype, × 6	497

PLATE 147.

FIGS. 1, 1*a*. *Porites baracoäensis*, new species. Two views of the type.	
1. Branch, natural size	499
1*a*. Part of branch, × 5	499
2, 2*a*, 3, 4. *Porites baracoäensis* var. *matazasensis*, new variety.	
2. Type, corallum, natural size; 2*a*, the same, × 5	500
3. Paratype, × 5	500
4. Paratype, × 5, shows intergradation with the typical form of the species	500

PLATE 148.

Porites panamensis, new species.

FIG. 1. Paratype corallum, natural size	504
2. Calices, × 8, of a paratype	504
3, 3*a*. Two views of the type.	
3. Corallum, natural size	503
3*a*. Calices, ×8	503

PLATE 149.

FIGS. 1, 1*a*, 1*b*. *Porites anguillensis*, new species. Three views of the type.	
1. Upper surface, natural size	504
1*a*. Lower surface, natural size	504
1*b*. Calices, × 5	504
2, 2*a*. *Porites douvillei*, new species. Two views of a cotype.	
2. Branch, natural size	501
2*a*. Calices, × 8	501
3, 3*a*. *Actinacis alabamiensis* (Vaughan). Two views of a small specimen from Flint River, near Bainbridge, Georgia.	
3. Corallum, natural size	486
3*a*. Calices, × 5	486

PLATE 150.

FIGS. 1, 1*a*, 2, 3, 4. *Porites toulai*, new species. Page.
- 1, 1*a*. Type, natural size; 1*a*, calices, × 8, of the type 501
- 2. Paratype, natural size 501
- 3. Second paratype, natural size 501
- 4. Calices of a third paratype, × 8 501

5. *Porites anguillensis*, new species. Specimen from Empire, Canal Zone, natural size 505

PLATE 151.

FIGS. 1, 1*a*. *Porites douvillei*, new species. Two views of a cotype.
- 1. Corallum, natural size 501
- 1*a*. Calices, × 8 501

2, 2*a*, 3, 3*a*, 4. *Porites* (*Synaraea*) *howei*, new species. Views of the three cotypes.
- 2. Branch, natural size; 2*a*, part of the same branch, × 3 505
- 3, 3*a*. Two views, natural size, of the same branch 505
- 4. Calices, × 8, of a third branch 505

PLATE 152.

Porites (*Synaraea*) *macdonaldi*, new species.

FIG. 1. A cotype, natural size 506

2. A second cotype, natural size 506

3, 3*a*. Two views of a third cotype.
- 3. Natural size 506
- 3*a*. Part of surface, × 3 506

4. A fourth cotype, natural size 506

5, 5*a*. Two views of a specimen referred to this species.
- 5. Corallum, natural size 507
- 5*a*. A calice, × 8 507

A. Five Islands Harbor, Antigua.

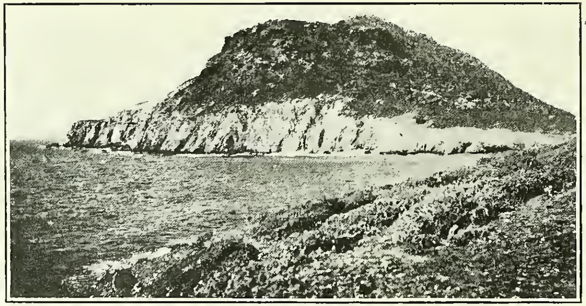
B. Spencer Bay, Antigua.

C. Publiken Bay, St. Bartholomew.

D. St. Jean Bay, St. Bartholomew

WEST INDIAN SHORE LINES.

For explanation of plate see page 507.



A. Pointe Blanche, St. Martin.

B. East Side of Crocus Bay, North Side of Anguilla.

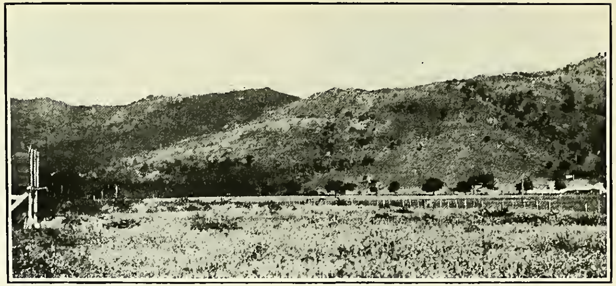
C. Calls Pond, Anguilla.

D. Shore, South Side of Aguilla, Looking Toward St. Martin.

WEST INDIAN SHORE LINES.

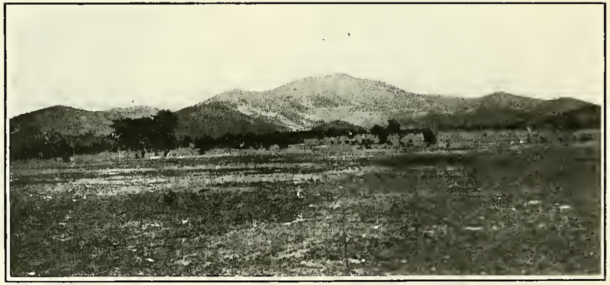
For explanation of plate see page 507

A. Looking into the Mouth of Charlotte Amalia Harbor, St. Thomas.



B. Cliffs on Southern Shore of St. Thomas.

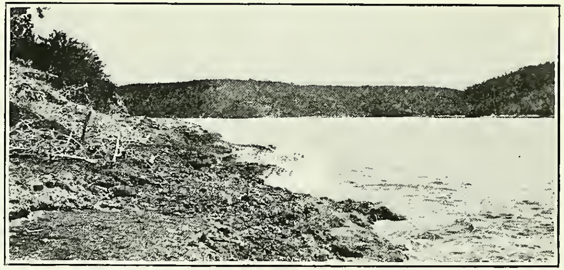
C. Alluvial Plain at Head of an Embayment, St. Thomas.



D. Mountains on North, Limestone Plain on South, St. Croix.

WEST INDIAN SHORE LINES.

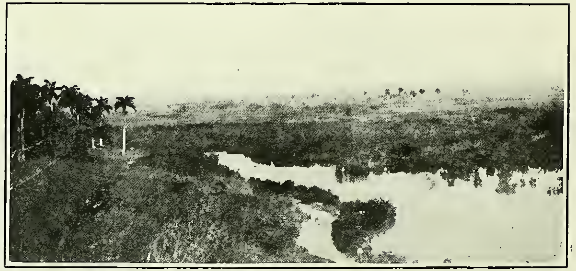
For explanation of plate see page 508



A. SANTIAGO HARBOR, CUBA, LOOKING INTO THE HARBOR; SLIGHTLY ELEVATED CORAL REEF ROCK IN LEFT FOREGROUND.

B. SANTIAGO HARBOR, CUBA, LOOKING SEAWARD THROUGH ITS MOUTH.

C. YUMURI GORGE, MATANZAS, CUBA.

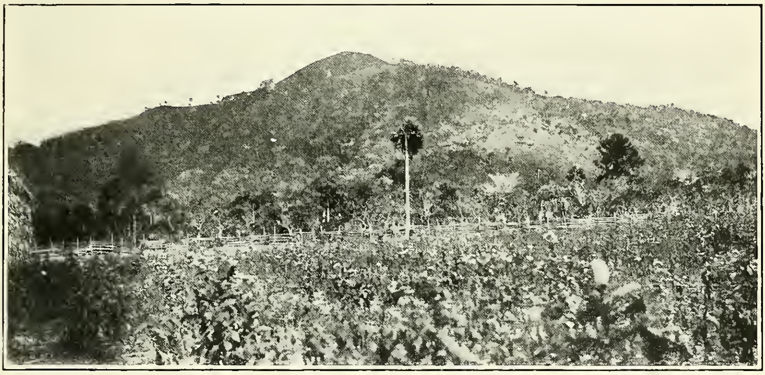


D. YUMURI VALLEY ABOVE THE GORGE.

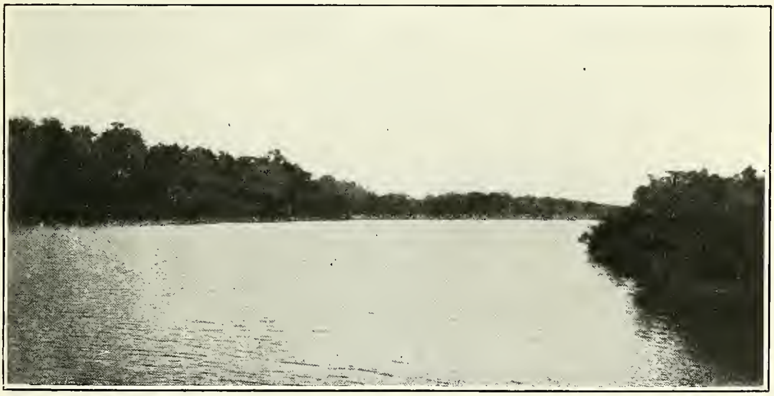
WEST INDIAN SHORE LINES.

FOR EXPLANATION OF PLATE SEE PAGE 508.

A. The General Plain.



B. Daguilla, a Monadnock of Hard Rock.



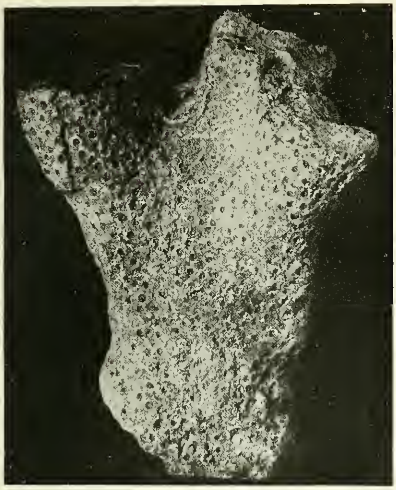
C. Lower Part of Course of Santa Fe River.

VIEWS OF ISLE OF PINES, CUBA.

For explanation of plate see page 508.

Model of Gulf of Mexico and Caribbean Sea.

For explanation of plate see page 508.



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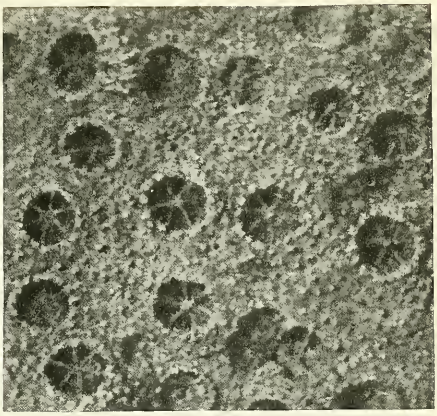

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3

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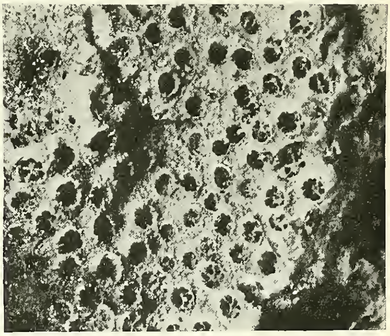
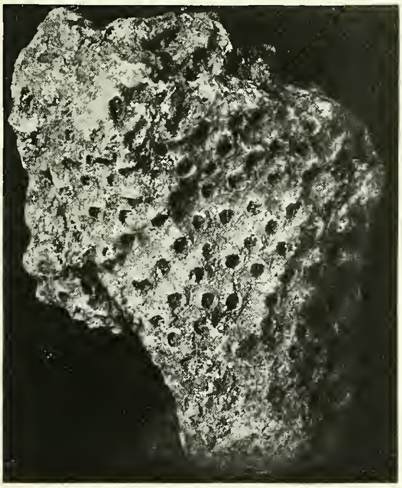


4a ×3



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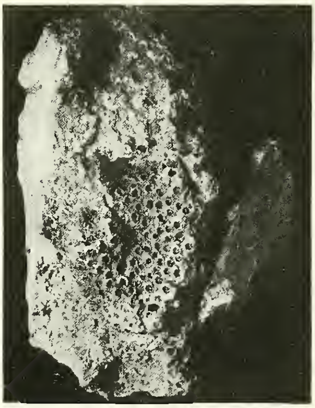
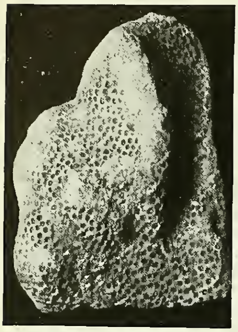


4

FOSSIL CORALS FROM CENTRAL AMERICA AND WEST INDIES.

FOR EXPLANATION OF PLATE SEE PAGE 508.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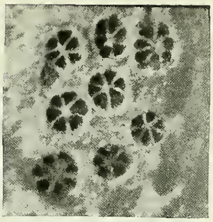
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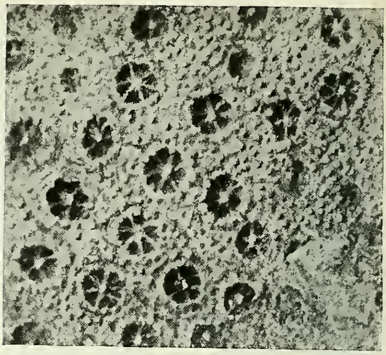
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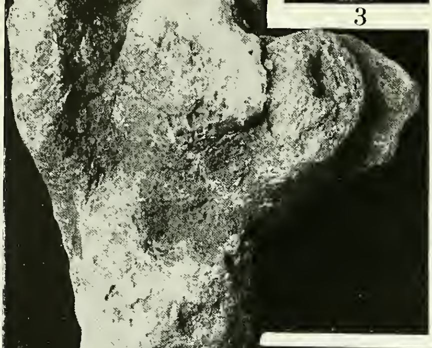
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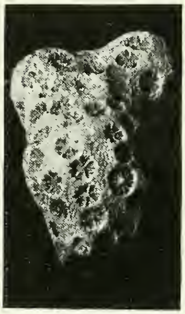
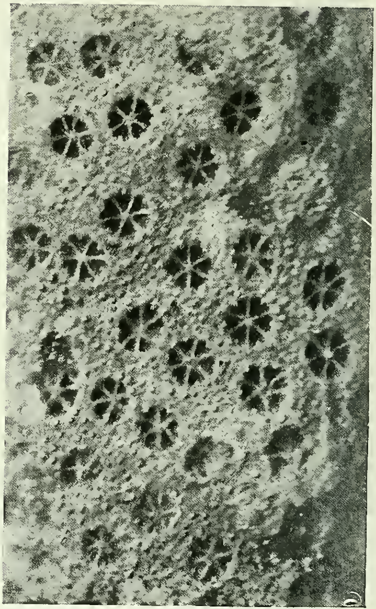
6


7

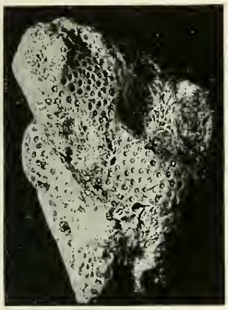

5a ×3


6a ×3


7a ×8

FOSSIL CORALS FROM CENTRAL AMERICA AND WEST INDIES.

FOR EXPLANATION OF PLATE SEE PAGE 508.



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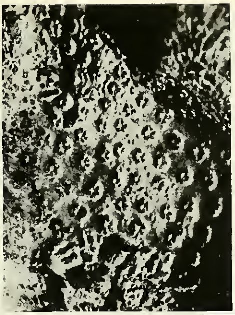

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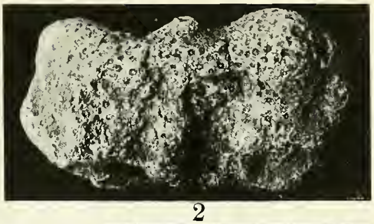

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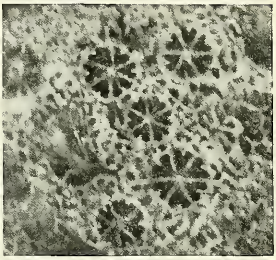
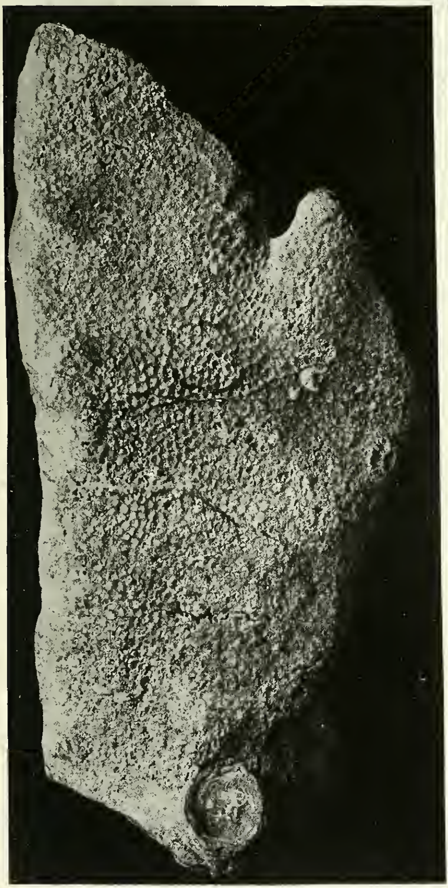


2a X 8

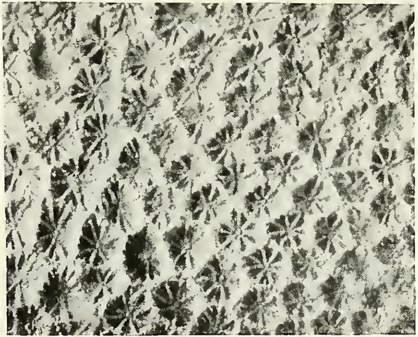


4

3

3a

3b X 8



4a X 5

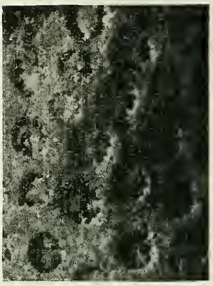
Fossil Corals from Central America and West Indies.

For explanation of plate see page 509.

3 X 2

3a X 2

1 X 5



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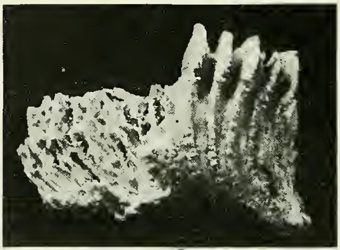

3b X 2

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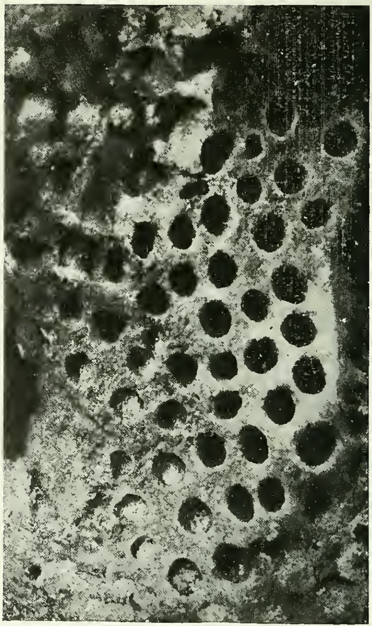


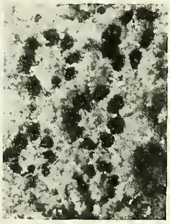
2a X 5

Fossil Corals from Central America and West Indies.

For explanation of plate see page 509.


1


2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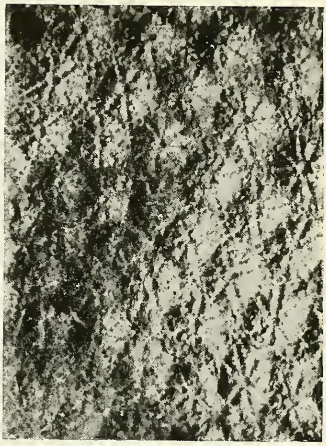
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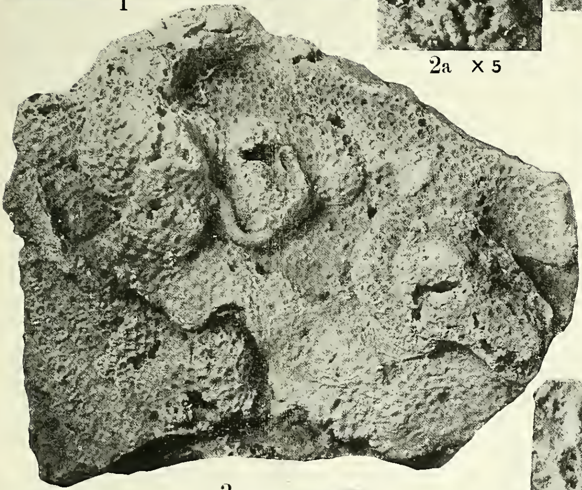
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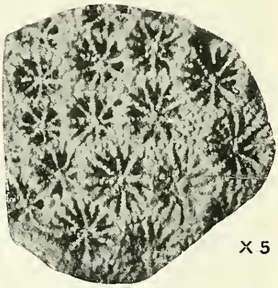
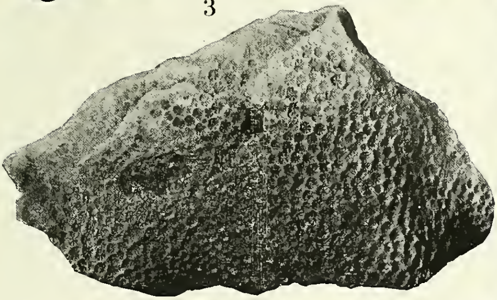

× 5

3a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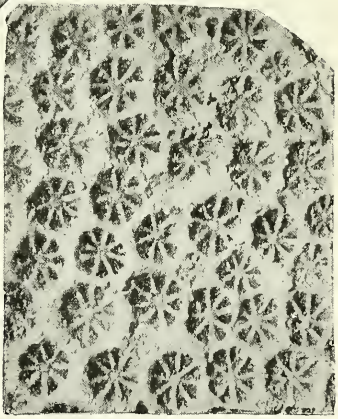
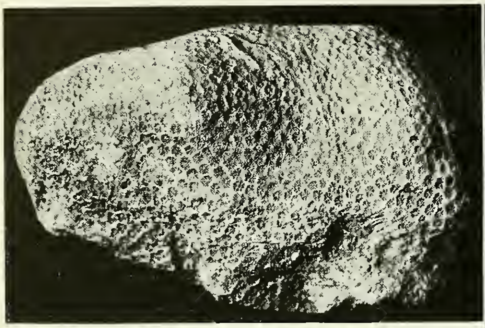

4a × 5

FOSSIL CORALS FROM CENTRAL AMERICA AND WEST INDIES.

FOR EXPLANATION OF PLATE SEE PAGE 509.



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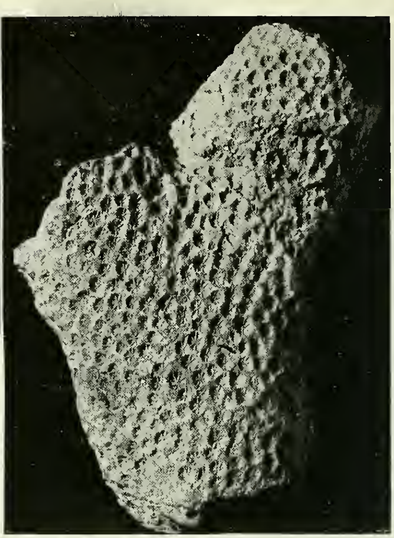

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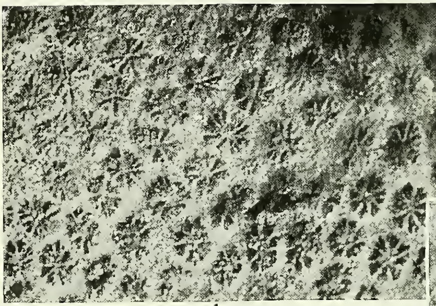
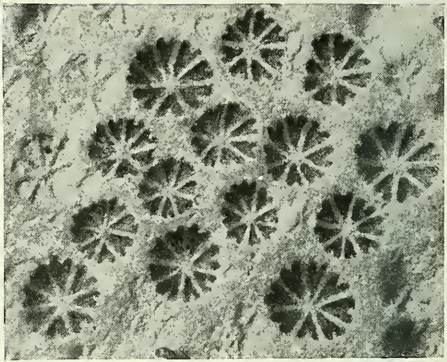
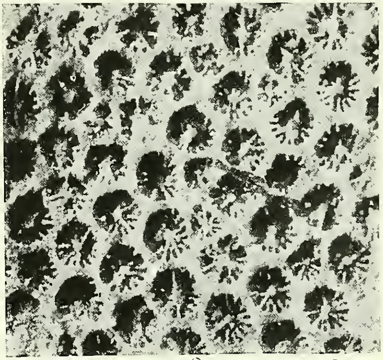


1a ×5



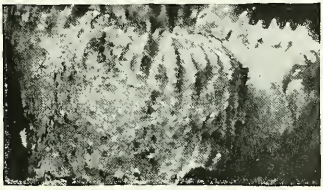
3a ×5



2 ×5

4 b ×3

4

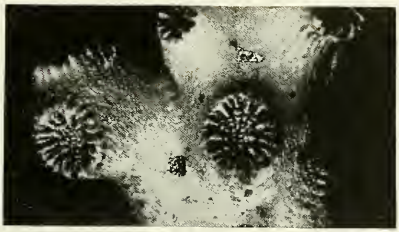


4a ×4

FOSSIL CORALS FROM CENTRAL AMERICA AND WEST INDIES.

FOR EXPLANATION OF PLATE SEE PAGE 539.

1



1a X 4

2

3

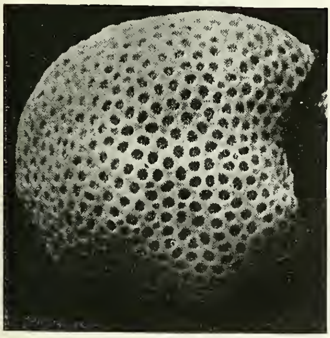
4 X 2

1b X 4

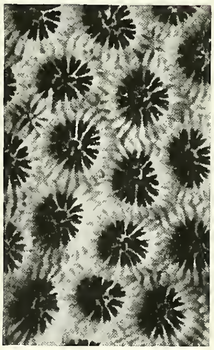
6 X 2½

5 X 2½

6a X 3



7 X ⅚

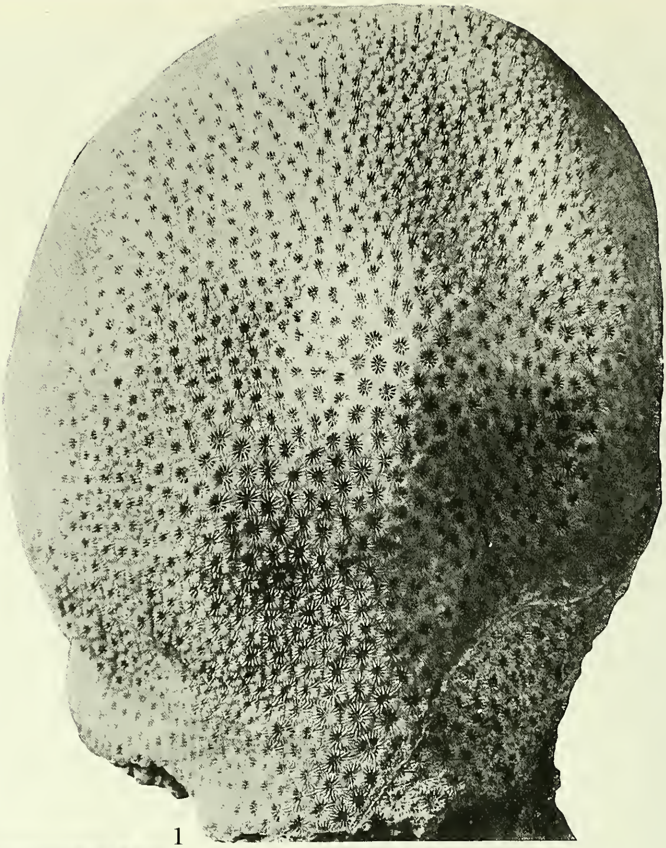


7a X 3⅓

7b X 3⅓

FOSSIL CORALS FROM CENRTAL AMERICA AND WEST INDIES

FOR EXPLANATION OF PLATE SEE PAGE 510.



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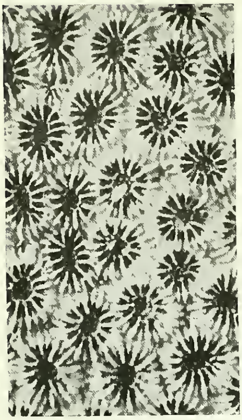
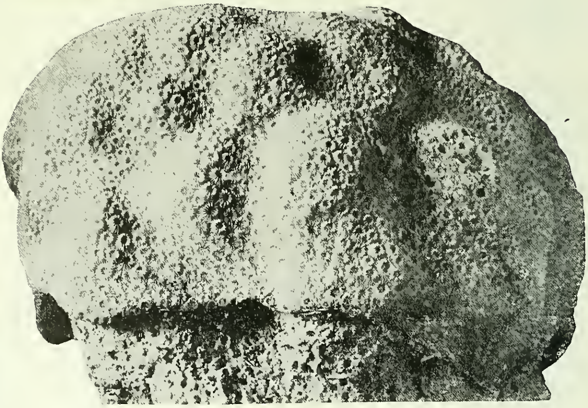


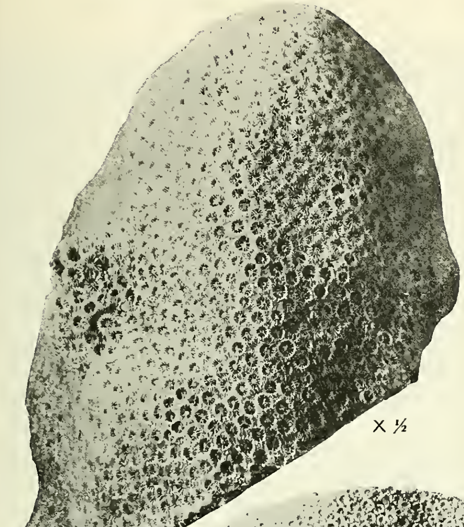
1a X 3



2 X ½

Fossil Corals from Central America and West Indies.

For explanation of plate see page 510.



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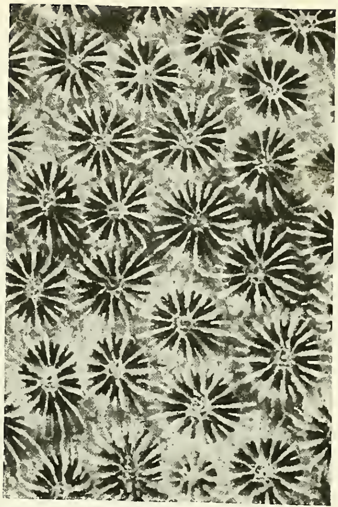
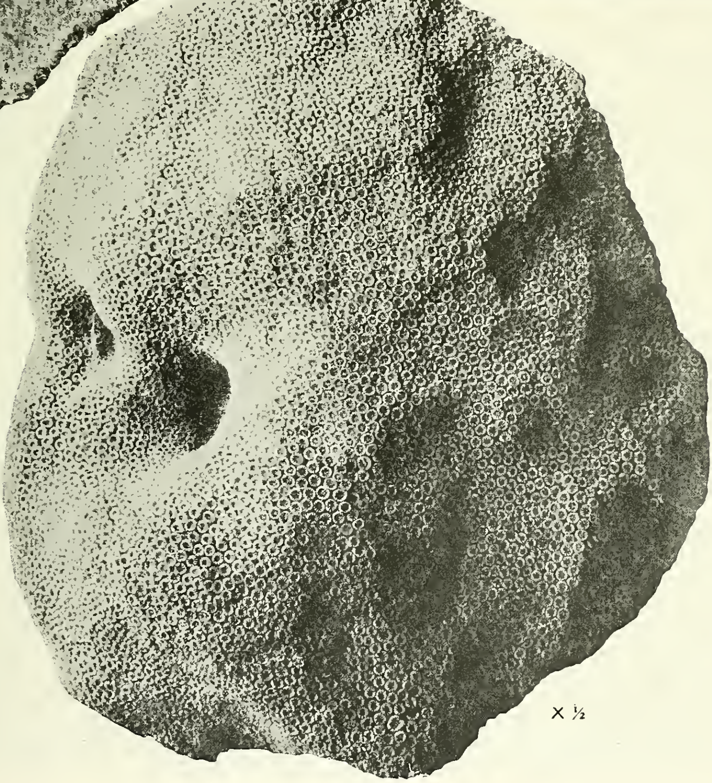


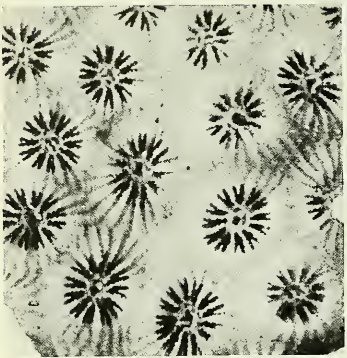
1a



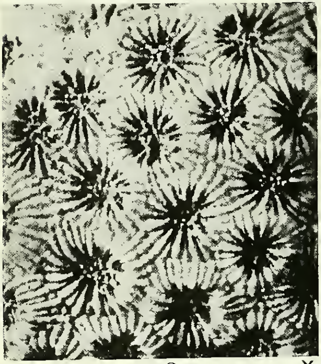
2

Fossil Corals from Central America and West Indies.

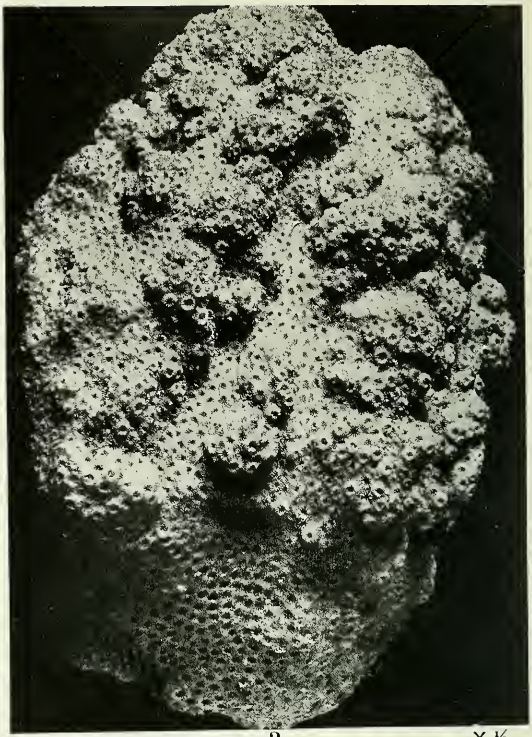
For explanation of plate see page 510.



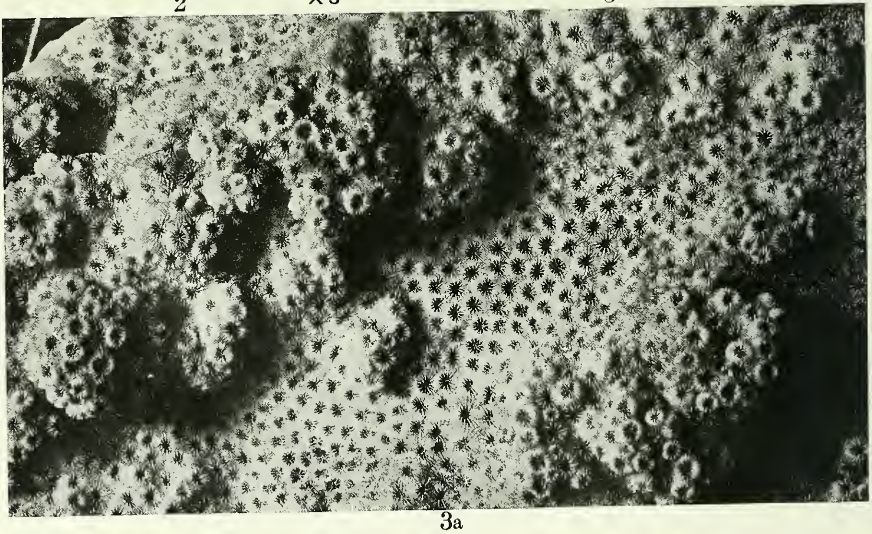
1 X 3



2 X 3



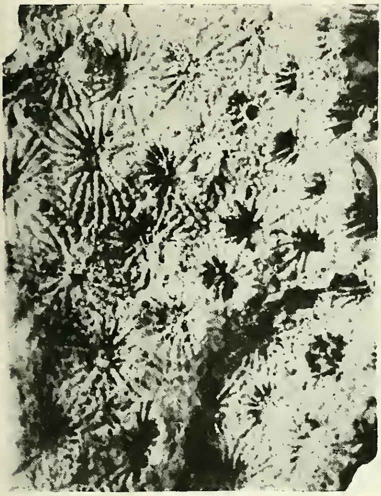
3 X ½



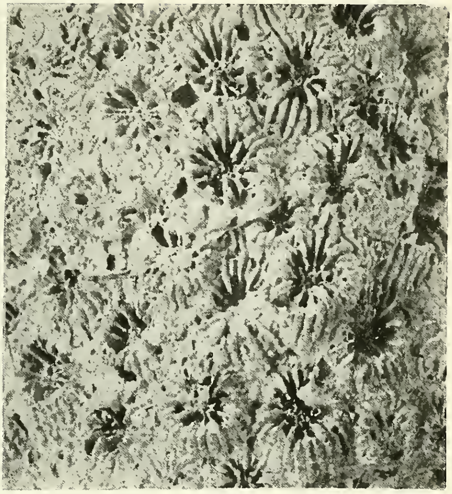
3a

FOSSIL CORALS FROM CENTRAL AMERICA AND WEST INDIES.

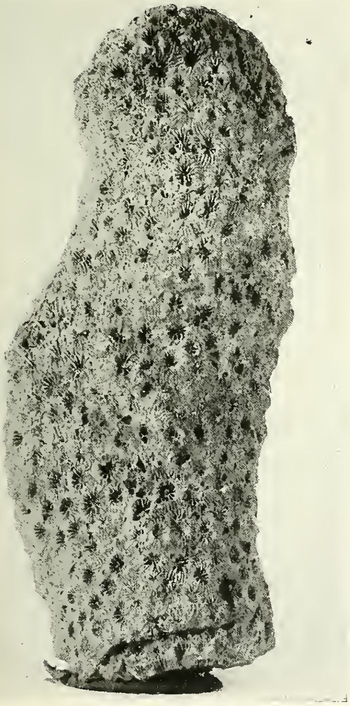
FOR EXPLANATION OF PLATE SEE PAGE 510.



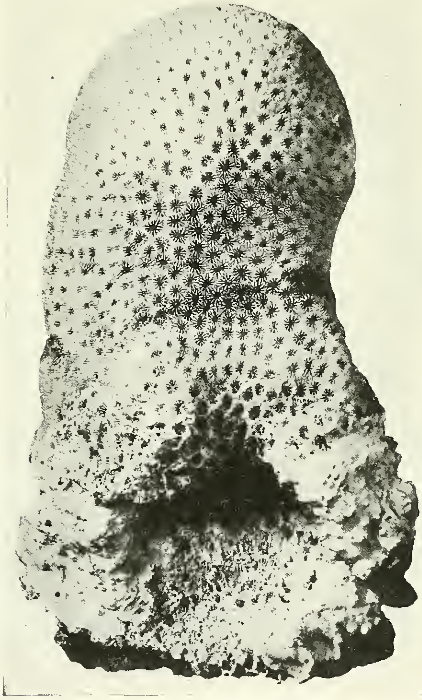
1 × 3



3a × 3



3



2

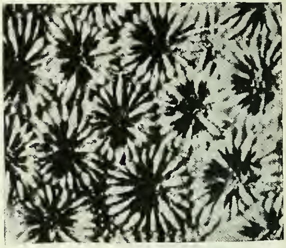
FOSSIL CORALS FROM CENTRAL AMERICA AND WEST INDIES.

FOR EXPLANATION OF PLATE SEE PAGE 510.

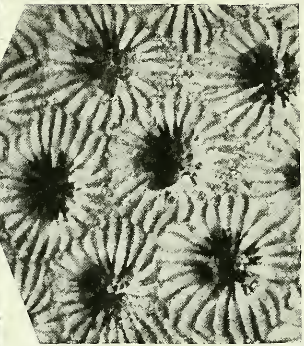
1

1a ×3

2a ×5



2b ×3



3 ×3

2

4a ×3

4

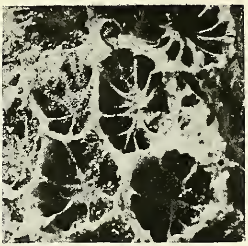
FOSSIL CORALS FROM CENTRAL AMERICA AND WEST INDIES.

FOR EXPLANATION OF PLATE SEE PAGE 511.

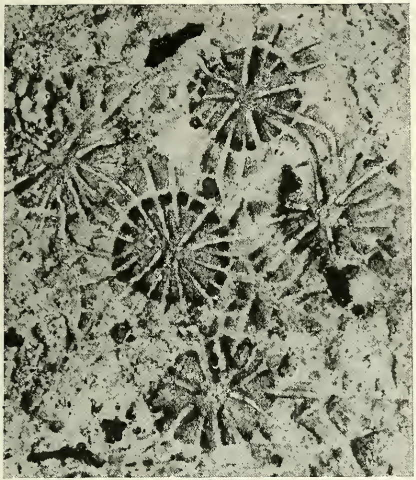
1

1a ×4

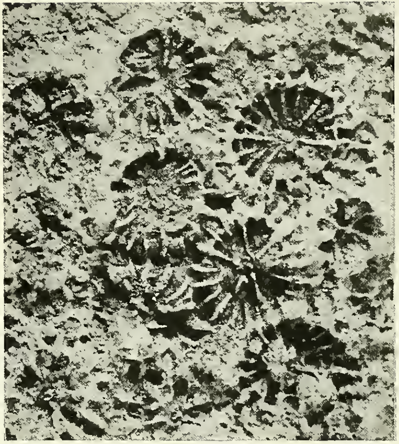
6



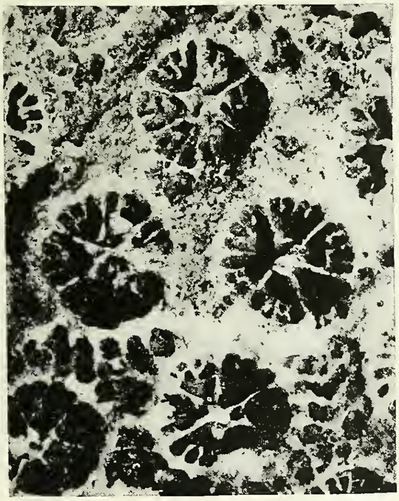
6a ×4



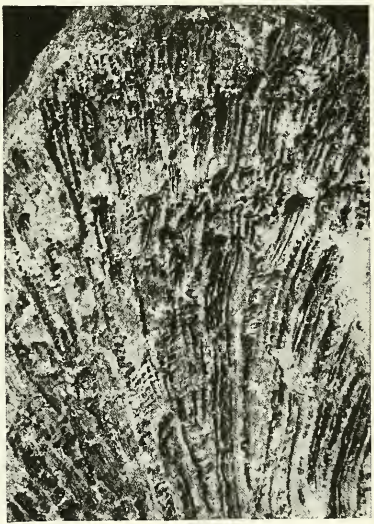
2 ×3⅓



3 ×3⅓



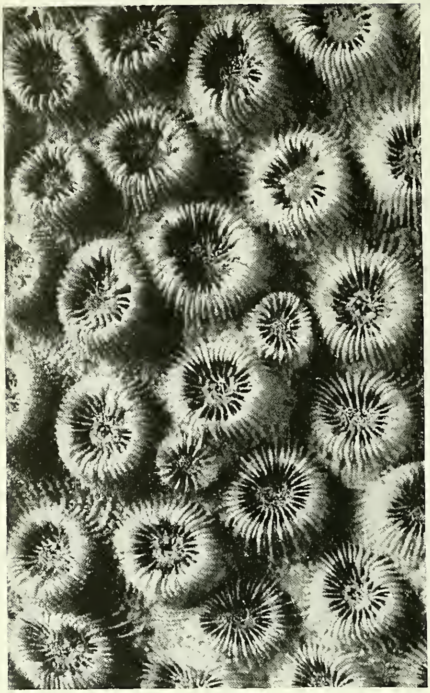
5 ×3⅓



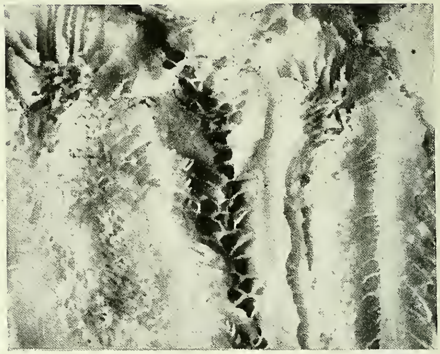
4

FOSSIL CORALS FROM CENTRAL AMERICA AND WEST INDIES.

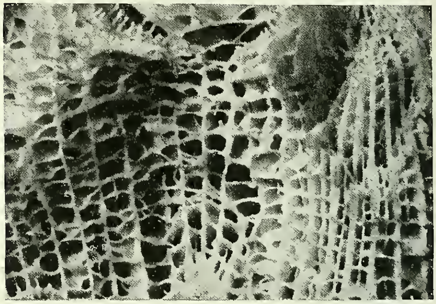
FOR EXPLANATION OF PLATE SEE PAGE 511.



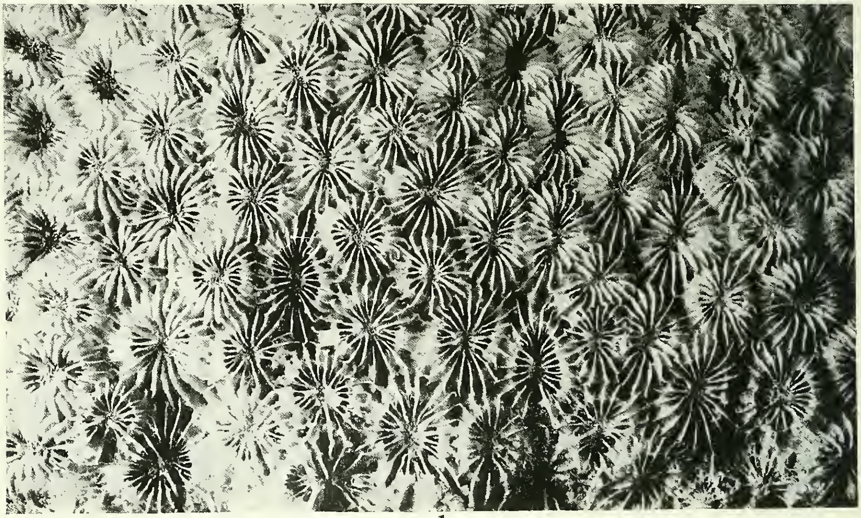
1



1b ×2



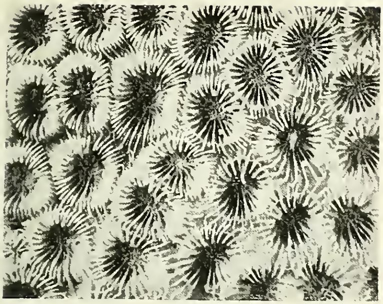
1c ×2



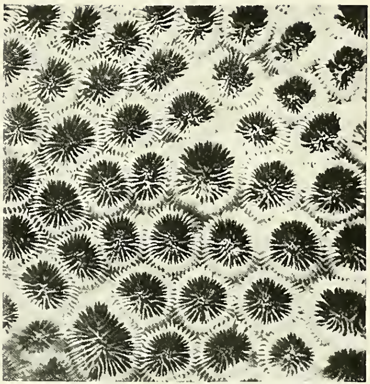
1a

Fossil Corals from Central America and West Indies.

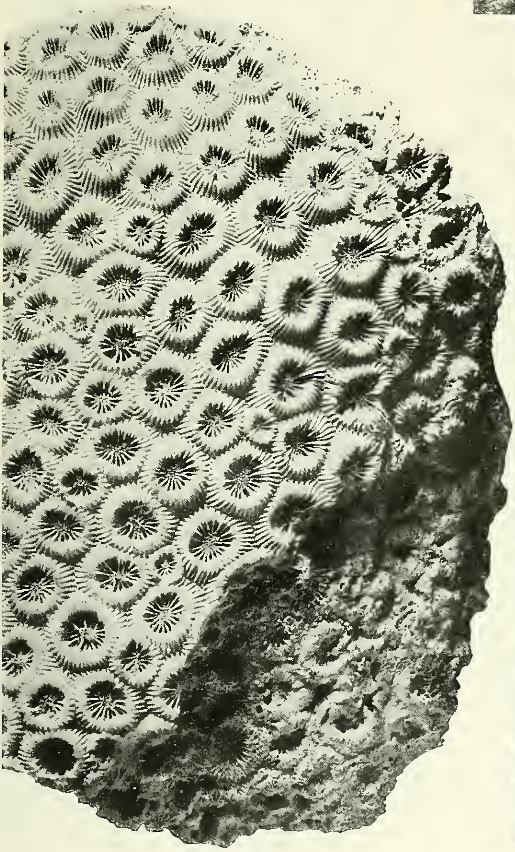
For explanation of plate see page 511.



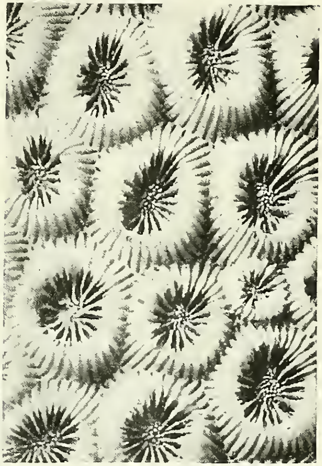
1



2



3

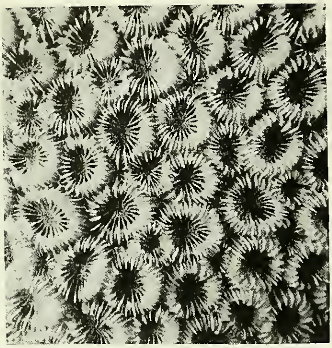


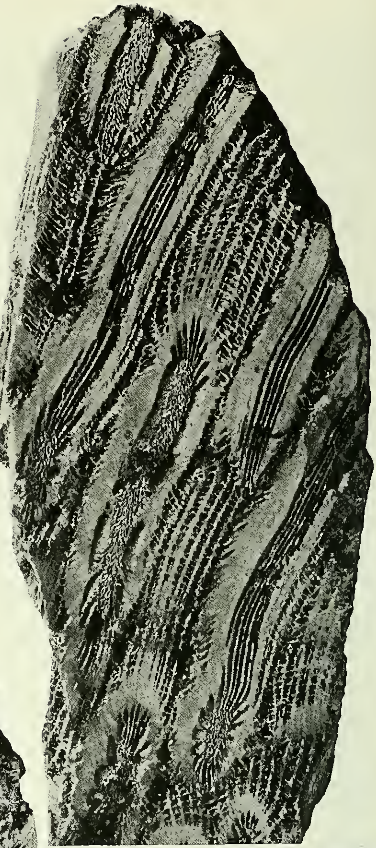
3a ×2

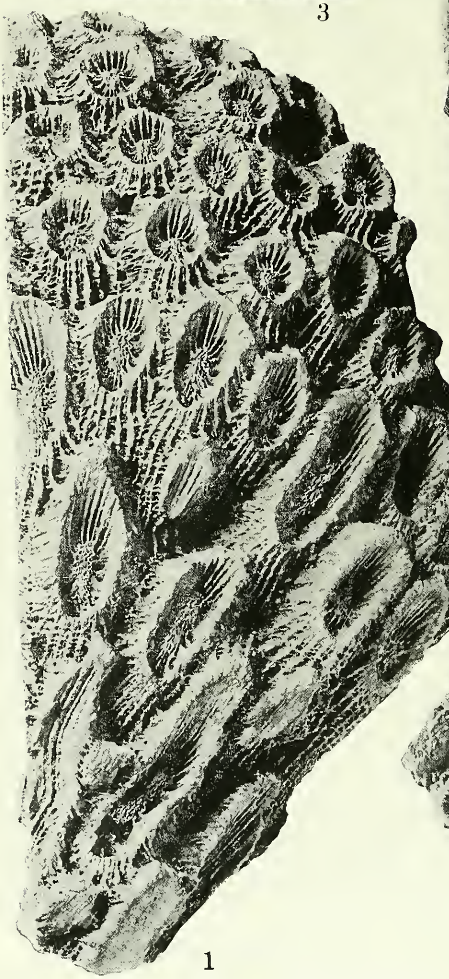
3b ×2

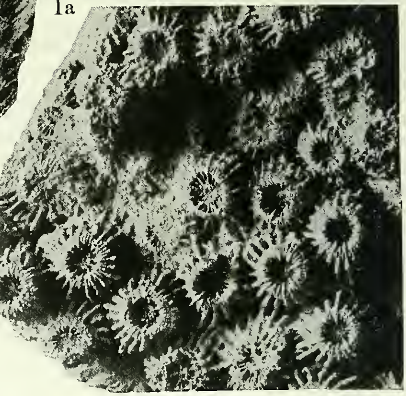
FOSSIL CORALS FROM CENTRAL AMERICA AND WEST INDIES.

FOR EXPLANATION OF PLATE SEE PAGE 511.


3

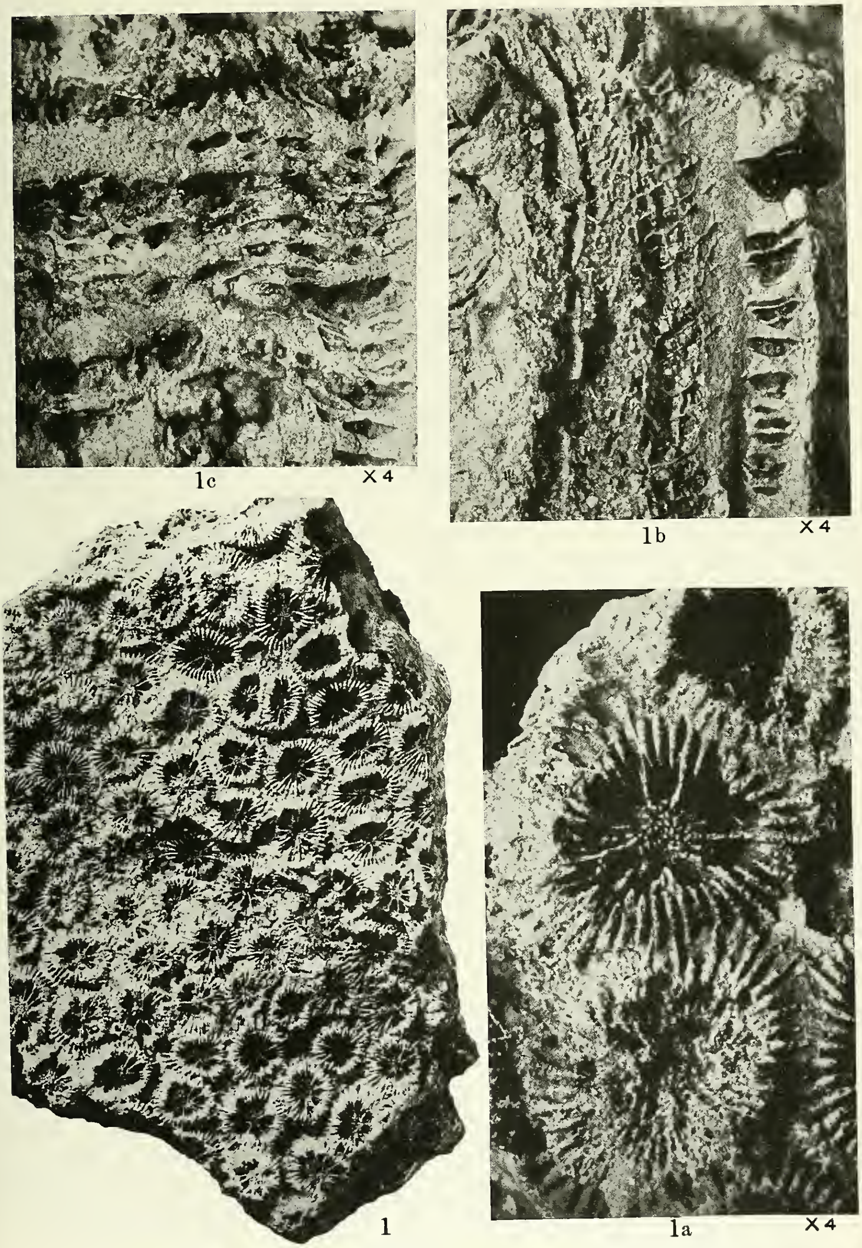

1a


1


2

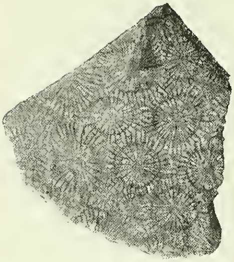
Fossil Corals from Central America and West Indies.

For explanation of plate see page 512.



FOSSIL CORALS FROM CENTRAL AMERICA AND WEST INDIES.

FOR EXPLANATION OF PLATE SEE PAGE 512.



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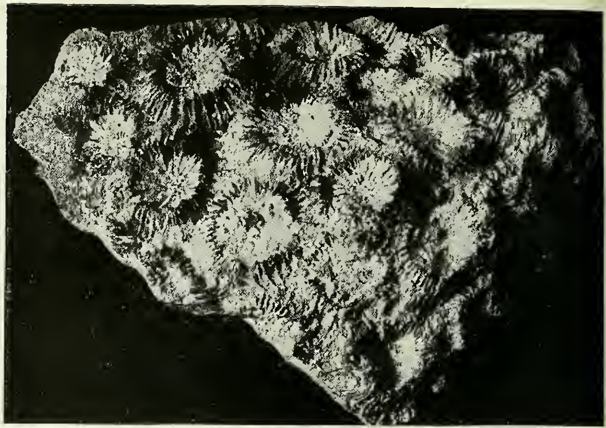

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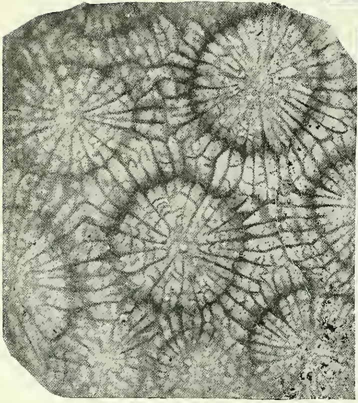
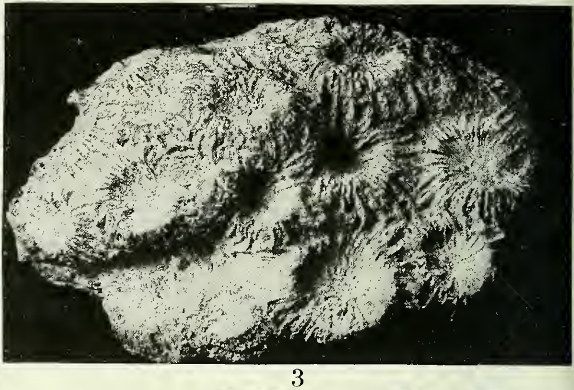
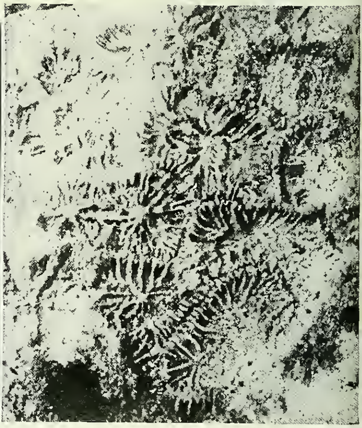


1a ×3



3

3a

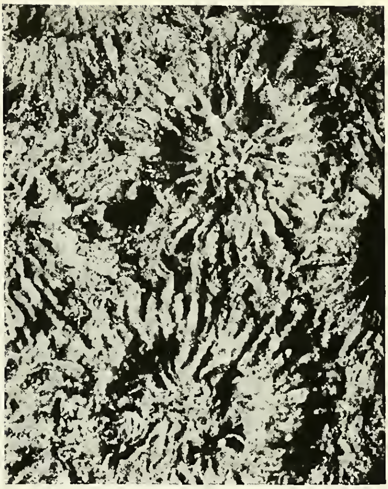


4 ×3½

Fossil Corals from Central America and West Indies.

For explanation of plate see page 512

1

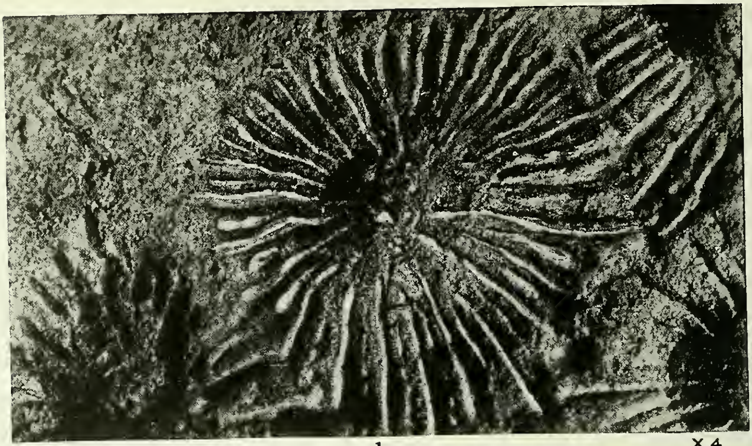


2 X 4

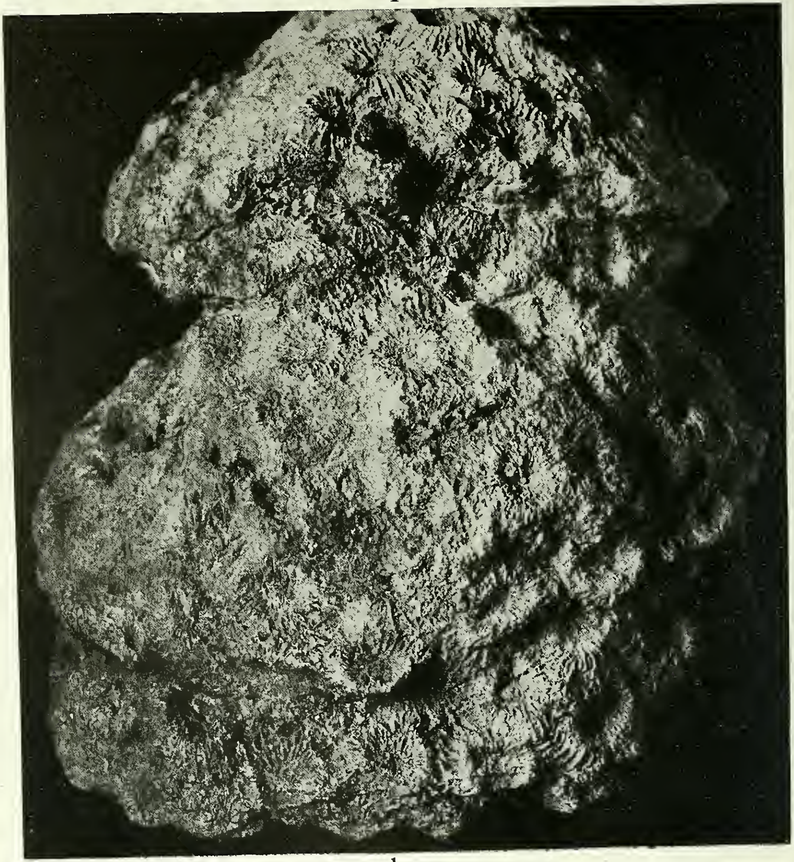
3

FOSSIL CORALS FROM CENTRAL AMERICA AND WEST INDIES.

FOR EXPLANATION OF PLATE SEE PAGE 12.



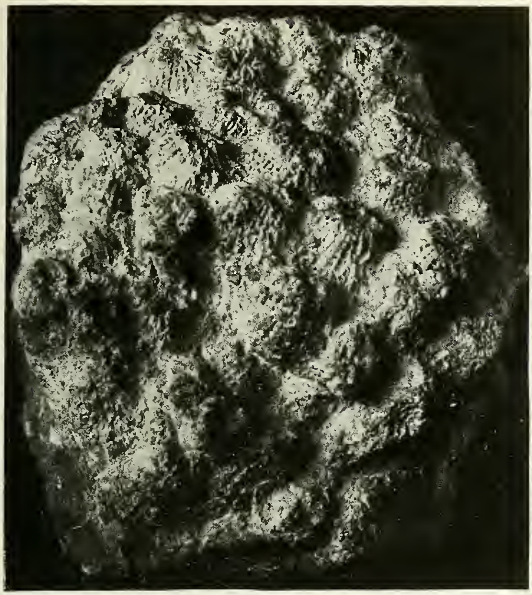
1 X 4



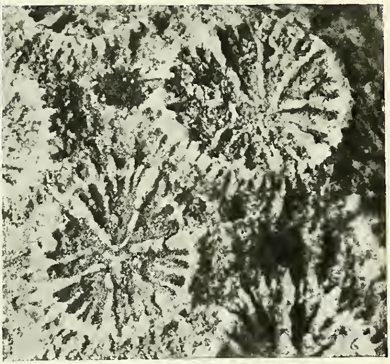
1a

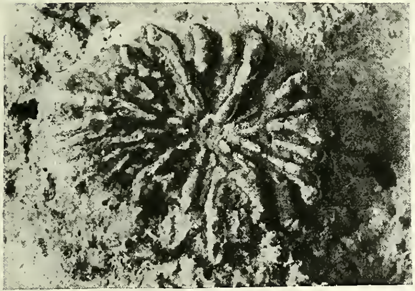
Fossil Corals from Central America and West Indies.

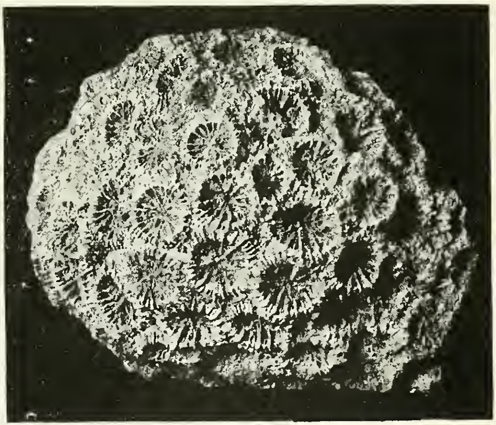
For explanation of plate see page 512.

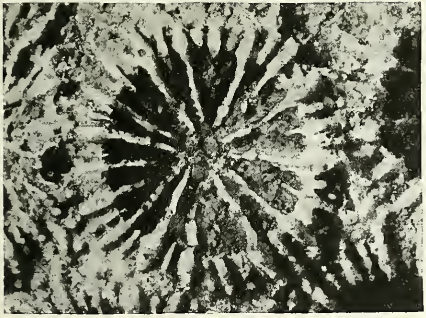

3


1


1a ×4


3a ×4


2


2a ×4

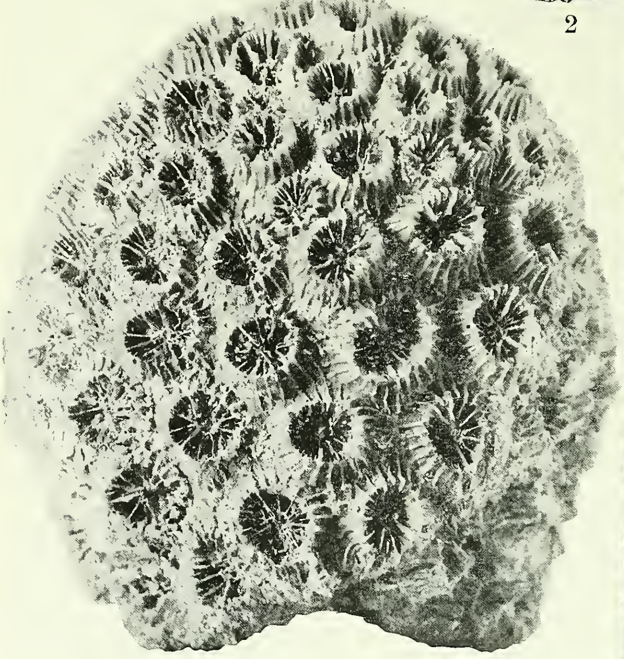
FOSSIL CORALS FROM CENTRAL AMERICA AND WEST INDIES.

FOR EXPLANATION OF PLATE SEE PAGE 512.

1

2

2a ×2

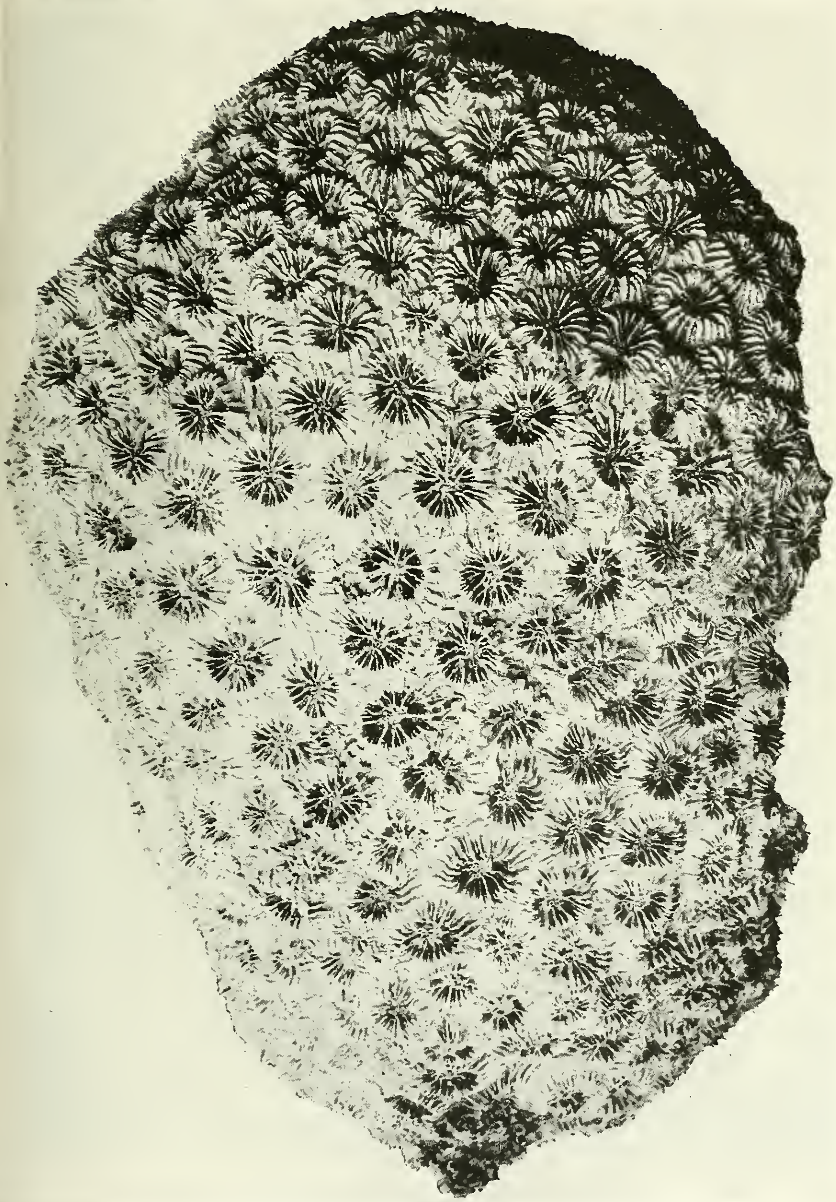


3

3a ×2

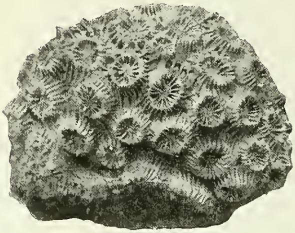
Fossil Corals from Central America and West Indies.

For explanation of plate see page 513.

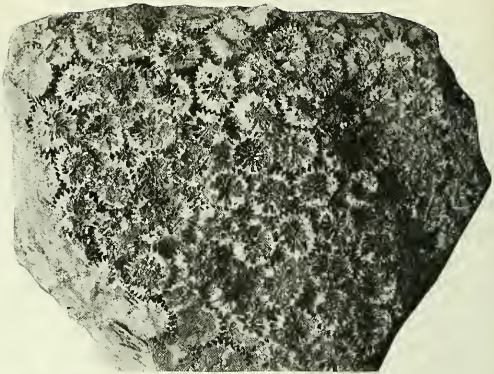


Fossil Corals from Central America and West Indies.

For explanation of plate see page 513.

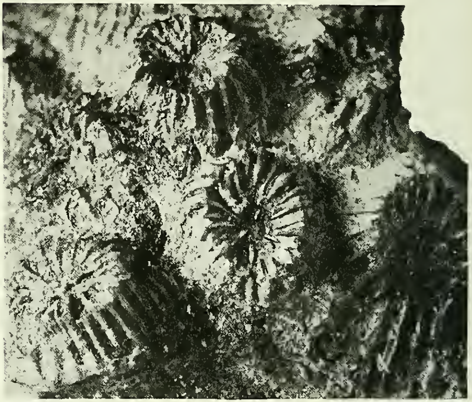


1

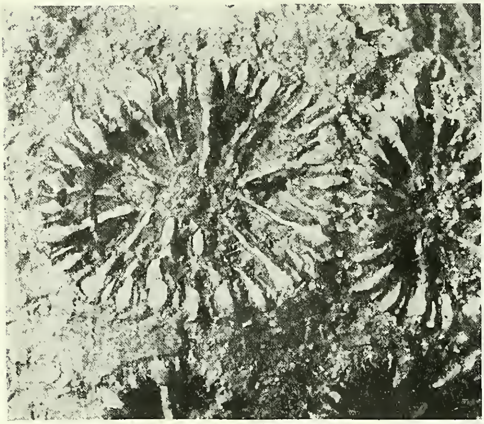


2

3



3a ×2

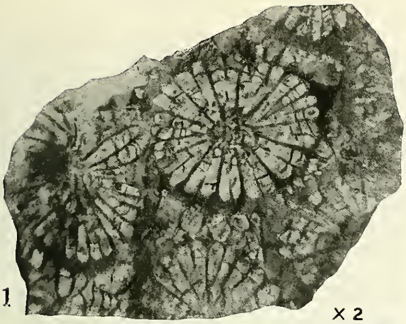


4 ×4

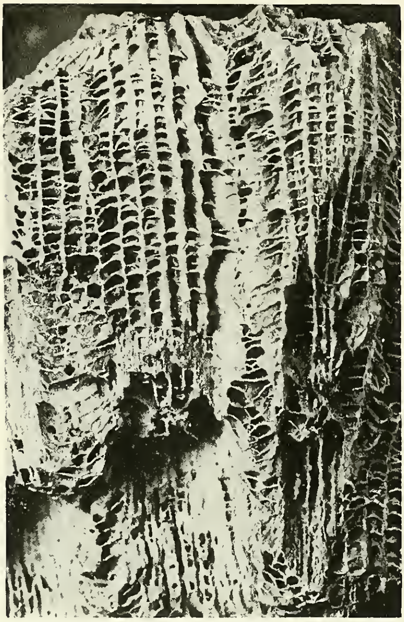
4a

Fossil Corals from Central America and West Indies.

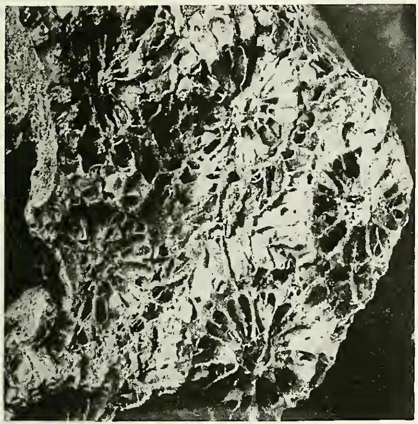
For explanation of plate see page 513.



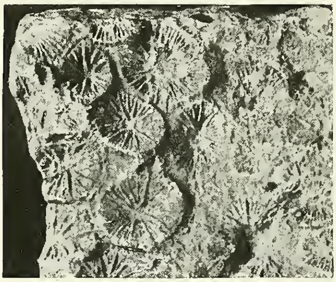
1 × 2



2a × 2



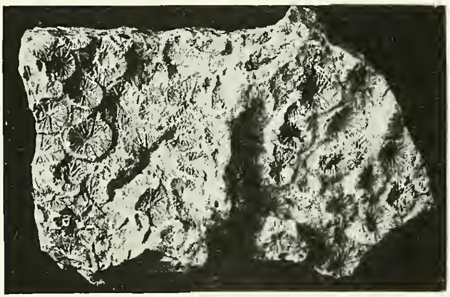
2 × 2



4a × 2

3

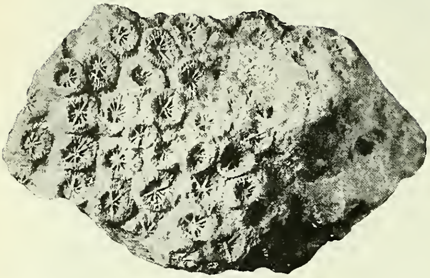
3a × 2



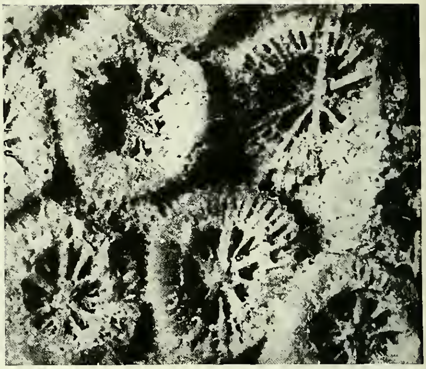
4 × 2

FOSSIL CORALS FROM CENTRAL AMERICA AND WEST INDIES.

FOR EXPLANATION OF PLATE SEE PAGE 513.

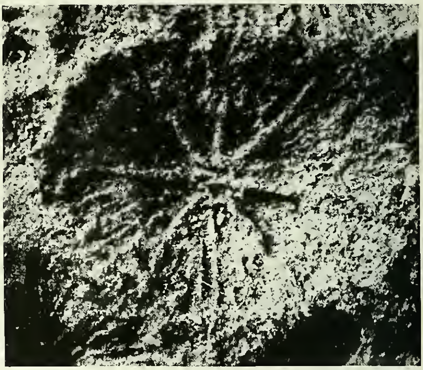


1



1a ×4

2



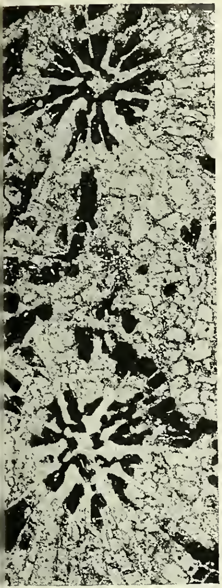
2a ×6

3

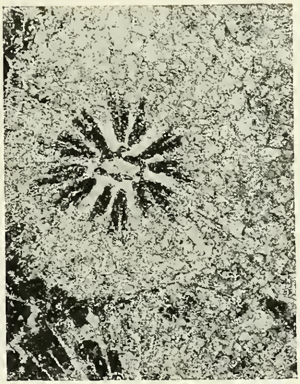
3a ×6

FOSSIL CORALS FROM CENTRAL AMERICA AND WEST INDIES.

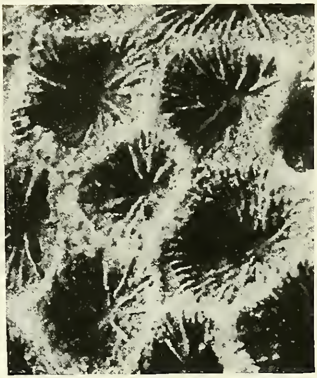
FOR EXPLANATION OF PLATE SEE PAGE 513.



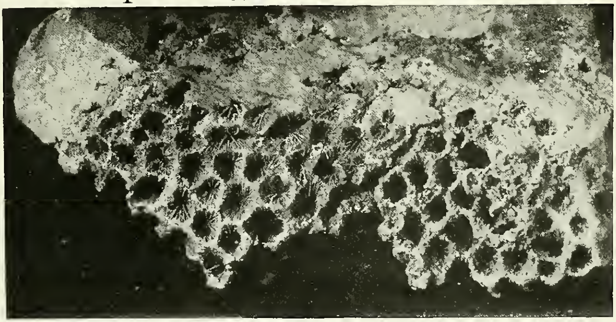
2 × 6



1 × 6



4a × 4



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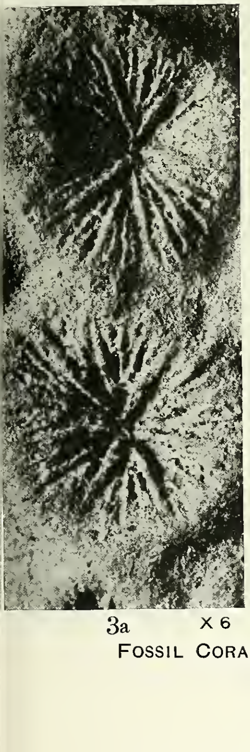
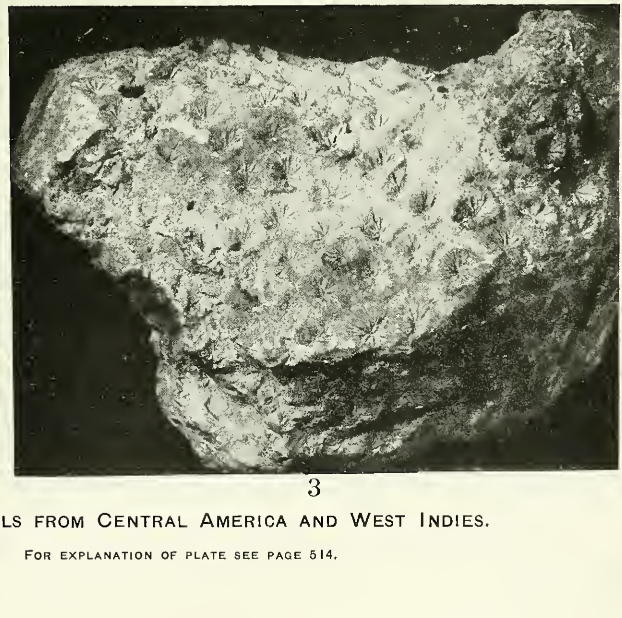


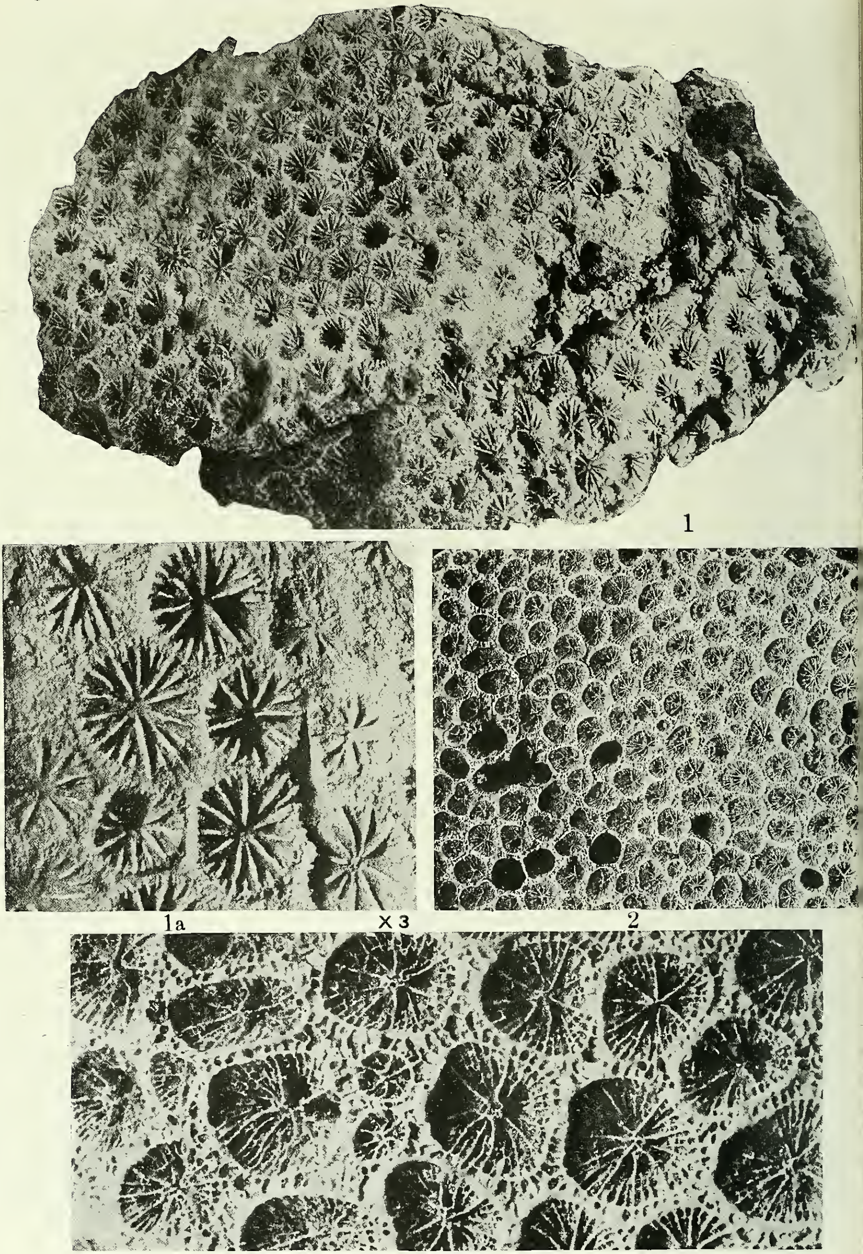
3a × 6



3

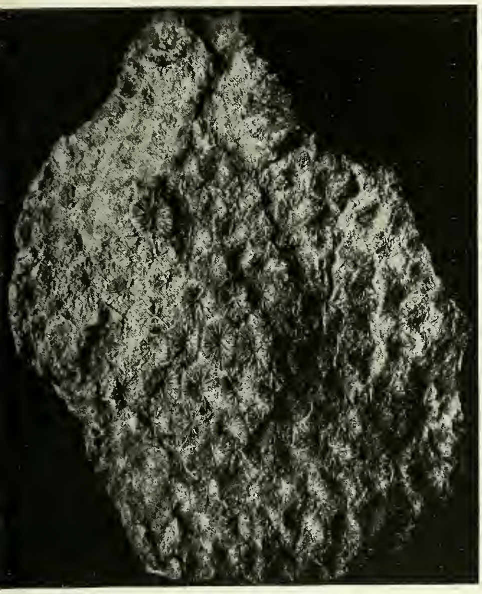
FOSSIL CORALS FROM CENTRAL AMERICA AND WEST INDIES.

FOR EXPLANATION OF PLATE SEE PAGE 514.

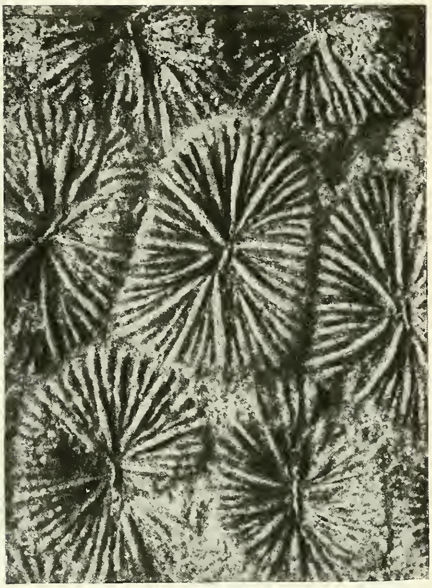


Fossil Corals from Central America and West Indies.

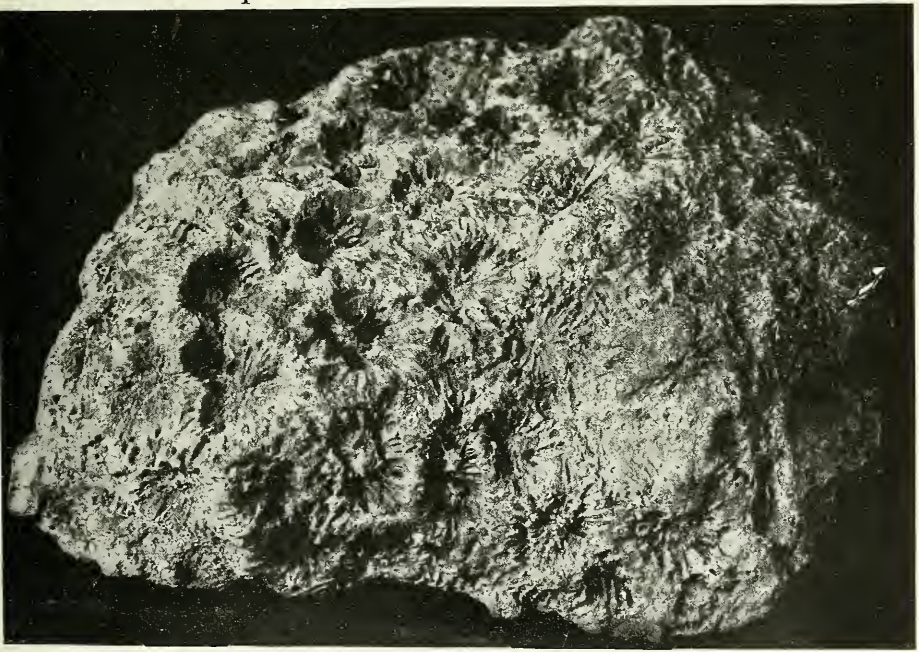
For explanation of plate see page 514.



1



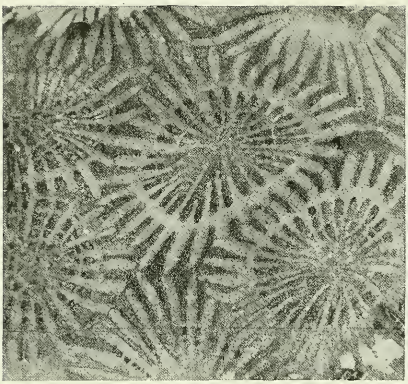
1a ×4



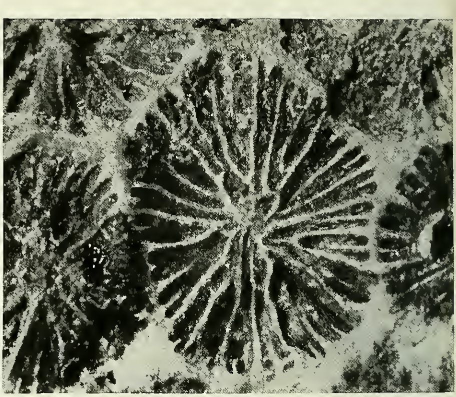
2

FOSSIL CORALS FROM CENTRAL AMERICA AND WEST INDIES.

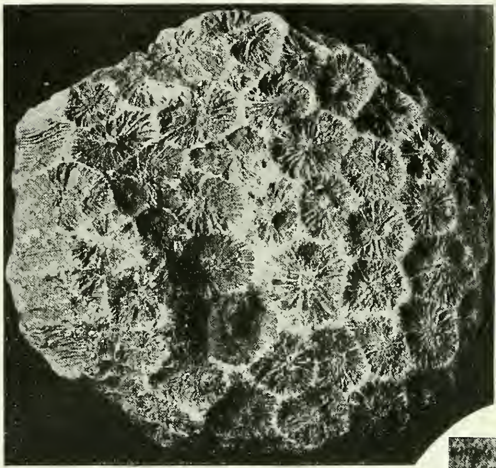
FOR EXPLANATION OF PLATE SEE PAGE 514.



1 × 2



2a × 4



2

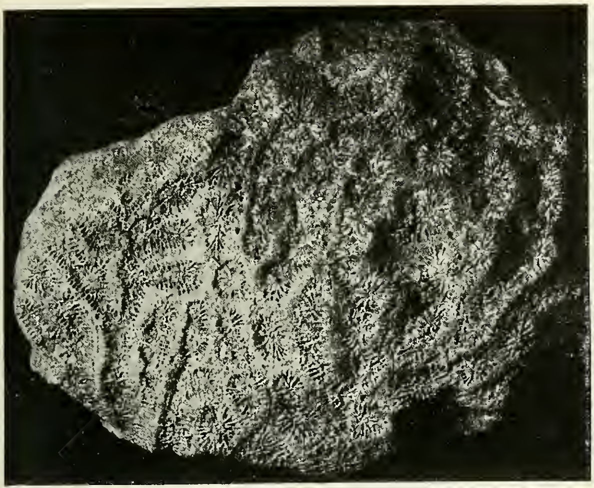
3

4

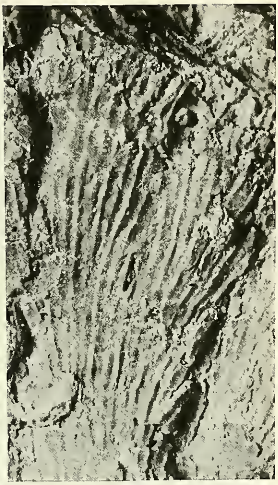
4a × 4

Fossil Corals from Central America and West Indies.

For explanation of plate see page 514.

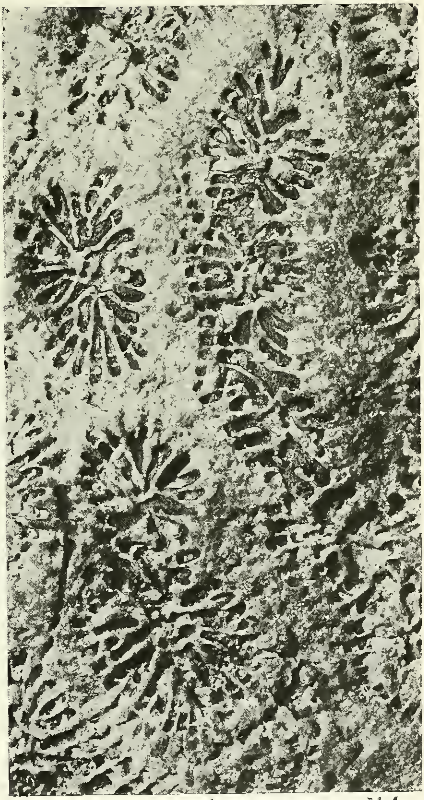


1



2a ×2

2



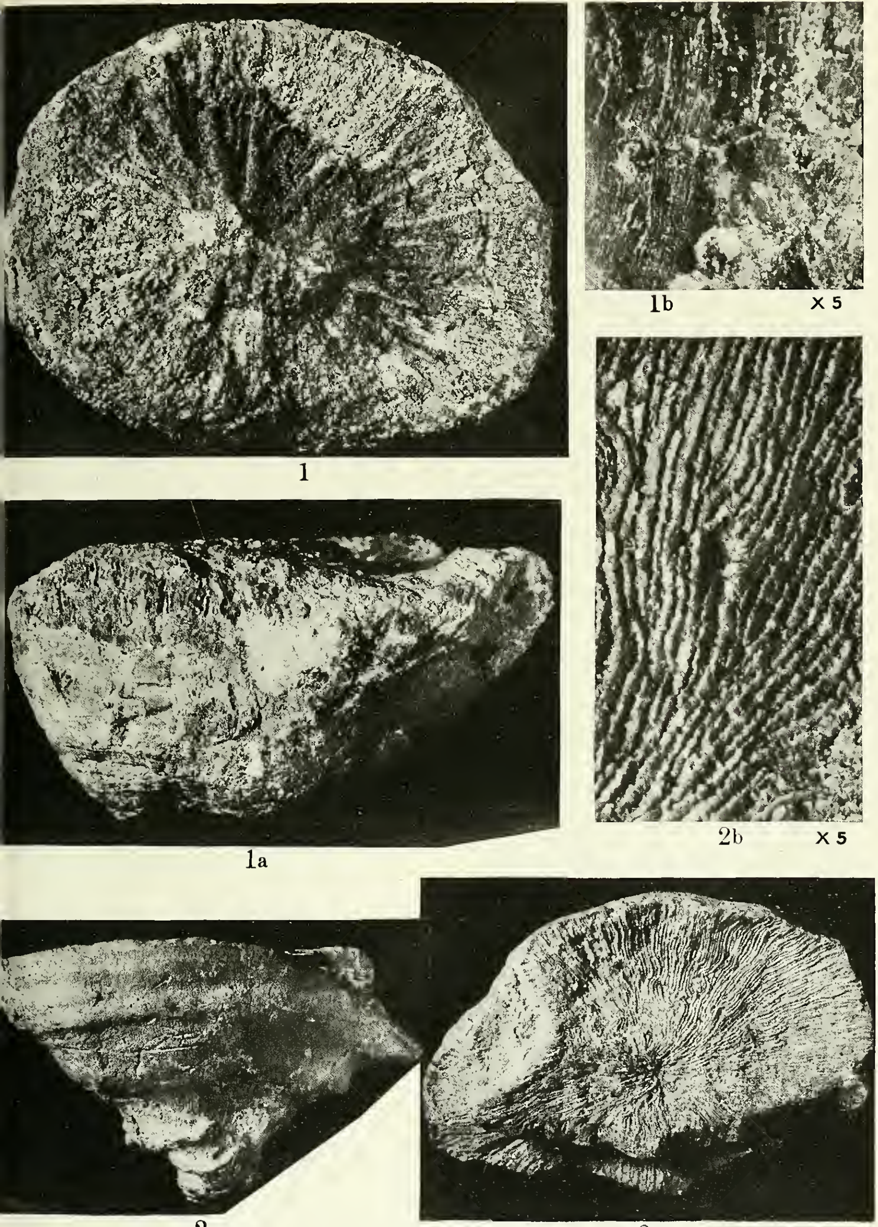
1a ×4

FOSSIL CORALS FROM CENTRAL AMERICA AND WEST INDIES.

FOR EXPLANATION OF PLATE SEE PAGE 514.

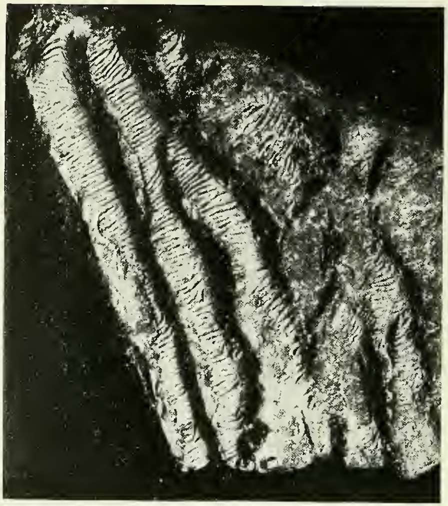
Fossil Corals from Central America and West Indies.

For explanation of plate see page 515.



Fossil Corals from Central America and West Indies.

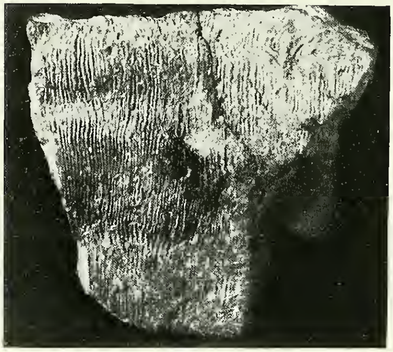
For explanation of plate see page 515.



1

1a ×2

2

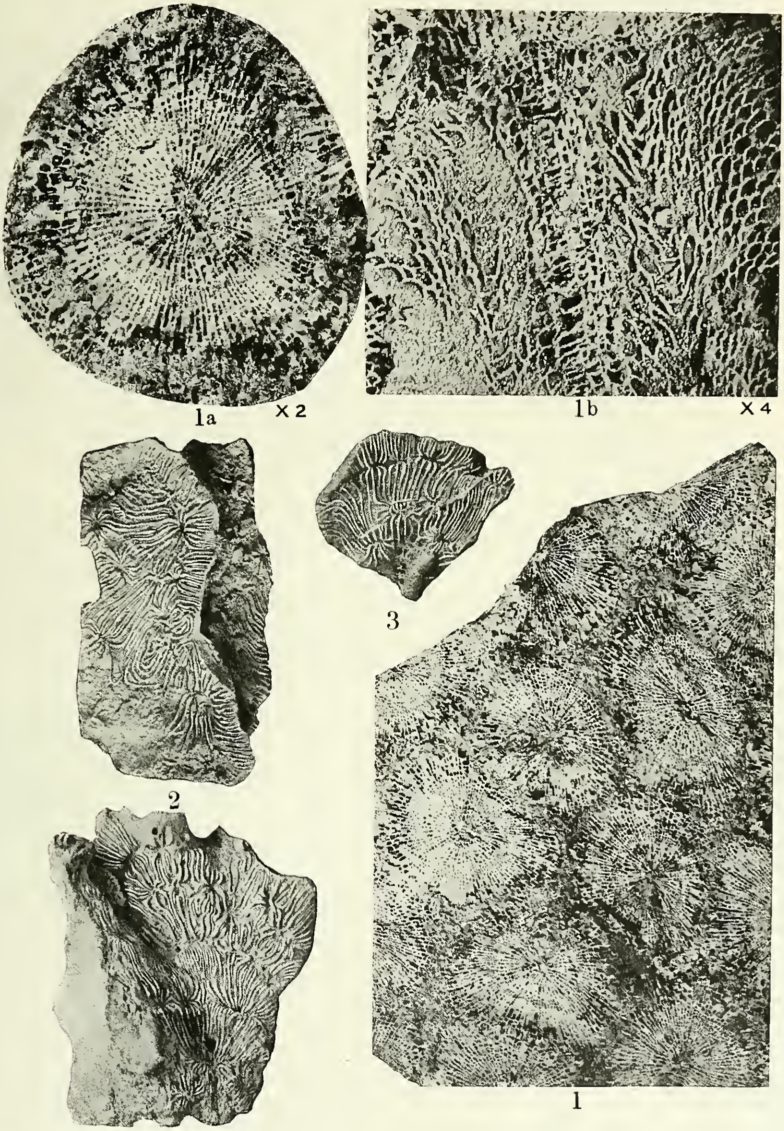


2a

2b ×4

Fossil Corals from Central America and West Indies.

For explanation of plate see page 515.

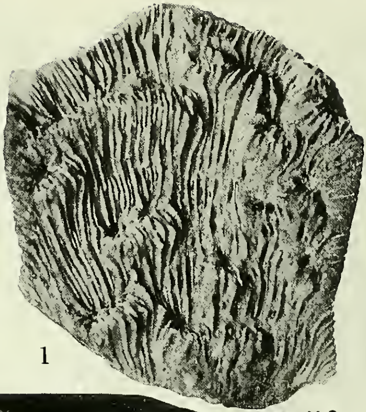


FOSSIL CORALS FROM CENTRAL AMERICA AND WEST INDIES.

FOR EXPLANATION OF PLATE SEE PAGE 515.

1a

× 2



1

× 2

2a

× 2

2

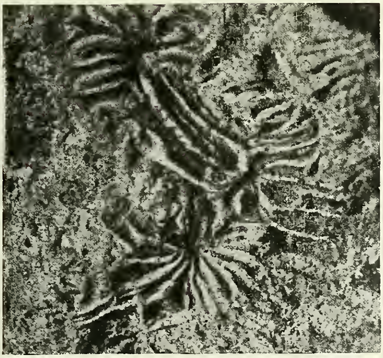
3

FOSSIL CORALS FROM CENTRAL AMERICA AND WEST INDIES.

FOR EXPLANATION OF PLATE SEE PAGE 515.

1

1b ×4



1a ×4

2a ×4

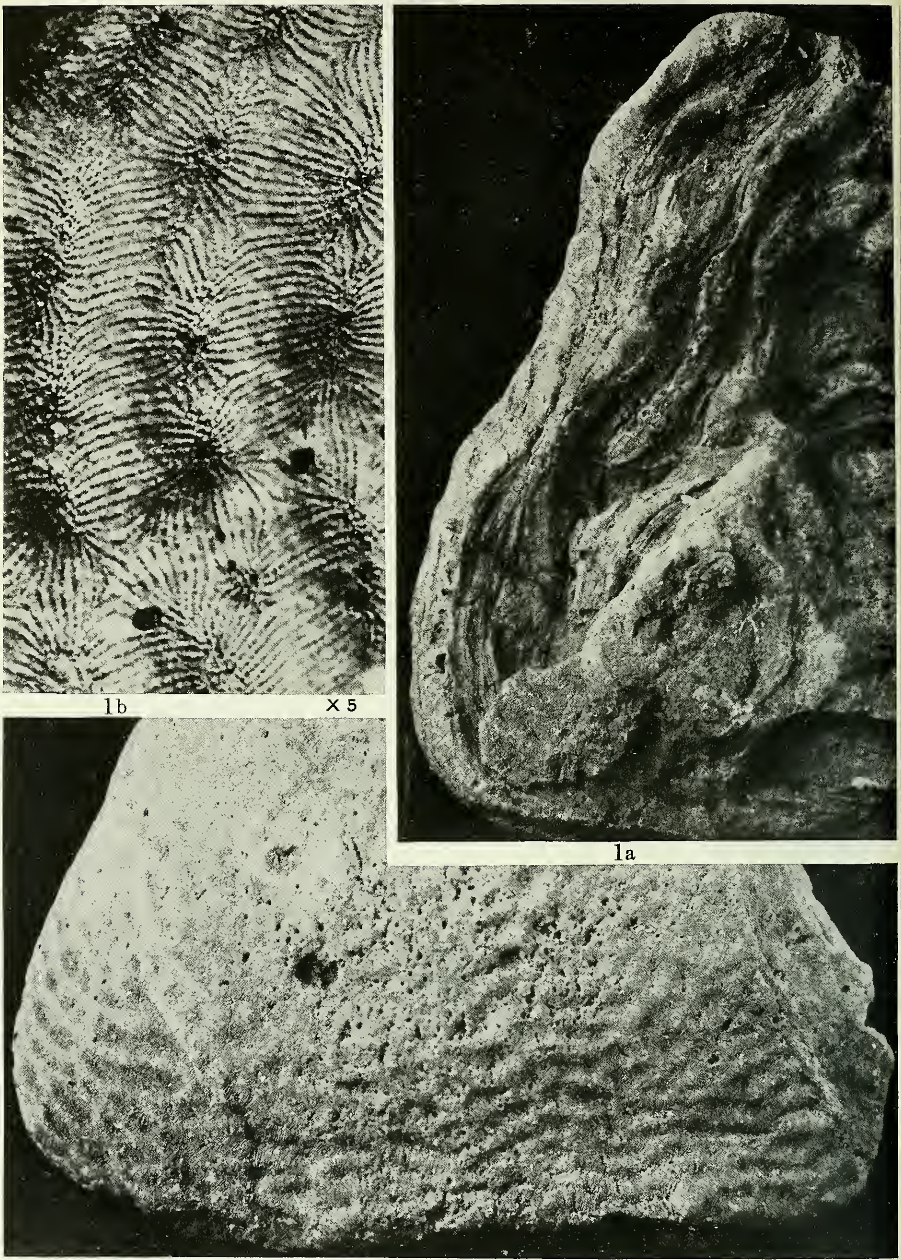
2

3

3a ×4

FOSSIL CORALS FROM CENTRAL AMERICA AND WEST INDIES.

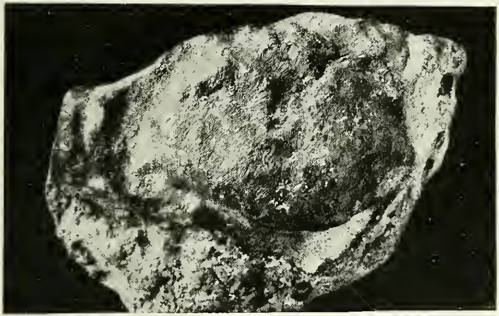
FOR EXPLANATION OF PLATE SEE PAGES 515 AND 516.



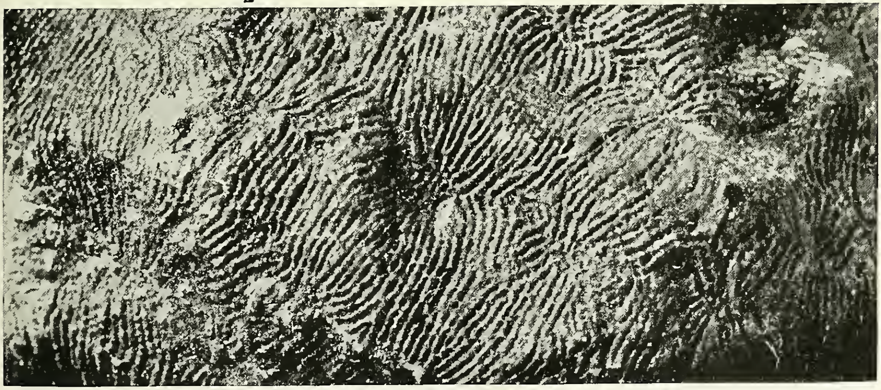
Fossil Corals from Central America and West Indies.

For explanation of plate see page 516.


1

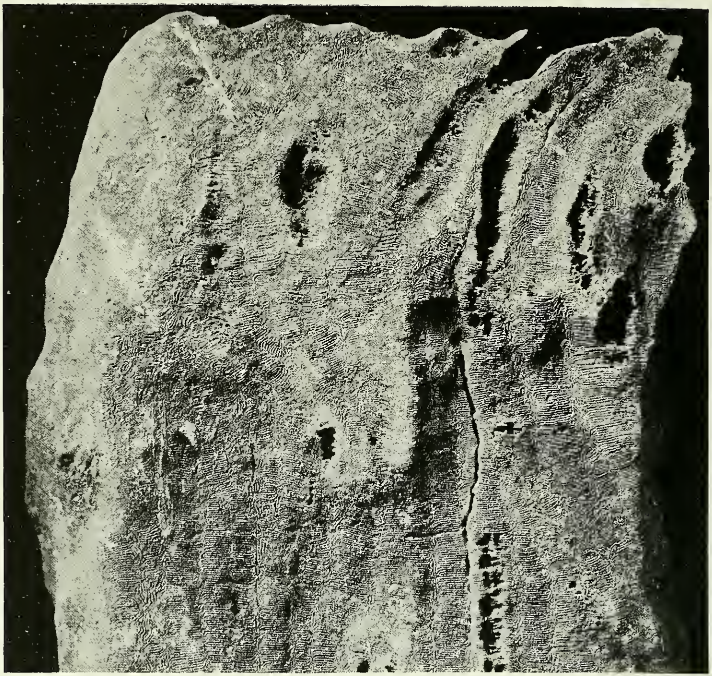

2


1a X 5

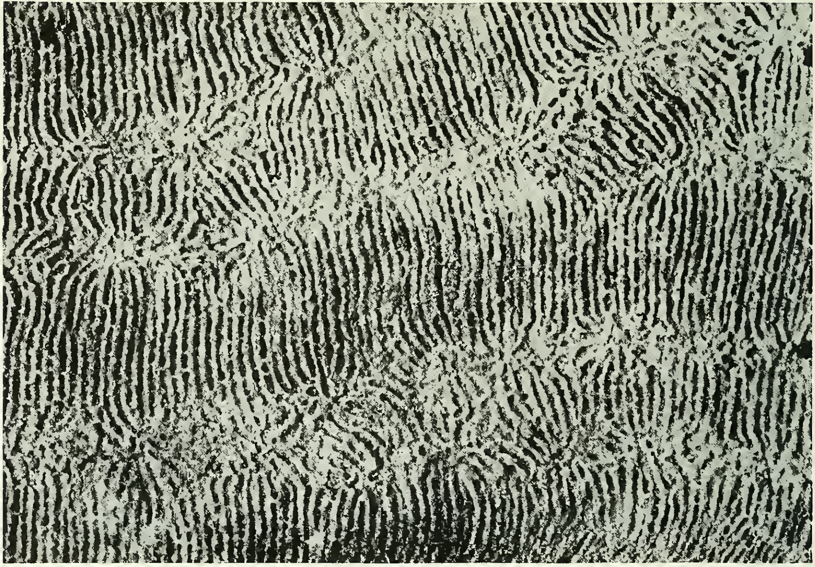

2a X 5

Fossil Corals from Central America and West Indies.

For explanation of plate see page 516.



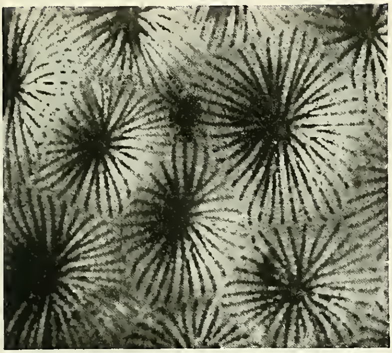
1



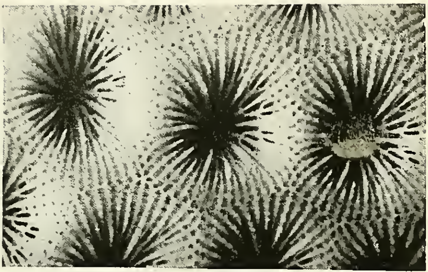
1a ×5

Fossil Corals from Central America and West Indies.

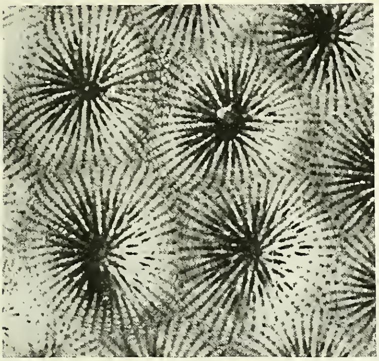
For explanation of plate see page 516.



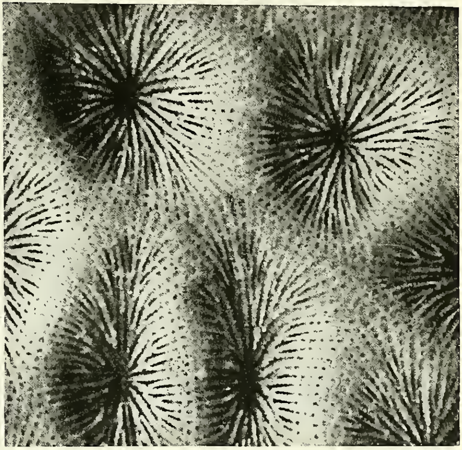
1 × 6



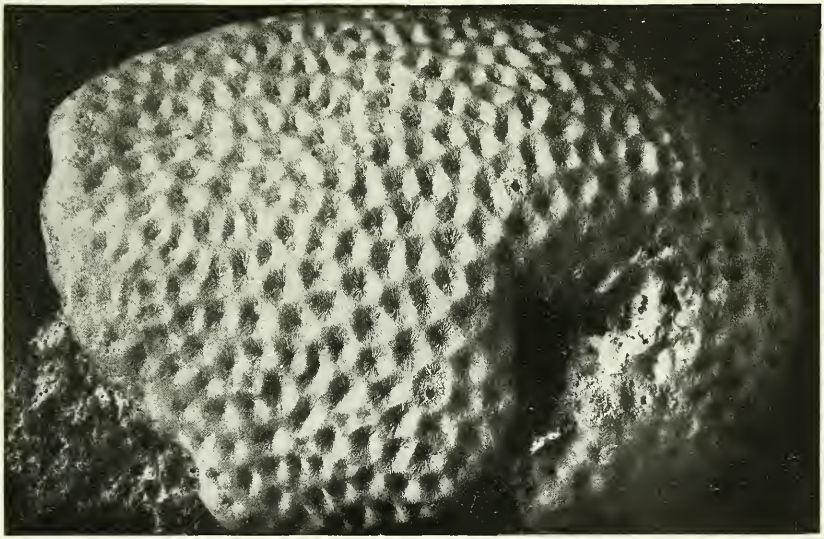
3 × 6



2 × 6



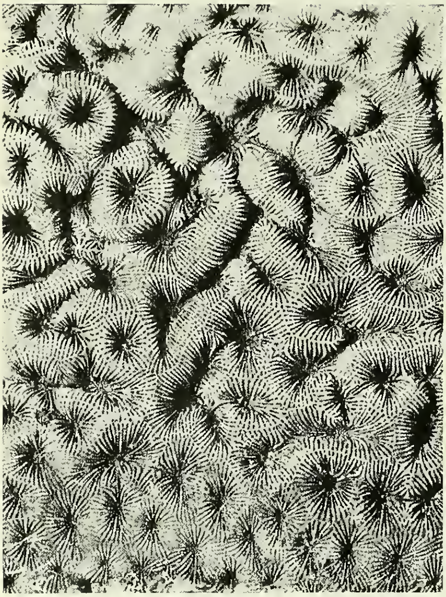
4a × 6



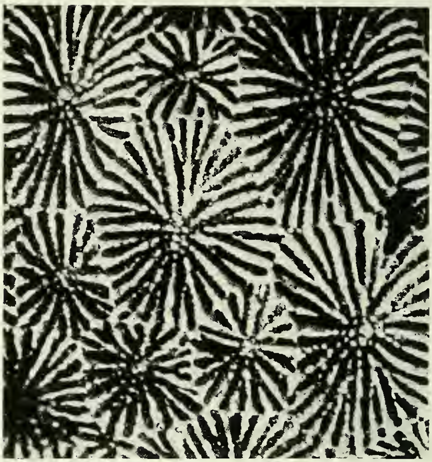
4

Fossil Corals from Central America and West Indies.

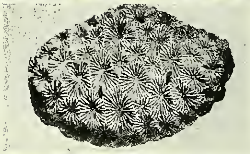
For explanation of plate see page 516.



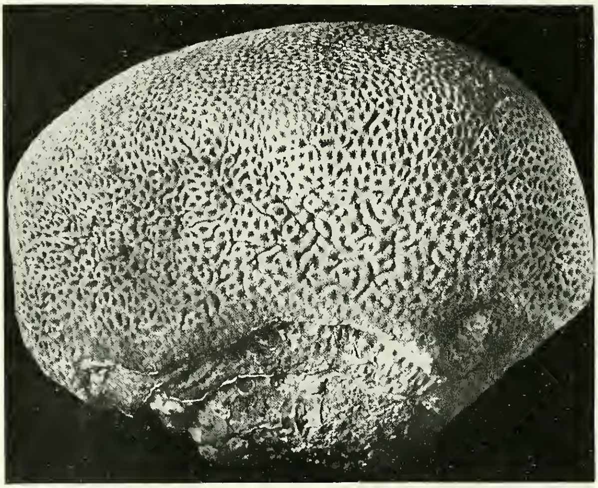
2a × 2



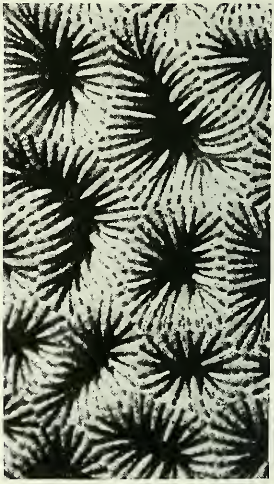
1a × 6



1



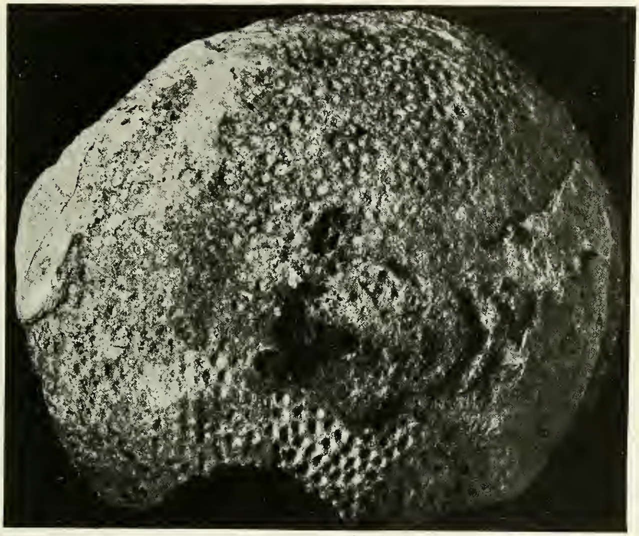
2 × ½



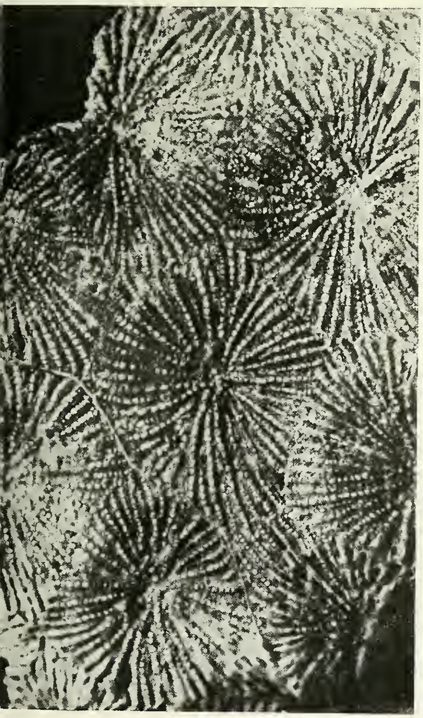
2b × 6

Fossil Corals from Central America and West Indies.

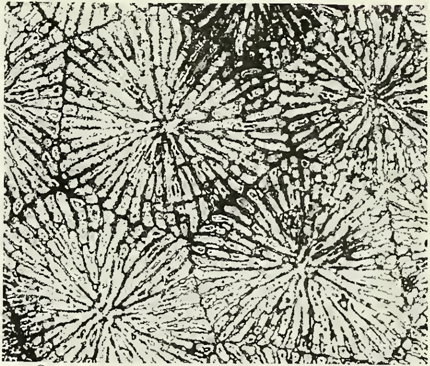
For explanation of plate see page 516.



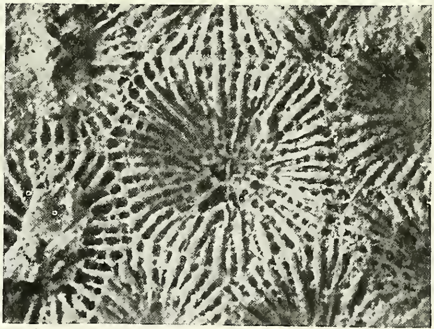
1 × ½



3 × 6



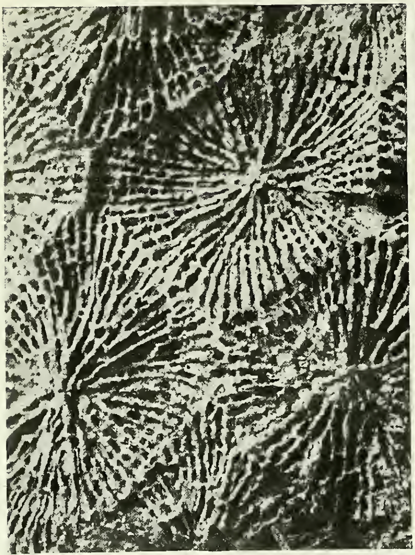
2 × 6

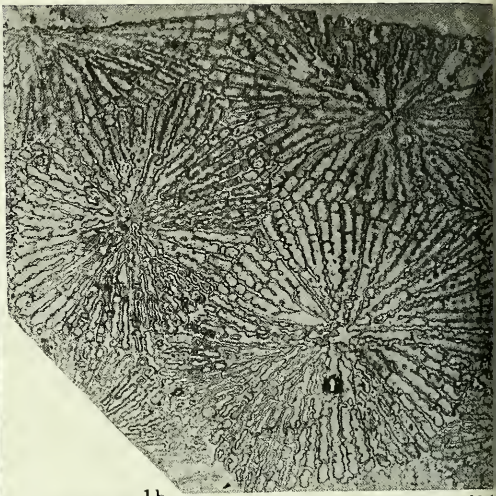


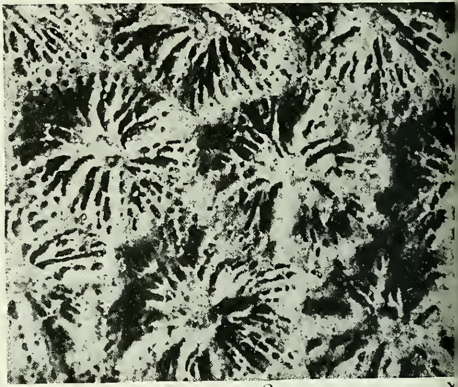
1a × 6

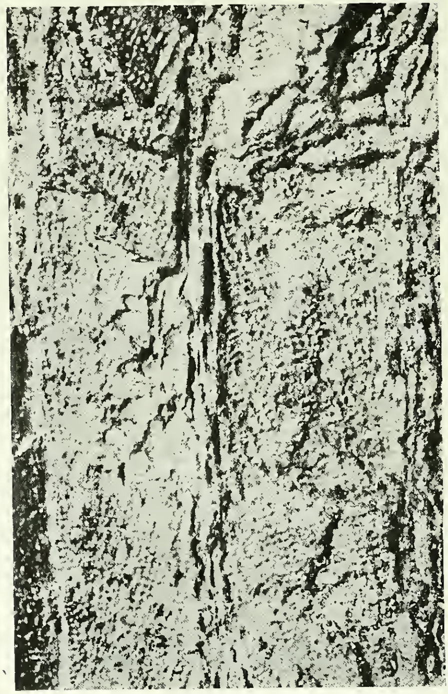
Fossil Corals from Central America and West Indies.

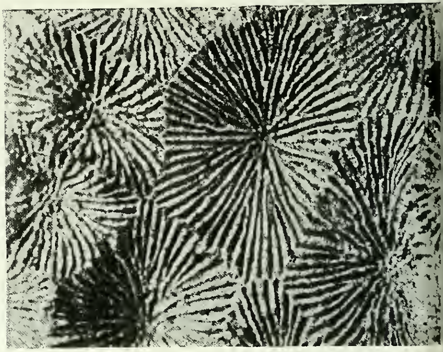
For explanation of plate see page 517.


1 × 6


1b × 6

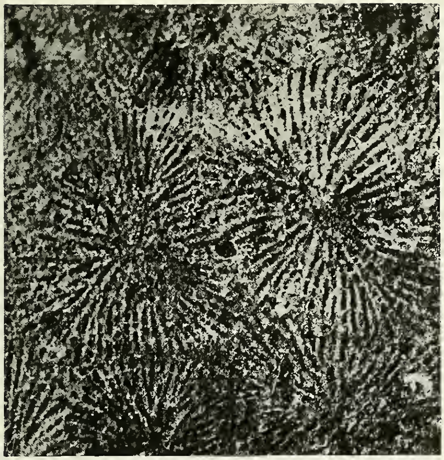

2


1a × 6

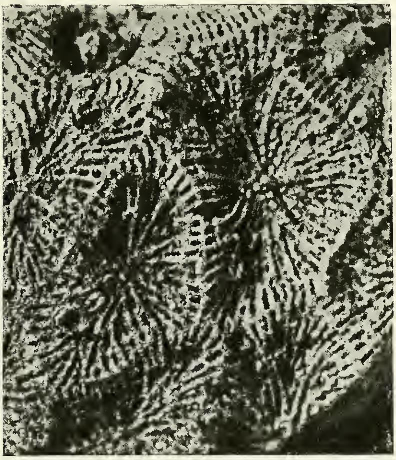

3

FOSSIL CORALS FROM CENTRAL AMERICA AND WEST INDIES.

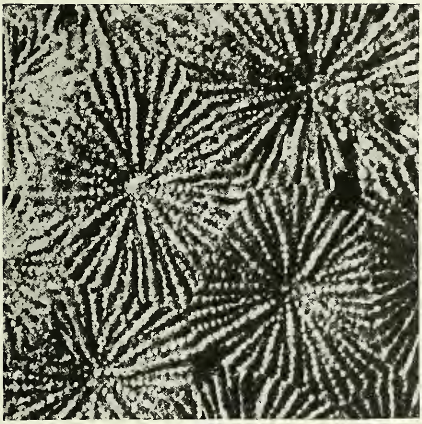
FOR EXPLANATION OF PLATE SEE PAGE 517.



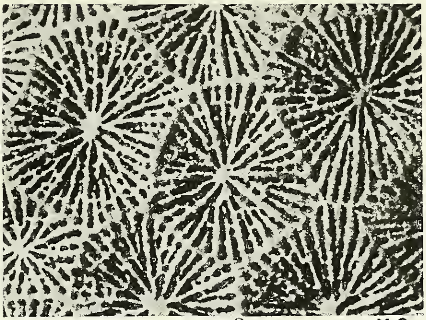
1 X 6



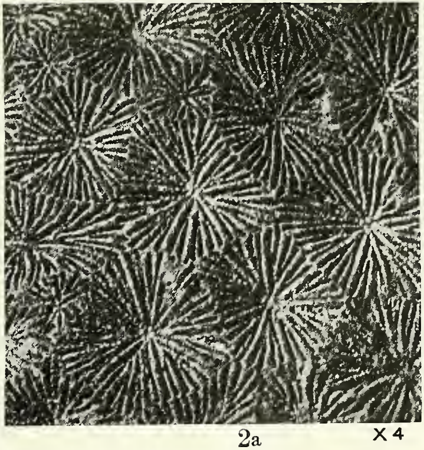
1a X 6



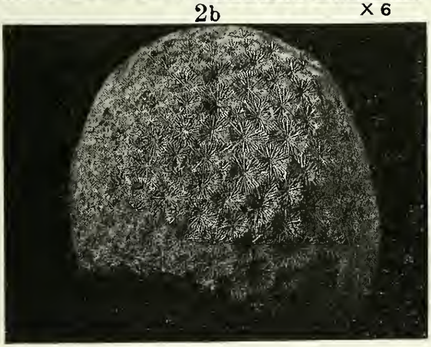
2b X 6



3 X 6



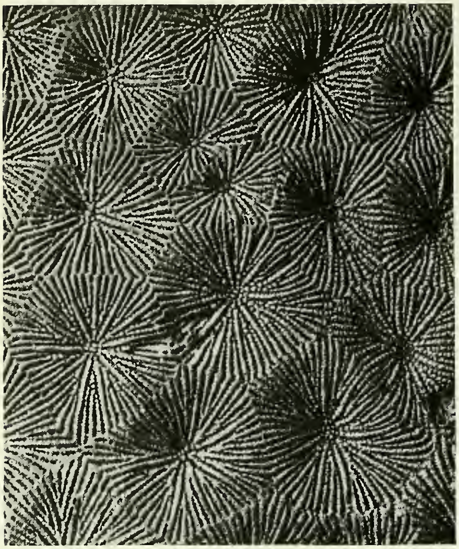
2a X 4



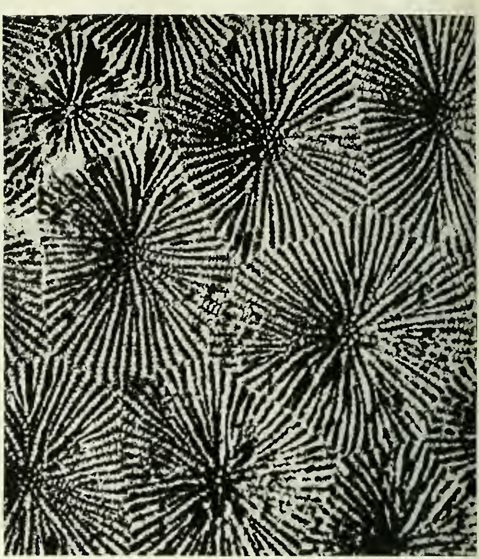
2

FOSSIL CORALS FROM CENTRAL AMERICA AND WEST INDIES.

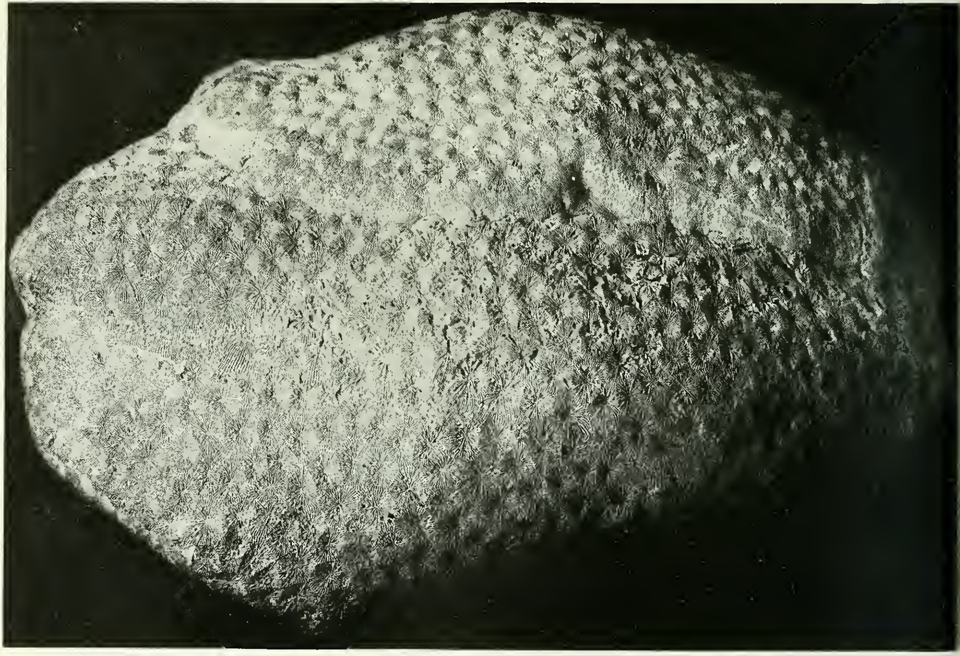
FOR EXPLANATION OF PLATE SEE PAGE 517.



1a ×4



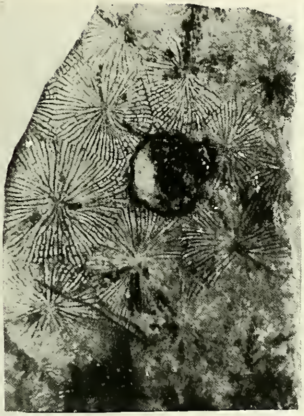
2 ×6



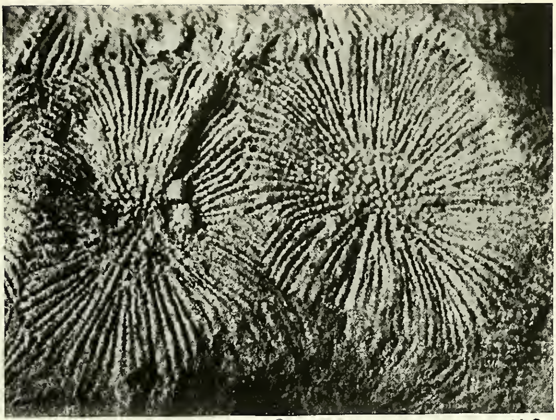
1

Fossil Corals from Central America and West Indies.

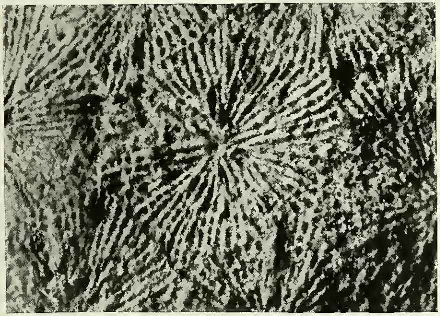
For explanation of plate see page 517.



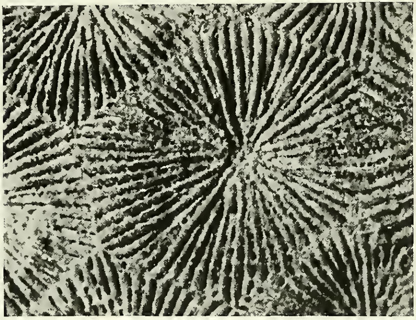
1 × 3



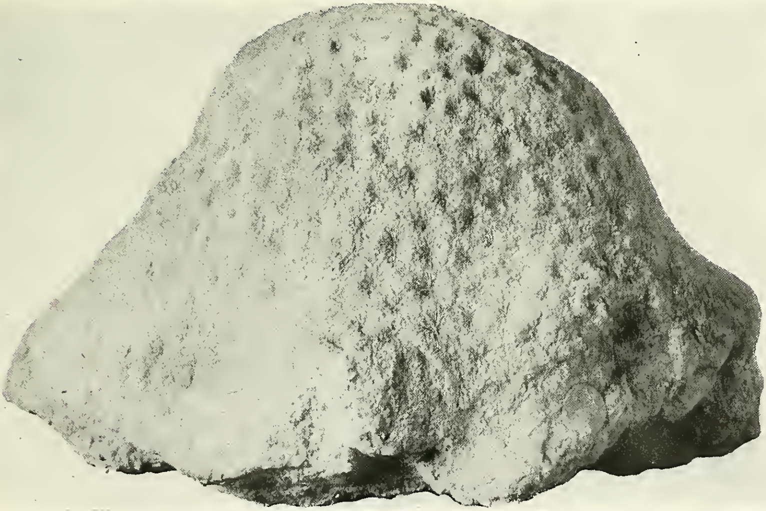
3 × 6



2a × 6



4 × 6

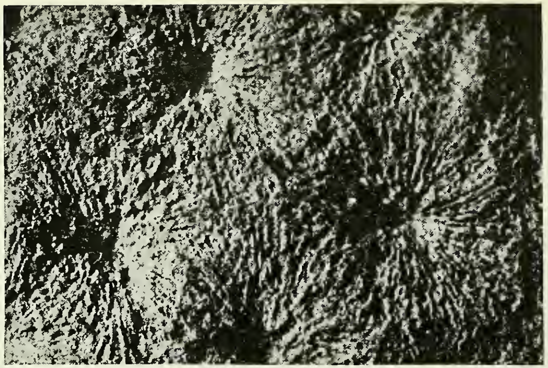


2

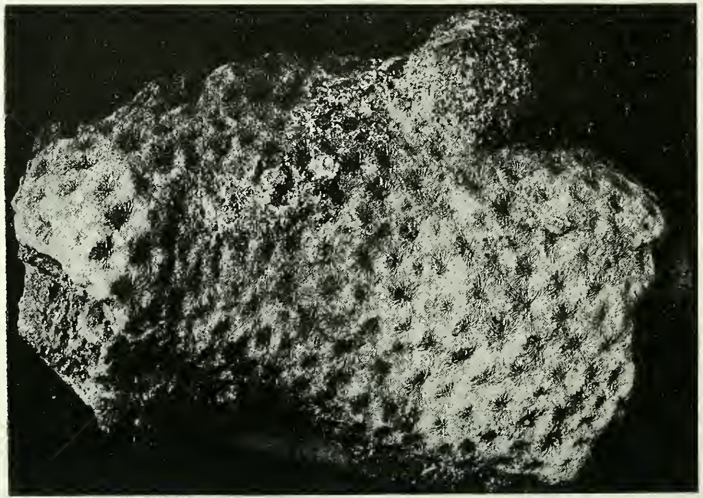
Fossil Corals from Central America and West Indies.

For explanation of plate see page 517.

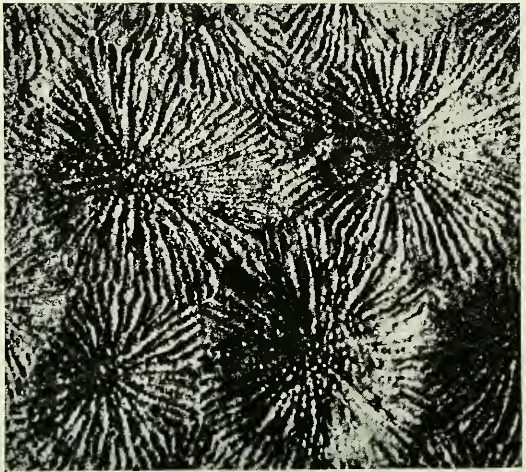
1



1a X 6



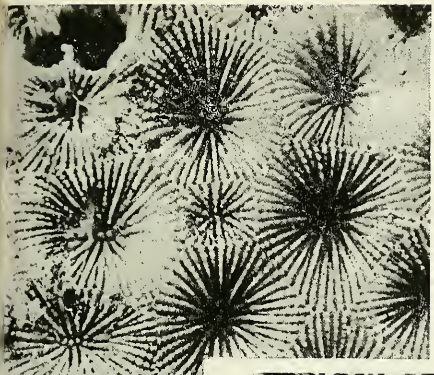
2



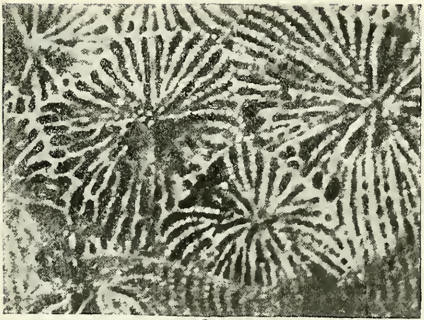
2a X 6

Fossil Corals from Central America and West Indies.

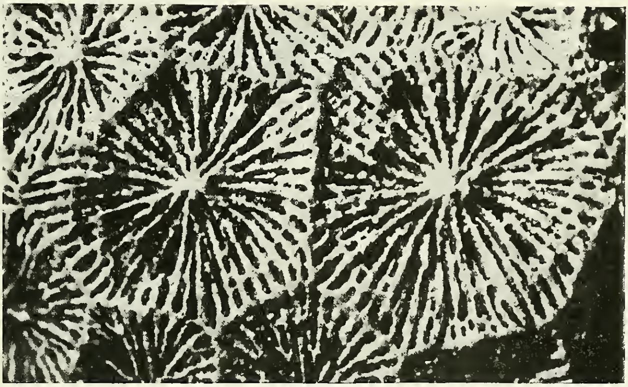
For explanation of plate see page 517



1 X 6



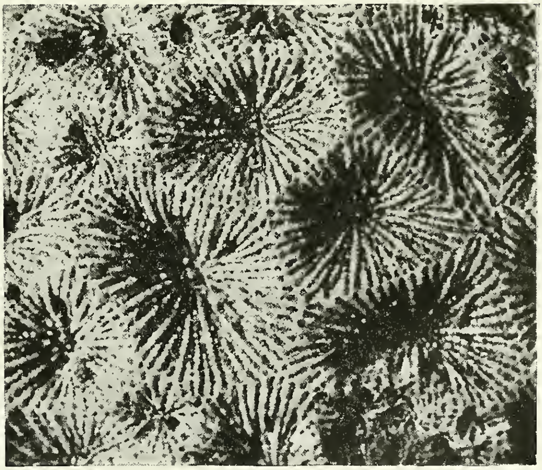
2a X 6



2b X 6

2

3



3a X 6

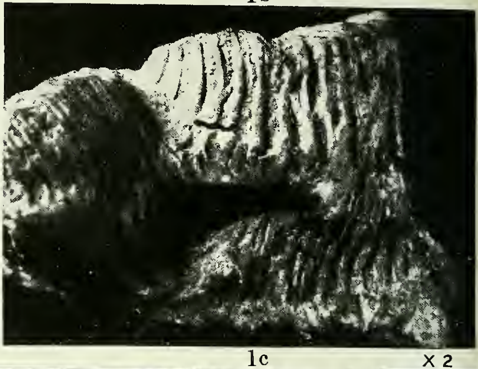
FOSSIL CORALS FROM CENTRAL AMERICA AND WEST INDIES.

FOR EXPLANATION OF PLATE SEE PAGE 518.

1

1b

1a



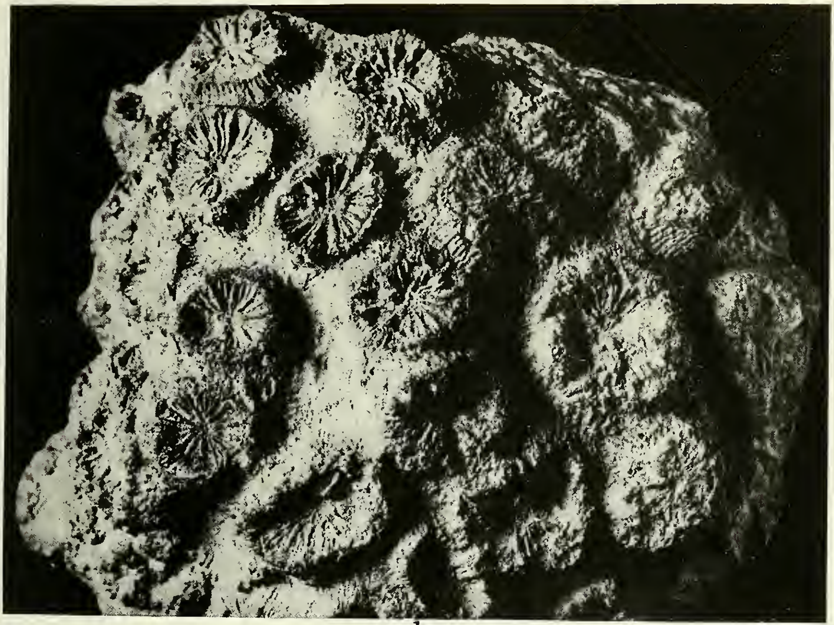
1c X 2

1d X 4

1e X 4

Fossil Corals from Central America and West Indies.

For explanation of plate see page 518.

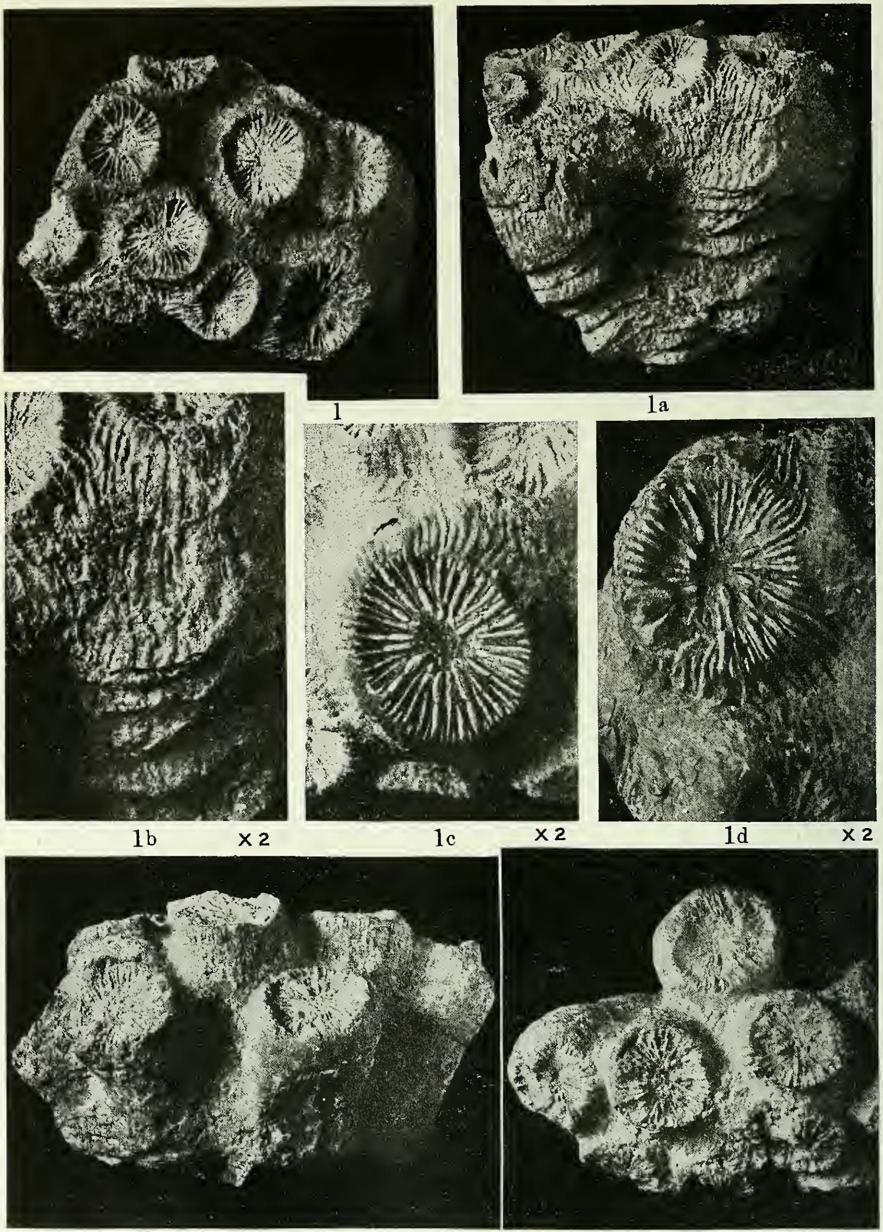


1

1a

FOSSIL CORALS FROM CENTRAL AMERICA AND WEST INDIES.

FOR EXPLANATION OF PLATE SEE PAGE 518.



1

1a

1b ×2

1c ×2

1d ×2

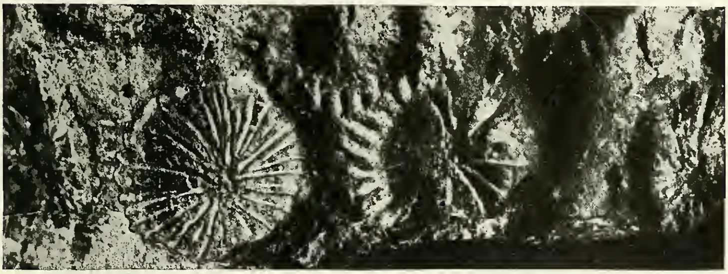
2

2a

FOSSIL CORALS FROM CENTRAL AMERICA AND WEST INDIES.

FOR EXPLANATION OF PLATE SEE PAGE 518.

1



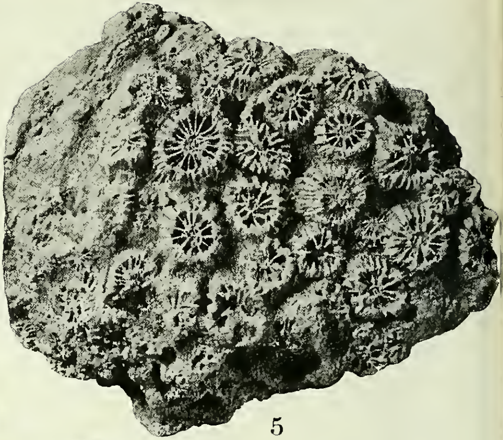
1b ×2

1a

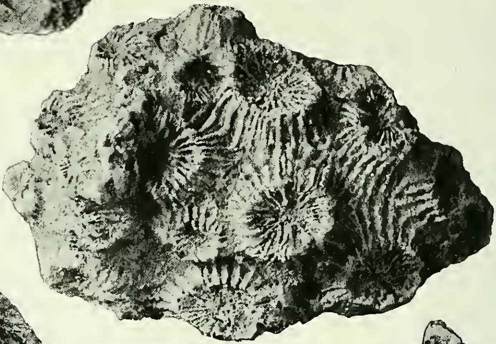
Fossil Corals from Central America and West Indies.

For explanation of plate see page 518.

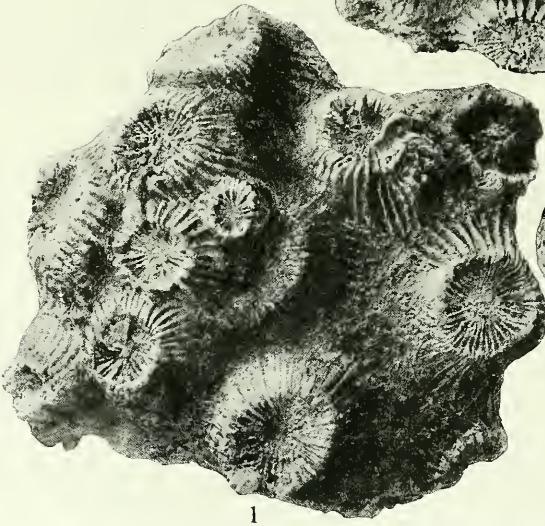
3



5



2

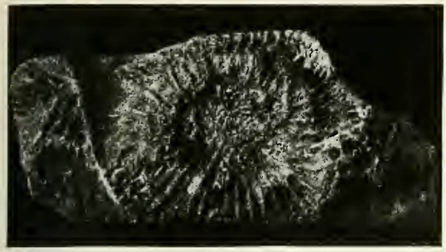


1

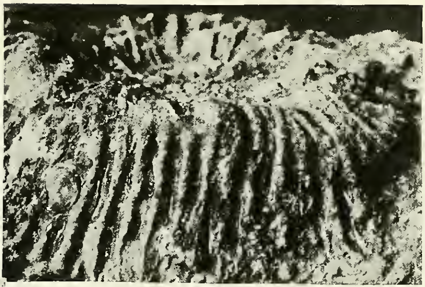
4

Fossil Corals from Central America and West Indies.

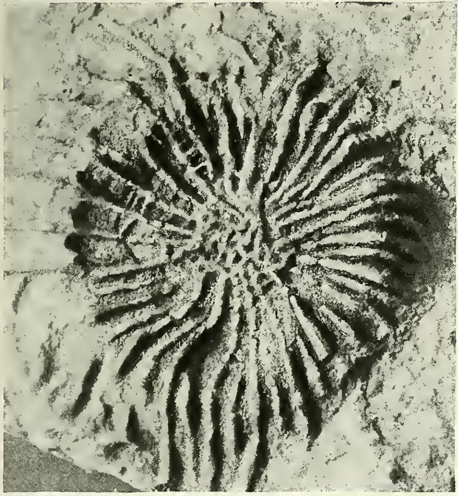
For explanation of plate see page 519.



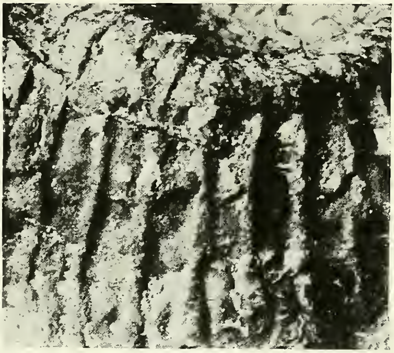
2



2b X 2

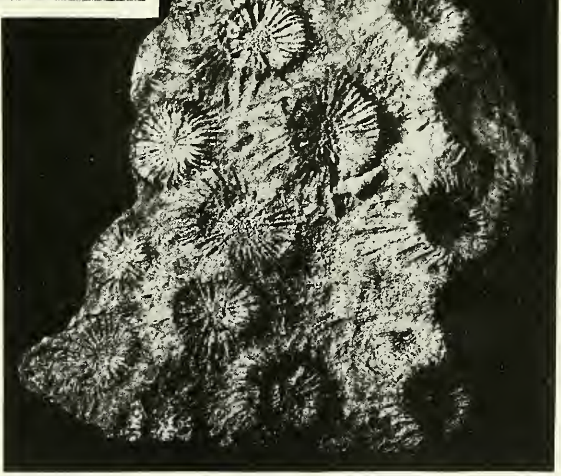


1b X 4



1a X 4

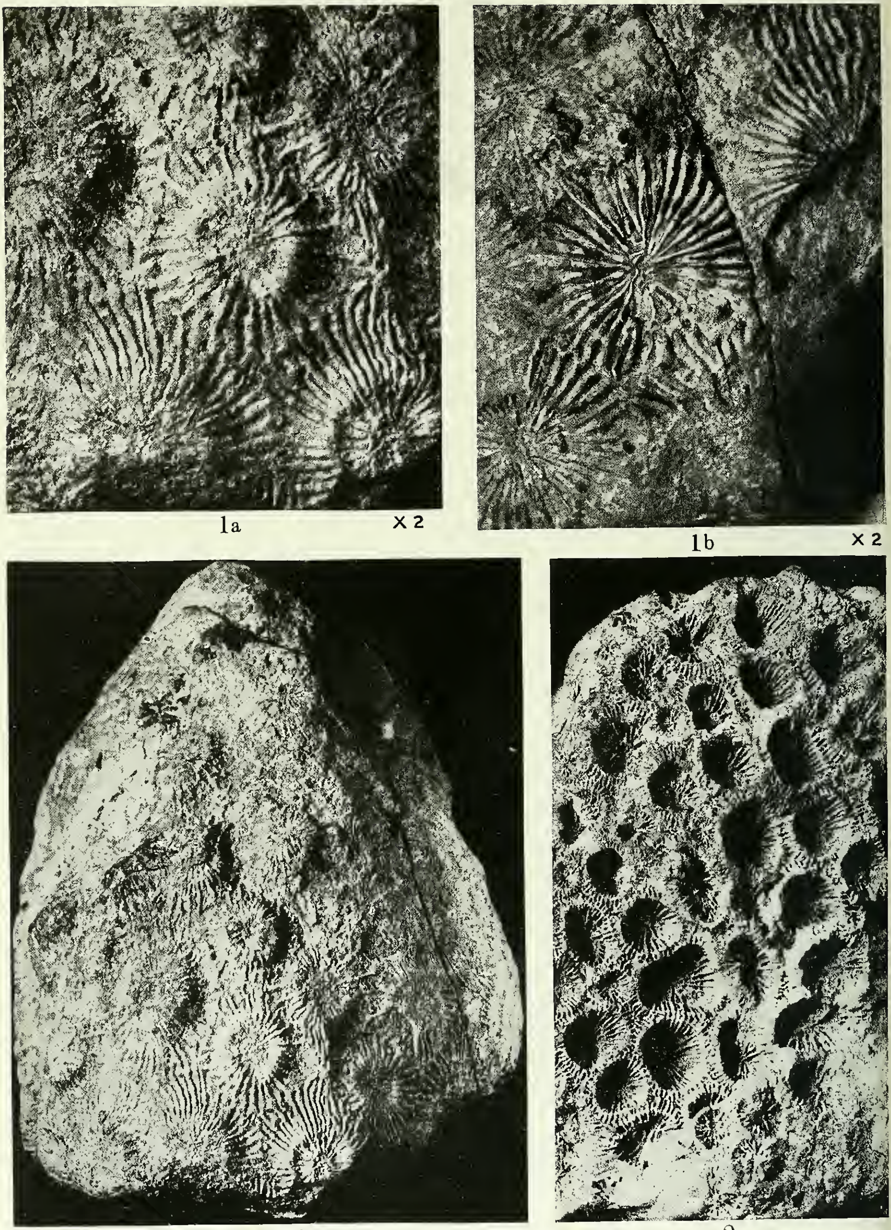
2a



1

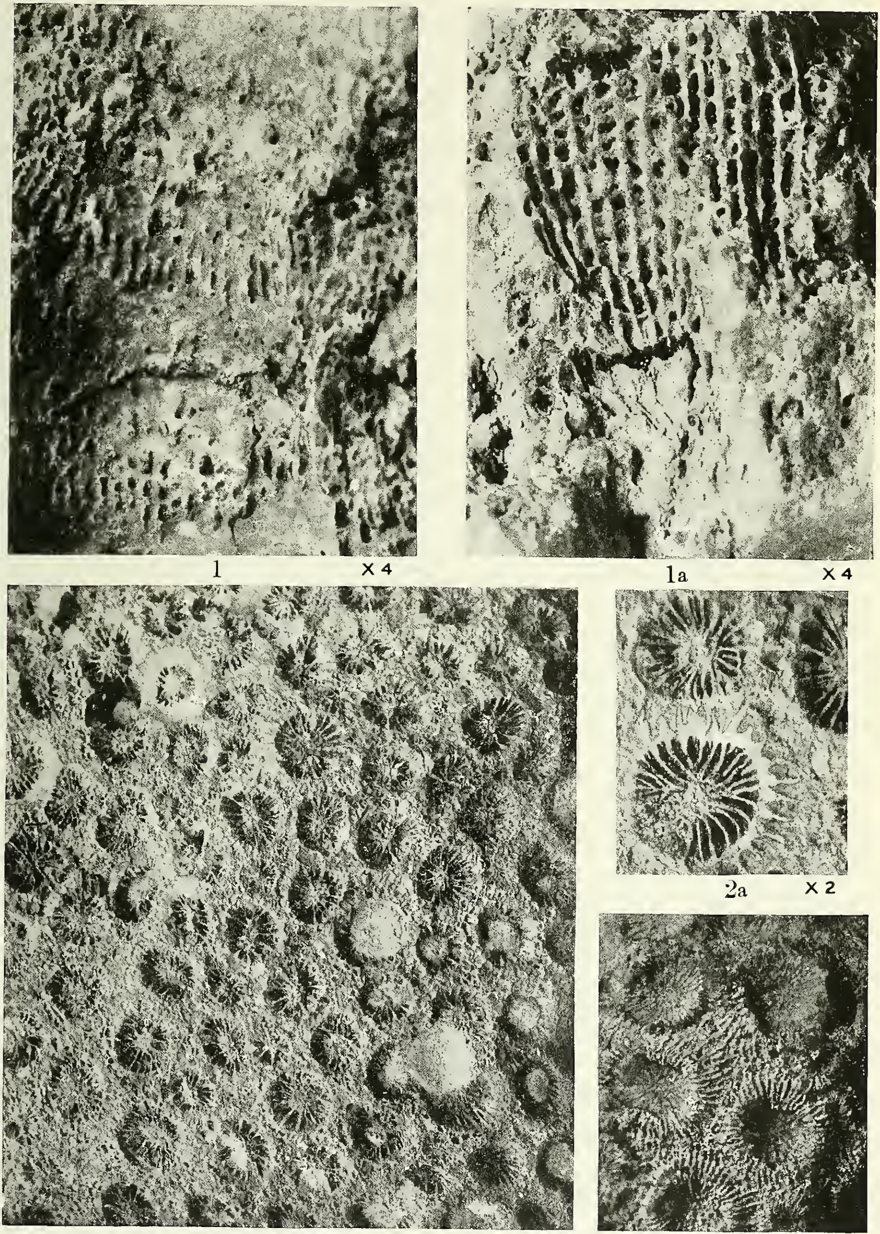
Fossil Corals from Central America and West Indies.

For explanation of plate see page 519.



Fossil Corals from Central America and West Indies.

For explanation of plate see page 519.



1 X 4

1a X 4

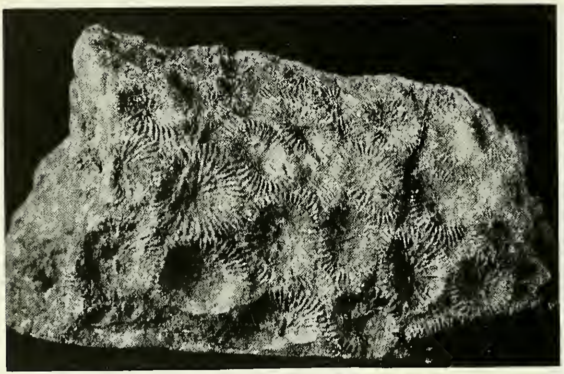
2

2a X 2

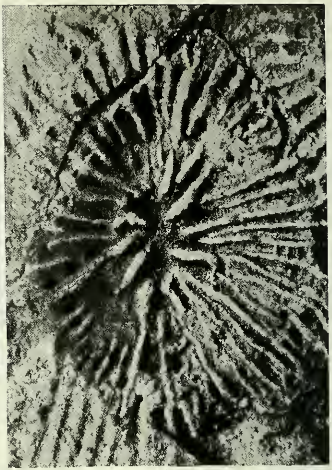
3

Fossil Corals from Central America and West Indies.

For explanation of plate see page 519.

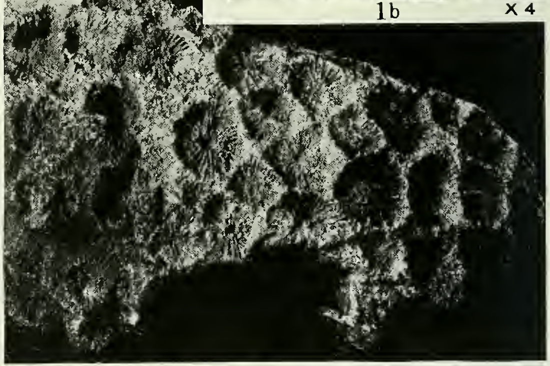


1

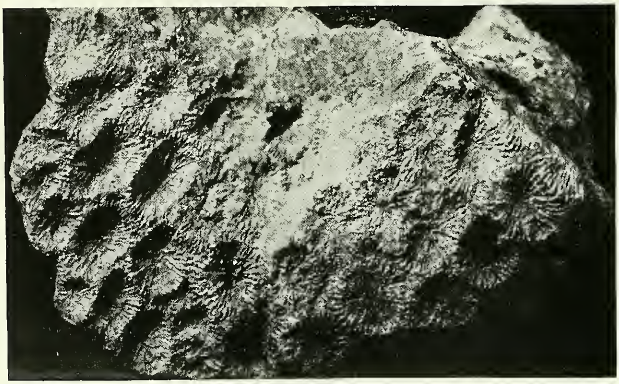


1b X 4

4



3

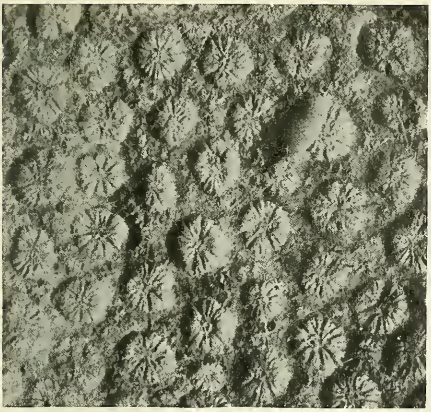


2

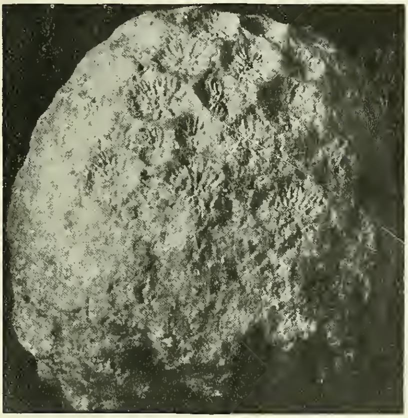
1a X 2

Fossil Corals from Central America and West Indies.

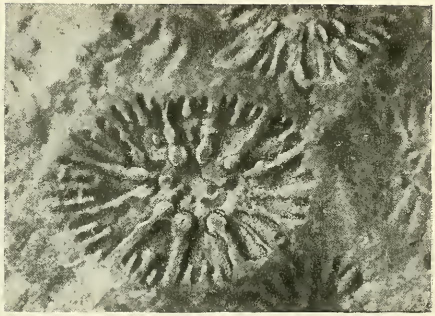
For explanation of plate see pages 519 and 520.



1



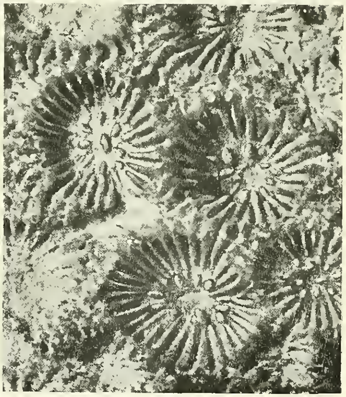
2



2a ×4

2b ×4

3

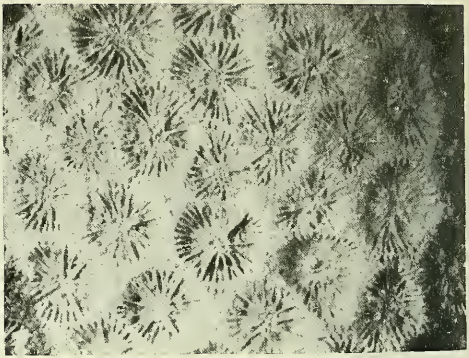


3a ×4

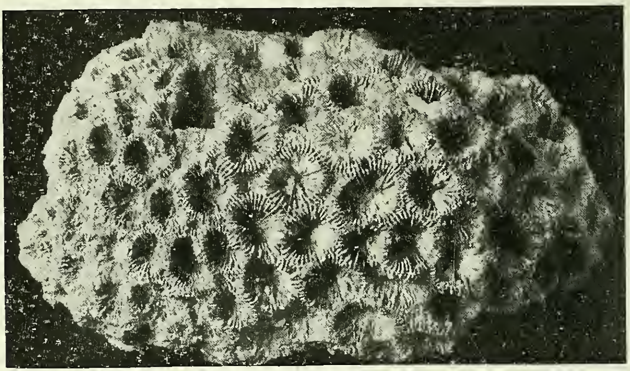
Fossil Corals from Central America and West Indies.

For explanation of plate see page 520.

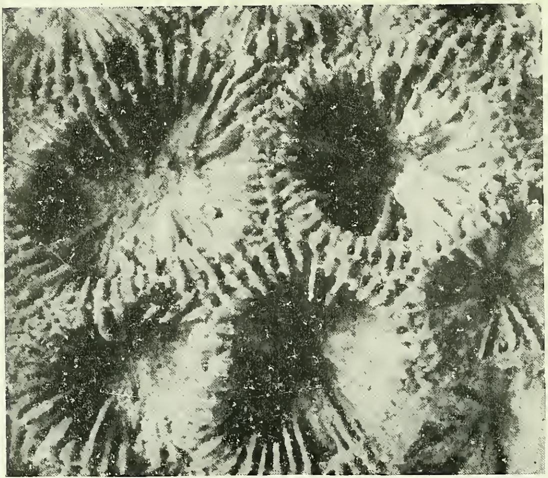
1



2 X 2



3

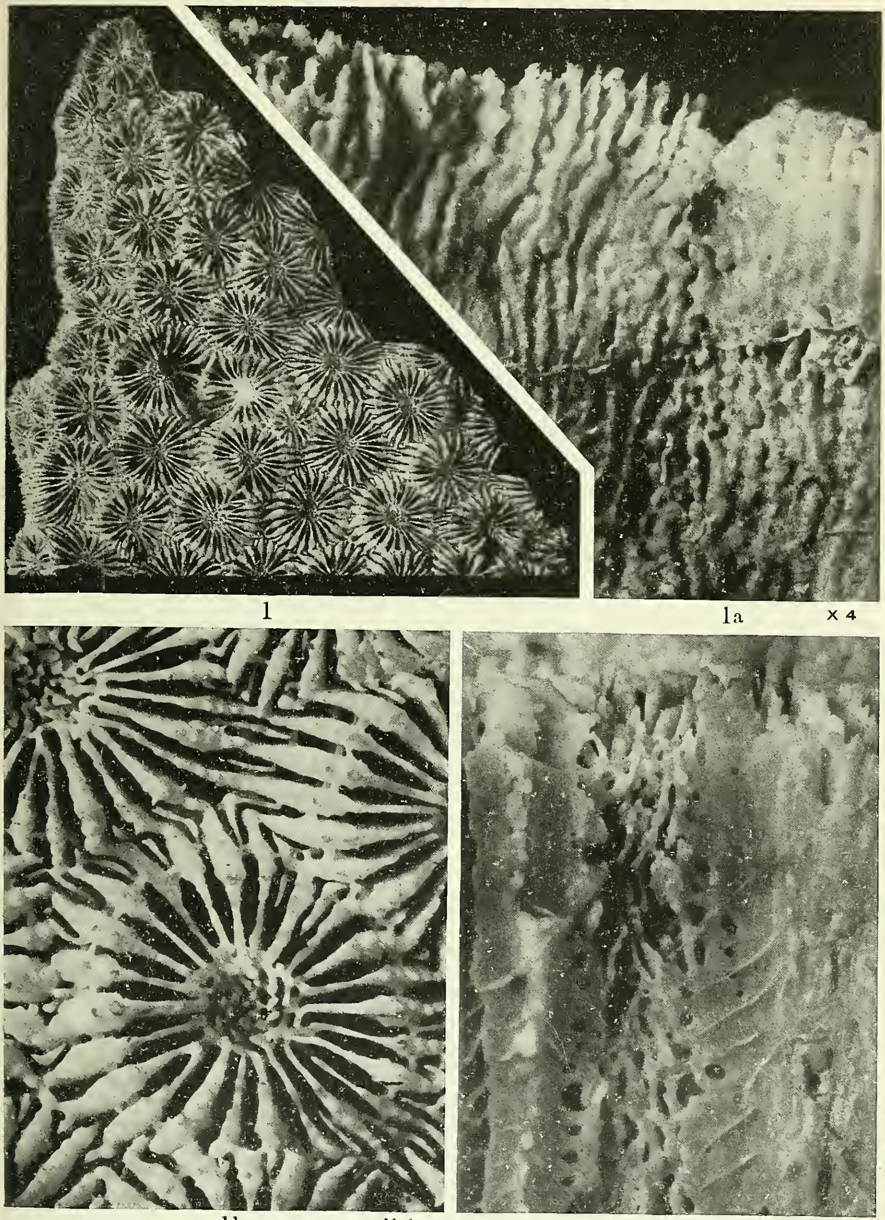


3a X 4

3b X 4

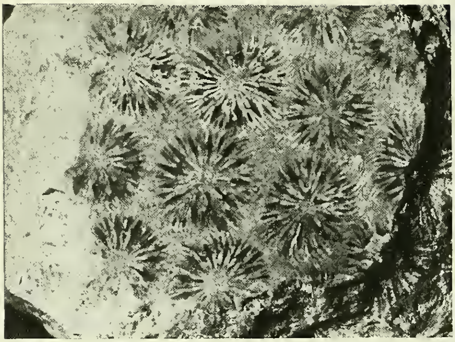
FOSSIL CORALS FROM CENTRAL AMERICA AND WEST INDIES.

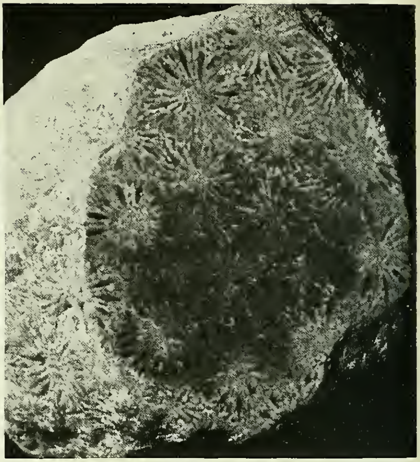
FOR EXPLANATION OF PLATE SEE PAGE 520.



Fossil Corals from Central America and West Indies.

For explanation of plate see page 520.

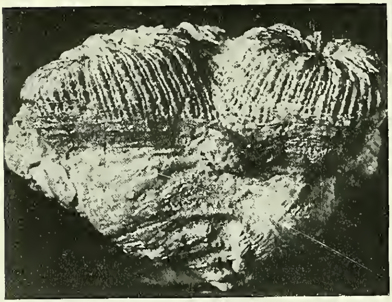

1

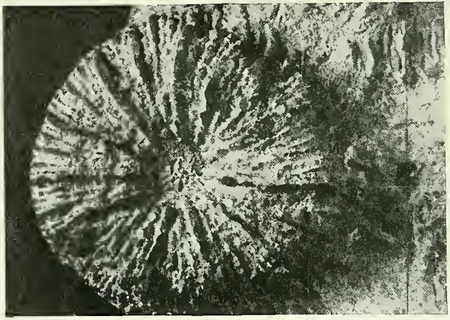

2


4a


3


4

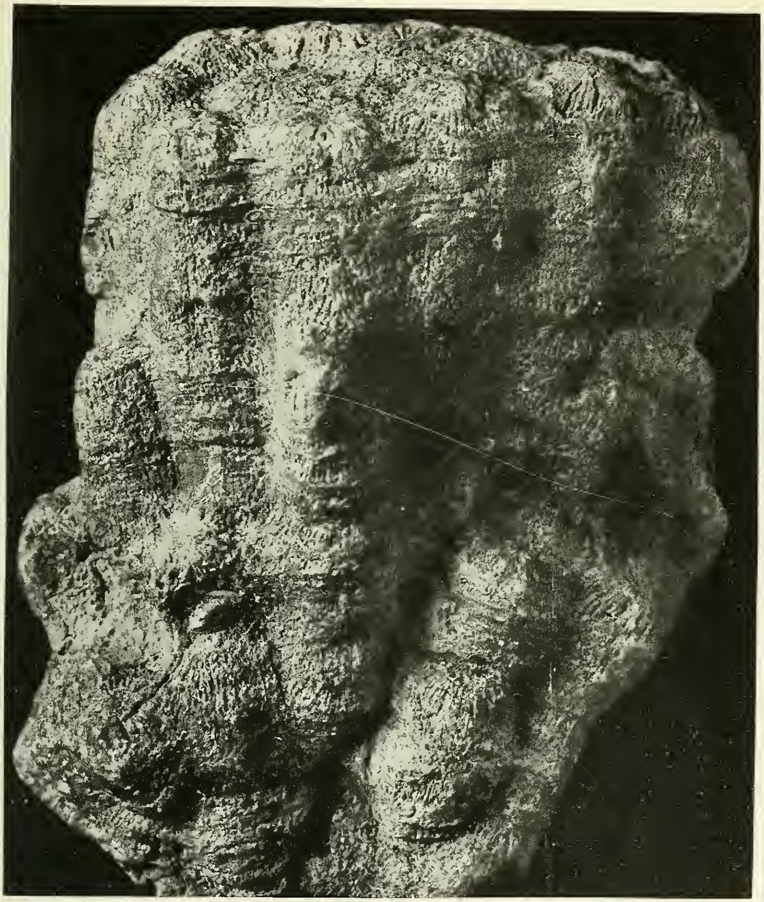

5a


5b ×2


5

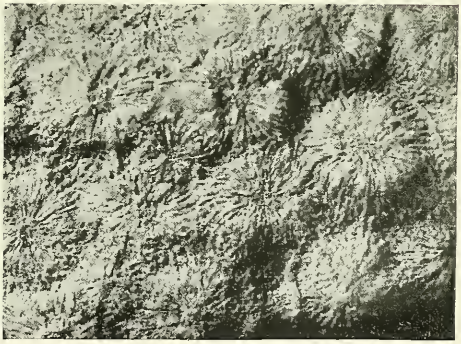
FOSSIL CORALS FROM CENTRAL AMERICA AND WEST INDIES.

FOR EXPLANATION OF PLATE SEE PAGE 520



1

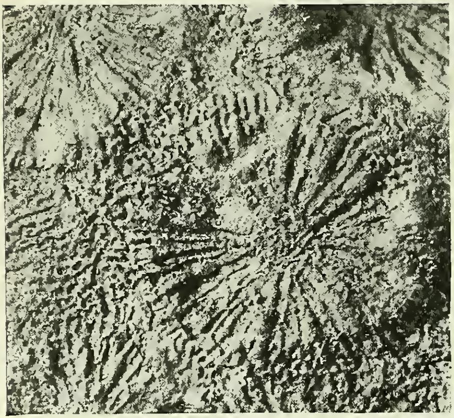
1a X 2



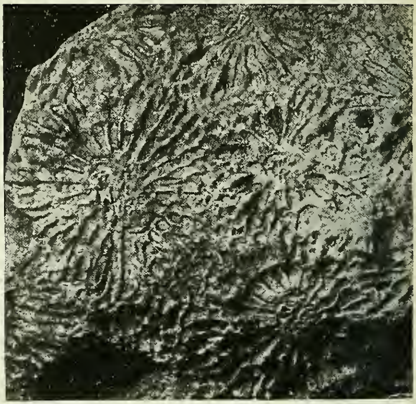
1b

FOSSIL CORALS FROM CENTRAL AMERICA AND WEST INDIES.

FOR EXPLANATION OF PLATE SEE PAGE 521.

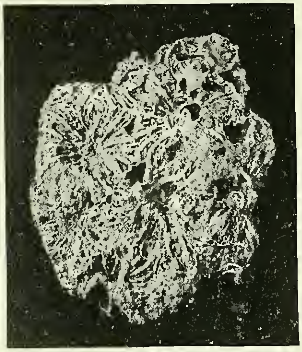


3 × 2



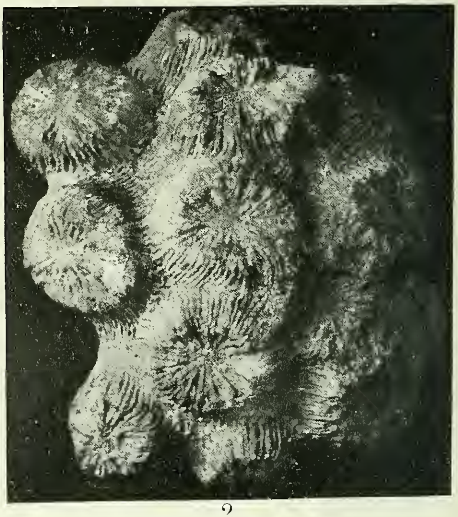
4 × 2

4a × 2



5

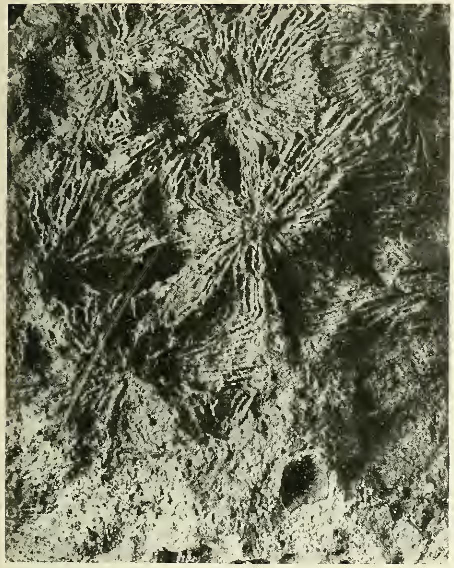
1



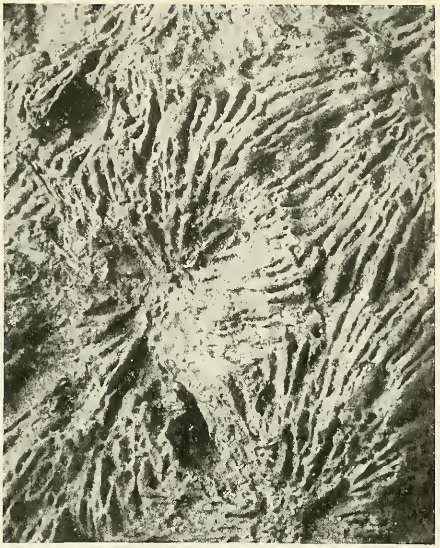
2

FOSSIL CORALS FROM CENTRAL AMERICA AND WEST INDIES.

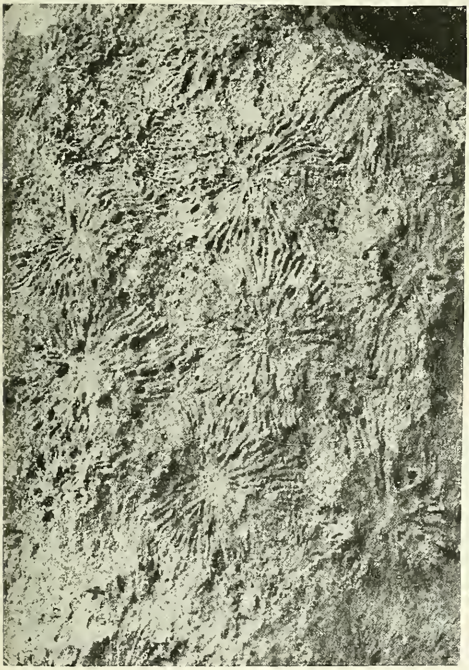
FOR EXPLANATION OF PLATE SEE PAGE 521.



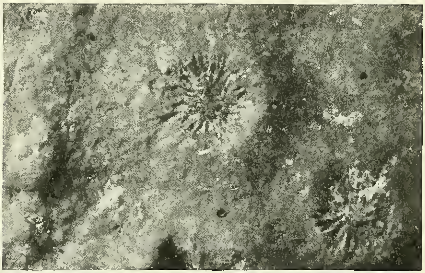
2



2a ×2



1



3a ×2

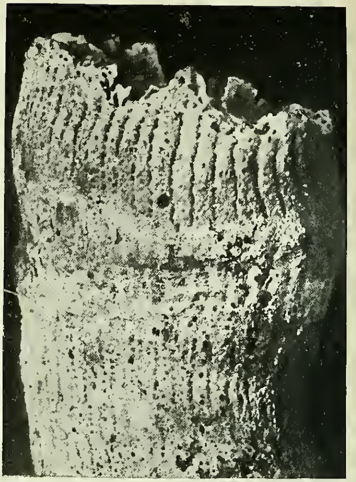
3

FOSSIL CORALS FROM CENTRAL AMERICA AND WEST INDIES.

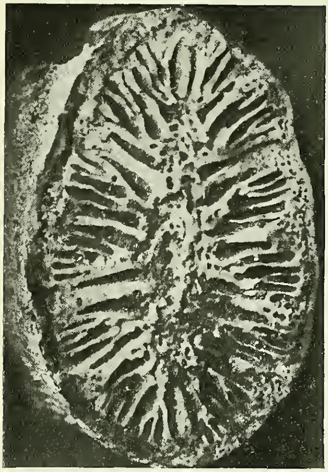
FOR EXPLANATION OF PLATE SEE PAGE 521.

1b × 3

1

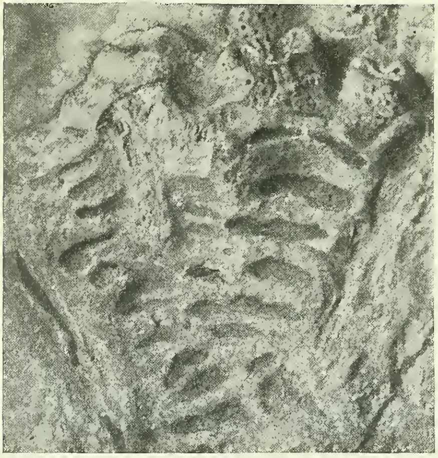


1a × 4

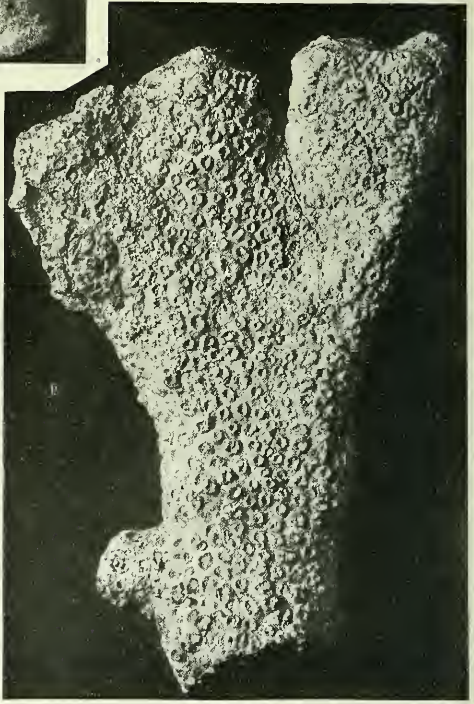


2a × 3

2



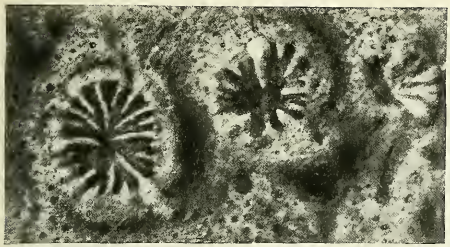
3a × 3



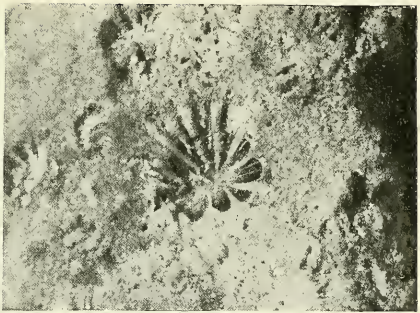
3 × ½

FOSSIL CORALS FROM CENTRAL AMERICA AND WEST INDIES.

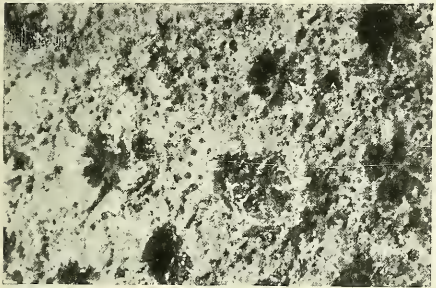
FOR EXPLANATION OF PLATE SEE PAGE 521.



1 X 6

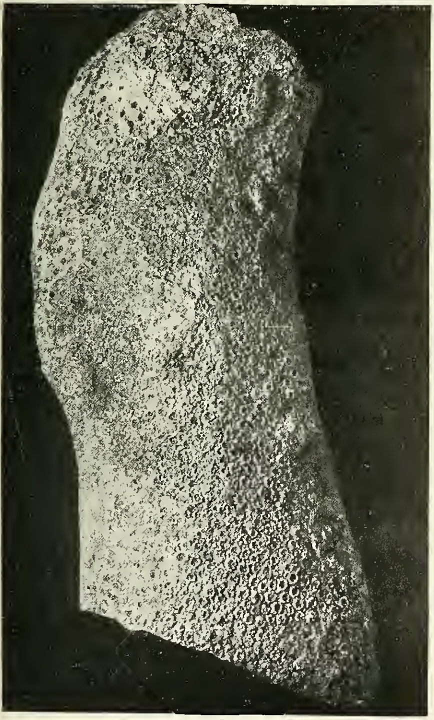


2a X 6

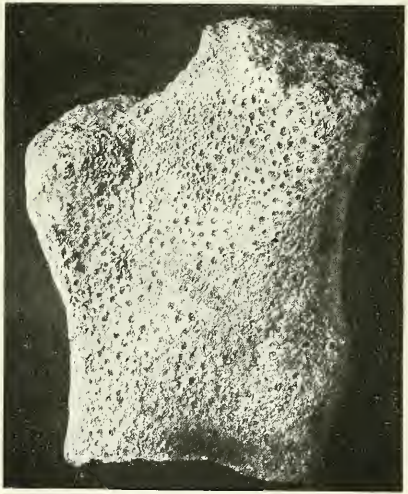


4a X 6

2



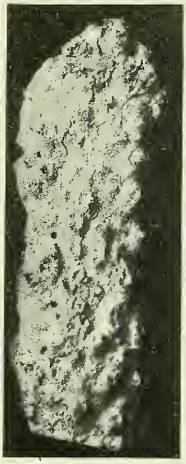
3 X ½



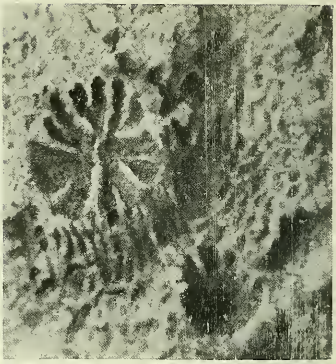
4 X ½

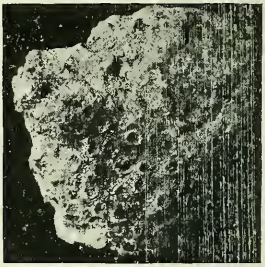
FOSSIL CORALS FROM CENTRAL AMERICA AND WEST INDIES.

FOR EXPLANATION OF PLATE SEE PAGE 521.


1


3a ×3

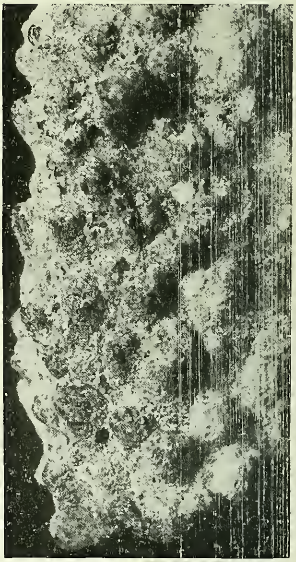

1b ×8


2


3

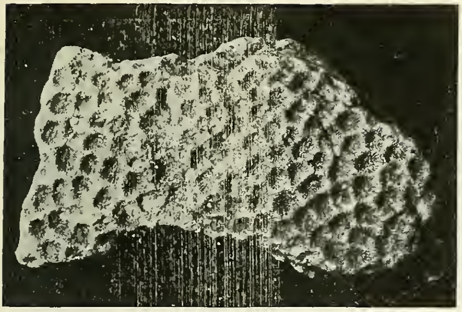

1a ×3


4


4a ×3

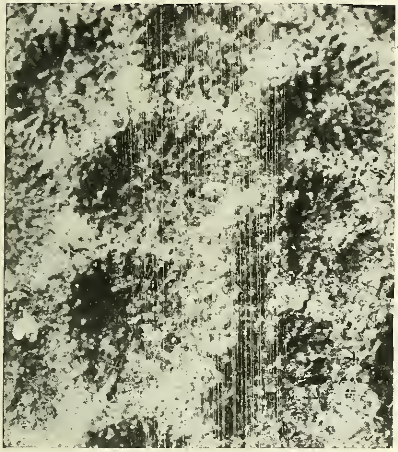
Fossil Corals from Central America and West Indies.

For explanation of plate see page 522.



1

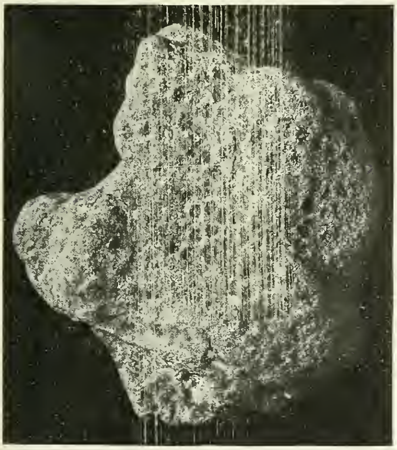
2b ×3



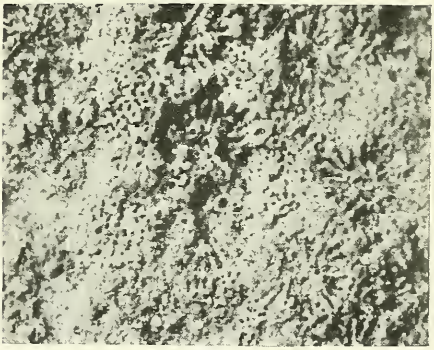
1a ×6

2

2a



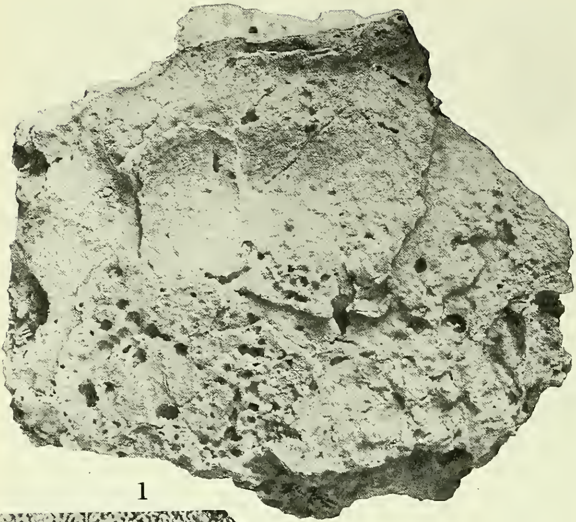
3



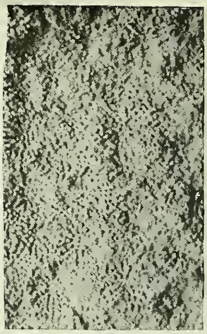
3a ×6

FOSSIL CORALS FROM CENTRAL AMERICA AND WEST INDIES.

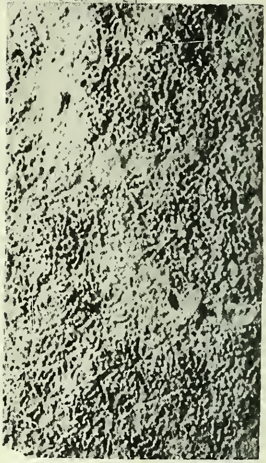
FOR EXPLANATION OF PLATE SEE PAGE 522



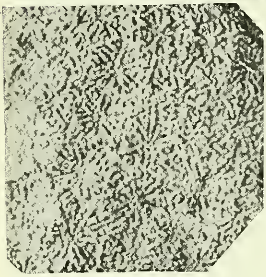
1



1a × 3

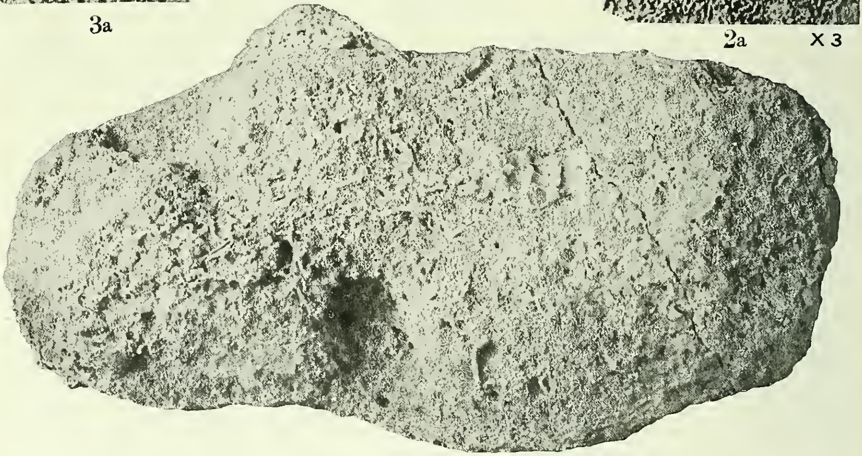


2a × 3



3a

3

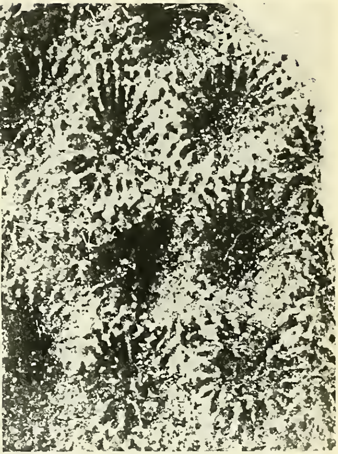


2

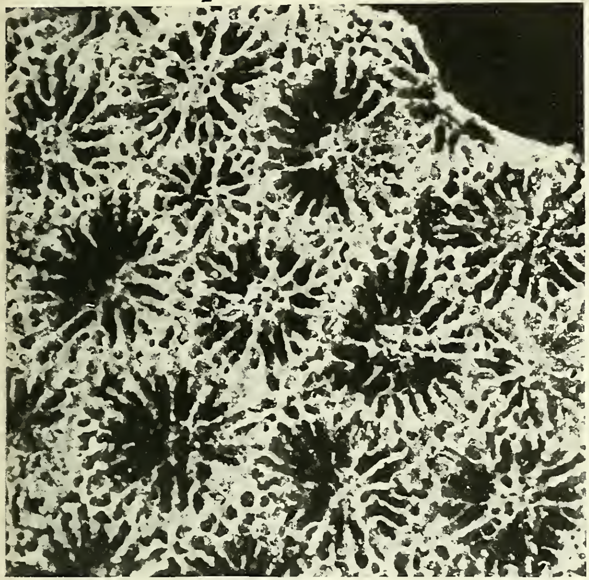
FOSSIL CORALS FROM CENTRAL AMERICA AND WEST INDIES.

FOR EXPLANATION OF PLATE SEE PAGE 522.

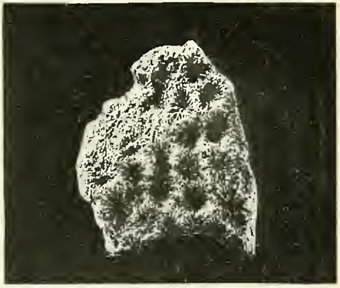
2



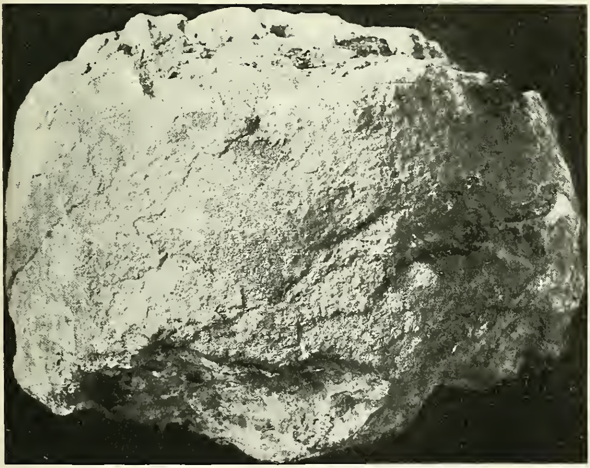
3a ×4



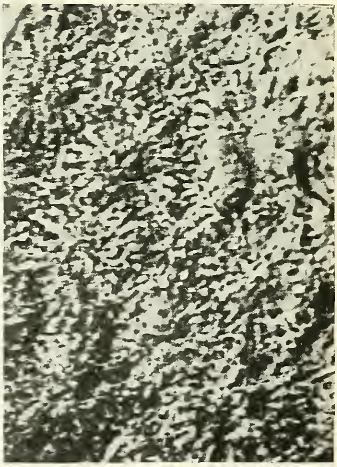
2a ×6



3



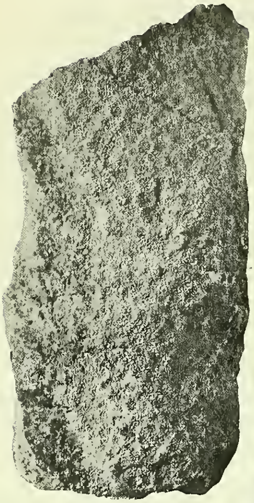
1 ×½



1a ×6

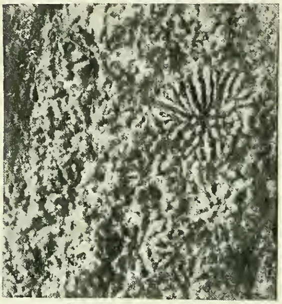
Fossil Corals from Central America and West Indies.

For explanation of plate see page 522.



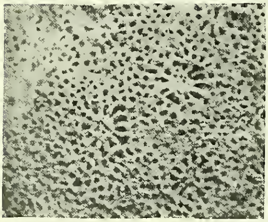
5

5a × 6



6a × 6

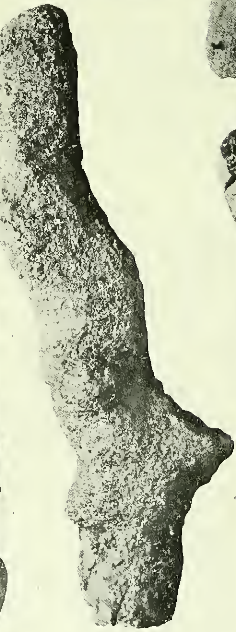
6



2a × 5

1

2

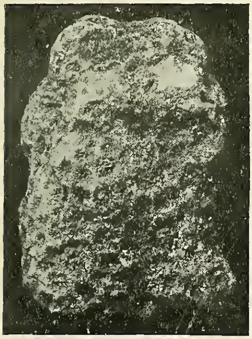


3

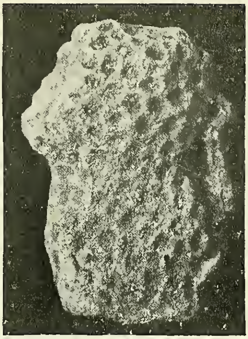
4

Fossil Corals from Central America and West Indies.

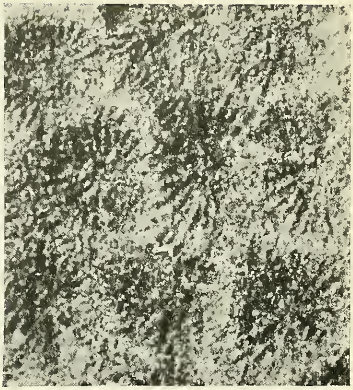
For explanation of plate see pages 522 and 523.



1

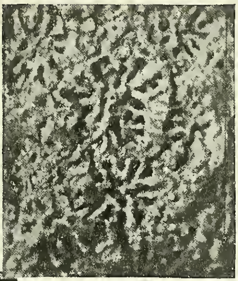


2



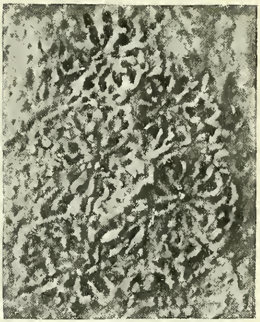
3 × 6

7



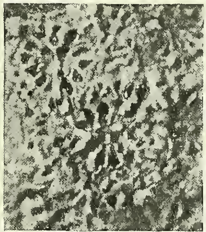
9 × 6

8

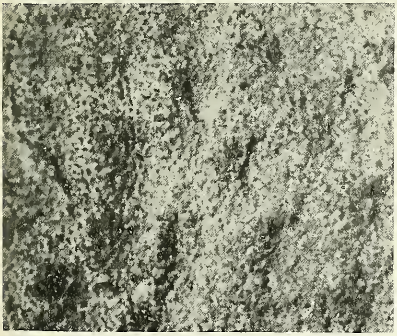


6b × 6

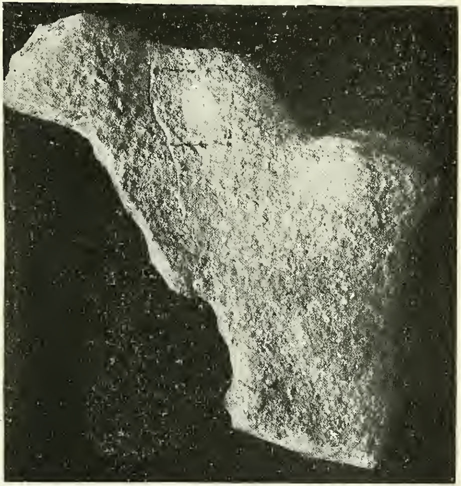
6



6a × 6



5 × 6



4

FOSSIL CORALS FROM CENTRAL AMERICA AND WEST INDIES

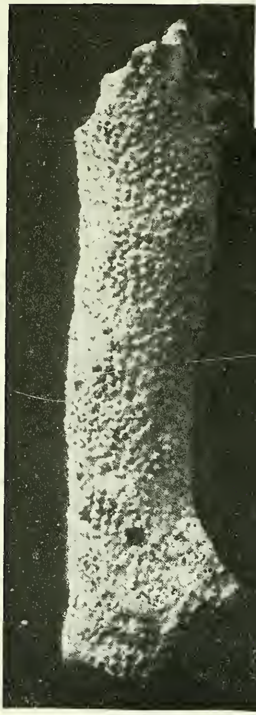
FOR EXPLANATION OF PLATE SEE PAGE 523.

1

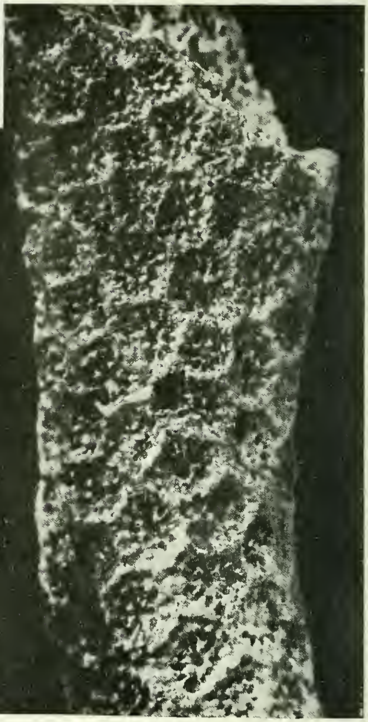
2

3 × 5

4 × 5



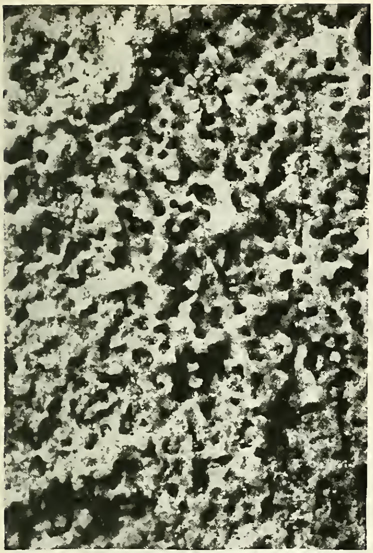
2a × 5



1a × 5

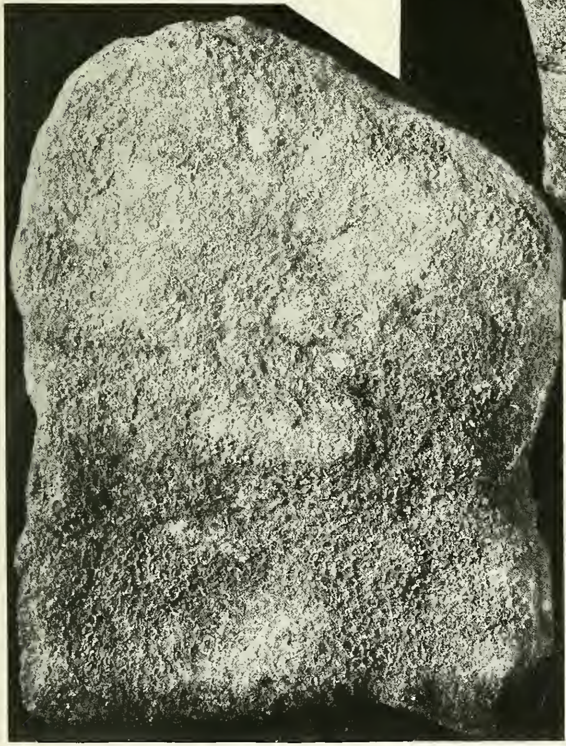
Fossil Corals from Central America and West Indies.

For explanation of plate see page 523.



3a ×8

1



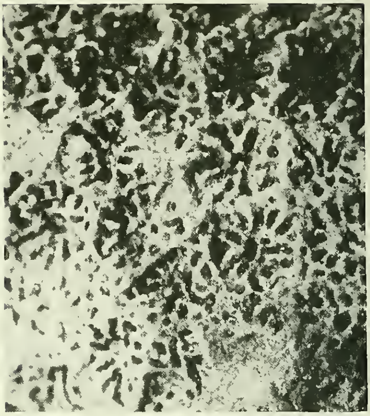
3

2 ×8

Fossil Corals from Central America and West Indies.

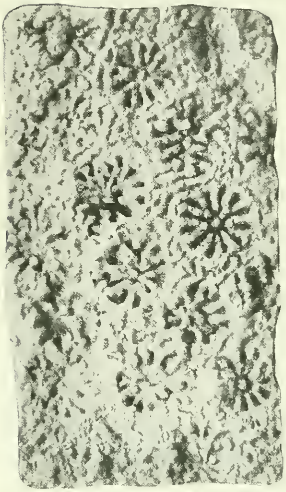
For explanation of plate see page 523.

3

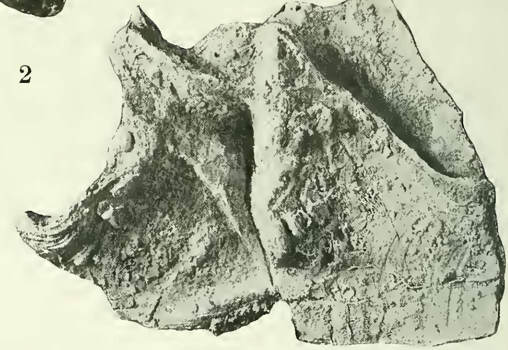


2a X 8

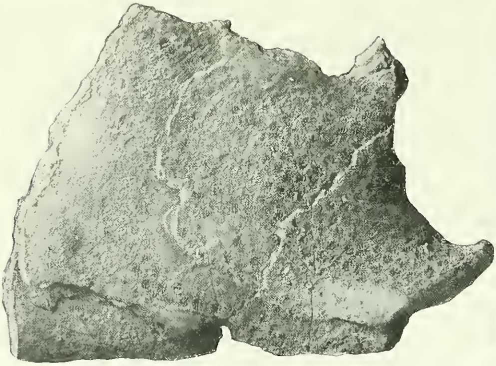
2



1b X 5



1a



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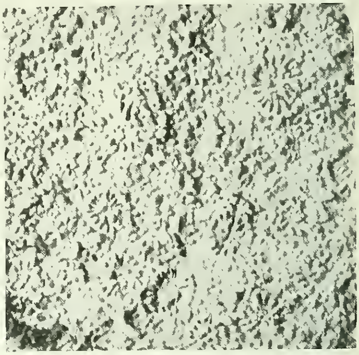
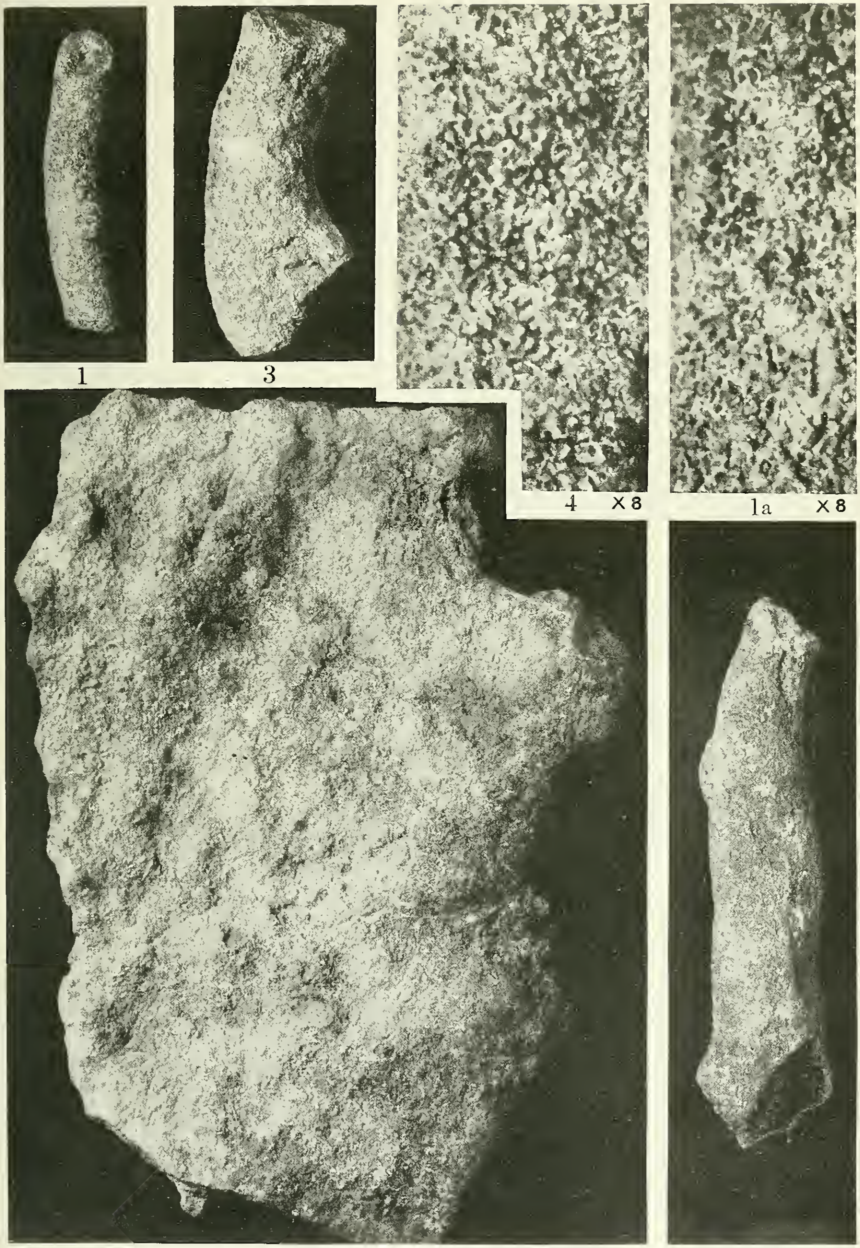


3a X 5

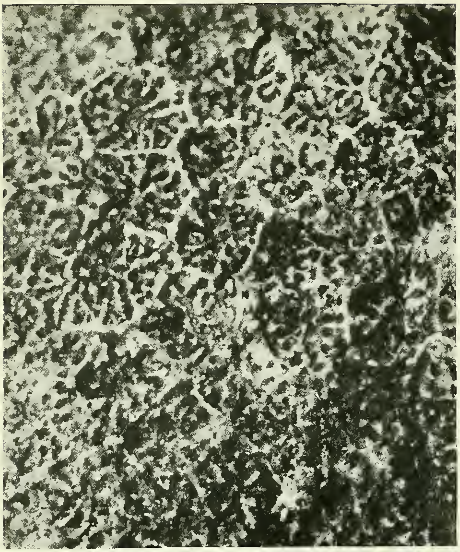
Fossil Corals from Central America and West Indies.

For explanation of plate see page 523.



Fossil Corals from Central America and West Indies.

For explanation of plate see page 524.



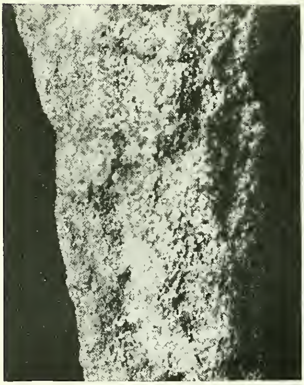
1a ×8

1

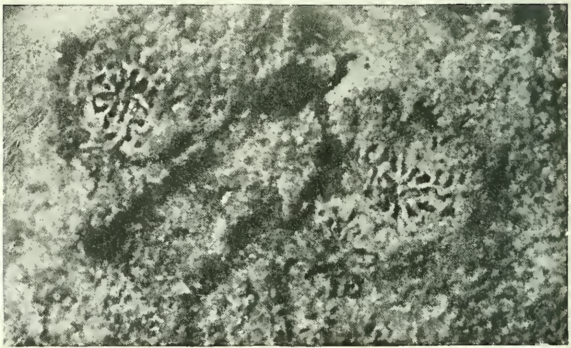
2

3

3a



2a ×3

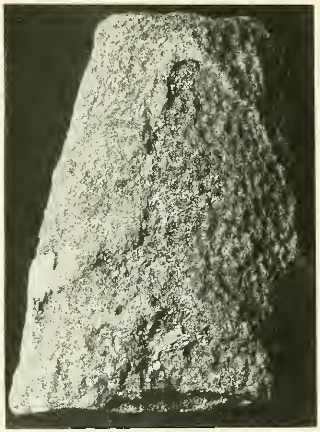


4 ×8

Fossil Corals from Central America and West Indies.

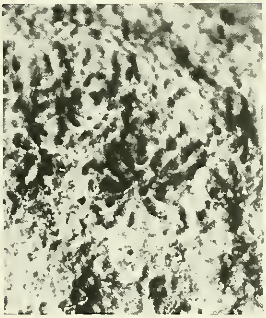
For explanation of plate see page 524.

1

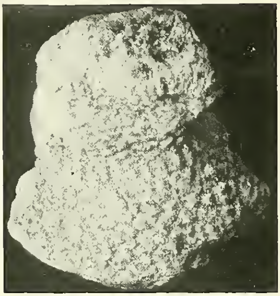


2

3



5a ×8



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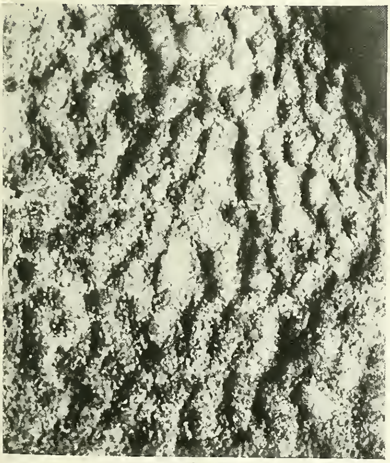
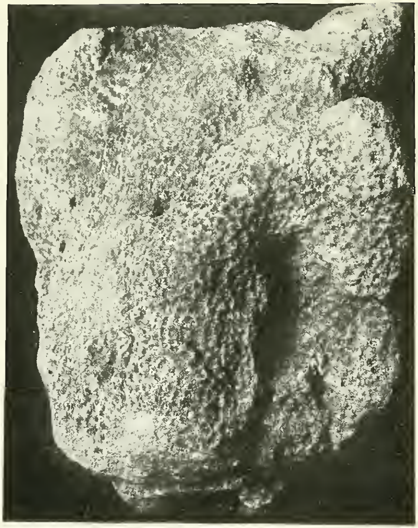


3a ×3



5

FOSSIL CORALS FROM CENTRAL AMERICA AND WEST INDIES.

FOR EXPLANATION OF PLATE SEE PAGE 524.

INDEX.

[The names treated as valid are printed in roman type, while the synonyms are in italics.

6